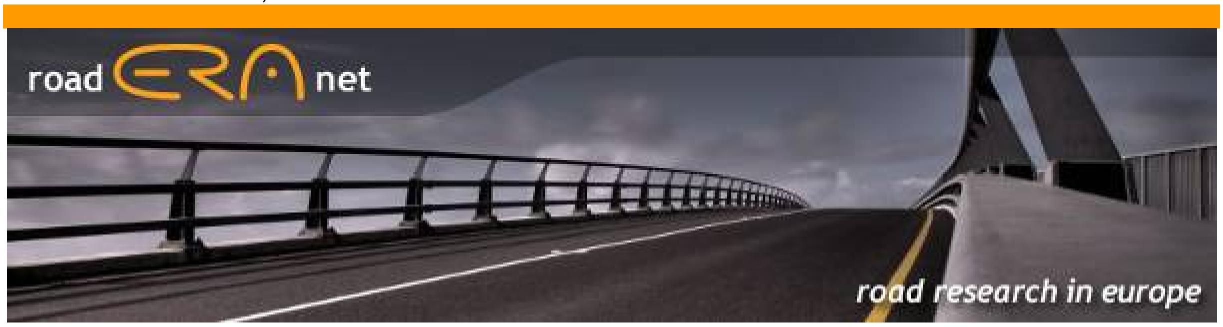

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Self-Explaining Roads Literature Review and Treatment Information

Deliverable Nr 1

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Executive Summary

This report has been prepared as part of the SPACE project (Speed Adaptation Control by Self-Explaining Roads). SPACE is a project funded by the ERA-NET Roads research programme 'Safety at the Heart of Road Design'. The programme comprises five projects that aim to explore the concepts of 'forgiving roads' and 'self-explaining roads', and to provide practical tools and guidance for road authorities for use in their efforts to improve road safety. This report provides a traditional literature review and information about 'self-explaining' treatments. It also directs the focus of the remaining work to be undertaken as part of the SPACE project.

The literature review explores the evolution of the term 'self-explaining roads' and discusses various approaches to the concept. The report tracks the use of the term from the original Dutch founders (Theeuwes and Godthelp, 1992; 1993) through to present day practical interpretations of the concept.

Theeuwes and Godthelp (1992; 1993) first used the phrase 'self-explaining roads'. Their original meaning related to the degree to which roads were 'understandable' through the process of categorisation by the road user. It was suggested that safe design could elicit safe behaviour, as clear and consistent road categories would allow road users to have appropriate expectations of how they should behave. This approach has synergy with earlier work on 'road readability' (Mazet *et al.*, 1987; Mazet and Dubois, 1988) and the role of expectancy in determining driver behaviour (Näätäanen and Summala, 1976; Malaterre, 1990).

Although the original meaning of the term self-explaining roads centred on the concept of categorisation, in this report it is argued that over time the popular meaning of the term has broadened to include many additional interpretations. These include psychological concepts such as intuitive and understandable design, consistency, readability and psychological traffic calming. The definition of self-explaining roads adopted by SPACE acknowledges the original and pure meaning of the term, while at the same time embracing some of the psychological ideas that the concept has gathered over time.

This report provides some information about 'self-explaining' treatments that may have an impact on speed choice and would be appropriate for use on rural, single carriageway, higher volume roads (those that would be the responsibility of a National Road Administration).

For the purpose of this report, the treatments are organised according to the type of road section on which they might be applied: curves, transitions, intersections and links. Information about each treatment (or group of treatments) is provided, alongside studies that indicate their effectiveness for encouraging appropriate speed choice (where available in the literature). Additional approximate information on cost per site (initial and maintenance), impact on passive safety, suitability under different weather conditions, environmental impact, likely acceptability by authorities, and compatibility with design standards are given. As expected, there are few reliable sources of published information on treatments, particularly regarding their impact on speed choice. In the absence of high quality information being available in the literature, an expert panel have been consulted in order to 'fill in the gaps'. This exercise also highlighted particular areas where further studies are required.

Following the treatment information, the final section of this report provides a summary of the implications for the later Work Packages in the SPACE project. Treatments that are suitable for use at curves and at transitions have been evaluated as offering the greatest potential, and so will be studied further in Work Packages 3 and 4.

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The work described in this report was managed by the Safety Statistics and Engineering Group in the Safety Division of the Transport Research Laboratory. The authors are grateful to Ben Johnson who carried out the technical review and auditing of this report.

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1 Introduction

“ERA-NET ROAD – Coordination and Implementation of Road Research in Europe” was a Coordination Action funded by the 6th Framework Programme of the EC. The partners in ERA-NET ROAD (ENR) were United Kingdom, Finland, Netherlands, Sweden, Germany, Norway, Switzerland, Austria, Poland, Slovenia and Denmark (www.road-era.net). Within the framework of ENR this joint research project was initiated. The funding National Road Administrations (NRA) in this joint research project are from Austria, Belgium (Flanders), Denmark, Finland, Germany, Hungary, Ireland, Norway, Slovenia, Sweden, the Netherlands and the United Kingdom.

This report has been produced as part of the SPACE project (Speed Adaptation Control by Self-Explaining Roads). SPACE is a project funded by the ERA-NET Roads programme ‘Safety at the Heart of Road Design’.

Improving road infrastructure safety can be achieved by making roads forgiving and self-explaining. Self-explaining roads reduce crash likelihood and forgiving roads mitigate crash severity.

The aim of SPACE is to identify ‘self-explaining’ treatments that lead to the adoption of speeds that are safe and appropriate to conditions. SPACE will identify treatments that offer the greatest potential for speed reduction through a traditional literature review, international expert panel review, expert workshops and driving simulator experiments (see Figure 1). This will lead to guidance on how to improve the safety of the road network.

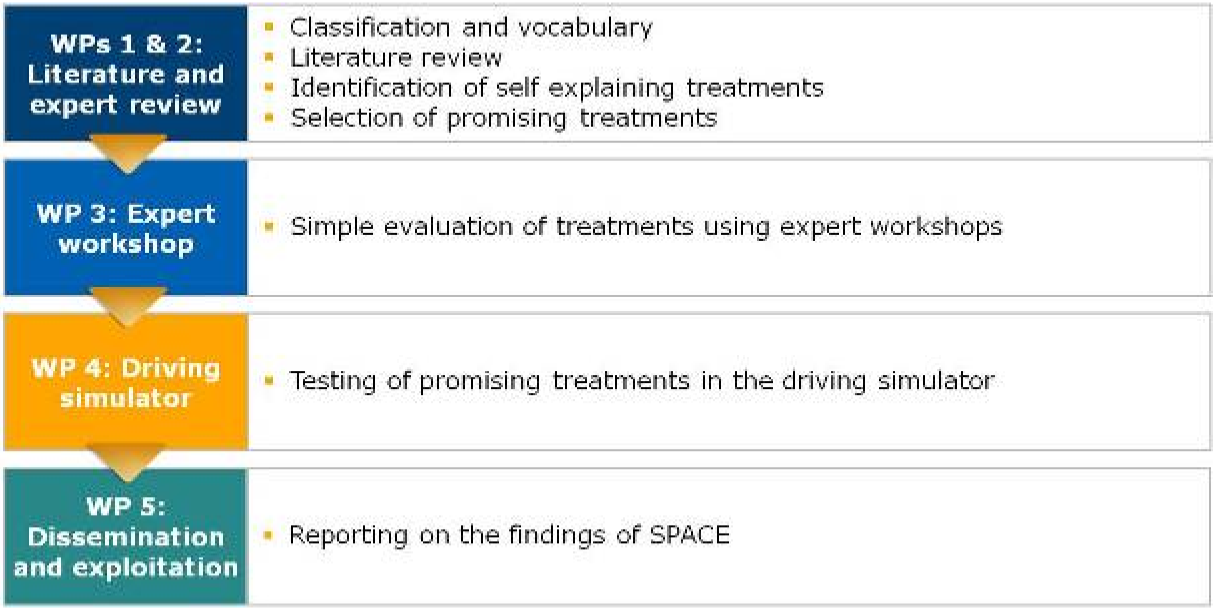

Figure 1: The SPACE project Work Packages

1.1 This Report

This report is the deliverable associated with the first two Work Packages of SPACE. These Work Packages aimed to:

- Provide the building blocks for the remainder of the work in SPACE (comprising the expert workshop and driving simulator tasks)
- Give a common vocabulary for the concept of 'Self-Explaining Roads' (SERs)
- Identify specific questions that remain unanswered and that SPACE may be able to address
- Identify the most promising treatments for further investigation

This report provides the following:

- A traditional literature review on the development of the concept of self-explaining roads over time (Section 2)
- Information about self-explaining road treatments to provide guidance on treatments that may be effective in reducing vehicle speeds at curves, transitions, intersections and on links (Section 3)
- Selection of treatments (or combinations of treatments) that should be investigated further (Section 4)

2 Literature Review

According to the Oxford English Dictionary, the phrase 'self-explaining' has been in use for nearly three centuries to convey the meaning of 'that which can be understood by itself without specific explanation'. The addition of the word 'road' to the phrase did not occur until much later, in fact less than two decades ago, and then in Dutch rather than English.

In the early 1990s, there was a reappraisal of traffic safety policy in the Netherlands, leading to the adoption of the principle of 'Intrinsic Safety', which aimed to replace traditional policies of accident reduction with a top-down systems approach aimed at accident prevention. For some time prior to this, Dutch cognitive psychologists from the TNO Institute for Perception had been investigating such topics as how drivers internally represent different types of roads (e.g. Riemersma, 1988), and the role of driver expectation in search strategies (e.g. Theeuwes, 1991). In 1992, TNO published a report for the Dutch Ministry of Transport with the title of '*Begrijpelijkheid van de weg'*, which was translated as 'self-explaining roads' (Theeuwes and Godthelp 1992). To aid dissemination, a shortened version was presented at an international conference the following year and published in the proceedings (Theeuwes and Godthelp, 1993), and subsequently as a journal article (Theeuwes and Godthelp, 1995a).

The basic message of the self-explaining road principle – that it can produce 'a traffic environment which elicits safe behaviour simply by its design' (Theeuwes and Godthelp, 1993) – was well received. As well as the major policy initiatives of the period, such as the Dutch 'Intrinsic Safety' and the Swedish 'Vision Zero', there was a more general move towards the goal of accident prevention, with safety being designed 'into the system'. The self-explaining road message fell on fertile ground, and within a decade the terms self-explaining road concept, self-explaining road principles, and even self-explaining road philosophy were in widespread use, not just in Europe but across the globe, and often in situations far-removed from those envisaged by the original authors. The development of the concept and the changes associated with this will be examined in more detail later, but first it is necessary to look more closely at the concept itself.

2.1 Characteristics of Self-Explaining Roads

At first sight, the notion of a 'self-explaining road' is a difficult one. How can a road explain itself, any more than a chair can explain itself? The idea that a driver will see that a road is explaining itself to them, and will therefore adapt their behaviour accordingly seems at first sight to be both simplistic and implausible. To get a better understanding of what is explained to whom, and how, it is necessary to go back to basic principles.

The first publication on the topic (Theeuwes and Godthelp, 1992) was entitled '*Begrijpelijkheid van de weg*'. The word '*begrijpelijkheid*' does not translate directly into English, but the verb '*begrijpen*' means to understand, and the adjective '*begrijkelijk*' is usually translated as 'understandable'. However, the authors used the term 'self-explaining', possibly because they felt that 'understandable roads' would not portray adequately the complex mental processes they were postulating. It is interesting to note that a number of Dutch publications subsequently used the English phrase 'self-explaining' (e.g. Martens, Comte and Kaptein, 1997; Godthelp, 2005), while a recent German article (Matena and Weber, 2010) employs the literal translation '*selbsterklärende*'. The important point, though, is that whatever the philosophical puzzles and linguistic uncertainties associated with it, the term 'self-explaining roads' is now firmly established in the vocabulary of traffic safety.

As noted earlier, the self-explaining road concept is based in cognitive psychology with its focus on the study of internal mental processes. Two of these processes are central to the concept: categorisation and expectancy.

Categorisation refers to the manner in which people try to recognise, understand and differentiate between objects or items. There are a number of theories of how people categorise items, some suggest that people categorise on the basis of a collection of features, others on the basis of prototypical representations. Theeuwes and Godthelp (1993, p57) subscribe to the 'prototype' theory "...through experience road users will develop a prototypical representation with respect to different types of roads. When the physical appearance of a specific road environment is homogeneous and physically different from other types of road environment, it is expected that a prototypical representation will easily develop." They go on to point out that the converse is also true, citing the earlier work of Riemersma (1988), who showed that official road categories did not correspond to the subjective categories of road users, which can lead to inappropriate driving behaviour. Quoting Theeuwes and Godthelp (1993, p58) once more: "Inadequate *[road]* categorization is dangerous because the inadequate categorization will induce inadequate expectations."

Theeuwes (2002) discusses expectancy in a book chapter that places the self-explaining road idea in a broader theoretical context. He stresses the importance of 'top down expectations' in the perception of the road environment, and argues that "it is clear that extremely dangerous situations may occur when the design of the traffic environment induces incorrect expectations regarding the spatial arrangements of objects in that scene ... because expectations play such an important role it is crucial that the design of the roads is adjusted to these expectations" (p142).

There was nothing novel about either of these two processes. The notion of mental categories of roads had been proposed several years earlier by Mazet and her colleagues (Mazet, Dubois and Fleury, 1987; Mazet and Dubois, 1988), who also coined the term 'road readability'. Similarly, expectancy has long been of interest to both traffic psychologists and highway engineers. Näätäanen and Summala (1976) outlined three types of expectancy in their book on driver behaviour, while Malaterre (1990) in his review of in-depth accident studies had argued that expectancy played an important role in accident involvement. On the engineering side, Alexander and Lunenfeld (1986) drew upon driver expectancies in the context of highway design in order to advocate the principle of 'positive guidance'.

What the self-explaining roads concept did do was to link these two processes in a theoretically plausible framework. Martens *et al.* (1997, p11) explain this in a concise fashion: "The traffic environment should provoke the right expectations concerning the presence and behaviour of other road users as well as the demands with regard to their own behaviour. In order to reach this goal, clearly distinct road categories must be used, each requiring their own specific driving behaviour."

A further component of the original self-explaining road concept was the problem of Dutch rural roads. "In the Netherlands, the design of freeways and *woonerfs* [residential roads] are to some extent self-explaining and inherently safe. On the other hand, a very large proportion of Dutch roads – for example the 80 km/h rural roads – are not designed according to the safety principles mentioned above" (Theeuwes and Godthelp, 1993, p62). This conclusion draws upon the earlier work of Riemersma (1988) and others, and has been a recurrent feature in discussion of the topic in subsequent years. Theeuwes and Godthelp go on to note that "purely on theoretical grounds, it is possible to identify some criteria which will increase the self-explaining character of roads. When developing the 'road of the future' one should start with a few easily recognisable and distinguishable road categories ... self-explaining roads should fulfil the following tentative criteria:

- Unique road elements (homogeneous within one category and different from all other categories)
- Unique behaviour for a specific category (homogeneous within one category and different from all other categories)
- Unique behaviour should be linked to unique road elements
- The layout of crossings, road sections and curves should be linked uniquely with the

particular road category

- One should choose road categories that are behaviourally relevant
- The same category should connect a section which psychologically is interpreted as a single unit
- There should be no fast transitions going from one road category to the next
- When there is a transition in road category, the change should be marked clearly
- When teaching the different road categories, one should not only teach the name, but also the behaviour required for that type of road
- Category-defining properties should also be visible at night
- The road design should expel speed differences and differences in direction of movement
- Road elements, marking and signing should fulfil the standard visibility criteria
- Traffic control systems should be uniquely linked to specific categories."

These 'tentative criteria' were clearly important to the original authors, since they appear in slightly modified form twice more in later publications (Theeuwes, 2000; 2002). What is striking, however, is the lack of detail in the original concept. Furthermore, although the modelling of traffic processes was much in vogue during this period (see Grayson, 1997), no attempt was made by the original authors to portray graphically how their imputed mechanisms were intended to operate and at what level. Self-explaining roads started more as theoretical considerations than as practical guidance to designers, but this does not seem to have diminished the enthusiasm with which the concept has been adopted. It has, however, meant that the concept has increasingly been interpreted in different ways and for purposes sometimes far removed from the intentions of what one might call 'the Dutch founding fathers'. This process, and the changes involved, will be examined in the next section.

2.2 The Development of Self-Explaining Roads

In the first decade of its history, the self-explaining road concept was progressed in two ways. The first was wider dissemination by the original authors through conference papers, book chapters, and journal articles (Theeuwes and Godthelp, 1993; 1995a; 1995b, Theeuwes, 1994; 1998; 2000; 2002), though little new empirical data were reported during the period.

