
# SPACE, Speed Adaption Control by Self-Explaining Roads; Final Report

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# Deliverable Nr 6 – SPACE, Speed Adaption Control by Self-Explaining Roads; Final Report

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# Executive summary

This document summarises and describes the SPACE project (Speed Adaption Control by Self-Explaining Roads). This is a European project looking at the meaning of self-explaining roads and what types of measures are most effective in achieving the objectives of speed adaption through self-explaining roads. The SPACE project is funded by ERA-NET Road.

The concept of Self-Explaining Roads has evolved greatly over time and is originally based on Theeuwes and Godthelp (1992; 1993). They described roads being 'understandable' through their clear belonging to a particular category of road. 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 recognizes the broader, and arguably more practical, meanings that the term has gathered over two decades. The definition recognizes the role of categorization 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.

A series of consultations with experts and driver simulation tests were conducted and focused on SER-treatments at curves and transitions, because 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 at transitions into villages, towns and/or semi urban areas.

One key finding of the five national expert workshops is that professionals were particularly uneasy about the notion of single treatments being applied in isolation. Furthermore, the experts agreed to consistently treat bends with a hierarchy of treatments mapped closely to the severity of the curve. This was also tested in the following driver simulation tests.

With the help of a moving base driving simulator the effectiveness on speed reduction of a consistent treatment regime in relation to curve severity was evaluated. In most cases (35 participants, combination of 3 curve severity and 3 treatment levels, two groups: consistent and inconsistent use of treatments) there were significant effects for treatment levels, severity of the curve, order and for subject. There was also an interaction between group and curve that means that curve severity significantly reduced the average speed among those with consistent treatment to a greater degree than for the inconsistent group.

From this analysis, it was clear that combinations of treatments work more effectively than single treatments and that consistency of treatment is important for drivers.

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# 1. Introduction

"The objective of the SPACE project (funded by ERA Net Road; eranetroad.org) was to define what is meant by the term "self-explaining roads" and to investigate what treatments might be used in order to encourage drivers to adopt speeds that are safe and appropriate to conditions. This will lead to tools that can identify unsafe or non-explaining areas of the network and that are able to estimate the potential safety benefits of the road safety measure. To manage the work in this project it was divided into a number of work packages. The first work package looked at literature and research relating to self-explaining roads and sought to define for the purpose of this project what this term meant. In addition, identification of self-explaining treatments was carried out in work package two. This is described in Section 2 and 3 of this report. The third work package went onto evaluate the treatments through consultation with experts at a series of workshops, conducted in different countries across Europe, as described in Section 4. The work included how to conduct the workshops e.g. an interview guide was developed and guidelines for collecting pictures to be used in the workshops were created. Following from this, the fourth work package involved taking some of the treatments (as selected by experts in workshop package 3) and using these in driver simulator tests in order to identify the impacts of these treatments on drivers' behaviour. This is described in Section 4. The final work package five was dedicated to management of the project and reporting of the findings. The work packages and the work flow can be seen in Figure 1. The Work package one was led by TRL, United Kingdom and WP two by KFV, Austria. Those WP´s worked close together. WP three was led by BRRC, Belgium and the WP´s four and five was led by VTI, Sweden. VTI Sweden also acted as coordinator of the project and worked close with FEHRL, Belgium in WP five regarding dissemination.

