**ERASER**

# Road User Pilots in Different European Countries

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**Evaluation to Realise a common Approach to Self-explaining European Roads**

# Deliverable Nr 2 – Testing the self-explaining nature of roads: the effects of combinations of road features in different European countries

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# Executive summary

Road safety can benefit from roads that are designed in a way that is self-explanatory for drivers. Indicating an appropriate driving speed is a main issue in self-explaining road design. Previous research has focused on the impact of different design elements on speeding behaviour, but it is less clear how universal these effects are. This was the focus of an online questionnaire study for the ERASER ERANET-roads project on self-explaining roads. It was conducted simultaneously in 6 European countries (N=307): Austria, Germany, the Netherlands, Great Britain, Ireland and Sweden. In total, 24 pictures of rural roads were presented; each a different combination of road width, separation of driving direction, vegetation of the roadside environment and the number of lanes per direction. Participants indicated their own driving speed as well as a safe speed limit on these roads. Results indicated that there are particular road features whose effects could be considered relatively self-explaining in the purest sense as they are similar for all countries (road width and vegetation). Effects of other road features, (lanes and type of separation) differed per country. This implies that extra communication (e.g. in an information campaign) or complementing roads with more self-explaining features, might enhance the desired speed behaviour.

Also in this project, a system for automated video analysis was used to collect the actual driving speed data for validation purposes. Two sites at a 2+1 road in southern Sweden were filmed using several cameras in order to be able to cover longer sections (200 and 100 m respectively). The video analysis system was adjusted so that the data from each individual camera could be connected into continuous speed profiles. Comparison with the questionnaire answers for the same road design showed good correspondence between the stated and actual driving speeds.

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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.eranetroad.org. Within the framework of ENR this joint research project was initiated. The funding National Road Administrations (NRA) in this joint research project are Austria, Belgium, Finland, Hungary, Germany, Ireland, Netherlands, Norway, Slovenia, Sweden and United Kingdom.*

In most European countries road categorization is based on road network planning. Usually, network planning considers several aspects such as hierarchical structure, functional structure and a general channelization of traffic flows. Thus, administrative and engineering aspects are taken into account together with political targets regarding the development of traffic in the future.

Indisputably, these aspects are important and essential for road network planning. However, the complex road categorization system has finally led to a high number of different road categories. These mirror the complexity of the road network structure from the technical point of view but do not necessarily meet road users' requirements.

With the stated aim of the European Union to diminish road accidents, the concept of self-explaining roads has become widely known (see next paragraph for a definition). Whereas a road section can be self-explaining, redesigning entire road networks along self-explaining principles is regarded as additional prerequisite to safer European roads. In Europe, several countries have already implemented or are currently implementing such SER approaches. However, because the SER concept mainly provides rather generic principles, the actual implementation differs largely between countries. Furthermore, little is known about how each of these approaches affects road user behaviour and subsequently road safety. Thus, a discussion is needed of what makes a road and a road network self-explaining. From this discussion, criteria have to be derived along which SER approaches can be compared and evaluated. In order to do so, the term SER has to be defined in a way which allows the further steps to be derived.

In the State of the Art, different approaches to SER and SER networks were discussed. As described there, a successful SER approach should include at least two components. The first follows directly from the definition of SER introduced by Theeuwes and Godthelp (1995), the second one follows indirectly:

> *"Traffic systems having self-explaining properties are designed in such a way that they are in line with the expectations of the road users. The [...] "Self-Explaining Road" (SER) is a traffic environment which elicits safe behaviour simply by its design."(Theeuwes & Godthelp, 1995, p. 217).*

The first component therefore requires that self-explaining roads are designed in a way that they elicit relatively safe behaviour, e.g. a speed that is appropriate for the road design and traffic situation. The second component requires the entire road-network to be designed along the self-explaining principles as well, in order to support the construction and persistence of expectations. This last component requires that roads are heterogeneous in design between road categories and homogenous in design within road categories. This design principle should be applied consistently on every road section. Serious violations of this rule are a threat to the support of expectancies and appropriate driving behaviour (e.g. Theeuwes & Godthelp, 1995).