The second impetus came through EU initiatives, and in particular the MASTER project, which was concerned with methods to reduce vehicle speeds on European roads. Two of the deliverables from this project are of direct interest. The first (Martens *et al.*, 1997) was a comprehensive literature review of the effects of road design on speed behaviour, and made reference to the potential role that self-explaining roads could play in this context. The second deliverable (Kaptein and Claessens, 1998a) was even more relevant, in that it was a driving simulator study of the relation between cognitive classification and driving behaviour. The results from this deliverable were also widely disseminated in a variety of contexts (Kaptein and Claessens, 1998b; Horst and Kaptein, 1996; Horst and Kaptein, 1998; Martens, Kaptein, Clasessens and Hattum, 1998; Kaptein, Janssen and Claessens, 2002). Prior to this study, empirical support for the self-explaining road concept had come predominantly from laboratory experiments in which subjects sorted and categorised visual scenes; this was the first to look at 'real' behaviour, albeit with somewhat equivocal results, as will be discussed later.

As mentioned earlier, the self-explaining road concept, or rather the messages associated with it, soon found a receptive audience, particularly among practitioners. The timing was favourable. Years of success with remedial treatments on roads had led to concerns about diminishing returns, safety audits were becoming routine, and highway engineers were shedding their traditional conservatism and adopting innovation. Into this mix came self-explaining roads, with the promise of a traffic environment that would elicit safe behaviour 'simply through design', and where appropriate driving speeds would become automatic. It is no surprise, therefore, to find the term appearing increasingly in the literature after the turn of the century.

Innovation was in the air in the UK at this time. For example, Shaw and Mayhew (2000) refer to the ineffectiveness or inappropriateness of conventional traffic calming in rural areas, and describe a scheme to influence driver behaviour by enhancing the total road environment through a 'self-explaining' road design. The same scheme was reported by Ralph (2001) as drivers being made 'more sensitive to village surroundings by using a self-explaining road design'.

Elliott, McColl and Kennedy (2003) included the self-explaining road concept in their examination of measures that could reduce driver speeds through 'psychological' means (their quotation marks). Their assessment remained reasonably faithful to the intentions of the originators of the concept, which has been far from the case with many who have used the term in the last decade. For example, Thomas (2004) praised the self-explaining road concept because it could reduce 'visual clutter', claiming that 'narrowing rather than widening roads, using natural materials for traffic calming and creating a more natural environment are all important parts of the self-explaining roads approach'. In reality, few if any of these ideas were apparent in the original Dutch literature.

Kennedy *et al.* (2005) refer to self-explaining roads as being those 'on which drivers naturally adopt the correct speed'. This reflects a broadening of the concept in UK to include the notion of non-physical innovative traffic calming measures.

There was also interest being shown in the topic on the other side of the world. Baas and Charlton (2005) describe the application of self-explaining roads in New Zealand. They follow the Dutch approach in emphasising the importance of a clearly recognisable hierarchy of road types. However, in a later publication Charlton (2007a) considerably extends the concept by defining self-explaining roads as those that take an area-wide (as opposed to a localised) approach to traffic calming and speed management. Self-explaining roads have also been adopted by the Australians as part of their 'Safe System Infrastructure' initiative (Turner, Tziotis, Cairney and Jurewicz, 2009, p7), using a succinct definition: "a self-explaining road is a term from the Netherlands which describes a road which is designed in such a way that drivers will automatically understand what is required of them, including speed choice".

In 2001, a group of American highway engineers undertook a study tour to Europe (Brewer *et al.*, 2001) and identified a number of 'potentially transferable practices', one of which was self-explaining roads. Despite a number of presentations at the Transportation Research Board (mainly by European researchers), the concept does not seem to have been so readily adopted in America to the same extent as it has in Europe. This could be a result of the federal system there, or it could more simply be natural caution. To quote Ivan, Garrick and Hanson (2009, p2): "The idea of drivers naturally selecting appropriate speeds as a result of their perception of the total roadway environment is described in some European countries as designing 'self-explaining roads'. Even though this approach is gaining momentum, gaps still exist in the knowledge about how various components of the road environment and their interaction affect a driver's chosen speed". Given the limited empirical data to date to support the self-explaining roads concept (see later), this might not seem an unreasonable position.

Meanwhile, on mainland Europe the original intentions of the self-explaining roads principle have remained firm. In the Netherlands, the concept has become an important part of road safety policy (Kraay, 2002; Wegman and Aarts, 2005). An important empirical contribution was made by Aarts and Davidse (2007), who argued that predictability needed to be supported by what they term 'essential recognisability characteristics' (ERCs). While their approach follows conventional self-explaining roads principles (the road environment should conform to the expectations of road users in order to prevent errors that could lead to crashes ... these expectations are based on the characteristics of road types), the specification of ERCs has the potential to provide more concrete guidance to practitioners.

Elsewhere in Europe, the concept was also being adopted as a part of national road strategies. Herrstedt (2006) stated that the self-explaining and forgiving road is a new way of thinking in planning and designing road infrastructure, and also goes on to point out that a major part of the road safety problem is related to rural roads.

In Germany, the self-explaining roads concept is now fully integrated into national guidelines for rural roads (Weber and Hartkopf, 2005; Richter and Zierke, 2009; Matena and Weber, 2010). The EU RIPCORD project has also provided valuable input to this area (Matena *et al.*, 2006; Weller and Schlag, 2007).

It is clear that the self-explaining road concept has become part of the highway engineer's vocabulary in a relatively short space of time; indeed, Brilon and Lippold (2005) maintain that roads should become self-explaining. The extent to which this has been supported by empirical evidence is examined in the next section.

2.3 Empirical Evidence for the Effects of Self-Explaining Roads

In this section we describe some of the empirical work in the literature, examining the effects of various measures that have been described as self-explaining road-related on speed and other road user behaviours. Throughout the review we shall see that work has generally followed the development of the concept itself in terms of the focus and research questions being addressed.

The very early references in the literature tend either to be attempts to illustrate the importance of expectancy, or tend to be attempts to demonstrate the ways in which road categorisation can lead to behaviours (typically related to speed) that are favourable in terms of road safety outcomes. Theeuwes (1991) is one prototypical example of the former. In a visual search task when drivers were asked to search for traffic signs in a road scene, search time was 1112ms when the traffic sign was in the expected location, but 1745ms when the traffic sign was located on the wrong side of the road (this was achieved through mirroring the picture in the vertical plane).

Additional data along these lines are cited in Theeuwes and Godthelp (1995a) showing that search time was around 200ms higher, and error rate was around 60% higher (16% compared to 10%) when searching for traffic-related stimuli in unexpected, rather than expected locations in a scene. This effect of expectancy on object detection time more generally is well-established in the literature (e.g. Biederman, Mezzanotte and Rabinowitz, 1982), and the references here are in some ways simply early examples of a basic cognitive psychology finding being demonstrated in traffic-related contexts. Although such findings illustrate that traffic scenes result in certain expectancies in drivers as to the location of objects, they do not demonstrate direct effects of the support or violation of such expectancies on driver behaviour.

The key to unravelling the actual effects of expectancy within the self-explaining road concept will be dependent on data becoming available linking such expectancies clearly to outcomes. That is to say, we know that expectancies will play a part in how drivers engage with the driving environment. However it is by quantifying the effects of expectancy violation on behaviours that are known to be related to collision risk (e.g. speed, errors of detection of vulnerable road users[1]) that we can begin to understand the road-safety implications of different forms of expectancy violation.

The Kaptein *et al.* (2002) study can be seen as an evolution of the empirical work within the self-explaining road literature, in that it went beyond expectancy and focused on categorisation of road types, and how this impacted on speed choice. The study used a picture sorting task and a related simulator task (discussed later). In the picture sorting task, participants were asked to sort pictures of roads into piles on the basis of each pile sharing characteristics of road user behaviour on the part of the driver, and in terms of what might be expected from other road users. The key finding was that when the stimuli used were 'self-explaining' versions of motorways, motor-roads, 80 km/h roads for motorised traffic only, and 80 km/h roads for motorised and slow moving traffic, a more consistent categorisation emerged from participants' sorting than when pictures of existing examples of these roads were used. This finding confirms that if participants are given examples of roads that are demonstrably similar (within categories) or varied (between categories) along dimensions that are visibly deducible, they incorporate such similarities and variations within their categorisations of the road.

It is also worth mentioning that participants in such studies already have some experience as drivers. Little if any work specifically within the self-explaining road literature has focused on looking at how expectancies will differ between drivers of differing levels of experience, and indeed with different motivations. The ease with which 'correct' expectations are acquired might be another fruitful area for further work, especially considering the very much higher collision risk faced by new drivers worldwide, which traditional driver training and education has failed to address adequately (Helman, Grayson and Parkes, 2010).

A more recent example of using picture stimuli to examine categorisation comes from Weller, Schlag, Friede and Rammin (2008), who asked people to rate pictures of rural roads on the dimensions of the Road Environment Construct List (RECL – Steyvers, 1993; 1998). A factor analysis of ratings showed that road categorisation could be explained by three high-level factors, termed 'monotony', 'comfort' and 'demand'. Speed ratings (again to the pictures) were explained well by the 'comfort' and 'monotony' factors. In addition Weller *et al.* showed that three clusters of roads resulted from these factors, namely:

- Cluster 1 roads which were narrow, had a poor surface, and had no centre line (low monotony, low comfort, high demand)
- Cluster 3 roads which were wide, had a good surface, had road markings, a very good sight distance, and a low curvature change rate (high monotony, high comfort and low demand)
- Cluster 2 roads which fell between the other two clusters in terms of surface and width, but had a higher curvature change rate than cluster 3 roads (low monotony, high comfort, low demand)

Speed ratings also predicted cluster membership in 19 out of 21 cases. These data show that road categorisation can be linked to speed ratings in the laboratory, and also to psychological variables that are plausibly related to driver speed choice. Comfort, demand, and monotony have all been identified in the literature as having either a theoretically plausible or an empirically demonstrated impact on speed choice.

In addition to picture-based studies examining expectancy effects and the principles underling categorisation, other studies have sought to increase external validity by using high-fidelity simulators to examine the impact of self-explaining roads on behaviour. For example Kaptein *et al.* (2002) asked participants to drive on simulated roads of each category (A=motorways, B=motor-roads, C=80 km/h roads for motorised traffic only, and

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[1] In laboratory studies motorcycles are more difficult to detect when they are much less frequent in the stimulus set than cars, compared to when motorcycles and cars are shown with equal frequency. This mimics the low frequency of motorcycles among road traffic (Hole, Tyrell and Langham, 1996) and is one reason given for the so-called 'looked but failed to see' accidents involving motorcyclists.

D=80 km/h roads for motorised and slow moving traffic), when these categories were either defined according to self-explaining road principles, or according to existing examples. The main finding was that on category B and D roads the self-explaining road designs elicited significantly faster driving speeds; in addition the standard deviation of speeds on some self-explaining road designs was lower.

Accident risk increases as mean speeds rise (Finch, Kompfner, Lockwood and Maycock, 1994; Taylor, Baruya and Kennedy, 2002; Nilsson, 2004; Elvik, Christensen and Amundsen, 2004), and may decrease as speed variability (or differential) reduces (Solomon, 1964). West and Dunn (1971) questioned Solomon's results in relation to slower moving vehicles; however they have supported the findings for vehicles travelling at higher than average speeds. Therefore it is difficult to determine the real safety impact of the Kaptein *et al.* (2002) study.

Observational studies on the effects of self-explaining roads on behaviour have also been attempted. The focus of these studies reflects the evolution of the self-explaining road concept from applying to road user expectancies and road classification, to being associated with any number of what might be called 'innovative' road safety interventions. Herrstedt (2006) provides a good example, and reports data from various observational studies looking at before/after effects on behaviour of various treatments inspired by the self-explaining road concept. One example is from an introduction of the new '2 minus 1' cross section profile (with a narrow cross section and no centre line), to replace the standard two-lane profile (see Richter and Zierke, 2009, described below).

Herrstedt reports some data from an evaluation of this new profile, showing that speed was still high (no data are reported on the change in speed) after the change. Drivers also behave as intended when meeting oncoming traffic, by encroaching onto the edge areas as required, avoiding collisions with oncoming traffic. However Herrstedt also reports that at locations along the road where 'speed reducers' were installed (these are pinch points designed to reduce speed at specific locations, and which stop people encroaching onto the edge areas through placement of bollards) drivers did not seem to behave as intended, often failing to yield to oncoming traffic, resulting in some accidents. In a recommendation that hints at the evolution of the self-explaining road concept beyond its original meaning Herrstedt suggests that in terms of what needs to be done in such cases "The conclusion is already quite clear: it is necessary to add a sign to the narrowing to make it clear for all drivers who should go first." According to the original concept, signs would not be expected to figure highly in lists of features associated with self-explaining roads. In another finding reported by Herrstedt we see a good illustration of the fact that the widening of the self-explaining road concept can make it difficult to be sure of the mechanisms by which treatments have their effects.

Lahrmann (2005, as cited in Herrstedt, 2006) reports an evaluation of speed changes after central dividers (coloured surfacing) were installed between the centre lines on a rural road in the County of Northern Jutland, and concludes that speed went down after the treatments. However the treatments not only included the dividers; they also included signs indicating that overtaking was now prohibited, and a reduction in the speed limit. It seems plausible in this case that the changes in speed were not attributable to interventions inspired by the self-explaining roads concept, but to very clear changes in the implied enforcement regimen.

Richter and Zierke (2009) used observational and simulation methods to examine the impact of new markings on a design-class 4 (low volume) German road on vehicle speeds. Before the road was re-paved the lining consisted of a centre line splitting the 5.7m wide road into two lanes of 2.85 m each. After the re-paving the lines were replaced with a single 4.2m centre lane marked with broken lines 0.75m from each edge – a so-called '2 minus 1' profile. Observed 85th percentile speeds on the road dropped by around 10% after the new lines were painted. These findings were repeated in a driving simulator study. A general decrease in speed was observed with the new markings (around 5%) although noticeably at junctions, a speed increase was observed with the new markings. As with the Kaptein *et al.* (2002) data, a more homogenous speed profile was observed with the new markings.

The data from Richter and Zierke are interesting in that they illustrate a recurrent shortcoming of studies in the self-explaining road literature; the mechanism by which change occurs is often assumed to relate to the self-explaining road concept, with little consideration being given to alternative explanations. It is not clear if the changes in speed observed by Richter and Zierke were due to the 'simpler categorisation' posited by the authors or instead were due to changes in the road *per se*. For example drivers may simply have been responding to a narrowing of the road space available when oncoming traffic was encountered. An increase in perceived task difficulty (due to an unusual layout where there is the possibility of meeting other vehicles in the same lane) or a drop in perceived comfort may have been the cause of changes in speeds, and these variables do not necessarily have anything to do with self-explaining roads and their original conceptualisation as a way of facilitating road categorisation and road user expectancy. Moreover, the longevity of these effects is unknown.

In summary, the evidence for the effectiveness of self-explaining road principles on behavioural outcomes is scarce. There is a little evidence that these principles lead to more homogenous speed choice, both from simulation and 'picture based' studies, although increases in mean speed choice have also been demonstrated. A future focus of research might be to examine the relative interplay between speed differential and absolute mean speeds, in an attempt to understand which of these is most amenable to influence through self-explaining road principles. The literature provides more support for the existence of key self-explaining road principles in the first place; however it is not clear how such findings can add to what is already known about driver (and indeed general human) cognition and perception from outside the self-explaining road literature. Elliot *et al.* (2003) provide a good review of how some knowledge regarding perception and cognition can be related to the driving task in the form of treatments designed to elicit specific perceptual and cognitive effects to reduce speed. Elliot *et al.* found that speed reductions using 'psychological' measures were generally smaller than those seen with physical measures, and that the effects may lessen over time.

2.4 Self-Explaining Roads Today

It was noted earlier that the term self-explaining roads is now in general use; indeed, a recent Google search showed that more than half a million websites now include the phrase. To traffic engineers faced with the challenge of improving safety, the notion of a new type of road that would reduce errors by 'eliciting safe behaviour through design' and 'evoking correct expectations from road users' was very attractive.

It could be argued that the reason that the concept has been applied in ways and contexts far removed from those originally envisaged is because a principle was offered in the absence of detailed practical guidance. It is not altogether surprising, therefore, to find that despite, or possibly because of, the absence of any formal definition, the concept and its principles have been interpreted so widely. Practitioners have used the term very broadly to describe innovative engineering interventions aimed at error and speed reduction.

2.5 The Way Forward

A good starting point in any effort to disentangle the self-explaining road concept from the extra meanings that it has collected in the last two decades is the topic of traffic calming. Some have seen self-explaining roads as a form of, or even synonymous with, traffic calming. This view can be questioned. The objective of traffic calming is speed reduction, and is achieved through devices that physically restrict achievable (and comfortable) speeds. While speed reduction may be seen as one of the (implicit) aims of self-explaining roads, the way in which traffic calming is achieved, by coercive physical measures, does not sit well with the psychological concept of self-explaining roads. Traffic calming schemes physically influence behaviour and can be considered self-enforcing, whereas self-explaining roads attempt to influence the road user psychologically. Some more recent work on 'psychological traffic calming' however does sit more comfortably with the concept of self-explaining roads.

One concern is that diluting the term may lead to a reduction in the intellectual rigor with which the original concept was developed. At the same time though, the degree of rigour applied to the original meaning is questionable. Take for example the issue of categorisation. This is central to the original self-explaining roads concept, as well as suggesting an explanation for the problems relating to rural roads in the Netherlands. It should be noted, however, that the studies of road categorisation that have been carried out to date have very largely been based on small, unrepresentative samples. No data have yet been presented to show that the driving population at large understands the concept of road categories; small scale laboratory studies are the norm, and normative data are lacking.

