SPEED ADAPTATION CONTROL BY SELF-EXPLAINING ROADS (SPACE)

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Abstract

This paper describes the SPACE project (Speed Adaptation Control by Self-Explaining Roads). This is a European project, funded by ERANET Road initiative, looking at the meaning of self-explaining roads and what types of measures are most effective in achieving the objectives of self-explaining roads. A series of consultations with experts and driver simulation tests were conducted. 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.

Keywords: Self-explaining roads; speed adaptation, driver behaviour.

1. Introduction

The objective of the SPACE project (funded by the ERANET Road initiative) 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. The work in this project 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 this work package.

The second work package went onto evaluate the treatments through consultation with experts at a series of workshops, conducted in different countries across Europe. Following from this, the third work package involved taking some of the treatments (as selected by experts in workshop package 2) and using these in driver simulator tests in order to identify the impacts of these treatments on drivers' behaviour.

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, p. 62) 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.

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 paper 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

In the early stages of this project, a state-of-the-art literature review on the development of the concept of self-explaining roads over time was carried out so that potential self-explaining treatments could be identified and evaluated. Those treatments that may be useful in order to encourage road users to adopt lower speeds and that may be interpreted as "self-explaining" were explored. An inclusive approach was taken: treatments were included even though many of the treatments would have been rejected by purists. The reviewed treatments 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 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.

3.1. 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 severity of the curve.

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

3.2. 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 strips, 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.

3.3. 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

3.4. 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.

3.5. 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 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.

4.1. 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. 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.

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.

Prior to the shooting of the movies, some experiments with different camera positions on different vehicles were conducted 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 D2 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.

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.

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 driver simulator study, conducted in Sweden. 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 adaptation, 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 were a curve warning sign, at medium level curve warning sign and chevron curve sign and at high level curve warning signs, 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 1):

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)

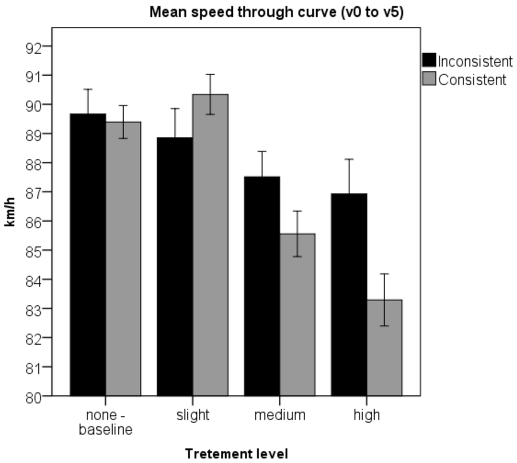
v5: 280 m after curve starts (curve ends)

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

Figure 1. 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 (vo) 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.



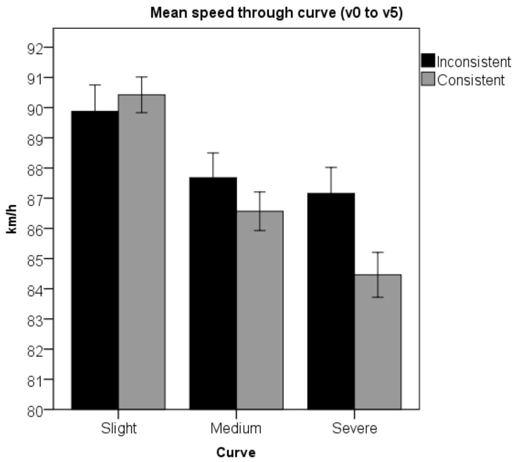


Figure 2. Mean speed through curve (v0 to v5) separated for treatment level and curve severity.

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.

5. Conclusions

The literature review carried out as part of this study demonstrates that the term "self-explaining road" has been in use since the 1990s. It was also apparent that the term SER means different things to different people and there is a clear need for guidelines on how SER can be used and what types of treatments might create safe driving conditions where road design fits the expectations of the road users.

Conclusions arising from the workshops include the following:

- Single treatments are less effective as a combination of treatments
- Definition of SER is different for existing roads and newly planned or constructed roads.
- Video sequences a useful method for expert evaluation
- In terms of the long term effect and cost-effectiveness, different circumstances for the video sequences are not that useful.

Conclusions arising from the simulator studies demonstrate the following:

- Consistent use of treatments according to the severity of curves is important.

Acknowledgements:

The authors would like to acknowledge that this project has been carried out with funding from ERANET Road.

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