In this WP (WP2 of ERASER: Road User Pilots in Different European Countries), we make a next step towards bridging the gap between fundamental knowledge concerning self-explaining roads and the practical, hands-on knowledge that road authorities require. In the present deliverable, we will focus on the first component: the design of a road that elicits relatively safe behaviour. The second component is taken into account by focusing on one particular type of road in the road network: the rural road. First, some background information will be presented as a framework for the study reported in this deliverable relating it to issues discussed in the State of the Art and the aim of ERASER in general.

The first chapter of this deliverable will start with a brief introduction to the theoretical background of self-explaining roads (Paragraph 1.1) and introduces the concept of „credibility“ (Paragraph 1.2). Paragraph 1.3 describes different research methods that have been applied in previous research, followed by a description of the approach taken in the research for this deliverable (Paragraph 1.4). The following two chapters report the two studies conducted: a questionnaire study and a study using automated video analysis. The final chapter provides a summary and discussion of all results and presents some conclusions.

## 1.1 *Self-explaining, predictable and safe roads*

The idea behind self-explaining roads is that roads can be designed in such a way that drivers can quickly 'read' them and recognise on what kind of road they are driving. Self-explaining roads communicate by design, and answer questions like: How should I behave here? And how can I expect others to behave? Design elements can be used that are self-explaining on their own, like cycle lanes on roads where cyclists can be expected (see Aarts & Davidse, 2007; Kaptein, Theeuwes & van der Horst, 1996). Also combinations of design elements that fit well to each other (e.g. design elements expressing the speed limit regime, road users allowed etc.) can be used. This is particularly important for making road categories recognisable.

Figure 1 illustrates how making roads recognizable can contribute to the prevention of crashes (e.g., Aarts & Davidse, 2007). If a road has a recognizable design, it is more likely to evoke the appropriate expectations concerning a road user's own behaviour and that of other road users. Consequently, all road users are likely to display more homogeneous and predictable behaviour than on roads with less recognizable designs. Eventually, this behaviour is likely to become more routine, leading to fewer and less dangerous errors, resulting in a reduction of crashes.

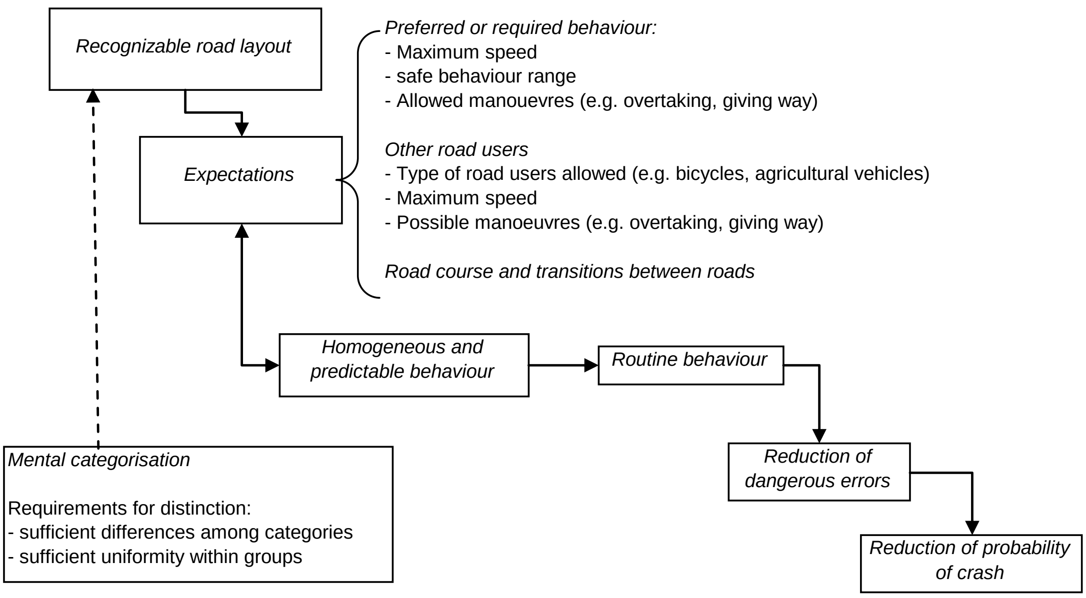


Figure 1 Flow-chart of recognizable layout and predictable behaviour (e.g., Aarts & Davidse, 2007).