At a more theoretical level, there remains the problem of translating the high level principles of the original self-explaining road concept into mechanisms that could affect road user behaviour. It would not seem unreasonable to ask whether categorisation is essential to elicit the appropriate behaviour and error reduction that is the stated goal of self-explaining roads. Could not good design alone achieve this without the need for elaborate cognitive models?

There is a further issue, this time a practical one. Different countries have different systems of road hierarchies, and it would seem unrealistic to suppose that long distance travellers must therefore have a series of mental templates that need to be consulted every time that they cross a border. This is not simply a transnational issue either. Nearly a decade ago, Rothengatter and Schagen (2002) raised the concern that policies of decentralised government could pose problems for the implementation of high levels of consistency within road categories, and that local needs might counteract self-explaining ones.

There is also the role of expectancy. It is hypothesised that unless drivers have the correct expectancies regarding the road they are on, then driver errors might result. The idea certainly has intuitive appeal; however it could also be argued that uncertainty can lead to a more cautious driving style, and that this in itself (mainly through lower speeds) might have a positive safety impact.

Saad (2002) places the self-explaining road concept in the context of earlier work on positive guidance (Alexander and Lunenfeld, 1986) and road readability (Mazet *et al.*, 1987), and notes that these approaches are similar in that they emphasise the need to structure the road network in a homogeneous and consistent manner, taking into account the tasks that must be completed by road users and constraints on their execution. In a similar vein, Hale and Stoop (1988) refer to the interface between road designers and road users, and the need for compatibility between the formal rules employed by road designers and the informal rules employed by those who use the roads.

The self-explaining road concept stands as an intuitive notion based on a high-level appreciation of how people seem to go about the business of making visual and behavioural sense of their world. The concept is probably best seen as one way in which knowledge of cognitive psychology can help give an understanding of how some drivers might behave in some circumstances. However, a cautionary note is in order. The early advocates of self-explaining roads held that they were capable of improving safety by reducing errors. Theeuwes (2002, p131) made the point explicitly: "Because better education, information and enforcement may have only limited effects on accident reduction, it is absolutely critical that the road environment is designed in such a way that human errors are reduced to a minimum. The crucial question is which design principles can reduce the probability and consequences of an error during driving".

The basic assumption appears to be that if road users can recognise the road category and therefore have 'correct expectations', then appropriate behaviour will follow, errors will be reduced, and safety will be enhanced. What is missing from this scenario is the role of volition (the free choice of the road user). When traffic levels allow for free flow (as is the case on many rural roads) then driving becomes a self-paced task; as such it becomes subject to the influence of a far wider range of variables than those used in the once fashionable task demand models (for a review, see Michon, 1985). Just because a self-explaining road can in theory present drivers with all the necessary information for them to develop correct expectations about that road does not mean that all of them will respond with 'appropriate behaviours'. The considerable body of recent evidence regarding the role of intentional violations in accident causation suggests that the enthusiasm for self-explaining and self-enforcing road design should be tempered with a certain degree of realism. Martens *et al.* (1997, p30) recognise this when discussing self-explaining roads: "If the layout of the road explains on what road category the driver is driving and what driving behaviour is expected, unintentional speeding may disappear" (italics added). Given all of the other variables that can influence speed choice, it seems unlikely that self-explaining roads will result in appropriate speeds for all drivers, all of the time.

2.6 The SPACE Definition of Self-Explaining Roads

For the purposes of the remaining work to be undertaken in SPACE and for the Sections that follow in this report, a definition of self-explaining roads has been developed. This is a practical definition and although the original meaning is acknowledged, it also reflects the way in which the term has evolved over timew. The definition is as follows:

"Theeuwes and Godthelp (1992) suggested that roads are self-explaining when they are in line with the expectations of the road user, eliciting safe behaviour simply by design. This definition is largely theoretical and, where it is practically applied, it is based on road categorisation principles. In practice the term self-explaining roads has been widely adopted and has evolved to include many aspects of innovative highway engineering, including the concepts of intuitive and understandable design, consistency, readability and psychological traffic calming."

The SPACE project aims to focus on measures that influence the sensory perception and cognition of road users (not just in terms of categorisation), particularly in relation to appropriate speed choice. The Section that follows summarises some treatments (largely for rehabilitation/retro-fitting) that could be considered 'self-explaining'. These are organised according to the type of road section that they can be used on:

- Curves (Section 3.2)
- Transitions (Section 3.3)
- Intersections (Section 3.4)
- Links (Section 3.5)

3 Treatment Information

3.1 Approach

In order to provide treatment information, the first step was to identify individual treatments that could be considered to be 'self-explaining' and may have an effect on speed choice. The focus on speed choice resulted from the requirement for SPACE to focus on speed, while other projects being completed for ERA-NET Road had a wider remit.

According to the requirements of the ERA-NET Road Programme Executive Board, the treatments should be suitable for use on roads that are:

- Rural
- Single carriageway
- Higher volume (the responsibility of a National Road Administration)

In total, 72 individual treatments were identified by the project team.

These were grouped according to the type of road section to which they would be applied:

- Curves
- Transitions
- Intersections
- Links

Many treatments overlapped, as they are designed to work in similar ways and in combination, therefore these were further grouped.

There is a debate regarding the 'purity' of some of the treatments and whether they truly are 'self-explaining'. Our approach has been to include any treatment that *may* be considered self-explaining and this issue will be further considered during later Work Packages.

A template was developed to contain information about treatments in a consistent 'fact sheet' style format. Treatments were assigned across the Work Package team and the literature was searched to find the required information in the template.

Where possible, the information gathered was based upon high quality published sources. However, there are relatively few, well controlled, studies that exist for 'self-explaining' treatments, and so it was necessary to consult with a number of experts to gain their expert opinion on information missing from the scientific literature. Where information has been obtained from the literature, citations and references have been included. Where no citations have been made, the information is the opinion of a panel of experts involved in the SPACE project.

3.2 Curves/Horizontal Alignment

According to a literature review completed by Charlton and de Pont (2007), driver errors associated with curves result from three issues: failure of driver attention, misperception of speed and curvature, and poor lane position.

A key principle is that signing and marking should be consistent (e.g. Retting and Farmer, 1998): if several curves of similar severity have similar signing and are followed by a more severe curve with the same signing, drivers may not slow down sufficiently. A particularly severe curve, or one that occurs unexpectedly after a long straight section, is likely to require additional or novel treatment in order to inform drivers to take extra care.

Along a route, there should ideally be a logical hierarchy for curve signing and marking so that the more severe the curve, the more the signing and marking encourages drivers to slow down and adopt an appropriate speed for the curve. The US has a system of signing requirements in the latest version of the Manual on Uniform Traffic Control Devices (MUTCD, 2009) based on the difference between the speed limit (or the prevailing speed on the approach to the curve) and the advisory speed for the curve. Other hierarchies have been proposed, for example by Herrstedt and Greibe (2001) and by Transport Scotland (Wither, 2006), but do not appear to be in general use.

Driver speed choice is thought to depend mainly on curvature and approach speed (Kerman, McDonald and Mintsis, 1982; McLean, 1995) so that influencing approach speed is important for reducing speed on the curve itself. On a good road surface, the limiting speed for car drivers is determined by the level of comfort the driver will tolerate rather than the risk of slipping; the coefficient of friction only becomes important when skid resistance is low or there are adverse weather conditions. By contrast, trucks are likely to roll over rather than skid if they traverse curves too quickly, and this occurs at relatively low speeds. Motorcycles have a much greater need for a high coefficient of friction from the road surface than do cars (IHIE Guidelines for Motorcycling).

Standard signing for curves comprises an advance warning sign to indicate the presence of the curve, possibly including an advisory or compulsory speed limit to indicate a “safe” speed for the curve, and appropriate road markings. In addition, depending on the severity of the curve, chevron signs and/or marker posts, and skid resistant surfacing may be used. Usually the road either retains normal camber round the curve or has superelevation to aid the driver. The use of a warning sign alone is assumed to be common to all curves and is not considered further in this report.

In recent work by Helman, Kennedy and Gallagher (2010), six treatment levels (as shown in Figure 2) were studied using speed estimates and a naturalistic driving methodology. Unfortunately the relative contribution of each individual treatment type was not studied, and so cannot be reported in each of the sections that follow.

In the Helman *et al.* (2010) experiment there were six different curves all ‘mocked up’ with six treatment levels. Drivers were asked to give an estimate of the speed they would be doing at the point depicted in the picture, if that was the view from their car. It was found that speed estimates varied as a function of the ‘level’ of treatment; more treatments led to significantly lower speed estimates, with around a 7 mph (11 km/h) difference between the ‘no treatment’ and ‘all treatments’ condition.

Data from an in-vehicle data recorder showed that the average speeds chosen when driving through curves varied with the curve geometry (i.e. tighter curves elicited lower speeds) but also with the total amount of treatments on the curves (e.g. warning signs, chevrons, junction warnings, ‘slow’ in road). These data suggest then that drivers are sensitive to various sources of information when choosing their speed through curves on rural roads; note that the partial correlation between speed and curve geometry was still statistically significant although small after the correlation between speed and signing and lining was controlled for in the analysis.

No treatment

Curve/bend warning sign

Curve/bend warning sign and SLOW markings

Curve/bend warning sign, SLOW markings and chevron sign

Curve/bend warning sign, SLOW markings, chevron sign and coloured surface

Curve/bend warning sign, SLOW markings, chevron sign, coloured surface and VAS

Figure 2: Images of a curve with 6 levels of treatment created using Adobe Photoshop (driving on the left) (from Helman *et al.*, 2010, used with permission)

The types of measures that might improve speed adaptation at curves are covered in the Sections that follow:

- Chevron signing/hazard marker posts (Section 3.2.1)
- Lining (Section 3.2.2)
- Vehicle Activated Signs (VAS) (Section 3.2.3)
- Surface treatments (Section 3.2.4)
- SLOW markings (Section 3.2.5)
- Transverse rumble strips (Section 3.2.6)
- Optical bars (Section 3.2.7)
- Visibility and sight distance (Section 3.2.8)
- Alignment (Section 3.2.9)

3.2.1 Chevron Signing/Hazard Marker Posts

Description

Chevrons and hazard marker posts (post-mounted delineators) are devices used at the roadside to delineate the road. In a broad sense "delineation" stands for any device or treatment that aims to outline the path of the road. Delineating devices give the driver visual clues regarding the path of the road. Delineation can include chevrons/marker posts and lining (Section 3.2.1).

Abrupt changes in horizontal alignment require delineation treatments to assist drivers in approaching and negotiating the road successfully.

The advantage of using marker posts in addition to lining is that they remain visible in adverse weather conditions, particularly when there is snow on the road. They are also helpful where there is a change in the vertical alignment on the approach to a curve. These additional forms of delineation are also particularly important at night.

Marker posts and chevron signs are the most common treatments (other than lining) used to delineate alignment over the curve length. Generally chevrons will be used on more severe curves, but both could be used on the same curve.

Some countries use a series of single chevrons (see Figure 3); whereas in the UK a single sign comprising several chevrons is more common (see Figure 4).

In a simulator study, Charlton and de Pont (1997) found that the advance warning signs alone were not as effective at reducing speeds as when they were used with chevron sight boards and/or repeater arrows.

Figure 3: Curve with high frequency of run-off-the-road accident (left) and possible treatment with chevron markers (right) (Czech Republic, 1st class road I/50 near city of Brno)

Figure 4: UK style chevron signs used in conjunction with SLOW markings and curve warning sign, created using Adobe Photoshop (driving on the left) (from Helman *et al.*, 2010, used with permission)

Marker posts have traditionally been of constant height, positioned at constant intervals round the curve at a constant offset from the road. Various guidance documents are available on this, for example the Walloon region guidance document (Autoroutes et routes de Wallonie). Two variants have been traced in the literature.

In the US, Hungerford and Rockwell (1980, as cited in Godley, Fildes, Triggs and Brown, 1999) used marker posts (or post delineators) to create 'positive perceptual illusions' on rural curves. The posts were placed in an "ascending laterally diverging system, with the height increasing from ground level to 10 feet (3 meters) and the lateral placement increasing from 0 to 20 feet (0 to 6 meters)" (p.35) (see Figure 5). This arrangement was designed to give the illusion of the curve being tighter than it really was.

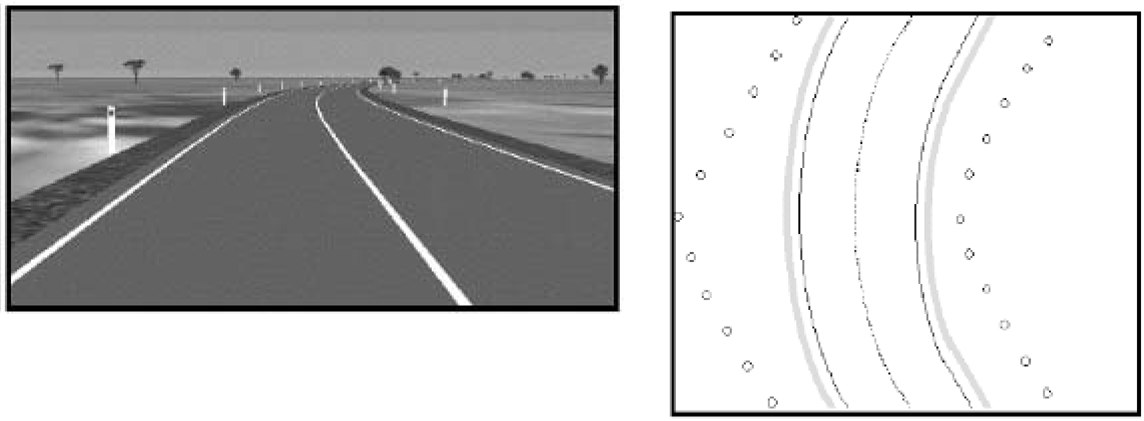

Figure 5: Innovative use of marker posts with ascending height and diverging lateral positions on both sides (from Hungerford and Rockwell, 1980, used with permission from MUARC)

Hungerford and Rockwell (1980) showed pictures of the arrangement to participants who were asked to rate the sharpness of the curve. As expected, participants perceived the curve to be tighter when the ascending laterally diverging treatment had been used. The treatment was then used on several rural curves in Ohio, which successfully reduced real speeds particularly for higher speed drivers.

Godley *et al.* (1999) found interesting effects when they studied the marker post arrangement proposed by Hungerford and Rockwell in a driving simulator experiment. Placement of lateral diverging posts on the outside of the curve reduced speeds by approximately 3.2 km/h when drivers were on the inside of the curve, but encouraged faster speeds when drivers were on the outside of the curve. Increasing the height (ascending placement) of the marker posts did not reduce speeds above the speed reduction from the lateral diverging placement on the inside curve, but led to slower speeds on the outside curve (by 3.5 km/h). When posts ascended in height, lane position was disrupted on the outside curve such that drivers were 7cm closer to the median. This means that drivers would be less likely to run-off the road. Godley *et al.* conclude that ascending posts with diverging lateral positions on the outside of curves should be beneficial for both the inside and outside curve.

In the UK, a remedial measure for motorcyclist collisions is the WYLIWYG ("where you look is where you go") system[2] devised by Buckingham County Council. The measure involves the use of marker posts deliberately positioned to lead riders' eyes to the "vanishing points" along the whole length of the curve. Posts are spaced at equal intervals of 7 to 10m at a constant offset from the road; the difference from conventional schemes is in using the vanishing points to determine the start and end of the set of posts. Buckinghamshire County Council reports great benefits on a small number of curves, but the scheme does not appear to have been tested widely.

How it Works

Good delineation of a curve can 'explain' the path of the road to the road user, showing the safe limits of the road. With good delineation drivers are more aware of sharp curves. Chevron signs are the most common sign other than the curve warning sign.

The use of special reflector posts that are ascending and are placed a diverging lateral positions as they approach the middle of the curve does seem to have potential to slow driving speeds.

2 www.homezones.org.uk/WYLIWYG.htm

Treatment Information

Cost per site or km **(high, med-high, med, med-low, low)**	Initial	Medium -low
	Maintenance	Medium-low, though marker posts may reduce ability to mow grass verges.
Effectiveness (in enabling appropriate speed choice) **(high, med-high, med, med-low, low)**	Overall	Medium-high
	Car	Medium-high
	Truck	Medium-high
	Motorcycle	Medium-high
Impact on passive safety **(very positive, positive, neutral, negative, very negative)**	Overall	Marginally negative due to increase in roadside obstacles; though this depends on the type of marker post used (e.g. flexible plastic marker posts have no passive safety effect).
	Car	Neutral
	Truck	Neutral
	Motorcycle	Marginally negative (see above).
Likely effectiveness for countries with high non-compliance with speed limits/rules **(high, med-high, med, med-low, low)**		Medium
Suitability in different weather conditions, at day and night, and different lighting conditions		Good
Is this feasible for tunnels?		Yes
Is this feasible for bridges?		Yes
Other safety impacts		None
Environmental impact		None
Acceptability by authorities		Good
Compatibility with existing design standards		Compatible
Additional guidance		Passively safe posts should be used for signs. It is best not to 'over-use' such measures since the impact of the unusual markings may diminish if they are too common. Signs should be used consistently, i.e. all dangerous curves should be marked in a similar manner. Efforts should be concentrated on particularly surprising curves, e.g. those that follow long, straight road sections. The permanence of the perceptual treatments (e.g. marker posts with diverging lateral positions) is unknown.