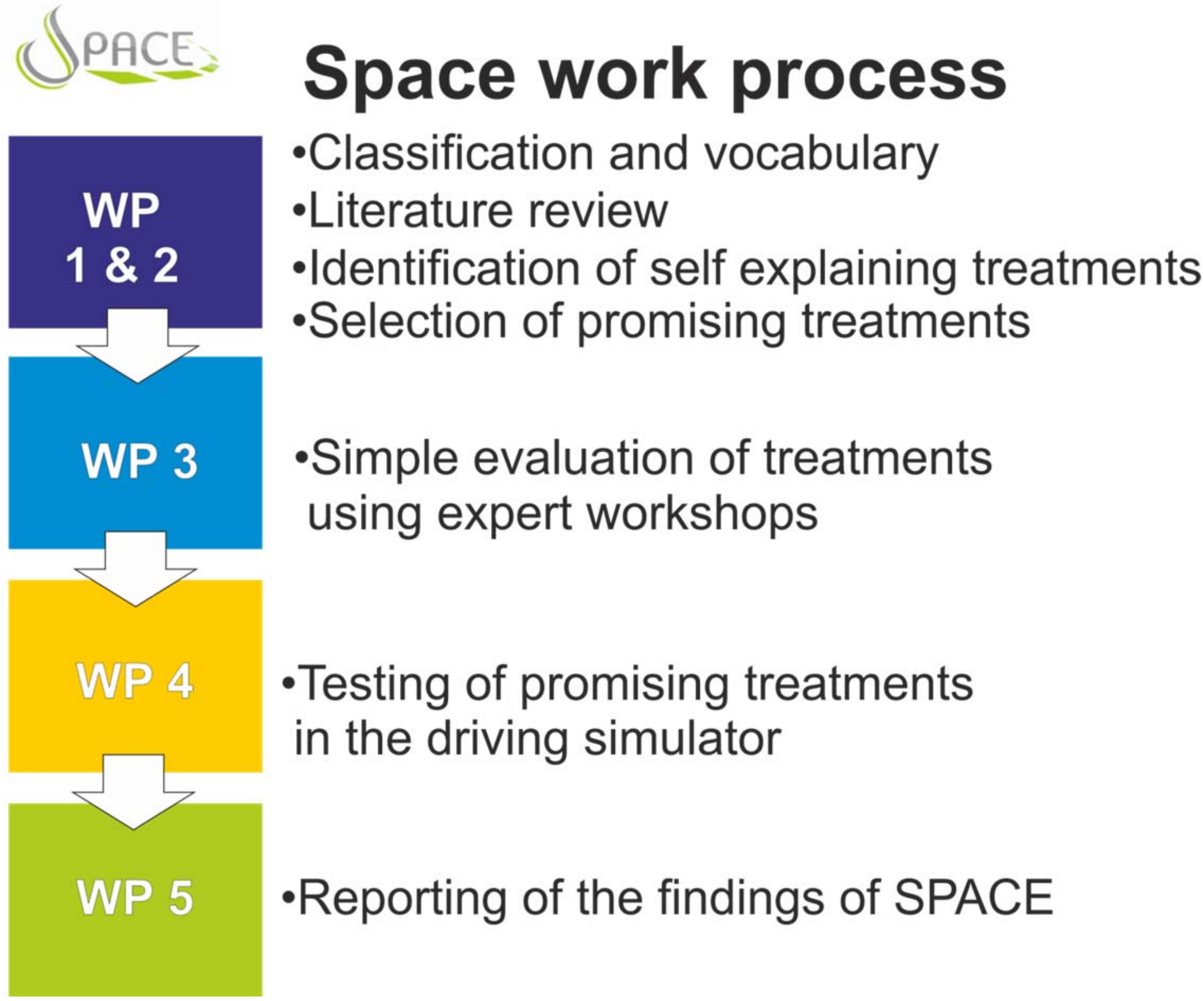



**Figure 1 SPACE work flow**

## 2. Self-explaining roads

The phrase “self-explaining roads” first appeared in literature in the 1990s. 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). The word ‘begrijpelijkheid’ does not translate directly into English, but the verb ‘begrijpen’ means to understand, and the adjective ‘begrijpelijk’ is usually translated as ‘understandable’. Subsequent Dutch publications use 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 basic message of the Self-Explaining Road principle is that a traffic environment can be provided ‘which elicits safe behaviour simply by its design’ (Theeuwes and Godthelp, 1993). Two psychological processes are central to the concept: categorisation and expectancy. Theeuwes and Godthelp (1993, p57) suggest: “...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 suggest “Inadequate categorization is dangerous because the inadequate categorization will induce inadequate expectations” (p58). Theeuwes (2002, p142) stresses the importance of ‘top down expectations’ 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".

There was nothing novel about consideration of these two processes in driving behaviour. 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'. 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 categorization and expectancy in a theoretically plausible framework.

Theeuwes and Godthelp (1993, p62) 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." 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).

Since the first publications, the original authors have continued to disseminate through conference papers, book chapters, and journal articles (Theeuwes and Godthelp, 1993, 1995a, 1995b; Theeuwes, 1994, 1998, 2000, 2002), though little new empirical data was reported during the period. In addition, EU initiatives have provided some impetus, particularly through the MASTER project (Managing Speeds of Traffic on European Roads,1998).

The self-explaining road concept soon found a receptive audience, particularly among practitioners. Years of success with remedial treatments on roads had led to concerns about diminishing returns, and more proactive approaches to road safety management were becoming popular. Into this mix came self-explaining roads, with the promise of a traffic environment that would elicit safe behaviour simply through design.

Other innovative work on self-explaining roads progressed in UK during this time (e.g. Shaw and Mayhew, 2000; Ralph, 2001) and the idea of 'psychological traffic calming' was explored (Elliot, McColl and Kennedy, 2003; Kennedy et al., 2005). In New Zealand the topic was investigated by Baas and Charlton (2005) who follow the Dutch approach in emphasising the importance of a clearly recognisable hierarchy of road types. However, in a later publication Charlton (2007) 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 et al., 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.

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. 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 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 in a new culture faced with the challenge of building safety into the system at the design stage, the prospect of a new type of road that could reduce errors because they could 'elicit safe behaviour through design' and 'evoke correct expectations from road users' was a very attractive one. The problem, however, lay in the fact that its attractiveness lay more in principle than in practice. In the absence of any clear guidance as to what self-explaining roads were, as opposed to what they could do, then the way was open to different interpretations, and for the concept to be used to a variety of different contexts, from English rural villages to New Zealand residential areas, as well as the design standards in European countries.

The SPACE project, which this document describes, set out to develop a modern and practical definition of Self-Explaining roads and the following definition was used:

"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 SERs 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."

# 3. Self-explaining treatments

The state-of-the-art literature review carried out, in the early stages of this project, on the development of the concept of self-explaining roads over time allows the project partners to identify and already start to evaluate potential self-explaining treatments. Those treatments that may be useful in order to encourage road users to adopt more appropriate speeds and that may be interpreted as "self-explaining" were explored in a second stage during a number of national expert's workshops.

An inclusive approach was taken: treatments were included even though many of the treatments would have been rejected by purists. According to the requirements of the ERA-NET Road Programme Executive Board, the treatments should be suitable for use on roads that are: suitable for higher volume rural, single carriageway roads. In total 72 individual treatments were identified by the project team. These were grouped 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) was provided, alongside studies that indicate their effectiveness for encouraging appropriate speed choice (where available in the literature). Additional information including approximate 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 was presented.

As anticipated, there were 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 internal expert panel was consulted in order to 'fill in the gaps'. This exercise also highlighted particular areas where further studies are required in order to ensure a greater understanding of the impact of different treatments on speed choice.

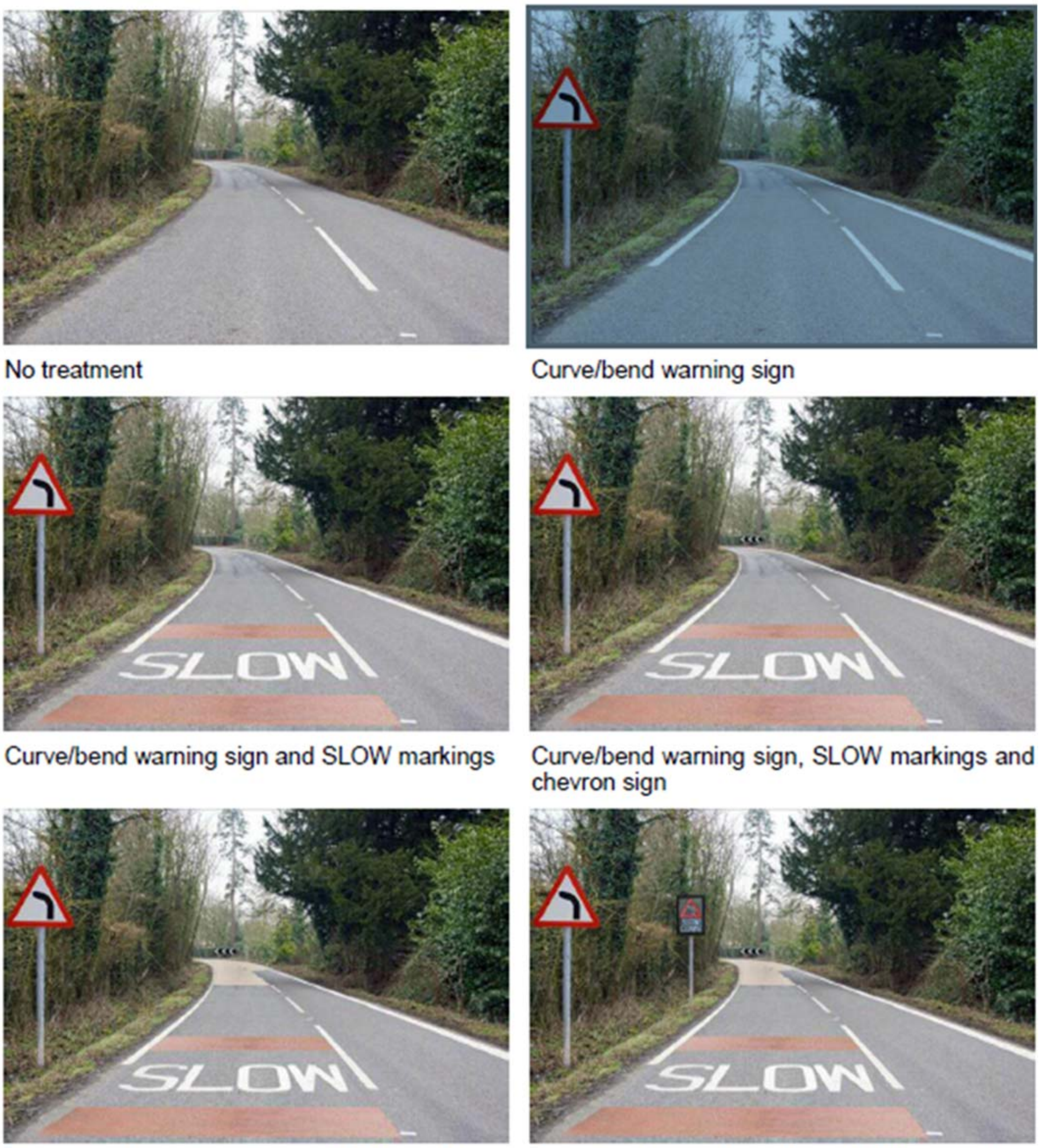
In the following section, treatments suitable for influencing speed choice at curves, transitions, intersections and links are provided.