A few notes should be made at this point. First, it should be pointed out that there is a distinction between a road layout that is recognisable and a road that is truly self-explaining. As mentioned in Chapter 6 of the State of Art, it would be preferable if appropriate behaviour could be deduced from the mere “look and feel” of a road without prior knowledge (i.e. self-explaining design). However, in reality, there will always be road sections where this is not the case and the road layout is not truly self-explaining. In those instances, the road designer will need to fall back on standardization, of which the meaning has to be learnt. This works best when design elements (or combinations of design elements) are consequently and consistently used for particular road types. Here, the categorization principle of uniformity within categories and heterogeneity between categories (e.g., Theeuwes & Godthelp, 1995) is of particular importance in order to prevent confusion among road users. The meaning of the design can often only be inferred when seen in the context of other design variants, but when the meaning is known, the road layout ultimately can become recognisable. An example of this would be the green centre marking that is used to indicate regional through roads (speed limit of 100 km/h, access restriction for vulnerable road users and slow traffic) in the Netherlands. This green centre marking is not self-explaining as it does not evoke the feel of a particular speed limit and particular access restrictions. However, the rule "Green = 100" can be a strong rule that can be learned easily, and a design element that is easy to recognize when applied consequently in appropriate situations (Stelling-Konczak et al., 2011).

A second note is that easy recognition of a road does not guarantee that crashes are prevented altogether. The psychological mechanism of recognition reduces the probability of fatal errors; however, it does not influence the more physical aspects that are relevant for road safety. For example, fatal crashes are more likely to occur if pedestrians would be allowed on a road with a design that is recognised by drivers as a ‘fast’ road. This could evoke high speeds, which do not fit to the mixture of fast traffic with vulnerable road users. This problem can be solved by designing roads in such a way that it is not only self-explaining or recognisable, but also fits to its functionality. In a safe system approach of road traffic, the functionality of a road is the starting point for a safe design, which includes a good fit with speed limit, access restrictions for particular types of road users and manoeuvres allowed (e.g., Wegman & Aarts, 2006). A more subtle example is a road with a 'high speed design' without physical (hardly over-rideable) separation of driving directions. In such a case, access restrictions and even manoeuvres allowed might be recognisable by the design of the road, however, the design does not prevent that drivers might cross the road accidentally, and might collide on the other side with an oncoming car. Here again, a self-explaining or recognisable road design can only be considered as 'safe' when it also fits to the more physical aspects that are relevant when crashes come into play. This issue of self-explaining design and the fit with physical safety by design will be elaborated further in WP3 (WP3 of ERASER: Road Authorities Pilots, development of a decision support tool). In this WP, we focus on the combination of design elements that evoke safe behaviour of drivers in an intuitive way. Speed behaviour will be the central theme, while it is a core issue in road safety and can be influenced by a self-explaining road design.

## 1.2 *A way of supporting safe behaviour: credible speed limits*

In studies in which self-explaining and recognisable roads are investigated, speed turns out to be an important issue for road users (e.g., Aarts & Davidse, 2007; Weller et al., 2008). Furthermore, speed is a central issue in road safety, given the importance of speed in crash causation and its direct influence on crash severity (Aarts & van Schagen, 2006; Elvik, 2009). Safety can be improved, when drivers choose a speed that fits to the conditions and design of the road. With design, the speed choice can be influenced by acting on the intuitive feel of what speed is appropriate. In Chapter 6 of the State of Art, which focuses on "What makes a road self-explaining?", a hierarchy of measures towards appropriate speeds is mentioned as important to consider for self-explaining roads.