3.2.2 Lining

Description

'Delineation' stands for any device or treatment whose aim is to outline the road. Delineating devices give the driver visual clues regarding the path of the road. Delineation can include signing/marker posts (Section 3.2.1) and lining.

Changes in horizontal alignment require additional delineation treatments to assist drivers in approaching and negotiating the curve successfully. These additional forms of delineation are particularly important at night.

Measures include centre lines, edge lines and cats eyes. In the UK, the centre white line becomes a warning line or a double white line on a curve, depending on the forward visibility. The centre line may be emphasized by the use of 1m wide central hatching if the road is sufficiently wide to accommodate this (see Figure 6). The hatching is aimed at reducing head-on collisions. White lining should be retro-reflective to improve night-time delineation.

Figure 6: One metre central hatching used at a curve on a single carriageway road (driving on the left)

Some innovative lining techniques suggested by Rockwell, Malecki and Shinar (1975, as cited in Godley *et al.*, 1999) are shown in (Figure 7). These involve a painted line treatment to the inside edge on a rural road curve to accentuate the inside perspective angle and increase perceived curvature. According to Rockwell *et al.* (1975) this induced slower speeds on the approach to a bend/curve.

Godley *et al.* (1999) studied this lining technique in a simulator and found limited use from the hatching treatment: when hatching was 55cm wide there was no effect on speed; when it was 35cm wide it encouraged faster driving when placed in the drivers' side of the road during inside curves.

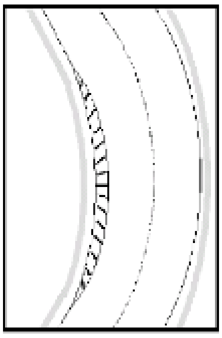

Figure 7: Innovative use of inside hatching (driving on the left) (from Godley *et al.*, 1999, used with permission from MUARC)

'Active' road studs have a built-in light source (based on solar power) rather than simply reflecting drivers' headlights. Using these studs to delineate a curve may help to reduce crashes in the dark on unlit roads or in areas prone to fog. They are expensive if used over a long stretch of road, but can be specifically targeted at curves. No reports of their effectiveness were traced. There is potential for the use of intelligent road studs in future applications.

How it Works

Good lining treatments at the edge and median can 'explain' the path of the road to the road user, showing the safe limits of the road. It can help drivers to control their approach speeds on curves and improve lane discipline. Moreover, good lining can help improve the rate at which the edge of the road degrades with wear. Improved techniques such as retro-reflective markings and the use of active road studs enhance delineation at night and in poor weather conditions (except snow).

Treatment Information

Cost per site or km (high, med-high, med, med-low, low)	Initial	Low
	Maintenance	Low
Effectiveness (in enabling appropriate speed choice) (high, med-high, med, med-low, low)	Overall	Medium-high
	Car	Medium-high
	Truck	Medium-high
	Motorcycle	Medium-high
Impact on passive safety (very positive, positive, neutral, negative, very negative)	Overall	Neutral
	Car	Neutral
	Truck	Neutral
	Motorcycle	Neutral
Likely effectiveness for countries with high non-compliance with speed limits/rules (high, med-high, med, med-low, low)		Medium-high
Suitability in different weather conditions, at day and night, and different lighting conditions		Suitable and effective in most conditions, with the exception of snow and dense fog. Active road studs are suitable for dense fog.
Is this feasible for tunnels?		Yes
Is this feasible for bridges?		Yes
Other safety impacts		Possible negative impact on the stability of motorcyclists with thick lining and low friction surface. Longitudinal rumble strips may be combined with good lining. These have positive safety effects as they alert the driver to poor lane position.
Environmental impact		Both paints and plastics used for road marking normally contain chemicals that are dangerous to health in high concentrations (Elvik and Vaa, 2004).
Acceptability by authorities		Good
Compatibility with existing design standards		Compatible
Additional guidance		It is best not to 'over-use' such measures since the impact of the unusual markings may diminish if they are too common. Markings should be used consistently, i.e. all dangerous curves should be marked in a similar manner. Efforts should be concentrated on particularly surprising curves, i.e. those that follow long, straight road sections. The permanence of the perceptual treatments (e.g. innovative inside hatching markings) is unknown.

3.2.3 Vehicle Activated Signs

Description

Vehicle Activated Signs (VAS) are signs that automatically light up when a vehicle approaches the sign or when an approaching driver exceeds a pre-set threshold. These often repeat a fixed warning sign and can display a message such as 'Slow Down' or may present other negative feedback such as a negative emoticon (i.e. unhappy face). Drivers travelling at a speed that is regarded as unsuitable for the conditions on that particular stretch of road will activate the sign. The signs may run on mains electricity, battery or be solar or wind-powered.

In the UK, Winnett and Wheeler (2003) investigated the effect of VAS that display a curve/bend warning sign when a vehicle is travelling above a certain threshold speed (set at the 50th percentile speed) at three rural curves. The signs were located between 50m and 100m in advance of the apex of the curve and gave drivers a clear view of the sign for at least 3 seconds. Winnett and Wheeler found a reduction in mean speed of between 2 and 7 mph (3 to 11 km/h) after one month. There was no evidence that drivers were becoming used to these signs, but there have since been anecdotal reports from some local authorities that the benefits of more recent installations are lower. Possible reasons are the proliferation of this type of sign or their use in locations that are unsuitable or poor sign location.

Figure 8: Vehicle activated curve/bend warning sign (driving on the left)

How it Works

Vehicle activated signs work by targeting faster drivers and reminding them of the oncoming hazard.

Treatment Information

Cost per site or km **(high, med-high, med, med-low, low)**	Initial	Medium
	Maintenance	Medium
Effectiveness (in enabling appropriate speed choice) **(high, med-high, med, med-low, low)**	Overall	Medium-high
	Car	Medium-high
	Truck	Not targeted at trucks
	Motorcycle	Medium-high
Impact on passive safety **(very positive, positive, neutral, negative, very negative)**	Overall	Medium-low
	Car	Medium-low
	Truck	Low
	Motorcycle	Medium-low
Likely effectiveness for countries with high non-compliance with speed limits/rules (high, med-high, neutral, med-low, low)		Medium-high
Suitability in different weather conditions, at day and night, and different lighting conditions		Suitable
Is this feasible for tunnels?		Yes
Is this feasible for bridges?		Yes
Other safety impacts		
Environmental impact		Low, because signs are blank when not illuminated
Acceptability by authorities		Acceptable
Compatibility with existing design standards		Yes
Additional guidance		It is best not to 'over-use' such measures since the impact of the unusual markings may diminish if they are too common. Markings should be used consistently, i.e. all dangerous curves should be marked in a similar manner. Efforts should be concentrated on particularly surprising curves, e.g. those that follow long, straight road sections. The effect of VAS may not be permanent.

3.2.4 Surface Treatments

Description

The use of skid-resistant surfacing on a curve can improve road holding, particularly for motorcyclists. The surfacing can be coloured, in order to draw drivers' attention to the curve (Figure 9). Unfortunately the example on the right hand side of Figure 9 is less than desirable due to the position of the concrete barrier and the abrupt and un-cushioned end of the barrier.

Short sections of coloured surface can make drivers aware of a change in environment or highlight other traffic management measures, but is unlikely to reduce speeds. On curves, coloured surfacing is anticipated by drivers to have good skid-resistant properties and this can have the consequence that some drivers actually speed up. As a result, some local authorities in the UK avoid the use of coloured surfacing on curves. On a rural road in particular, coloured surfacing can be visually intrusive (as it has to be in order to be effective). Any benefit from the use of colour is most likely to be in highlighting the presence of other (usually more physical) measures. There may be some circumstances where the use of coloured surface treatment could add value to a scheme (Helman *et al.*, 2010).

Figure 9: A curve with a high number of run-off-the-road crashes (left) and an effort to improve the situation by using a coloured surface (right) (Czech Republic, 1st class road I/50 near city of Brno) [Note poor positioning of barrier and unsafe barrier end]

How it Works

The change in colour alerts road users to the oncoming curve, and may result in drivers adapting their speed. Changes in colour are often red or buff (a lighter and less vibrant colour) for car traffic and green or blue for cycle traffic. The skid-resistant properties also enable drivers to control their speeds better but drivers who are aware of the higher grip attributes may choose to travel at a higher speed.

Treatment Information

Cost per site or km **(high, med-high, med, med-low, low)**	Initial	Medium
	Maintenance	Medium: Colour fades incurring additional costs
Effectiveness (in enabling appropriate speed choice) **(high, med-high, med, med-low, low)**	Overall	Medium-low
	Car	Medium-low
	Truck	Medium-low
	Motorcycle	Medium-low
Impact on passive safety **(very positive, positive, neutral, negative, very negative)**	Overall	Neutral
	Car	Neutral
	Truck	Neutral
	Motorcycle	Neutral
Likely effectiveness for countries with high non-compliance with speed limits/rules **(high, med-high, med, med-low, low)**		Medium
Suitability in different weather conditions, at day and night, and different lighting conditions		Suitable and effective in most conditions, with the exception of snow and dense fog, though anti-skid properties may help in poor weather conditions. Red/buff coloured surfaces are not very visible at night.
Is this feasible for tunnels?		Coloured surfacing is likely to be less effective
Is this feasible for bridges?		Yes
Other safety impacts		Possible positive effect in terms of anti-skid properties. Possible negative impact on the stability of motorcyclists due to surface changes.
Environmental impact		Colour schemes may not be aesthetically pleasing.
Acceptability by authorities		Good
Compatibility with existing design standards		Compatible
Additional guidance		It is best not to 'over-use' such measures since the impact of the unusual markings may diminish if they are too common. Markings should be used consistently, i.e. all dangerous curves should be marked in a similar manner. Efforts should be concentrated on particularly surprising curves, e.g. those that follow long, straight road sections. On typical black asphalt carriageways, light colouring will be more conspicuous in dark conditions. Stable friction from the classical pavement to the coloured surfacing should be maintained as far as possible.

3.2.5 SLOW Markings

Description

The SLOW marking on the roadway can help to remind drivers to reduce speed as they approach a curve. In the UK, the word SLOW complements a curve warning sign and may be repeated if the curve is particularly hazardous (UK Traffic Signs Manual, Chapter 5). The SLOW marking could also be used in conjunction with horizontal bar markings as shown in Figure 10.

This treatment may not be feasible across all of Europe due to language differences. For example, slow in German is ‘Langsam’ or ‘Langsamer’ which may be too long for the width of the road.

Figure 10: Curve treatment created using Adobe Photoshop (driving on the left) (from Helman *et al.*, 2010, used with permission)

The Pennsylvanian Department of Transport, PennDOT, has used similar curve warning markings with the word SLOW and an arrow indicating the direction of the curve. The marking is accompanied by two transverse bars in order to emphasise the treatment. PennDOT developed this treatment for application at curves where there were a high number of crashes (McGee and Hanscom, 2006).

How it Works

The treatment is intended to alert drivers to the presence of a curve and to encourage them to slow down.

According to McGee and Hanscom (2006) the PennDOT advance curve marking has been shown to reduce overall speeds by 6 to 7 percent.

Treatment Information

Cost per site or km **(high, med-high, med, med-low, low)**	Initial	Medium-low
	Maintenance	Medium-low
Effectiveness (in enabling appropriate speed choice) **(high, med-high, med, med-low, low)**	Overall	Medium-high
	Car	Medium-high
	Truck	Medium-high
	Motorcycle	Medium-high
Impact on passive safety **(very positive, positive, neutral, negative, very negative)**	Overall	Neutral
	Car	Neutral
	Truck	Neutral
	Motorcycle	Neutral
Likely effectiveness for countries with high non-compliance with speed limits/rules **(high, med-high, med, med-low, low)**		Medium
Suitability in different weather conditions, at day and night, and different lighting conditions		Suitable and effective in most conditions, with the exception of snow and dense fog.
Is this feasible for tunnels?		Yes
Is this feasible for bridges?		Yes
Other safety impacts		Possible negative impact on the stability of motorcyclists with thick lining.
Environmental impact		Both paints and plastics used for road marking normally contain chemicals that are dangerous to health in high concentrations (Elvik and Vaa, 2004).
Acceptability by authorities		Good
Compatibility with existing design standards		Compatible
Additional guidance		It is best not to 'over-use' such measures since the impact of the unusual markings may diminish if they are too common. Markings should be used consistently, i.e. all dangerous curves should be marked in a similar manner. Efforts should be concentrated on particularly surprising curves, e.g. those that follow long, straight road sections. On typical black asphalt carriageways, black/white provides the greatest colour contrast and is most conspicuous in dark conditions. Confusion should be avoided by taking care not to use such markings in locations near to intersections/accesses.

3.2.6 Transverse Rumble Strips

Description

Rumble strips or areas are small raised areas laid across the roadway with a vibratory, auditory and visual effect. The transverse strips can be laid out in a single group or in a series of groups, usually with decreasing spaces between them. Transverse rumble strips are used to alert road users to the presence of a hazard (as shown in Figure 12). They are suitable for use on the approach to severe curves, intersections or transitions.

Rumble strips can be effective in reducing speeds initially, but tend to become less so over time since their vibratory effect tends to be less when traversed at higher speeds (Wheeler, 2002). Their other main disadvantage is that they are noisy and therefore cannot be used near housing.

In the UK, Wheeler reported on three sites at curves with reductions in either collisions or speeds, depending on the measurements undertaken. Barker (1997) reported on one site where, over the year following installation, the mean speed on the apex of the curve was reduced by 3 mph (nearly 5 km/h).

Figure 11: Transverse rumble strips used on approach to a village (driving on the left)

Figure 12: Transverse rumble strips

How it Works

Rumble strips have been used on approaches to intersections, severe curves and at transitions. They work because driving over them can be unpleasant. However, driving at higher speeds can reduce this effect

If these are placed at decreasing intervals, they can make the driver feel like their speed is being maintained or is increasing, and cause them to slow down.

Treatment Information

Cost per site or km **(high, med-high, med, med-low, low)**	Initial	Medium
	Maintenance	Medium
Effectiveness (in enabling appropriate speed choice) **(high, med-high, med, med-low, low)**	Overall	Medium
	Car	Medium
	Truck	Medium
	Motorcycle	Medium
Impact on passive safety **(very positive, positive, neutral, negative, very negative)**	Overall	Neutral
	Car	Neutral
	Truck	Neutral
	Motorcycle	Neutral
Likely effectiveness for countries with high non-compliance with speed limits/rules **(high, med-high, med, med-low, low)**		Medium
Suitability in different weather conditions, at day and night, and different lighting conditions		Suitable and effective in most conditions, with the exception of snow and dense fog.
Is this feasible for tunnels?		Yes
Is this feasible for bridges?		Yes
Other safety impacts		Adequate signage of transverse rumble strips may be necessary. Possible negative impact on the stability of motorcyclists.
Environmental impact		Traditional rumble devices can generate considerable external noise and vibration. Both paints and plastics used for road marking normally contain chemicals that are dangerous to health in high concentrations (Elvik and Vaa, 2004).
Acceptability by authorities		Good
Compatibility with existing design standards		Compatible
Additional guidance		It is best not to 'over-use' such measures since the impact of the unusual markings may diminish if they are too common. Markings should be used consistently, i.e. all dangerous curves should be marked in a similar manner. Efforts should be concentrated on particularly surprising curves, e.g. those that follow long, straight road sections. The permanence of the perceptual treatments is unknown.

3.2.7 Optical Bars

Description

As shown in Figure 14, Optical Bars are transverse stripes spaced at gradually decreasing distances. The rationale for using them is to increase drivers' perception of speed and cause them to reduce speed. The Optical Speed Bar name comes from this intended visual effect on drivers' speed as they react to the spacing of the painted lines. Optical bars can cover the whole carriageway (Figure 13), or just the edges (peripheral optical bars) (Figure 14).

Optical bars are high contrast, painted or thermo-plastic strips, usually 60 cm wide. The preferred material is thermoplastic because of the exposure to traffic volume over time. They are placed across the driving lane, over lengths of 50 to 400 metres, and usually on the approach to a hazard (e.g. may be appropriate for use at curves, intersections and perhaps transitions). Transverse lines are generally spaced at decreasing distances apart in the direction of travel.

In the UK, bar markings are transverse coloured stripes across the full half-width of the roadway (across one lane), spaced at gradually decreasing intervals. On the approach to curves, red bar markings have been shown to reduce speeds by between 1 and 7 mph (2 to 11 km/h) at a small number of sites (Wheeler, 2002). However, it is not known to what extent this benefit is maintained over time. Yellow bar markings on the approach to rural roundabouts have been found to be very effective.