### Curves

As the speed choice of road users on curves mainly depends on curvature and approach speed (Kerman, McDonald and Mintsis, 1982; McLean, 1995), the reduction of speed on the curve itself can be achieved by influencing approach speed. A key SER principle is that signing and marking should be consistent (e.g. Retting and Farmer, 1998). Curves with a similar severity should be signed in the same way. Along a route, a logical hierarchy for curve signing and marking is necessary to support the road users' ability to categorize the curves and adapt the driving behaviour according to the severe of the curve. Examples of six levels of treatments can be seen in Figure 2

In general, treatments have to be used consistently and should be concentrated on particularly surprising or sharp curves. It is best not to 'over-use' such measures, otherwise the impact of the unusual markings may diminish if they are too common. The following treatments may influence the speed choice of road users on curves:

- Chevron Signs/ Marker Posts
- Lining
- Vehicle Activated Signs (VAS)
- Surface Treatments
- SLOW markings
- Transverse Rumble Strips
- Optical Bars
- Visibility and sight distance
- Alignment




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)**

### Transitions

Transitions relate to changes in the type or function of a road along a route. One common transition is the entrance to a town or a village, this kind of transition is generally called a gateway and is connected with a change of the speed limit. But the treatments on transitions also include a change in the characteristics of the road (e.g. classification, speed limit).

Treatments on transitions can be used to alert road users to a change in road type or road function and encourage the drivers to reduce the driven speed. A different type of driving and speed is required, for example where there may be a higher number of pedestrians and/or bicyclists. Gateways usually consist of a number of features:

Physical measures (e.g. build outs, islands, median treatments)

Signing and lining treatments (e.g. edge markings, hatching, dragons teeth)

- Surface treatments (e.g. coloured textures and/or surfaces, transverse rumble trips, optical bars)

Combinations of measures have been found to be most effective (Kennedy et al., 2005). Measures need to be continued beyond the gateway in order to maintain speed reductions through the village itself. Research by TRL into village gateway schemes (e.g. Wheeler and Taylor, 1999 and references therein) found that physical measures at gateways achieve greater reductions in mean speeds as simple signing and marking measures or measures with high visual impact e.g. coloured surface or dragons teeth.

### Intersections

The number of intersections on a road has a major impact on the crash frequency. Treatments at intersections that may be interpreted as 'self-explaining' tend to warn of the presence of intersections. Those treatments may encourage appropriate speed choice at intersections by emphasizing the presence of the junction include:

- Additional or enhanced signing
- Lining/roadway markings
- Surface treatments
- Layout and junction type
- Visibility

### Links

In the framework of the SPACE project 'links' refer to straight sections of road in between intersections and transitions. The analyzed treatments included road attributes and design elements as well as treatments per se. For example lanes (width and number of lanes in each direction), surface quality and treatment, illusory lane width markings, median and edge treatments, barriers, shoulder or repetitive roadside objects.

### Treatments for further investigation

It was recommended that treatments that are used at curves and transitions offered the greatest interest to the SPACE project since, at these stretches of road, speed is particularly critical.

For curves, it is important that the road user adopts an appropriate speed that is in accordance with the severity of the curve. This is particularly interesting when considering the notion of categorisation in self-explaining roads since it is hypothesised that curve treatments should be hierarchical and consistent in accordance with curve severity, so that the severity of the curve might be recognised and an appropriate speed selected.

In the case of transitions, drivers need to be encouraged to adopt appropriate speeds since they may encounter vulnerable road users, and speed is particularly critical to the survivability of collisions for this group.

# 4. Methods to evaluate international SER treatments

Following from the selection of treatments, two methods to evaluate the treatments was devised. The first involved consultations with external experts in a series of workshops conducted across Europe to obtain their feedback on the likely impacts of different SER treatments. Secondly, some treatments were tested in driver simulator studies conducted in Sweden.

### Expert workshops

The SER treatments addressed in the workshops following from the literature review were limited to curves and transitions since speed has a critical role to play in loss of control crashes at curves and also in potential conflicts with vulnerable road users following transitions into villages, towns and/or semi urban areas.

The participants of the workshops organised in Belgium, Czech Republic, Sweden, Ireland, and Austria were experts on road safety, regional and municipal road administrators, and representatives of stakeholder organisations such as automobile clubs, national motorcycle drivers associations and national organisations of transport companies, all from the countries where the workshops were organised or from neighbouring countries.

The concept of all workshops was identical: the same questionnaires and the same video and photo material were used at all workshops (*Table 1*, *Table 2* and *Table 3*). During the morning sessions the participants discussed the definition of SER treatments and gave their vision on the conditions that make a SER treatment efficient or not. During the afternoon sessions a series of examples of SER treatments were presented and the participants gave their comments on the examples.