So, ideally, the road design is self-explaining and evokes speed behaviour that is appropriate for the legal situation and function of the road. When the speed limit and road design fit to the speed behaviour that a majority of drivers would expose on such a road, a speed limit can be considered as 'realistic' (Fildes & Lee, 1993), 'acceptable' (Risser & Lehner, 1998) , or 'credible' (e.g., Goldenbeld & van Schagen, 2007). It should be noted that credibility of a particular speed limit is always relative to other speed limits and that it is not an absolute measure. For example, an 80 km/h speed limit for a road that has the 'look and feel' of a road with a 100 km/h speed limit will be less credible than a 100 km/h speed limit would be. Furthermore, as not only road design but also personality factors and dynamic factors play a role in speed choice, a credible speed limit will lead to most but not all drivers complying with it. However, a good fit between the design and the functionality of a speed limit can play an important role in driver acceptance of the speed limit posted, and road safety in general.

To convert the concept of credibility to practical applications that can help improve the self-explaining nature of the road in terms of speed, it is necessary to be able to relate a certain degree of credibility to specific road design features in relation to the posted speed limit. Ideally, the design fits so well and is so self-explaining for the speed limit posted, that it largely evokes the appropriate speed behaviour.

Credibility of speed limits has been found to be influenced by primary and secondary factors (van Nes et al., 2007). Primary credibility factors more or less physically force drivers to adapt their speed. Secondary credibility factors influence the speed choice more indirectly by using some kind of information from the environment that is more or less consciously processed. Each feature can have accelerating or decelerating effects, depending on the appearance.

### 1.2.1 **Primary credibility factors: physical speed reducers**

First of all, speed can be reduced by implementing road design elements that physically prevent most drivers from choosing a high speed. One of the most prominent speed reducing measures of this kind are speed humps (see literature overviews of e.g. Elliott, McColl & Kennedy, 2003; Martens, Comte & Kaptein, 1997). For this reason, speed humps are implemented, especially in domestic areas, where safe traffic mixture requires low speeds. Another speed reducing factor, which is more relevant for rural roads, is the sight distance (e.g. Liang et al., 1998). The sight distance is determined by the horizontal and vertical alignment of the road, such as road curves and hills. As a matter of fact, a short sight length only reduces speed if the sight is blocked over a longer distance and therefore for a longer duration; short disruptions of the sight length do not have any effect.

### 1.2.2 **Secondary credibility factors: visual, acoustic and haptic speed reducers**

Secondly, elements that provide visual, acoustic or haptic feedback to the driver about his or her speed, can influence speed choice. Road design as well as road environment characteristics can provide an optical flow which can result in vibrations and reduced driving comfort. An example of a characteristic that provides this type of feedback is road surface. Several studies have shown that a grooved road surface (e.g. cobbles or bricks) reduces speed compared to a more level road surface (e.g. van Driel, Davidse & van Maarseveen, 2004; Martens, Comte & Kaptein, 1997; van Nes et al., 2007). Some research also suggests that not only the type of road surface plays a role in the effect on driving speed, but also the quality of the road surface; for example, renovated asphalt on a road can increase driving speed by a few km/h (e.g. Leden, Hämäläinen & Manninen, 1998).

Furthermore, the road environment also provides feedback on driving speed and can therefore influence speed choice. Several studies showed that the presence of trees or buildings close to the road reduces speed, whereas an open road environment increases speed (Elliott, McColl & Kennedy, 2003; Ivan, Garrick & Hanson, 2009; Martens, Comte & Kaptein, 1997). The type of vegetation also makes a difference: trees have been shown to reduce speed more than bushes (de Ridder & Brouwer, 2002). The researchers explain this finding by the fact that trees are more dangerous in a collision than bushes. This makes them conclude that not only the density of obstacles is important, but also the perceived hazard of these obstacles. Furthermore, speed is reduced more when there are obstacles at both sides of the road rather than only one side having obstacles.

Another secondary road characteristic that is known to influence speed is road width and lane width. In general, it can be stated that wider roads evoke higher speeds (e.g., Cohen, 1997; Elliott, McColl & Kennedy, 2003; Martens, Comte & Kaptein, 1997). This also includes the number of lanes and emergency lanes of a road that are not physically separated from each other and give the road a wider image, even if other lanes are meant for traffic from the opposite direction (e.g., Goldenbeld & van Schagen, 2007; Martens, Comte & Kaptein, 1997). Martens and colleagues (1997) found that reduced speeds were reported particularly when lanes were narrower than 4 metres. Also temporary narrowing of roads has a speed reducing effect at that location.