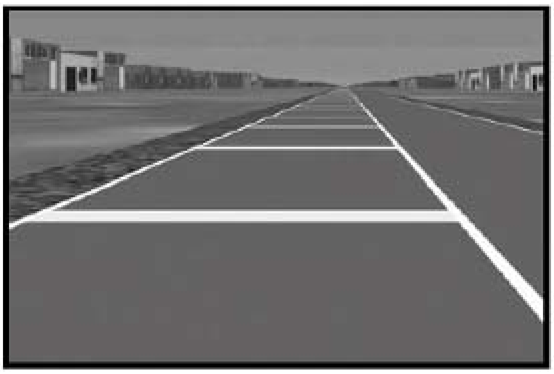

Figure 13: Transverse optical bars (driving on the left) (from Godley *et al.*, 1999, used with permission from MUARC)

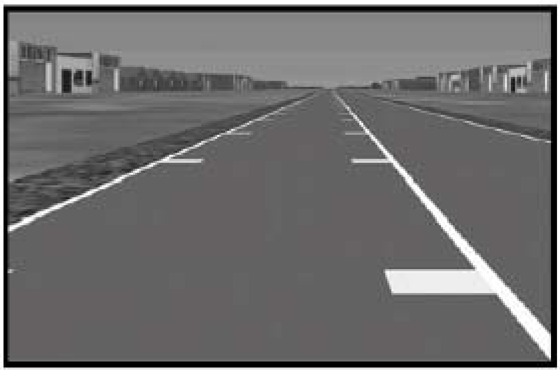

Figure 14: Peripheral optical bars (driving on the left) (from Godley *et al.*, 1999, used with permission from MUARC)

Godley *et al.* (1999) studied the effects of transverse optical bars and peripheral optical bars on speed choice. These were not specifically applied to curves, and so the results are reported in Section 3.4.3.

McGee and Hanscom (2006) cite studies in New York, Mississippi, and Texas that show that the transverse pavement markings can reduce mean, 85th percentile speeds and speed variance. They suggest that 85th percentile speed reductions varied from 0 to 5 mph (0 to 8 km/h).

Peripheral optical bars (or speed reduction markings) are covered in the US Federal Highway Administration (FHWA) 2009 Manual on Uniform Traffic Control Devices (MUTCD) Part 3B.22. The guidance suggests that they can be used on the approach to an unexpectedly severe curve or change in vertical alignment.

In New Zealand, a scheme trialled by Charlton (2007b) using a simulator appears to have the potential to reduce speeds by up to 5 km/h (depending on the radius of the curve) and also improve drivers' lateral position, by combining the use of chevron signs with a herringbone pattern.

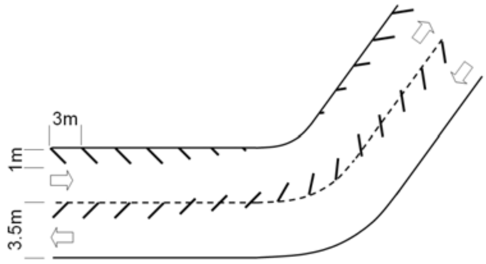

Figure 15: Images showing herringbone markings (driving on the left) (from Charlton, 2007b, used with permission from University of Waikato)

Martindale (in press) has recently undertaken two field studies to evaluate the effectiveness of herringbone markings used on the approach to an intersection and a bridge, both of which require drivers to reduce their speed on the approach in order to successfully negotiate them. The field studies were designed to follow on from the driving simulator work undertaken by Charlton and colleagues. Although the hazards in question are an intersection and a bridge, results may also have some relevance for the treatment of curves.

In the field trials, 85th percentile and marginal mean speeds were measured at three positions on the approach to a hazard (410m, 260m and 50m from the hazard) (see Figure 16). Measurements were taken before the treatment was applied, and at 2 weeks and 6 months post installation. Photographs of the treatment are shown in Figure 17.

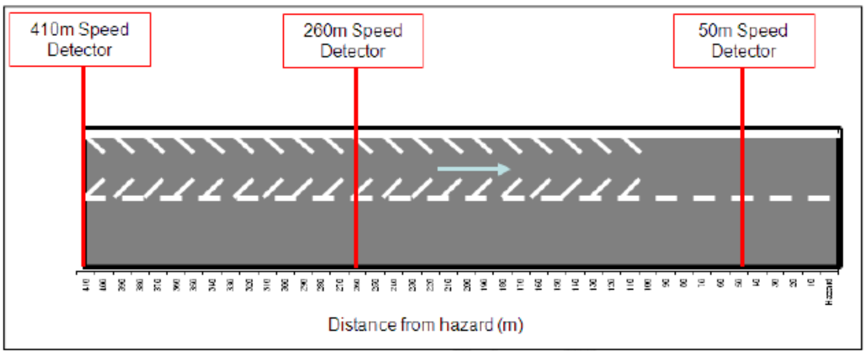

Figure 16: Speed detector locations used in the Martindale (in press) field studies (used with permission from Opus International Consultants Ltd. on behalf of NZTA)

Figure 17: Photographs of herringbone peripheral optical bar treatments (left – intersection, right bridge) (from Martindale, in press, used with permission from Opus International Consultants Ltd. on behalf of NZTA)

Vehicle speeds reduced on the approach to the hazards regardless of whether the treatment was present or not. However significant reductions in speeds were observed on the approach to the hazards above those observed prior to treatment. At the intersection site, speeds reduced significantly 2 weeks after the treatment was completed, at the beginning of the treatment (410m, 1.3 km/h marginal mean speed and 0.8 km/h 85th percentile speed) and immediately before the hazard (50m, 1.6 km/h marginal mean speed and 0.5 km/h 85th percentile speed). At the bridge site, significant speed reductions were only recorded at the beginning of the treatment (410m, 2.6 km/h marginal mean speed and 2.9 km/h 85th percentile speed), suggesting that the treatment may have an alerting effect.

For both sites, the treatment appeared to have an encouraging long term effect. After 6 months of installation, the speed reductions observed at the intersection site were higher at all speed detection positions (ranging from 2.3 km/h to 3.9 km/h). At the bridge site, speed reductions were significant at the beginning of the treatment (410m, 12.2 km/h marginal mean speed and 3.2 km/h 85th percentile speed) and just before the hazard (50m, 8.1 km/h marginal mean speed and 6.2 km/h 85th percentile speed).

Drakopoulos and Vergou (2003) studied real-life converging chevron markings (see Figure 18) as a method of reducing vehicle speeds by giving the illusion of the road narrowing and by increasing perception of speed as they were placed with reducing spacing. Although the study was not perfect due to data collection commencing after the treatment was installed, the findings suggested that the installation of converging chevron markings led to a reduction in speed on an exit ramp from a motorway of 12 mph (19 km/h).

Figure 18: Converging chevron markings (from Drakopoulos and Vergou, 2003, used with permission from AAAFTS)

How it Works

As spacing between bars gradually narrows, drivers sense they have increased speed and will slow down.

Optical Speed Bars, herringbone markings or converging chevron markings are intended for road sections where vehicles travelling at the design speed are required to slow for curves or other instances where traffic speeds should be reduced (e.g. transitions or intersections). To date, the treatment in the US has been restricted to known crash locations or situations requiring traffic to significantly reduce speed. Treatments of this type should be used sparingly in order to retain their effectiveness.

Treatment Information

Cost per site or km **(high, med-high, med, med-low, low)**	Initial	Medium-low
	Maintenance	Medium-low (peripheral optical bars may have lower maintenance costs)
Effectiveness (in enabling appropriate speed choice) **(high, med-high, med, med-low, low)**	Overall	Medium
	Car	Medium
	Truck	Medium
	Motorcycle	Medium
Impact on passive safety **(very positive, positive, neutral, negative, very negative)**	Overall	Neutral
	Car	Neutral
	Truck	Neutral
	Motorcycle	Neutral
Likely effectiveness for countries with high non-compliance with speed limits/rules **(high, med-high, med, med-low, low)**		Medium
Suitability in different weather conditions, at day and night, and different lighting conditions		Suitable and effective in most conditions, with the exception of snow and dense fog.
Is this feasible for tunnels?		Yes
Is this feasible for bridges?		Yes
Other safety impacts		Possible negative impact on the stability of motorcyclists with thick lining and low friction surface.
Environmental impact		Both paints and plastics used for road marking normally contain chemicals that are dangerous to health in high concentrations (Elvik and Vaa, 2004).
Acceptability by authorities		Good
Compatibility with existing design standards		Compatible
Additional guidance		It is best not to 'over-use' such measures since the impact of the unusual markings may diminish if they are too common. Markings should be used consistently, i.e. all dangerous curves should be marked in a similar manner. Efforts should be concentrated on particularly surprising curves, e.g. those that follow long, straight road sections. The permanence of the perceptual treatments is unknown, though initial results from Martindale (in press) are encouraging.

3.2.8 Visibility and Sight Distance

Description

At any point on a road, the available sight distance should be sufficient for a driver travelling at the design speed of the road to stop their vehicle safely without hitting a stationary object located on their path, and to see the geometry of the curve itself (PIARC, 2003).

According to Lee, Lee and Choi (2000, as cited in Charlton and de Pont, 2007) in Korea, speed on a curve is determined by forward visibility. They suggested that drivers slow down until their forward visibility is equal to their stopping sight distance as they approach and traverse the curve and then accelerate to their desired speed as visibility increases. However, Charlton and de Pont (2007) identified that Lee *et al.*’s data suggested that this was true only for smaller radius curves (less than 300m) and that on large radius curves the measured speeds were lower than those predicted by their model and so sight distance was not critical for these curves.

In road sections, most sight distance problems are related to the presence of horizontal or vertical curves. Obstacles located close to the roadway on the inside of curves can hinder visibility, such as embankments, vegetation, buildings, and so on (PIARC, 2003).

Figure 19: Insufficient visibility of the curve (1st class road I/50 near city of Brno)

How it Works

In the case of sight distance problems on curves, there are two main solutions:

- Where possible, adequate lateral clearance on the insides of curves should be provided to ensure stopping sight distance is up to standard
- Use of road signs and marking to enhance the conspicuity of the curve and to make drivers aware of the need to reduce their speed (see Sections 3.2.1 to 3.2.7)

Treatment Information

Cost per site or km **(high, med-high, med, med-low, low)**	Initial	Low, although costs can be high if additional verge width is required
	Maintenance	Low
Effectiveness (in enabling appropriate speed choice) **(high, med-high, med, med-low, low)**	Overall	Medium-low
	Car	Medium-low
	Truck	Medium-low
	Motorcycle	Medium-low
Impact on passive safety **(very positive, positive, neutral, negative, very negative)**	Overall	Neutral
	Car	Neutral
	Truck	Neutral
	Motorcycle	Neutral
Likely effectiveness for countries with high non-compliance with speed limits/rules **(high, med-high, med, med-low, low)**		Medium
Suitability in different weather conditions, at day and night, and different lighting conditions		Suitable
Is this feasible for tunnels?		No
Is this feasible for bridges?		No
Other safety impacts		None
Environmental impact		Removal of trees/foliage has a negative environmental impact.
Acceptability by authorities		Good
Compatibility with existing design standards		Compatible
Additional guidance		It is important to ensure that curves meet their country's standards for stopping sight distance or that measures to reduce speeds are undertaken. Innovative signing and lining may be required where there is poor conspicuity

3.2.9 Alignment

Description

The alignment of a road relates to the road's path in a horizontal and vertical plane (Elvik and Vaa, 2004). Consistency in alignment is essential. Optical illusions in the alignment and unexpected changes of the alignment should be avoided (PIARC, 2003). If there is no consistency in the alignment and no other treatments are possible, it is sometimes necessary to reconstruct the alignment of the road by:

- Increasing the radii of horizontal curves (effectively making curves less severe)
- Constructing transition curves
- Reducing the road's degree of deflection
- Increasing the distance between horizontal curves
- Reducing gradients
- Reducing the proportion of the road length which lies in sharp crest curves
- Reducing the proportion of the road which lies in sharp vertical curves


Figure 20: Examples of inconsistent alignment: sharp curve after long straight section worsened by position of trees in the background (left), curve on horizon (right)

How it Works

The road should not surprise the driver with unexpected changes in alignment. Improving the alignment make it easier to adopt appropriate speeds for curves, because the path of the road, and other road users, are more easily visible and predictable.

Treatment Information

Cost per site or km **(high, med-high, med, med-low, low)**	Initial	High
	Maintenance	Medium
Effectiveness (in enabling appropriate speed choice) **(high, med-high, med, med-low, low)**	Overall	High
	Car	High
	Truck	High
	Motorcycle	High
Impact on passive safety **(very positive, positive, neutral, negative, very negative)**	Overall	Neutral
	Car	Neutral
	Truck	Neutral
	Motorcycle	Neutral
Likely effectiveness for countries with high non-compliance with speed limits/rules **(high, med-high, med, med-low, low)**		Medium – high
Suitability in different weather conditions, at day and night, and different lighting conditions		Suitable
Is this feasible for tunnels?		No
Is this feasible for bridges?		No
Other safety impacts		If combined with work on the roadsides (e.g. roadside obstacles/safety barriers), could have other safety implications.
Environmental impact		Widening the verge may change the character of the road
Acceptability by authorities		Low due to cost and impact on land use
Compatibility with existing design standards		Compatible
Additional guidance		

3.3 Transitions

Transitions relate to changes in the type or function of road along a route. One common transition is the entrance to a town or village, known as a gateway. Treatments relating to gateways are covered in Section 3.3.1. Individual treatments are rarely used in isolation in this context and, as such, all gateway treatments are discussed under one subsection.

Transitions may also include other major changes in the characteristics of the road, for example speed limit changes or change in classification (e.g. dual carriageway to single carriageway road). Treatments that are relevant to these other transitions are discussed in Section 3.3.2.

The most critical transition in terms of speed adaptation is where the driver or rider is expected to reduce their speed when entering a less rural area where they may meet a higher number of pedestrians and/or bicyclists. Typical changes in speed limit in this case are from 60 mph to 30 or 40 mph in the UK, or from 90 km/h to 50 km/h in continental Europe. Often speed limit changes are progressive (e.g. 90 km/h to 70 km/h to 50 km/h). Clearly this change will require a speed limit sign, but by itself a sign will not always slow drivers sufficiently.

3.3.1 Gateways

Description

When the transition is from a rural road to a village or town, it is generally called a gateway. Its purpose is to alert the road user to a change in the type of environment to one where a different type of driving is required, for example where there may be a greater concentration of Non-Motorised Users (NMUs).

Gateways usually consist of a number of features; these may include physical measures such as build outs, islands, and median treatments in combination with lining, signing and surface treatments.

A build out is a feature extending into the roadway which slightly narrows the road. Where there are build outs on both sides of the road, the narrowing is sometimes referred to as a pinch point. Build outs and pinch points are generally physical but can also be created using hatching to visually narrow the road.

Unusual road linings and/or signings can be used to alert road users to a change in road type/function along a route, and encourage drivers to slow down. Such measures may include dragons' teeth/sharks' teeth, edge markings, hatching, illusory pinch point or channelization.

Unusual or radical signings can be used to alert road users to the fact that something fundamental is changing, and encourage drivers to slow down. The presence of a speed limit sign is critical in ensuring appropriate speed choice.

Unusual surface treatments can be used to alert road users to the fact that something fundamental is changing, and encourage drivers to slow down. Such measures may include coloured textures and/or surfaces (Section 3.2.4), and transverse rumble trips (Section 3.2.6) or optical bars (Section 3.2.7).

Research by TRL into village gateway schemes (e.g. Wheeler and Taylor, 1999 and references therein) found that simple signing and marking measures may reduce mean speeds by about 1-2 mph (2 km/h to 3 km/h) compared to a speed limit sign alone, whilst more comprehensive gateway measures with high visual impact (e.g. coloured road surfacing and dragons teeth) may reduce mean speeds by 5-7 mph (8 km/h to 11 km/h). When physical measures have been used at gateways (e.g. narrowings using build-outs), even greater reductions in mean speeds have been found, up to about 10 mph (16 km/h). In general, combinations of measures were found to be most effective (Kennedy *et al.*, 2005).

The research noted that measures need to be continued beyond the gateway in order to maintain speed reductions through the village itself. It should be pointed out that inhabitants of rural villages often object to the measures with the greatest visual impact such as red surfacing as being visually intrusive.

Figure 21 to Figure 27 show examples of gateways with various different treatments.

Figure 21: Gateways including signs, buildouts and hatching, image on right has the centre line removed (driving on the left) (Kennedy *et al.*, 2005, used with permission)

Figure 22: Gateway with speed limit change, dragons teeth marking, yellow backing boards for speed limit sign and speed roundels enhanced by coloured surfacing (driving on the left)

Figure 23: Gateway with dragons/sharks teeth marking (driving on the left)

Figure 24: Gateway with speed limit change, 'gate' feature, rumble strips and speed roundel (driving on the left) (Kennedy and Wheeler, 2001, used with permission)

Figure 25: Transition with coloured road surface (driving on the left)

Figure 26: Gateway with lateral and central islands

Figure 27: Example of a surface treatment in a transition area (from 70 to 50 km/h; entering a built-up area - Belgium)

How it Works

Gateways work by accentuating the signing that marks the transition point, usually where there is a change in speed limit. They make drivers and riders aware that they may now be expected to interact with NMUs.