*Table 1: Questions to be answered in the morning session*

- What is a self-explaining road (SER)?

  Provide some key-words that should be present in the definition of a SER
  Provide a definition

- What works?

  Give good practical examples of the concept of "self-explaining road" with the speed adaption by the road user as specific goal (or consequence)

- What doesn't work?

  Give examples where the implemented measures may not bring the expected result regarding speed adaption (=unsuccessful speed adaption measures)

*Table 2: Measures discussed during the workshops*

| | |
|---|---|
| Curves | Chevrons signs |
| | Central hatching & bollards |
| | Coloured surface treatments |
| | Transverse rumble strips |
| | Visibility and sight distance |
| | Alignment |
| Transitions (gateways) | Signs - Markings |
| | Hatching (lateral, central) |
| | Road furniture |
| | Lateral/Central islands |
| | Surface treatments |

*Table 3: Questions to be answered in the afternoon session*

- Which type of measure is discussed?
- What are the advantages of the measure?
- What are the inconveniences of the measure?
- Is this measure self-explaining and efficient in speed adaption?
- Are there any places known where this particular measure was implemented and if so, was this implementation successful?

The participants were also asked about the set-up of the workshops and the usefulness of video material for the evaluation of existing SER treatments. The videos and imagery presented to workshop participants had been collected by the partners in the SPACE project. The videos were shot from a camera in a vehicle driving on roads with different SER treatments. An objective of the project was to ask workshop participants about the effectiveness of SER treatments visible in the movies. Therefore, the movies had to give a very realistic experience of the filmed road environment, so that experts would be able to experience and see what the driver of the vehicle would experience and see Figure 3.


**Figure 3 Example of video material used during the workshop (source Deliverable 3)**

Prior to the shooting of the movies, some experiments with different camera positions on different vehicles were conducted at the BRRC and a choice of the appropriate camera lens was made. The best position of the camera seemed to be right next to the driver (that is, on the left from the driver when the vehicles drive on the right side of the road as in continental Europe). It is recommended to use a camera with view angle of at least 70° (35° to the left of the central axis) in order to make an accurate simulation of the view area of the driver, and the angle should not exceed 120°. A camera with 1920 x 1080 pixels was used to give a more than sufficient resolution for the purpose of the SPACE project workshops (see also Deliverable D2 of the SPACE project).

A detailed analysis of all workshop reports (see also Deliverable D3 of the SPACE project) showed that the opinions expressed by the participants are largely convergent but also sometimes differ on a number of points. For example, opinions differed on the effectiveness of the use of lane narrowing by red coloured median separation, marker posts and signing. Multiple factors can explain these differences of opinion: the expert's professional background; cost and maintenance parameters, different driver behaviour in different countries, prior experience with the treatment in a country, etc.

The workshop participants gave helpful recommendations to the SPACE partners for the selection of the few SER treatments on which further investigations would be conducted with a driving simulator. They very explicitly pointed on the potential of particular SER treatments for curves and transitions (see chapter 4 "Promising measures to be studied further" of deliverable 3).

A key finding from all expert workshops is that professionals were particularly uneasy about the notion of single treatments being applied in isolation. Consistency between different routes is important to ensure the treatment scheme does not make the road less safe. One promising notion is to consistently treat curves with a hierarchy of treatments mapped closely to the severity of the curve. Further scientific investigation on its efficiency would offer a low-cost SER treatment than can be applied directly by practitioners.

Other uniform conclusions at the workshops were that differences in the definition of SER appear in relation to whether the road was due to be rehabilitated (existing road) or newly planned and constructed, that cost and long-term efficiency of the SER treatments is a non-negligible problem directly linked with routine and habituation of those measures, and that effectiveness of a SER treatment depends on the environment in which it is implemented and on circumstances such as day and night, good and bad weather.

The workshop participants concluded that the use of video sequences showing examples of SER treatments can be useful in eliciting the view of experts and road authorities in the frame of particular "project level" studies, or used as material for workshops or training sessions. However, the approach may not be very effective as a "simple evaluation method" for experimentation purposes in order to determine the effectiveness of different SER treatments. The simplicity of the method makes it difficult to study in a rigorous way some of the aspects of user behaviour with respect to SER treatments, such as different circumstances (night/day, rain/dry weather) and the long term effect of a SER treatment. The experience at the SPACE project workshops shows that the use of video material can play a role in a preparatory phase, preceding a driver simulator study (see deliverable 2).

On two of the workshops a general questionnaire regarding factors that would cause a driver to slow down and lower the speed was used. Looking at the result it was interesting to see that road width was important in both countries but not the amount of water or ponds on the surface. In Sweden this (water ponds) was considered important for lowering the speed but not in Austria. The use of this type of questionnaire seems to have a great potential to be useful in the evaluation of possible European SER treatments. Each participant was asked to judge, in a scale from 1 to 5, how these 23 factors could be considered important for the speed adaption. 1 meaning slower the speed and 5 faster speed.

1. Visible cracks in the surface
2. Internal sound -road related
3. Water ponds on the road
4. Road side wire barriers
5. Homogenous (concrete) roadside barriers
6. No road side barriers
7. Road side barriers
8. Few heavy good vehicles (HGV)
9. Many heavy good vehicles (HGV)
10. Low volume traffic
11. High volume traffic
12. No rumble strips in the middle of the road
13. rumble strips in the middle of the road
14. Light coloured asphalt
15. Dark coloured asphalt
16. Uneven road surface
17. Even road surface

18. Unattractive road surroundings
19. Attractive road surroundings
20. Curvy roads
21. Straight roads
22. Narrow lanes (carriageway)
23. Wide lanes (carriageway)