Physical measures such as build outs or a central island, may force drivers to reduce their speed in order to negotiate them. Other measures are likely to have a more subtle effect on driver speed, by reminding them of the speed limit, by emphasizing the change in environment or by visually narrowing the road (hatching).

One means of providing visual narrowing is the suggestion by the National Roads Authority in the Republic of Ireland that gateway structures could be made particularly tall (Figure 28) to give the illusion of a narrower road (International Road Assessment Programme (iRAP)). A place with a clear sense of arrival might indicate a sense of ownership by the village, to which some drivers might respond by reducing speed (see Elliott *et al.*, 2003).

Figure 28: Gateway including signs, a median island and cross hatching (driving on the left) (image supplied by NRA)

Some unusual road markings, signings or surface treatments may alert drivers/riders to a change in road type, and influence their speed choice accordingly.

Illusory pinch points or channelization can be used to give the impression that the road is slightly narrower than it was previously. This may therefore result in drivers/riders slowing down. Markings can be used at either the edge of the road, in the median or in both locations. Care should be taken to ensure that drivers/riders do not change their lane position such that either run-off road or head-on crashes may become more likely.

Several studies have found that road users narrow their visual field of attention at higher speed. The ideal place for attention markers is close to the surface of the road or several meters above the eyes of the road users.

Treatment Information

Cost per site or km **(high, med-high, med, med-low, low)**	Initial	Depends on treatment adopted.
	Maintenance	Depends on treatment adopted.
Effectiveness (in enabling appropriate speed choice) **(high, med-high, med, med-low, low)**	Overall	Medium-high depending on treatment adopted.
	Car	Medium-high depending on treatment adopted.
	Truck	Medium-high depending on treatment adopted.
	Motorcycle	Medium-high depending on treatment adopted.
Impact on passive safety **(very positive, positive, neutral, negative, very negative)**	Overall	Mostly neutral, particularly if structures and posts are passively safe.
	Car	Neutral
	Truck	Neutral
	Motorcycle	Mostly neutral, physical measures may be a hazard; structures and signs need to be passively safe and markings need to be skid resistant.
Likely effectiveness for countries with high non-compliance with speed limits/rules **(high, med-high, med, med-low, low)**		Medium
Suitability in different weather conditions, at day and night, and different lighting conditions		Suitable and effective in most conditions, with the exception of snow and dense fog. Red/buff coloured surfaces are not very visible at night.
Is this feasible for tunnels?		No
Is this feasible for bridges?		No
Other safety impacts		Possible negative impact on the stability of motorcyclists with thick lining and low friction surface.
Environmental impact		The most effective measures are often the most visually intrusive. Both paints and plastics used for road marking normally contain chemicals that are dangerous to health in high concentrations (Elvik and Vaa, 2004).
Acceptability by authorities		Good
Compatibility with existing design standards		Compatible
Additional guidance		Physical measures are a good choice where there is a speeding problem. A combination of measures generally produces the best effect. Structures and signs need to be passively safe. Any surface features need to be skid resistant for motorcycles. Stable friction from the classical pavement to the coloured surfacing should be maintained as far as possible. Unusual treatments should be used infrequently to preserve their impact. The permanence of the perceptual treatments (e.g. tall signs) is unknown. There may be a novelty effect associated with VAS with effectiveness reducing over time. Improvements to lighting near gateways may have additional benefits.

3.3.2 Other Transitions

Description

Transitions other than gateways do not necessarily involve a change in the speed limit, but need drivers to become aware of the change in character of the road and to slow down.

Figure 29 gives an example of a transition to a narrower road.

Figure 29: Transition to narrower road using yellow backing boards to enhance signs and coloured surfacing for emphasis

How it Works

As for gateways, a combination of treatments is likely to work best. Physical treatments as less likely to be used, but changes in road markings such as rumble strips and coloured surfacing can be effective as they alert drivers to the hazard ahead even if they have little effect on speed.

Treatment Information

Cost per site or km **(high, med-high, med, med-low, low)**	Initial	Depends on treatment adopted.
	Maintenance	Depends on treatment adopted.
Effectiveness (in enabling appropriate speed choice) **(high, med-high, med, med-low, low)**	Overall	Medium-high depending on treatment adopted.
	Car	Medium-high depending on treatment adopted.
	Truck	Medium-high depending on treatment adopted.
	Motorcycle	Medium-high depending on treatment adopted.
Impact on passive safety **(very positive, positive, neutral, negative, very negative)**	Overall	Mostly neutral, particularly if structures and posts are passively safe.
	Car	Neutral
	Truck	Neutral
	Motorcycle	Mostly neutral, physical measures may be a hazard; structures and signs need to be passively safe and markings need to be skid resistant.
Likely effectiveness for countries with high non-compliance with speed limits/rules **(high, med-high, med, med-low, low)**		Medium
Suitability in different weather conditions, at day and night, and different lighting conditions		Suitable and effective in most conditions, with the exception of snow and dense fog.
Is this feasible for tunnels?		No
Is this feasible for bridges?		No
Other safety impacts		Possible negative impact on the stability of motorcyclists with thick lining and low friction surface.
Environmental impact		The most effective measures are often the most visually intrusive. Both paints and plastics used for road marking normally contain chemicals that are dangerous to health in high concentrations (Elvik and Vaa, 2004).
Acceptability by authorities		Good
Compatibility with existing design standards		Compatible
Additional guidance		Physical measures are a good choice where there is a speeding problem. A combination of measures generally produces the best effect. Structures and signs need to be passively safe. Any surface features need to be skid resistant for motorcycles. Stable friction from the classical pavement to the coloured surfacing should be maintained as far as possible. Unusual treatments should be used infrequently to preserve their impact. There may be a novelty effect associated with VAS with effectiveness reducing over time.

3.4 Intersections

The types of intersection occurring on rural single carriageway roads are:

- Major/minor priority cross roads
- Major/minor priority T-junctions
- Roundabouts
- Traffic signals (occasionally)

The number of intersections and access points per unit length along a route has a major impact on the crash frequency. At individual junctions the crash frequency increases with the number of legs, because of the associated increase in conflict points (PIARC, 2003). At major/minor intersections, the higher the proportion of traffic entering the intersection from the minor road, the higher the crash frequency is. Where there is a high proportion of traffic on the minor road at a major/minor intersection, conversion to a roundabout reduces the number of conflict points, in particular because right angle crashes (between vehicles entering the intersection at ninety degrees) are largely designed out. An additional benefit of roundabouts is that drivers have to slow down in order to negotiate them, so that crashes are less severe. Drivers going ahead on the major road at a major/minor intersection need to be aware of the intersection and the possibility of vehicles entering from the minor road. Those who are turning need to slow down in order to negotiate the junctions. Drivers on the minor road at a major/minor intersection or those approaching a roundabout or signal controlled intersection need to be able to slow down or stop in good time. Improving the conspicuity of intersections, especially those that are unexpected (e.g. the first after a long stretch with no intersections) can help drivers adapt their speed.

Advance warning signs and direction signs are typically used to warn of the presence of intersections. Treatments that may encourage appropriate speed choice at intersections by emphasizing the presence of the junction include:

- Additional or enhanced signing (Section 3.4.1)
- Lining/roadway markings (Section 3.4.2)
- Surface treatments (Section 3.4.3)
- Layout and junction type (Section 3.4.4)
- Visibility (Section 3.4.5)

3.4.1 Additional or Enhanced Signing

Description

Existing signs may be enhanced by the use of yellow backing boards (although these are visually intrusive). It may be appropriate to use Vehicle Activated Signs (VAS) to remind faster drivers/riders to reduce their speed.

For highlighting minor intersections, the National Roads Authority in Republic of Ireland use demarcation posts (see Figure 30) that identify the 'mouth' of the intersection.

Figure 30: Junction demarcation posts in the Republic of Ireland (used with permission from NRA)

How it Works

If drivers/riders are travelling on a minor road, there is a risk that they may enter the intersection without stopping. Enhanced signing helps to alert drivers to the presence of the intersection and the need to stop or give way.

If drivers/riders are travelling on a main road and intend to make a turning manoeuvre into a minor road, making them aware of the exact location of the turn will help them in adapting their speed for making the turning manoeuvre.

VAS work by alerting drivers to the presence of an intersection, some are activated only by higher speed drivers who are potentially at risk or who may pose a risk to other road users. They should be used in addition to conventional signing and sparingly in order to preserve their novelty. See also Section 3.2.3.

Treatment Information

Cost per site or km **(high, med-high, med, med-low, low)**	Initial	Low
	Maintenance	Low
Effectiveness (in enabling appropriate speed choice) **(high, med-high, med, med-low, low)**	Overall	Medium
	Car	Medium
	Truck	Medium
	Motorcycle	Medium
Impact on passive safety **(very positive, positive, neutral, negative, very negative)**	Overall	Sign posts need to be passively safe.
	Car	Sign posts need to be passively safe.
	Truck	Sign posts need to be passively safe.
	Motorcycle	Sign posts need to be passively safe.
Likely effectiveness for countries with high non-compliance with speed limits/rules **(high, med-high, med, med-low, low)**		High
Suitability in different weather conditions, at day and night, and different lighting conditions		Suitable and effective in most conditions, with the exception of dense fog.
Is this feasible for tunnels?		Yes
Is this feasible for bridges?		Yes
Other safety impacts		None
Environmental impact		Yellow backing boards are visually intrusive.
Acceptability by authorities		Good
Compatibility with existing design standards		Compatible
Additional guidance		VAS need to be used sparingly in order to preserve their novelty.

3.4.2 Lining/Roadway Markings

As for curves and transitions (see Sections 3.2.2 and 3.3.1).

3.4.3 Surface Treatments

Unusual surface treatments can be used to alert road users to the fact that something fundamental is changing, and encourage drivers to slow down. Such measures may include coloured textures and/or surfaces (Section 3.2.4), SLOW markings (Section 3.2.5) and transverse rumble trips (Section 3.2.6) or optical bars (Section 3.2.7). See also surface treatments in transitions (Section 3.3.1).

In driving simulator studies Godley *et al.* (1999) found that, for intersections, transverse lines were effective in reducing speed on the approach by up to 11 km/h. The effectiveness of speed reduction was not influenced by the spacing between lines, and peripheral optical bars were only slightly less effective than those covering the whole width of the lane. Godley *et al.* suggest that transverse lines alert drivers to a potential hazard and also influence perception of speed. Although they did not test this, Godley *et al.* (1999) suggest that their effect is likely to be long-term.

The field studies undertaken by Martindale (in press), provide evidence that peripheral transverse optical bars in a herringbone pattern can have significant and lasting effects on speed choice on the approach to an intersection (see Section 3.2.7). At the site where the treatment was used to slow vehicles on the approach to an intersection, significant speed reductions were observed of between 2 and 3 km/h at the beginning of the treatment (410m before the intersection) 2 weeks after installation. After 6 months of installation significant speed reductions were observed at the beginning of the treatment (12.2 km/h marginal mean speed and 3.2 km/h 85th percentile speed) and 50m before the intersection (8.1 km/h marginal mean speed and 6.2 km/h 85th percentile speed).

In the UK, considerable success has been achieved using transverse yellow bar markings on the approach to roundabouts on high speed roads, usually dual-carriageways (Helliar-Symons, 1981). Although speed reduction is often minimal, crashes have been found to reduce by 50% on the roundabout leg where they are used. Yellow bar markings are spaced at irregular decreasing intervals and are intended to increase the driver' perceived speed, encouraging them to slow down. They are particularly successful in situations where a driver has been travelling at high speed for some time. At some installations, they also have a vibratory effect. However, their use in UK is reserved for roundabouts.

Figure 31: Yellow bar markings on a dual carriageway approach to a roundabout

3.4.4 Layout and Intersection Type

Description

Redesigning intersections includes:

- Changes to the angle between roads
- Changes to the gradients of roads approaching the intersection
- Change of the intersection type
- Channelization

The use of channelization at an intersection is a measure to segregate different streams of traffic. It can be carried out using physical traffic islands, road markings (hatching) or a combination.

For example at a major/minor T-junction on a single-carriageway road, a separate lane can be created for drivers turning left (for continental Europe, right for countries who drive on the left) into the minor road. This will reduce the likelihood of the waiting vehicle being hit from behind. However, it will not reduce the speed of traffic going ahead on the main road and this may make it more difficult for traffic turning out of the minor arm of the intersection to join the road. In particular, traffic turning out of the minor road will have further to travel to complete the turn and this may increase risk. Whether there is a net safety benefit depends on the particular layout.

Figure 32 shows a rural intersection in South Moravia, Czech Republic near the Austria border, originally with very high accident rate. After reconstruction of all the signs and markings, the accident rate has dropped. However, there is still the problem of accidents because of the large area and high speeds on the major road. Only a paucity of drivers follow the speed limit of 70 km/h and real speeds are 100 km/h and more. Change in the type of intersection to a roundabout would probably lead to better safety.

Figure 32: Turning pockets provided for traffic turning left from the major road and right turning lanes provided, however vehicle speeds travelling through the junction are still high (1st class road, Czech republic)

If the intersection is a cross roads on a single carriageway road, options are:

- Convert to a roundabout
- Channelize the junction to segregate the traffic
- Stagger the cross roads so that it acts as a pair of T junctions

All of these will have safety benefits. In addition, a roundabout will reduce speeds on all approaches.

How it Works

Redesigning of intersections may improve conspicuity allowing road users to better judge the speed that they should negotiate the junction.

Redesigning intersections may make the intersection geometry clearer to road users and may simplify turning manoeuvres.

Figure 33: Unsafe layout of T-intersection ready for re-design (left), re-design of intersection into a roundabout where a large reduction in casualties and accidents has been observed (right)

Physical deflections (such as those found on the entry to roundabouts) reduce speeds and hence the severity of crashes. They also ensure that crashes do not occur at ninety degree angles.

Treatment Information

Cost per site or km **(high, med-high, med, med-low, low)**	Initial	High
	Maintenance	Medium
Effectiveness (in enabling appropriate speed choice) **(high, med-high, med, med-low, low)**	Overall	High if convert to roundabout. Medium for physical deflection.
	Car	High if convert to roundabout. Medium for physical deflection.
	Truck	High if convert to roundabout. Medium for physical deflection.
	Motorcycle	Medium
Impact on passive safety **(very positive, positive, neutral, negative, very negative)**	Overall	Positive
	Car	Positive
	Truck	Positive (although sharp angles may be problematic in terms of negotiation/roll-over)
	Motorcycle	Positive (although roundabouts may be problematic)
Likely effectiveness for countries with high non-compliance with speed limits/rules **(high, med-high, med, med-low, low)**		High if convert to roundabout. Medium for physical deflection.
Suitability in different weather conditions, at day and night, and different lighting conditions		Suitable
Is this feasible for tunnels?		No
Is this feasible for bridges?		No
Other safety impacts		It depends on the form of channelization, however separating traffic intending to make different manoeuvres reduces the amount of conflict and can provide a safe refuge for those waiting to make a turn. Roundabouts have less severe conflict points than T-junctions/crossroads. Can reduce severity of crashes through ensuring they are glancing blows rather than at ninety degrees.
Environmental impact		Some forms of channelization increase the footprint of the junction. Both paints and plastics used for road marking normally contain chemicals that are dangerous to health in high concentrations (Elvik and Vaa, 2004).
Acceptability by authorities		Good
Compatibility with existing design standards		Compatible
Additional guidance		Ensure safety is not compromised through re-design by completing Road Safety Audits. Ensure passive safety is not worsened through the placement of roadside furniture.

3.4.5 Sight Distances/Visibility

Description

Drivers approaching an intersection should have the full stopping sight distance required in order to be able to stop in good time. In addition, drivers on the minor road at a major/minor intersection should have sufficient visibility to be able to complete their turn safely. At a roundabout, drivers require good visibility of the adjacent leg and of the roundabout circulatory roadway so that they can see approaching drivers to whom they have to give way and other vehicles on the circulatory roadway.

How it Works

Having good sight distances/visibility at junctions helps drivers/riders to see the intersection geometry earlier, allowing them to choose appropriate speeds. On roads where the normal visibility requirements are not met, it may be possible to improve sight distances/visibility by removing visual obstructions.

In some cases, too much visibility can encourage greater speeds as it allows drivers to see that there are no other vehicles approaching. It may be appropriate to deliberately limit visibility on the approach to an intersection in order to increase uncertainty and slow vehicles down. However, care must be taken that normal visibility requirements are met. As an example, vehicles approaching a roundabout may be able to see from a distance that there is no vehicle approaching on the adjacent leg and may therefore fail to slow sufficiently to safely negotiate the roundabout. Visibility to the right may be reduced by screening until the vehicle is within 15m of the give way (yield) line. The screening (which could be suitable vegetation) should be at least 2m high in order to block the view of all road users. On dual carriageway roads, the screening is placed on the central reserve. It can also be used on single carriageway roads where there is a long splitter island.