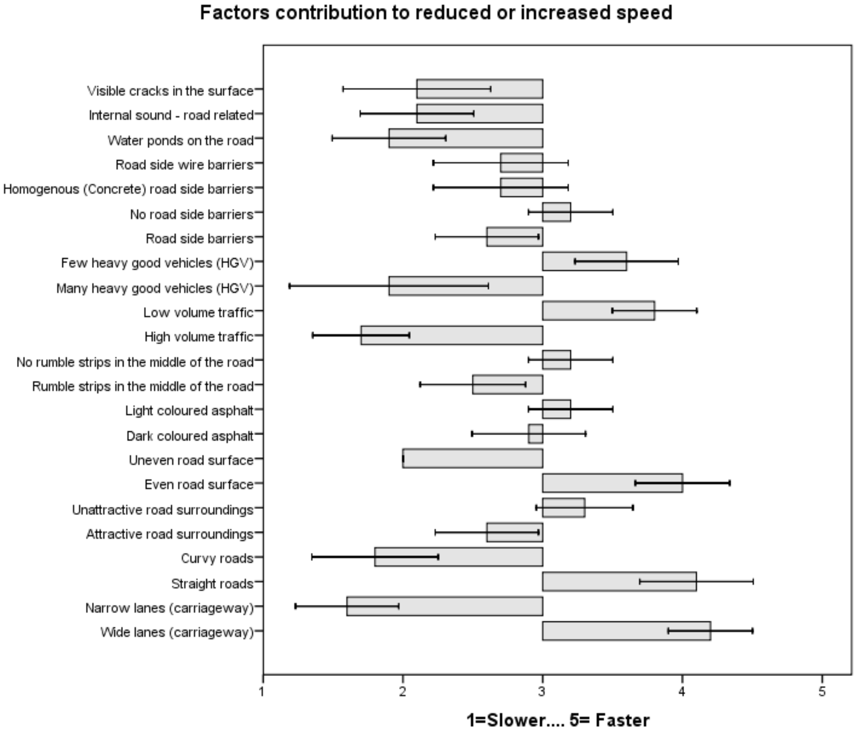



**Figure 4 Factors contribution to reduce the speed from the Swedish workshop.**

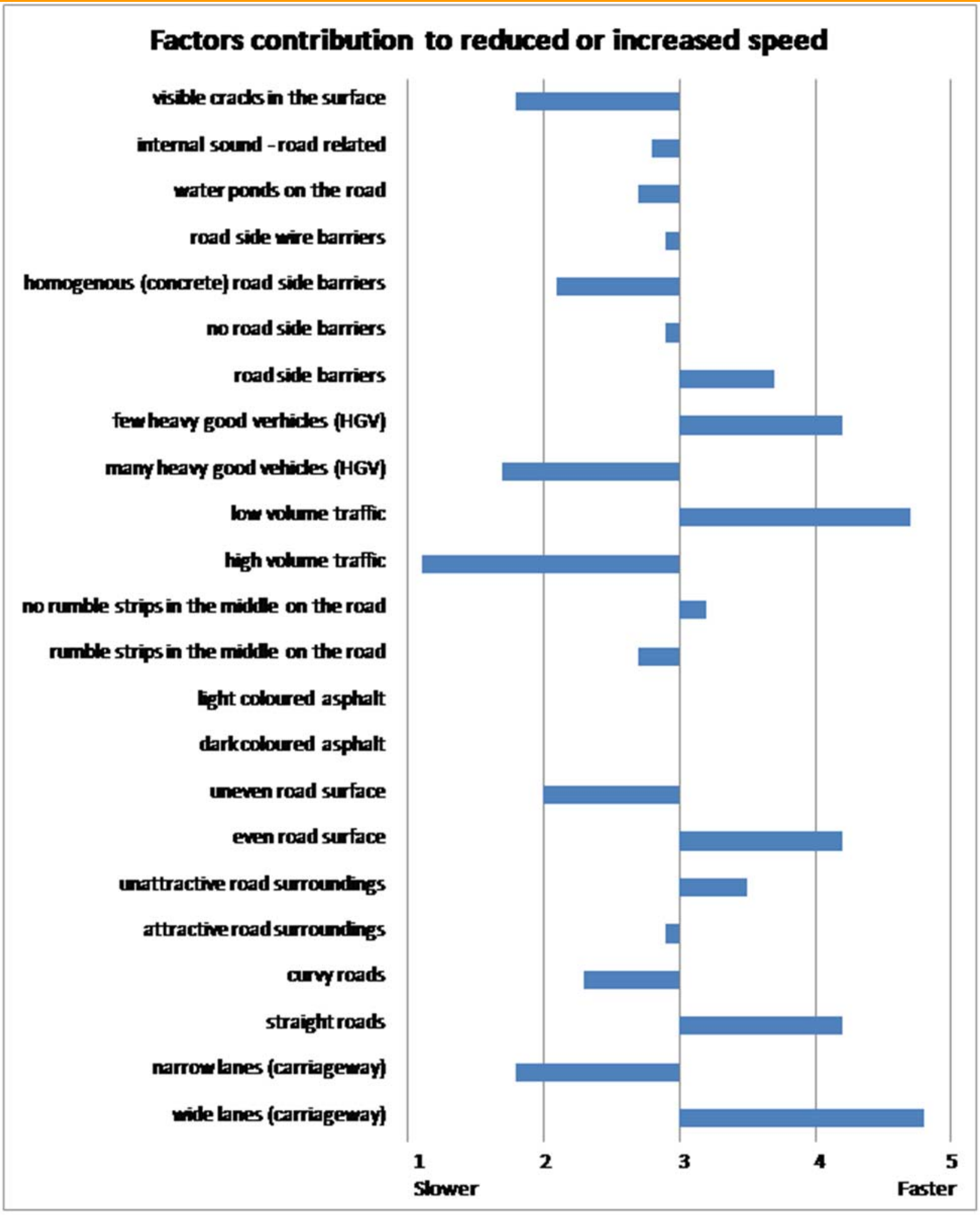



**Figure 5 Factors contribution to reduce the speed, from the Austrian workshop**

### *4.2 Driving Simulator Studies*

Following on from the workshops, a number of treatments identified by experts as being useful but requiring further analysis were chosen for a driving simulator study, conducted in Sweden. With VTI's driving simulators repeatable experiments can be carried out and realistic driving experiences created. This makes it possible, among other things, to study the effect of the driver's condition and driver support systems on driving performance see Figure 6.


**Figure 6 VTI's driving simulator used in the SPACE project**

The focus of this simulator study was on treatments at curves. The objective of the simulator study was to further evaluate the effectiveness of the chosen treatments in terms of speed adaption, and to determine whether a combination of treatments on curves according to their severity could help drivers correctly establish the severity of a curve in advance, and therefore adapt their speeds appropriately.

In total 35 participants, divided into two groups, drove approximately 47 minutes on a rural road with 3 baseline curves without treatment and 9 curves with treatment of varying levels. The road had a lane width of 3.5 m and a shoulder of 0.75 m. The shoulder line (edge line) and the centre line was intermittent and 0.10 wide. The road had marker posts with an inter-marker distance of 50 meters on sections without curves and with an inter-marker distance of 25 meter through the curves. In total three different treatment levels and three different curve severities were used. One group received treatments corresponding to the severity of the curve (slight curve – low treatment level; moderate curve – medium treatment level; severe curve – high treatment level); the other group experienced inconsistent treatments by being exposed to all nine possible combination of curve and treatments. The treatments at low level was curve warning sign, at medium level curve warning sign and a chevrons curve sign and at high level a curve warning sign, chevrons curve signs, median and side hatchings and transverse rumble strips.

The different treatments were activated sequentially. In the case of high treatment level the activation points were the following (see also Figure 7):

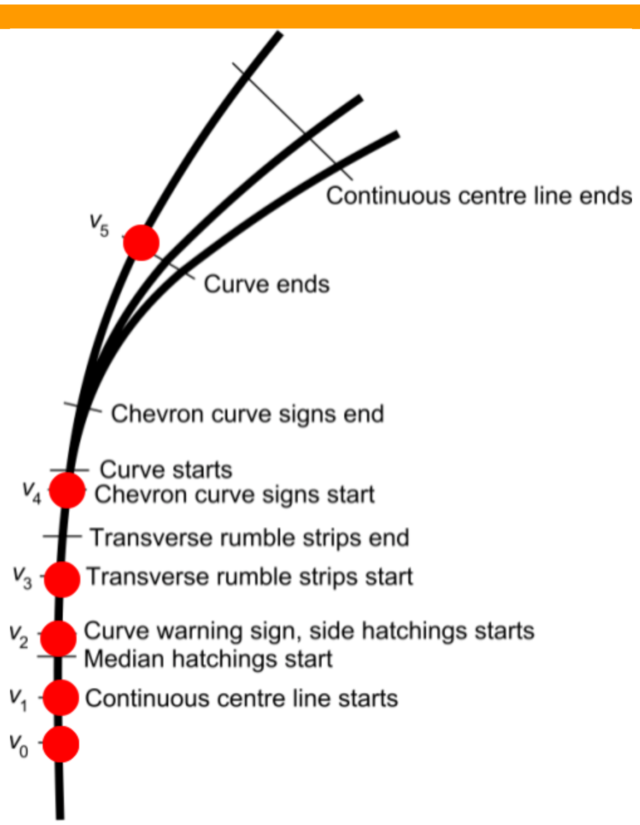



**Figure 7 The positions of the treatments along the curve. v0–v5 corresponds to the points at which speed was measured.**

v0: 350 m before curve starts (reference)

v1: 290 m before curve starts (continuous centre line starts)

v2: 215 m before curve starts (warning sign + side hatching starts)

v3: 140 m before curve starts (transverse rumble strips starts)

v4: 20 m before curve starts (first chevron sign)

v5: 280 m after curve starts (curve ends)

The activation points of the treatments in the low and medium levels were the same as for the high treatment level.

**Figure 8 The drivers' view of the scenario at the different points in case of high treatment level.**

The analysis of the effects on speed at each point (v0 to v5) was done with Mixed Model ANOVA. Dependent variables were speed measurements in the different points along the curve (v0 to v5) and the average speed through the total curve (from point v0 to v5). The analyses were done both for absolute speeds and for difference in speed compared to the speed at start of the curve (v0). Independent variables were consistent/inconsistent group; curve severity (1-3), treatment level (1-3) and time on task - order (1-9). No second level interactions were significant and therefore these interactions were not included in the final models. In addition the most severe curve was analysed separately in order to compare the groups.

In most cases there were significant effects for treatment levels, severity of the curve, order, and for subject. There was no significant main effect on group (consistent/inconsistent).

However, there was an interaction between curve and group, telling us that the consistent marking significantly reduced the average speed among those with consistent treatment. This holds true also for the speed at point v2, v3 and v5. There were no other significant interactions. If the difference in speed from the beginning of the curve (v0) to different points along the curve was computed the effect of group was significant at v1 and v2, in opposite to treatment, curve and time on task, see Figure 2. The most critical situation regarding speed reduction in curve is when the curve is severe. The analysis shows that there was an effect of consistent treatment in point v3 and v4. To summarize, the results support the hypothesis that a consistent treatment will contribute to a speed reduction.

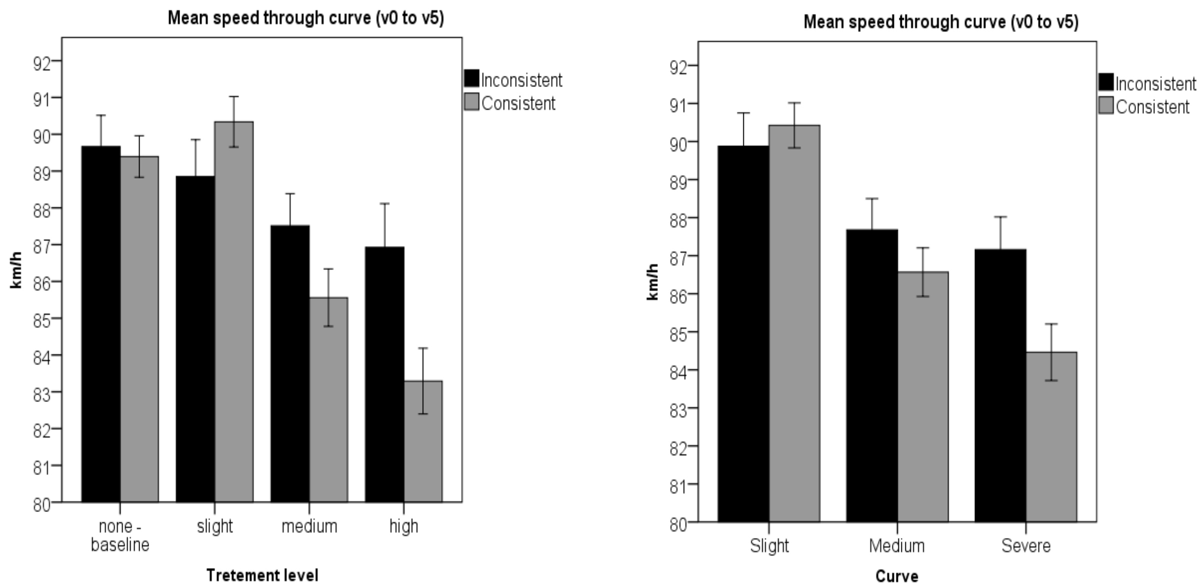



**Figure 9 Mean speed through curve (v0 to v5) separated for treatment level and curve severity**

In conclusion the result from the driving simulator study demonstrates one way to evaluate the effect of potential treatments (in this case categorized as “self-explaining treatments”) on speed choice. Furthermore, the results show that a consistent mapping of treatment levels to the severity of curves is a potential way to make drivers adapt their speed appropriately for the risk present.