Treatment Information

Cost per site or km **(high, med-high, med, med-low, low)**	Initial	Medium
	Maintenance	Medium
Effectiveness (in enabling appropriate speed choice) **(high, med-high, med, med-low, low)**	Overall	Medium
	Car	Medium
	Truck	Medium
	Motorcycle	Medium
Impact on passive safety **(very positive, positive, neutral, negative, very negative)**	Overall	Positive - removal of trees/foliage may also have passive safety benefits.
	Car	Positive - removal of trees/foliage may also have passive safety benefits.
	Truck	Positive - removal of trees/foliage may also have passive safety benefits.
	Motorcycle	Positive - removal of trees/foliage may also have passive safety benefits.
Likely effectiveness for countries with high non-compliance with speed limits/rules **(high, med-high, med, med-low, low)**		Medium-high
Suitability in different weather conditions, at day and night, and different lighting conditions		Suitable
Is this feasible for tunnels?		No
Is this feasible for bridges?		No
Other safety impacts		None
Environmental impact		Removal of trees/foliage has a negative environmental impact.
Acceptability by authorities		Good
Compatibility with existing design standards		Compatible
Additional guidance		Care is needed to ensure that if visibility is restricted it remains adequate. Restricting visibility is likely to be a site-specific solution, for example, at roundabouts, it is appropriate where the circulating flow past the entry is low. If not, other treatments may be more suitable.

3.5 Links

For the purposes of this paper, 'links' refer to straight sections of road in between intersections and transitions.

Unlike for the other Sections, this Section includes road attributes that may influence speed choice as well as 'treatments' per se. These may include:

- Lanes (width and number of lanes in each direction) (Section 3.5.1)
- Surface quality and treatment (Section 3.5.2)
- Illusory lane width markings (Section 3.5.3)
- Median and edge treatments (Section 3.5.4)
- Barriers (Section 3.5.5)
- Shoulder (Section 3.5.6)
- Repetitive roadside objects (Section 3.5.7)

3.5.1 Lanes

Description

The width of lanes and number of lanes in each direction are road design attributes that are likely to influence speed choice. It is however relatively unlikely that, in a rural situation, these attributes will be changed with the sole purpose of influencing speed.

On a single carriageway road, there is normally one lane in each direction. There are two ways in which extra lanes might be added, firstly the use of climbing lanes for slow vehicles and secondly in the 2+1 layout, which has two lanes in one direction and one in the other, allowing improved overtaking opportunities for the direction with two lanes. In the UK, this layout fell out of favour because of collisions at the changeover points, and the three lanes of 3.3m width were replaced by wide single carriageways having one lane of 5m width in each direction. Following this, 2+1 roads with improved markings at changeover points have been introduced into the UK (see design standard TD 70/08, DMRB 6.1.4). The UK version of the 2+1 layout did not have a median barrier and so head on collisions could still have been an issue.

A new 2+1 layout was devised in Sweden with a wire rope safety barrier in the median, as shown in Figure 34, to reduce changeover collisions in addition to reducing head-on collisions. A number of other countries such are Iceland and Ireland have adopted the design with a median barrier.

Figure 34: Type 3 carriageway design (2+1) in Ireland with two lanes in one direction and one lane in the opposite direction, which alternates every 1,500m, separated by a wire rope barrier (used with permission from NRA)

It is worth noting that the NRA in the Republic of Ireland now favours a 2+2 design with a median barrier as shown in Figure 35 over the 2+1 design (iRAP). The new 2+2 design has only a slightly wider footprint and only a slightly greater cost while offering greater benefits in terms of increased throughput and overtaking opportunity. Its other advantage is the elimination of the changeover points.

Figure 35: Type 2 carriageway design in Ireland consisting of 2 lanes in each direction separated using a wire rope barrier (used with permission from NRA)

According to Elvik and Vaa (2004), there are inconsistent results concerning the effect of lane width on the number of accidents. The width of a lane may influence drivers'/riders' speed choice. Overall collision rates go down with increasing lane width; however it is likely that speed may increase as lane width increases.

Lanes could be narrowed using hatching in the middle of the road, widening the hard shoulder at the edge of the road, or by designing lanes to be narrower as per the 2+1 or 2+2 designs. (Illusory measures covering road width are covered in Section 3.5.3).

If lane widths are reduced, then there may be other negative safety consequences due to greater proximity to roadside obstacles or to vehicles in the opposite direction and reduced lateral clearance. Very wide lanes can have negative safety consequences since they invite risky overtaking manoeuvres (see Figure 36).

Figure 36: Wide lane widths inviting risk overtaking manoeuvres in Czech Republic

How it Works

Increasing lane width generally has a positive effect on collision rates in countries where lane discipline is good (though as noted earlier, results of studies are inconsistent, Elvik and Vaa 2004). However, it is likely that drivers/riders will choose to adopt higher speeds on roads with wider lanes as they appear to be more 'open'. Moreover, higher quality roads tend to have wider lanes; therefore drivers/riders may choose faster speeds that are considered appropriate for higher quality roads. Narrowing lanes will have negative consequences in terms of reduced room for correction, and so the best approach may be to give the illusion that the lanes are narrow, but without reducing the lane width (see Section 3.5.3).

According to Elvik and Vaa (2004), Norwegian before-and-after studies, controlling for trends and regression to the mean, found that increasing the number of lanes from 2 to 4, or from 4 to 6, and adding a median reduced the frequency of injury accidents by 51%. However it is not known whether speeds increase or decrease with a greater number of lanes. An increase in the number of lanes may result in higher traffic speeds, as drivers perceive the road to be higher quality and therefore consider higher speeds to be appropriate. Any safety benefits may relate to the opportunity of safer overtaking manoeuvres.

Treatment Information

Cost per site or km **(high, med-high, med, med-low, low)**	Initial	High if increasing number of lanes, low if reducing lane width.
	Maintenance	Medium
Effectiveness (in enabling appropriate speed choice) **(high, med-high, med, med-low, low)**	Overall	Medium-low (if lane width or number of lanes is reduced).
	Car	Medium-low
	Truck	Medium-low
	Motorcycle	Medium-low
Impact on passive safety **(very positive, positive, neutral, negative, very negative)**	Overall	Negative (if lane width or number of lanes is reduced there may be reduced lateral room for correction).
	Car	Negative
	Truck	Negative
	Motorcycle	Negative
Likely effectiveness for countries with high non-compliance with speed limits/rules **(high, med-high, med, med-low, low)**		Some 2+1 design roads with wide shoulders can lead to erratic and chaotic traffic movements where discipline is poor, with drivers weaving and using the hard shoulder incorrectly.
Suitability in different weather conditions, at day and night, and different lighting conditions		Yes
Is this feasible for tunnels?		No
Is this feasible for bridges?		No
Other safety impacts		Reduced lane width reduces room for correction and distance from roadside obstacles. Reducing the number of lanes may lead to risky overtaking manoeuvres.
Environmental impact		Reduced lane width/number of lanes would not be acceptable due to reduction in capacity. Conversion to 2+1 layout is acceptable.
Acceptability by authorities		Reduced lane width/number of lanes would not be compatible as function and traffic volume will not match.
Compatibility with existing design standards		Care is needed to ensure that lanes are not too narrow (minimum 3.5m for 2+1 design in UK standard for Highways Agency roads).
Additional guidance		

3.5.2 Surface Quality and Treatments

Description

The quality of a road surface may affect drivers'/riders' speed choices. For example, drivers may adopt slower speeds on a differently coloured road surface or a different surface texture (this may only be appropriate on urban roads), or drive more quickly if they are not encountering pot holes regularly. The skid resistance of roads needs to be regularly checked to ensure it has not fallen to critically low levels, particularly on curves and the approach to junctions.

In terms of coloured surfacing, it should only be used to emphasize standard signing and marking at risky locations. It should not be used for long lengths of rural road, unless a cycle lane is added in order to narrow the roadway. The colour red is often associated with danger and so red is the colour most commonly used (see also Sections 3.2.4, 3.3.1, 3.4.3). However, red is visually intrusive and buff (a slightly lighter and less vibrant colour) may be preferable on rural roads.

Chevron surface markings are used to encourage appropriate headway distances between vehicles. The chevron markings are accompanied by signs asking motorists to keep 'two chevrons apart' (UK Highways Agency). Although the primary purpose of these markings is to encourage drivers to adhere to the two second rule for following distances, these measures may also impact upon vehicle speeds. This treatment is only approved for motorways in UK, and would certainly not be appropriate on roads that are not straight.

If a road surface is particularly poor with an even concentration of potholes, it is thought that this may improve safety by reducing vehicle speeds. This however is not an approach that would be recommended, particularly on primary routes, due to safety implications of negotiating a road with potholes at speed.

Re-asphalting roads does not appear to lead to statistically significant changes in the number of accidents, perhaps because the increased grip provided by the new surface compensates for any increase in traffic speeds. This is true for both injury accidents and accidents involving property damage only.

How it Works

The use of coloured surfacing to enhance signing and marking helps to emphasize the presence of a hazard and may increase alertness even if it does not affect speeds. On curves, drivers may assume it has good skid resistance and may therefore slow down less on the curve.

Treatment Information

Cost per site or km **(high, med-high, med, med-low, low)**	Initial	Medium (cost dependent on treatment undertaken).
	Maintenance	Medium
Effectiveness (in enabling appropriate speed choice) **(high, med-high, med, med-low, low)**	Overall	Medium for surface treatments. Negative speed consequences for surface quality improvements.
	Car	Medium
	Truck	Medium
	Motorcycle	Medium
Impact on passive safety **(very positive, positive, neutral, negative, very negative)**	Overall	Neutral
	Car	Neutral
	Truck	Neutral
	Motorcycle	Neutral
Likely effectiveness for countries with high non-compliance with speed limits/rules **(high, med-high, med, med-low, low)**		Medium
Suitability in different weather conditions, at day and night, and different lighting conditions		Suitable and effective in most conditions, with the exception of snow and dense fog. Red/buff coloured surfaces are not very visible at night. Great benefits for improved surface in poor weather conditions.
Is this feasible for tunnels?		Yes
Is this feasible for bridges?		Yes
Other safety impacts		May use coloured surface that also improves skid resistance. Possible negative impact on the stability of motorcyclists due to surface changes.
Environmental impact		Red is visually intrusive.
Acceptability by authorities		Good
Compatibility with existing design standards		Compatible
Additional guidance		It is best not to ‘over-use’ such measures since the impact of the unusual markings may diminish if they are too common.

3.5.3 Illusory Lane Width Markings

Description

Some road surface markings have been suggested to give the illusion of the roads being narrower, these include the Herringbone and Wundt patterns (see Figure 37 and Figure 38).

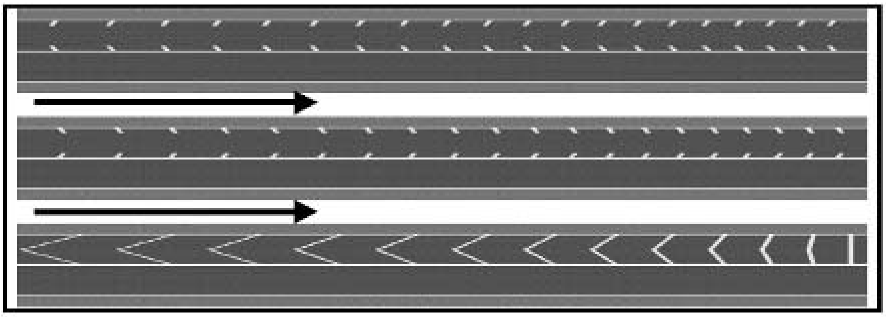

Figure 37: Herringbone pattern with lines pointing backwards (top), herringbone pattern with lines pointing forwards (middle), Wundt pattern (bottom) (from Godley *et al.*, 1999, used with permission from MUARC)

Figure 38: Drivers' view of herringbone (left) and Wundt patterns (right) in a simulator (from Godley *et al.*, 1999, used with permission from MUARC)

How it Works

Godley *et al.* (1999) tested these patterns as it was thought that they give the perceptual impression that the lane width is narrower than it is in reality. The desired result is for drivers/riders to reduce their speeds due to the increased perception of risk associated with narrow lanes.

The herringbone treatment tested by Godley *et al.* (1999) in a driving simulator was effective in reducing speed on the approach to a hazard, but no more so than other similar treatments such as peripheral transverse bars/lines (see Section 3.2.7). The speed reduction observed when the Wundt illusion had been used was no greater than for transverse bars/lines. There was no evidence that any of the treatments gave drivers the impression that the lane ahead was becoming narrower.

Drakopoulos and Vergou (2003) studied real-life converging chevron markings as a method of reducing vehicle speeds by giving the illusion of the road narrowing and by increasing perception of speed as they were placed with reducing spacing. Although the study only collected data after the treatment was installed, the findings suggested that the converging chevron markings led to a reduction in speed on an exit ramp from a motorway of 12 mph (19 km/h).

Treatment Information

Cost per site or km (high, med-high, med, med-low, low)	Initial	Medium
	Maintenance	Medium
Effectiveness (in enabling appropriate speed choice) (high, med-high, med, med-low, low)	Overall	Medium-high
	Car	Medium-high
	Truck	Medium-high
	Motorcycle	Medium-high
Impact on passive safety (very positive, positive, neutral, negative, very negative)	Overall	Neutral
	Car	Neutral
	Truck	Neutral
	Motorcycle	Neutral
Likely effectiveness for countries with high non-compliance with speed limits/rules (high, med-high, med, med-low, low)		Medium
Suitability in different weather conditions, at day and night, and different lighting conditions		Suitable and effective in most conditions, with the exception of snow and dense fog.
Is this feasible for tunnels?		Yes
Is this feasible for bridges?		Yes
Other safety impacts		Possible negative impact on the stability of motorcyclists with thick lining and low friction surface. Markings need to be skid resistant to ensure motorcycle safety. No negative impact on room to correct.
Environmental impact		Both paints and plastics used for road marking normally contain chemicals that are dangerous to health in high concentrations (Elvik and Vaa, 2004).
Acceptability by authorities		Herringbone markings would probably be acceptable.
Compatibility with existing design standards		The use of chevrons might be confused with hatching and may not be acceptable for this reason.
Additional guidance		It is best not to 'over-use' such measures since the impact of the unusual markings may diminish if they are too common. Their use should be reserved for alerting drivers to hazards. Taking relative treatment costs into account, the herringbone pattern and Wundt illusion cannot be recommended for implementation on the road over peripheral and full lane width transverse lines. The permanence of the perceptual treatments is unknown.

3.5.4 Median and Edge Treatments

Description

Treatments include line markings, reflective markings, centre and edge line rumble strips and road studs. Less common treatments such as 3D line markings and unusual patterns are also included in this category.

The Drenthe Province treatment was developed in Netherlands in order to reduce speed variance on 80 km/h rural roads which had a lot of slow-moving farm vehicles. The road was effectively narrowed by making it uncomfortable for car occupants who exceeded the speed limit unless they kept to the centre of the lane (2.25m wide). Larger vehicles were not affected. The white edge lines were replaced by 4m long rectangles of rough surface (chippings) interspersed by 4m gaps where the road surface remained unchanged. Rough surfacing was also used between the white dashes in the widened centre line. The mean speed of subjects in an instrumented car was reduced by up to 3 km/h. Driving simulator studies completed by Godley *et al.* (1999) suggested that the treatment reduced vehicle speeds by 1.88 km/h (compared to a wider control road).

As the Drenthe lane was too narrow for the Australian situation, Godley *et al.* (1999) tested two alterative perceptual treatments (one painted hatching and the other gravel) applied to the median (see Figure 39) in a driving simulator. These had a relatively wide marked median, with the additional benefit of increasing the separation of opposing vehicles. These measures were designed to influence speed independently of lane width by 'speed perception enhancement' (hatching) and 'discomfort avoidance' (gravel). The hatching treatment offered the greatest potential, with a speed reduction of 3 km/h on straight sections of road.

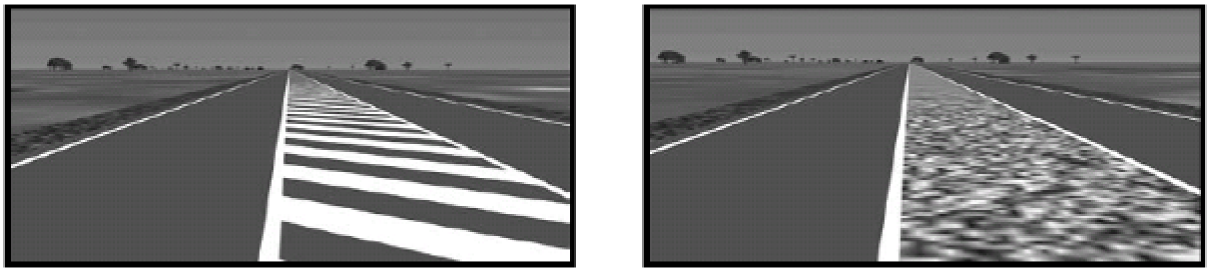

Figure 39: The narrow (2.5 metre) perceptual lane width roads with a median containing painted hatching (left) and white gravel (right) in a driving simulator (from Godley *et al.*, 1999, used with permission from MUARC)

Godley *et al.* (1999) also tested a chequered edge line in a driving simulator (Figure 40), however there was no speed reduction above that already observed for the hatching treatment.

Figure 40: Innovative centre and edge lines (from Godley *et al.*, 1999, used with permission from MUARC)

Milled rumble strips in the median have been trialled in Sweden (Anund, Kircher and Tapani, 2009; Anund *et al.*, 2008). These studies found that drivers reduced their speed by 2 km/h when these were present.