# 4. 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 categorization, 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 its 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 recognizes the broader, and arguably more practical, meanings that the term has gathered over two decades. The definition recognizes the role of categorization 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 effectiveness. 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 (expert workshops) and 4 (driving simulator experiment). 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.

One key finding from the expert workshop is that professionals were particularly uneasy about the notion of single treatments being applied in isolation. It may therefore be of benefit to move towards investigating the use of combinations of treatments in the WP4 driving simulator studies. One promising notion is to consistently treat bends with a hierarchy of treatments mapped closely to the severity of the curve. This has potential to offer not only scientifically interesting results but also results that can be applied directly by practitioners.

In order to identify what treatment for SER treatments to test in a driving simulator experiment, expert workshops, presenting identified SER treatments selected through literature seem to be a well working, stepwise process. The use of video sequences showing examples of SER treatments can be useful in eliciting the view of experts and road authorities during the workshops. Workshops can also be used on their own for certain evaluations. The use of workshops is particularly useful in the evaluation of the trans-national perspective. For this purpose common questionnaires can be a good tool to use. At two of the workshops a general questionnaire asking about the degree some factors would cause a driver to slow down and lower the speed was used. Looking at the result it was interesting to see that road width was important in both countries but not the amount of water or ponds on the surface. In Sweden this was considered important for lowering the speed but not in Austria. The use of this type of questionnaire has great potential to be useful in the European roads perspective.

Following the results from the workshops the next phase started. With the help of a moving base driving simulator the effectiveness on speed reduction of a consistent treatment regime in relation to curve severity was evaluated. One group of participants received treatments before curves that corresponded to the severity of the curve (slight curve – low treatment level; moderate curve – medium treatment level; severe curve – high treatment level); the other group had an inconsistent treatment with 9 different alternatives (combination of 3 curve severity and 3 treatment levels). In most cases there were significant effects for treatment levels, severity of the curve, order (time on task), and for subject. There was no significant main effect on group (consistent/inconsistent). However, there was an interaction between curve and group, telling us that curve severity significantly reduced the average speed among those with consistent treatment to a greater degree than for the inconsistent group. This holds true also for the speed at point v2, v3 and v5. A final argument for the effectiveness of consistent treatment is that if only the severe curve was looked at there was a significant effect of group.

As in most studies there are also here great individual differences when it comes to performance. This is especially the case for speed. In all models subjects has been used as a random factor nested for group (consistent/inconsistent) in order to take into account these facts. Even when the speed difference was computed by using the speed at the beginning of the curve as reference still the effect of subject was significant. No matter if absolute speed or relative speed measurements were used the effect of group was significant both for average speed and for speed at most of the points along the curve. This was in line with our expectations. However, when comparing the drivers' speeds during the baseline condition (no treatment) there were no differences in speed choice between the groups (consistent/not consistent). This indicates that the drivers before treatment started had the same preference of speed.

There is a risk that the design itself contributes to a feeling of uncertainty for the inconsistent group. They never know what will happen based on the treatments present. To test this, risk combinations A: slight curve – low treatment level; B: moderate curve – medium treatment level; C: severe curve – high treatment levels were compared for both groups. The result showed the highest reduction in speed in severe curves with high treatment level. There was no effect of group, but an interaction between group and curve. This results support an influence on speed due to consistent/inconsistent treatment – arguably the degree to which the road is self-explaining.

The most critical situation when it comes to driving through curves may occur in more severe ones. Therefore it was interesting to compare the effectiveness of a consistent high treatment level in severe curves for the two groups. The results show an average speed reduction of almost 3 km/h for the consistent group compared with the inconsistent group. This is positive and in line with our expectations.

The results from the experiment support the idea that a consistent treatment level in curves, in line with the severity of those curves, will contribute to speed reductions. This is supported since a greater speed reduction was observed in relation to curve severity with a consistent treatment level than with an inconsistent treatment level.

It is well known that the absolute level of speed in simulators is not trustworthy as a valid indicator of absolute speeds in real driving (Philip et al. 2005) and that the relative comparison is more accurate. It is difficult to say if the results in this study are externally valid in absolute terms for real driving, but it seems likely that the difference between the consistent and inconsistent treatment groups' speed choice is reflective of a relative difference that would be expected to exist in real driving. A study from the UK is relevant here; (Helman et al., 2010) used an instrumented vehicle to examine speed choice on curves on a rural road with a 60mph speed limit, and were able to show that speeds varied with curve severity and risk, and also (independently) with the levels of treatment present. A questionnaire study within the same investigation showed the same effect of increased levels of treatment corresponding to decreasing speed. Results like this, taken with results from the current study, suggest that one fruitful way in which the self-explaining road concept can be used to improve road safety is through the use of treatment levels that vary consistently with the level of risk/severity on rural road curves.

It is important to have written guidelines and a specified framework how the workshops should be conducted in order to be able to compare results. The guidelines and background material used for the workshop concept can be further developed. For instance it should be possible to use the same animated graphical scenarios that are developed prior to driving simulator experiments. This may enter a possibility to even evaluate future not yet built environment and SER treatments. Having this an expert group could decide whether it is necessary to continue with a driving simulator experiment or not.

In conclusion the results from the driving simulator study demonstrate one way to evaluate the effect of potential treatments (in this case categorized as “self-explaining treatments”) on speed choice. Furthermore, the results show that a consistent mapping of treatment levels to the severity of curves is a potential way to make drivers adapt their speed appropriately for the risk present on a given curve. For the most severe curves a consistent treatment regime (as opposed to an inconsistent one) might be expected to result in a speed reduction of around 3 km/h for the most severe curves and on the types of roads tested in the study.

# 5. Sources

Aarts, L. and Davidse, R. (2007). *The recognisability of rural roads in the Netherlands*. Proceedings of the European Transport Conference, Leiden, October 2007.

Alexander, G. and Lunenfeld, H. (1986). *Driver expectancy in highway design and traffic operations*. Report No FHWA-TO-86-1. Washington, DC: Federal Highways Administration.

Baas, P. and Charlton, S. (2005). *Influencing driver behaviour through road marking*. Roadmarkers Federation Conference, Christchurch, 2005. Auckland: NZ Roadmarkers Federation.