How it Works

Clear delineation is particularly important at curves (see Section 3.2.2); however it also has benefits in clearly showing the path of the road in straight stretches, although making the straight path of a road clear to drivers/riders may actually encourage higher speeds.

Removing the centre line may lead to slower speeds being adopted since drivers/riders may be concerned about meeting other vehicles. However this is unlikely to be acceptable on high volume single carriageway roads.

Unusual markings at the side or median may have speed reduction benefits, since complex visual environments may increase workload and result in speed reduction. Because drivers quickly become habituated to new markings, the markings would have to be used sparingly.

Treatment Information

Cost per site or km **(high, med-high, med, med-low, low)**	Initial	Medium
	Maintenance	Medium
Effectiveness (in enabling appropriate speed choice) **(high, med-high, med, med-low, low)**	Overall	Medium
	Car	Medium
	Truck	Medium
	Motorcycle	Medium
Impact on passive safety **(very positive, positive, neutral, negative, very negative)**	Overall	Neutral
	Car	Neutral
	Truck	Neutral
	Motorcycle	Neutral
Likely effectiveness for countries with high non-compliance with speed limits/rules **(high, med-high, med, med-low, low)**		Medium
Suitability in different weather conditions, at day and night, and different lighting conditions		Suitable and effective in most conditions, with the exception of snow and dense fog.
Is this feasible for tunnels?		Yes
Is this feasible for bridges?		Yes
Other safety impacts		Possible negative impact on the stability of motorcyclists with thick lining and low friction surface. The rough median treatments in the Drenthe design would constitute a hazard for motorcyclists. Mean lateral positions were closer to the opposing traffic on the Drenthe road, potentially increasing the chance of a head-on accident.
Environmental impact		Both paints and plastics used for road marking normally contain chemicals that are dangerous to health in high concentrations (Elvik and Vaa, 2004).
Acceptability by authorities		Good, except for the Drenthe system, where the rough surface may pose a hazard for motorcyclists
Compatibility with existing design standards		Compatible
Additional guidance		Perceptual techniques which make the environment seem more complex or less safe do have the potential to reduce speeds. It is important to ensure that measures that increase perceived risk do not increase actual risk. This type of measure should be used sparingly in order to retain its novelty value. Markings need to be skid resistant for motorcyclists. The permanence of the perceptual treatments is unknown.

3.5.5 Barriers

Description

The primary purpose of safety barriers at the side of the road is to prevent vehicles from running off the road and colliding with an obstacles or going down an embankment. Similarly, the primary purpose of median safety barriers is to retain vehicles and prevent head-on collisions with vehicles travelling in the opposite direction. Median barriers are used on the central reserves of motorways and rural dual carriageways, except where the central reserve is at least 10m wide. They are also used on the 2+1 and 2+2 single carriageway roads mentioned in Section 3.5.1. The presence of roadside or median safety barriers may influence driver speed choice, however it is unlikely that they will be installed with the sole purpose of influencing speed. In addition, the ‘forgiving roadside’, with no hazards within 10m of the running lanes, is safer.

There are three main types of barrier:

- Metal barriers (e.g. corrugated beam or open box beam)
- Concrete barriers
- Wire rope barriers

Figure 41: Different types of commonly used crash barriers (top left – corrugated beam barrier, bottom left – wire rope barrier, used with permission from NRA, right – concrete barrier)

How it Works

The presence of the barriers could mean drivers feel the road is more primary and so drive faster. Conversely it is possible that drivers/riders that are required to drive in proximity to solid looking features such as barriers may feel that this is risky and choose to reduce their speeds. It is also possible that some types of barriers may emphasise the longitudinal lines and even cause drivers to adopt higher speeds. Overall they should be regarded as a safety feature rather than a speed management tool.

Treatment Information

Cost per site or km **(high, med-high, med, med-low, low)**	Initial	Medium
	Maintenance	Medium
Effectiveness (in enabling appropriate speed choice) **(high, med-high, med, med-low, low)**	Overall	Medium-low depending on situation.
	Car	Medium-low
	Truck	Medium-low
	Motorcycle	Medium-low
Impact on passive safety **(very positive, positive, neutral, negative, very negative)**	Overall	Positive
	Car	Positive
	Truck	Positive
	Motorcycle	Positive (though most motorcyclists perceive wire rope barriers to be potentially very dangerous). The use of systems such as bike guard (protects motorcyclists from potentially harmful upright sections/posts) are appropriate on curves or where there are a great number of motorcyclists using the road.
Likely effectiveness for countries with high non-compliance with speed limits/rules **(high, med-high, med, med-low, low)**		Medium-low
Suitability in different weather conditions, at day and night, and different lighting conditions		Suitable, although some barriers in snowy conditions can be problematic since snow can drift up against the barrier
Is this feasible for tunnels?		Yes
Is this feasible for bridges?		Yes
Other safety impacts		In terms of passive safety, clear road sides are considered to be a better option than using safety barriers. Median barriers on single carriageway roads allow safer overtaking manoeuvres, potentially improving safety.
Environmental impact		None
Acceptability by authorities		Good
Compatibility with existing design standards		Compatible
Additional guidance		Consideration should be given to the beginning and end of the barriers to ensure these do not constitute a safety hazard (see Figure 41). There are many standards for the use of barriers, e.g. EU standards series EN1317-x.

3.5.6 Shoulder

Description

The presence of a paved or unpaved shoulder may influence driver speed choice; however it is unlikely that shoulders will be added or removed with the sole purpose of influencing speed.

Shoulders perform a number of functions, of which some are structural (e.g. providing lateral support to the running lanes and draining water from the trafficked section) and others are operational. The latter include:

- Increasing the effective width of the road and hence the lateral clearance from other vehicles
- Providing a recovery area for errant vehicles if a driver is distracted or loses control of his vehicle
- In some countries, allowing slower vehicles to pull onto the shoulder to let faster ones overtake
- Allowing vehicles that have broken down to be passed by other traffic (although if the shoulder is full width, it allows drivers to stop for other reasons)
- In some countries, they may be used by cyclists and even pedestrians if no footway is provided

Figure 42: Paved hard shoulder

How it Works

Different types of shoulders, narrow unpaved, narrow paved, or wide paved are usually present on different types of road. For example, wide, paved shoulders are rarely present on non-motorway roads. Drivers/riders may therefore use them as an indication of the road category.

The presence of hard shoulders may be associated with primary roads with the effect that some drivers may choose to increase their speed. Overall, though, roads with hard shoulders are safer than those without as they provide a safe refuge for those with a broken down vehicle and provide greater lateral clearance.

Full width hard shoulders may be used as an extra traffic lane or for emergency stops. They can encourage increased speed and more overtaking or undertaking. This potential behaviour amongst road users may perhaps explain why extra-wide hard shoulders do not appear to improve traffic safety.

Elvik and Vaa (2004) review a number of studies that have evaluated the effects on road safety of the way in which the width of the road is allocated between traffic lanes and hard shoulder. Any change in allocation between the road lanes and the hard shoulder leads to a reduction in crashes; therefore it is possible that the change itself is noticed by the road users which may lead to increased alertness (Elvik and Vaa, 2004). The effect on speed is unknown.

Treatment Information

Cost per site or km **(high, med-high, med, med-low, low)**	Initial	High
	Maintenance	Medium
Effectiveness (in enabling appropriate speed choice) **(high, med-high, med, med-low, low)**	Overall	Low
	Car	Low
	Truck	Low
	Motorcycle	Low
Impact on passive safety **(very positive, positive, neutral, negative, very negative)**	Overall	Positive
	Car	Positive
	Truck	Positive
	Motorcycle	Positive
Likely effectiveness for countries with high non-compliance with speed limits/rules **(high, med-high, med, med-low, low)**		Potential for using hard shoulders as additional lanes for undertaking, or for non emergency purposes.
Suitability in different weather conditions, at day and night, and different lighting conditions		Yes
Is this feasible for tunnels?		No
Is this feasible for bridges?		No
Other safety impacts		The presence of full width hard shoulders is positive in terms of improving lateral clearance from other vehicles and refuge areas for broken down vehicles.
Environmental impact		Additional land take may be required.
Acceptability by authorities		Good
Compatibility with existing design standards		Compatible.
Additional guidance		Paving shoulders allows for more effective recovery if control is lost.

3.5.7 Repetitive Roadside Objects

Description

The presence of repetitive or continuous roadside objects, such as street lighting, trees, walls or hedges may influence drivers' speed choice, however it is unlikely that these objects will be added or removed with the sole purpose of influencing speed.

Objects lining a road in a repetitive pattern 'frame the road', in the same way as continuous object. Trees and hedges may limit forward visibility and hence decrease speed, but care should be taken to ensure that minimum visibility standards are retained. Trees in particular should not be sited too close to the road on safety grounds.

Many loss of control accidents result in an impact with a tree and these crashes tend to have a high severity outcome. In Czech Republic and Germany fatal run-off road crashes most often involved a tree over other types of obstacle. In Czech Republic, run-off crashes with trees account for 20% of all fatalities.

Lighting columns are not normally used on rural single carriageway roads. In the event of lighting being required, it would be advisable to use lighting columns with improved passive safety, tested according to the European Standard EN12767.

In a driving simulator study, Godley *et al.* (1999) found that placing trees along the side of a road did not decrease vehicle speeds as much as expected, with a small reduction in speed during the first 100m in comparison to the control condition.

Figure 43: Trees and hedges

Figure 44: Lighting columns

How it Works

There are a number of contradictory hypotheses regarding repetitive roadside objects and their influence on speed:

- When trees (or hedges) line the side of the road, the road can appear as an alley or tunnel resulting in higher speeds
- Repetitive objects in peripheral vision may increase speed perception and therefore drivers may reduce speed (Godley *et al.*, 1999)
- Drivers may be aware of the risk associated with tree lined roads and so may reduce their speed
- Drivers may not be fully aware of the risk posed by trees at the side of the road due to

the false perception of ‘live’ objects being less rigid

- If roadsides were completely clear greater speeds may result from a feeling of the road being wide and open

It is less likely that a tunnelling effect would be elicited from lighting columns since columns are relatively narrow and generally have a spacing of 30m. In UK, the presence of lighting columns dictates the speed limit as they indicate a built up area. Lighting columns are not generally used on rural single carriageway roads, except at roundabouts.

Roadside safety involves the consideration of the safety implications of fixed hazards on the roadside i.e. power poles, drainage structures, trees, signs, bridge abutments, large scale advertising boards or road signs etc. If a hazard on the roadside presents an unreasonable risk to road users, it should be considered for removal or protection with a safety barrier.

Treatment Information

Cost per site or km **(high, med-high, med, med-low, low)**	Initial	Medium-low
	Maintenance	Low
Effectiveness (in enabling appropriate speed choice) **(high, med-high, med, med-low, low)**	Overall	Medium-low
	Car	Medium-low
	Truck	Medium-low
	Motorcycle	Medium-low
Impact on passive safety **(very positive, positive, neutral, negative, very negative)**	Overall	Very positive (if trees are removed).
	Car	Very positive
	Truck	Very positive
	Motorcycle	Very positive
Likely effectiveness for countries with high non-compliance with speed limits/rules **(high, med-high, med, med-low, low)**		Neutral
Suitability in different weather conditions, at day and night, and different lighting conditions		Yes
Is this feasible for tunnels?		No
Is this feasible for bridges?		No
Other safety impacts		Passive safety consequences of roadside objects.
Environmental impact		Removal of trees/foliage has a negative environmental impact.
Acceptability by authorities		Acceptable
Compatibility with existing design standards		Compatible
Additional guidance		Some countries have specific policies on the removal of trees from the roadside.

3.6 Conclusions

It is apparent that the scientific literature offers relatively little high quality evidence for individual treatments in terms of impact upon speed choice. Therefore it has been necessary to rely heavily on expert opinion in order to complete this section. This highlights the real need to further study and understand the effectiveness of different treatments, particularly on appropriate speed choice. Work Packages 3 and 4 will provide some opportunity to update the information provided in this section. In Work Package 3, the workshops will allow further expert data to be collected, and Work Package 4 will test the effectiveness of a small number of treatments in a driving simulator study.

4 Selection of Treatments for Further Investigation

This part of the work planned to select the most promising treatments for further investigation in SPACE on the basis of the information gathered from the literature review and expert review panel. The selection process considered all of the information gathered about treatments with an emphasis being placed on the likely effectiveness of the treatments, their cost, other safety impacts and their acceptability by road authorities.

As treatments have been grouped together into categories, it has not been possible to simply select several individual treatments for further examination. Moreover this may not be appropriate since treatments are rarely applied in isolation.

Therefore, the SPACE consortium members have elected to take forward two sets of self-explaining treatments for further investigation in Work Package 3: those that relate to speed choice at curves (see Section 3.2) and those that relate to speed choice at transitions (see Section 3.3).

'Speed choice at curves' is particularly relevant to a 'speed adaptation' focus, because loss of control/run-off road crashes are prevalent across Europe and a significant proportion of these are likely to be prevented through reduced (and appropriate) vehicle speeds. Curves offer a particularly interesting opportunity to examine the role of consistency and expectation. Also, it may be possible to categorise curves according to their geometry and the degree of surprise that a curve elicits, and this would allow the original categorisation focus of 'self-explaining roads' to be explored.

'Speed choice at transitions' is particularly relevant to our 'speed adaptation' focus, because it is particularly important to encourage reduced speeds at gateway transitions since there is a greater potential for conflict between motorised and non-motorised traffic in urban or semi-urban areas. Speed reduction is likely to play a significant role in safety outcomes, both in terms of accident prevention and also severity reduction.

As such, the treatments that relate to curves and transitions are those that are deemed to be most interesting in terms of speed adaptation and are most likely to lead to significant casualty reduction benefits.

5 Conclusions

The concept of 'self-explaining roads' has evolved greatly over time. The original meaning, as explored by Theeuwes and Godthelp (1992; 1993), related to roads being 'understandable' through their clear belonging to a particular category of road. Theeuwes and Godthelp suggested that, through accurate categorisation, road users would have appropriate expectations and therefore be able to adopt suitable and safe behaviour. This approach has synergy with earlier work on 'road readability' (Mazet *et al.*, 1987; Mazet and Dubois, 1988) and the role of expectancy in determining driver behaviour (Näätäanen and Summala, 1976; Malaterre, 1990).

The concept of a road that could 'elicit safe behaviour simply by design' was greatly attractive to road safety practitioners and researchers alike; however there was little practical guidance that accompanied early work on the subject. It is possible that the lack of practical guidance has led, in part, to the broadening of the term to encompass a wide variety of concepts, some being far removed from the original intended meaning.

For the purpose of the SPACE project, a definition has been produced that aims to protect some of the original meaning of the concept of self-explaining roads, but also recognises the broader, and arguably more practical, meanings that the term has gathered over two decades. The definition recognises the role of categorisation in the original work, but suggests that practitioners generally now understand the meaning of self-explaining roads to include other psychological concepts such as intuitive and understandable design, consistency, readability and psychological traffic calming.

In order to provide practical guidance on possible 'self-explaining' treatments (suitable for rural, single carriageway roads, with a relatively high volume) that may have an impact on speed choice, measures were assigned to the type of road which would be treated: curves, transitions, intersections and links. The approach was to search the available scientific literature for information about the treatments, and then to effectively 'fill in the gaps' in knowledge by asking experts for their opinion. As expected, there were relatively few scientific studies that provided information about the effectiveness of treatments, particularly in relation to their impact on speed choice. This highlights the need to further study the treatments, in particular to provide empirical evidence for their effectivenes. It is anticipated that some of the information included in Section 3 will be updated as a result of the expert workshops in Work Package 3 and the simulator study proposed in Work Package 4.

Treatments suitable for use at curves and at transitions (in particular gateways) were selected for further investigation in the SPACE project in Work Packages 3 and 4. These measures have the greatest potential since speed has a critical role to play in loss of control crashes at curves and also in potential conflicts with Non-Motorised Users (NMUs) following transitions into villages, towns and/or semi urban areas.

Abbreviations

AAAFTS:	American Automobile Association Foundation for Traffic Safety
BRRC:	Belgian Road Research Centre
CDV:	Centrum Dalšího Vzdělávání (Czech Republic)
cm:	Centimetres
ERCs:	Essential Recognisability Characteristics
IHIE:	Institute of Highway Engineers
iRAP:	International Road Assessment Programme
KfV:	Kuratorium für Verkehrssicherheit (Austrian Road Safety Board)
km/h:	Kilometres per hour
m:	Metres
mph:	Miles per hour
ms:	Milliseconds
MUARC:	Monash University Accident Research Centre
NRA:	National Roads Authority, Republic of Ireland
NMU:	Non-Motorised User (pedestrian or bicyclist)
NSW:	New South Wales
NZTA:	New Zealand Transport Agency
PennDOT:	Pennsylvanian Department of Transport
RECL:	Road Environment Construct List
SER:	Self-Explaining Road
SPACE:	Speed Adaptation Control by Self-Explaining Roads
TNO:	Netherlands Organisation for Applied Scientific Research
TRL:	Transport Research Laboratory
UCD:	University College Dublin
UK:	United Kingdom
VAS:	Vehicle Activated Signs
WYLIWYG:	Where You Look Is Where You Go

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