Biederman, I., Mezzanotte, R. and Rabinowitz, J. (1982). *Scene perception: detecting and judging objects undergoing relational violations*. Cognitive Psychology, 14, 143-177.

Charlton, S.G. (2007a). *Investigating roads that help drivers slow down*. Land Transport Research, March 2007, 1-3.

Charlton, S.G. (2007b). *The role of attention in horizontal curves: A comparison of advance warning, delineation, and road marking treatments*. Accident Analysis and Prevention, 39(5), 873-885.

Charlton S. G. and de Pont J. J. (2007). *Curve speed management*. Research Report 323. Land Transport New Zealand.

Deliverable D1 of the SPACE project, *Self-Explaining Roads Literature review and Treatment Information* 2011

Deliverable D2 of the SPACE project, *Methods to evaluate international SER treatments, Preparations for a workshop*. 2011

Deliverable D3 of the SPACE project, *Self Explaining Road Treatments: Report from expert workshop*, 2011

Deliverable D4 of the SPACE project, *Consistent treatment in relation to the severity of a curve; a driving simulator study*. 2011

Deliverable D5 of the SPACE project, *Technical note, comparison of methods*. 2012

Godthelp, H. (2005). *Europia: zicht op een veilige verkeerswereld*. In F Wegman and L Aarts (Eds.) Denkend over duurzam veilig. Leidschendam: SWOV.

Helman, S., Kennedy, J., and Gallagher, A. (2010). Curve treatments on the A377 between Cowley and Bishops Tawton: final report (PPR494). Crowthorne: Transport Research Laboratory.

Kennedy, J., Gorell, R., Crinson, L., Wheeler, A. and Elliott, M. (2005). '*Psychological' traffic calming*. *TRL Report 641*. Crowthorne: Transport Research Laboratory.

Kerman J A, McDonald M and Mintsis G A (1982). *Do vehicles slow down on bends? A study into road curvature, driver behaviour and design*. *PTRC, 10th Summer Annual Meeting, Proc Seminar K*, p57-67.

Kerman J A, McDonald M and Mintsis G A (1982). *Do vehicles slow down on bends? A study into road curvature, driver behaviour and design.* PTRC, 10th Summer Annual Meeting, Proc Seminar K, p57-67.

Kraay, J. (2002). *The Netherlands Transport Plan*. Proceedings of the ICTCT Workshop, Japan, 2002.

Martens, M., Comte, S. and Kaptein, N. (1997). *The effects of road design on speed behaviour: a literature review.* TNO Report TM 97 B021. Soesterberg: TNO Human Factors Research Institute.

Managing Speeds of Traffic on European Roads (1998), 4th Framework, http://virtual.vtt.fi/virtual/proj6/master/master_finalreport.pdf

Matena, S. and Weber, R. (2010). *Selbsterklärende Straßen – Vergleich der Ansätze in Europa.* Straße und Autobahn, 2010 (1), 25-33.

Mazet, C. and Dubois, D. (1988). *Mental organisation of road situations: theory of cognitive categorisation and methodological consequences*. Proceedings of the Conference on Road Safety Theory and Research Methods. Leischendam: SWOV.

Mazet, C., Dubois, D. and Fleury, D. (1987). *Catégorisation et interprétation de scènes visuelles: le cas de l'environnement urbain et routier.* Psychologie Française, Numéro Spécial, 85-96.

McLean J R (1995). *An international comparison of speed prediction relations*. Road and Transport Research 4 (3), 6-15.

Michon, J. A. (1985*). A critical view of driver behaviour models: what do we know, what should we do?* In L Evans and R Schwing (Eds.) Human Behavior and Traffic Safety. New York: Plenum Press.

Näätäanen, R. and Summala, H. (1976). *Road User Behaviour and Traffic Accidents. Amsterdam:* North Holland.

Philip, P., P. Sagaspe, et al. (2005). "Fatigue, sleepiness, and performance in simulated versus real driving conditions." Sleep 28(12): 1511-1516.

Retting, R. A., and C. M. Farmer. (1998). *Use of pavement markings to reduce excessive traffic speeds on hazardous curves*. *ITE Journal*, 68 (9), 30–36.

Richter, T. and Zierke, B. (2009). *Safe design of rural roads by normalized road characteristics*. Association for European Transport.

Shaw, M. and Mayhew, N. (2000). *Some innovations in rural safety*. Highways and Transportation, 47(5), 15-18.

Theeuwes, J. and Godthelp, H (1992). *Begrijpelijkheid van de weg (Self-explaining roads).* Report IZF 1992 C-8. Soesterberg: TNO Institute for Perception.

Theeuwes, J. and Godthelp, H. (1993). *Self-explaining roads*. In de Kroes and Stoop (Eds.) Safety of Transportation. Delft: University Press.

Theeuwes, J. and Godthelp, H. (1995a*). Self-explaining roads*. Safety Science, 19, 217-225.

Theeuwes, J. and Godthelp, H. (1995b*). Self-explaining roads: how people categorize roads outside the built up area*. Strategic Highway Research Program Conference, Lille, September 1994. Linköping: VTI.

Theeuwes, J. (2000*). Commentary on Rasanen and Summala 'Car drivers' adjustments to cyclists at roundabouts'*. Transportation Human Factors, 2, 19-22.

Theeuwes, J. (2002). *Sampling information from the road environment*. In R. Fuller and J. Santos (Eds.) Human Factors for Highway Engineers. Oxford: Elsevier.

Turner, B., Tziotis, M., Cairney, P. and Jurewicz, C. (2009). *Safe system infrastructure: national roundtable report.* Report ARR370. Vermont, Australia: Australian Road Research Board.

Weber, R. and Hartkopf, G. (2005*). New design guidelines – a step towards self-explaining roads?* Proceedings of 3rd International Symposium on Highway Geometric Design. Washington DC: Transportation Research Board.

Wegman, F. and Aarts, L. (2005). *Denkend over duurzam veilig*. Leidschendam: SWOV.

Weller, G. and Schlag, B. (2007). *Road user behaviour model*. RIPCORD Deliverable 1.6.2.

Bergisch Gladbach: BASt.

Weller, G., Schlag, B., Friedel, T. and Rammin, C. (2008). *Behaviourally relevant road categorisation: a step towards self-explaining rural roads*. Accident Analysis and Prevention, 40, 1581-1588.

Wheeler, A. and Taylor, M. (1999). *Traffic calming in villages on major roads*: final report. *TRL Report 385*. Crowthorne: Transport Research Laboratory.

Web page of the SPACE project: http:www.fehrl.org/space