## 1.3 *Research methods in previous research*

Literature describes multiple research methods that have been used to identify effects of specific road features on speed behaviour: photo-studies, simulator studies and field studies.

### 1.3.1 **Photograph studies**

Examples of studies using photographs are those of Aarts & Davidse, (2007), Goldenbeld & van Schagen, (2007) and Weller et al. (2008). Goldenbeld & Van Schagen (2007) for instance, studied credibility of speed limits by showing participants photographs of rural roads, which differed on elements such as road width, openness of the road environment, straightness of the road etc. They asked motorists to indicate their preferred speed and the speed they considered safe, without being informed about the actual speed limit of 80 km/h. The difference between the preferred speed or safe limit and the actual limit was considered an indication of the credibility of the speed limit in force. This photograph study showed that the credibility of a speed limit is indeed influenced by specific features of the road and the environment. This means that it is possible to improve the credibility of the limit by better tuning of the speed limit and certain features of the road and its environment. In this study, participants were asked to imagine how fast they would drive on such a road. The method of questioning - especially when it comes to behaviour – always raises the debate of about validity of the results. How do reported driving speeds relate to observed driving speeds? Research has indicated that observed speeds correlate well with drivers' self-reports of normal driving speed (e.g., West et al., 1993), which implies at least *relative* validity. To explain, relative validity indicates that if a higher driving speed is reported for a picture of a wider road compared to a narrower road, this will generally also be the case for actual driving speeds on these roads. However, the exact reported driving speeds might differ from the observed driving speeds. It is therefore important to take this into account when interpreting reported driving speeds. On the upside, questionnaire studies have the advantage that they easily allow for manipulation of the stimuli, are relatively low-cost and easy to administer. Easy manipulation of stimuli is especially useful when researchers want to vary certain factors while keeping others constant or when wanting to present pictures of situations that are hard to find in real life.

In some studies (e.g, Aarts & Davidse, 2007), photos were used twice: one group of participants were presented with the original photographs, while another group were presented with mostly the same photographs, but some were manipulated in Photoshop to give the total set a more homogenous look. The differences in results for both groups were an indication of the effect of the more homogenous look of the photographs. Although this study showed it is possible to use manipulated photographs, this approach is somewhat vulnerable for the fact that manipulations can be noticed by participants as being not quite natural. One way to overcome this problem is to use pictures. They can look very realistic – although not the same as photographs – and have the advantage of being manipulative on every detail.

### 1.3.2 **Driving simulator studies**

Another method, which fits better to the driving in real life – at least at face value – is the use of a driving simulator. Examples of such studies are for instance those of Aarts & Davidse (2008), Van Nes et al. (2008), Ben-Bassat & Shinar (2011) who studied the effect of road features on speed behaviour by using a driving simulator. Most of these studies used a within-subjects design and confronted participants with several variants of road design in a random order. All other elements of the design were kept as constant as possible. This allows for very systematic manipulation of variables and testing them in full experimental design to gather knowledge about the 'pure' effect of the variables under study. Another advantage of using driving simulators is that it is possible to measure more or less real driving behaviour without having to ask people to imagine explicitly what they think they would do in a particular situation. This makes the use of driving simulators less vulnerable for social desirable results, although participants may still be very aware that they are not in a real-life situation and in a testing scene. A large disadvantage of driving simulators is that it is a relatively expensive method expressed in costs of using a simulator, programming the environment to be tested on the simulator, as well as in time that is required to test each participant. Furthermore, part of the participants will fall out because of simulation sickness (e.g., Mourant & Thattacherry, 2000). Although driving simulator results may look more valid for real-life behaviour, still results should be interpreted with care (e.g., Godley, Triggs & Fildes, 2002). In general, results are interpreted in relation to each other, for instance comparing by differences in driving parameters between different scenarios.

### 1.3.3 **Field studies**

A third method that has been used is the field study. Using this method, behaviour is studied directly on the road (e.g. Rämä & Kulmala, 2000; Törnros, 1998; de Waard et al., 1995). This can be done in several ways. Putting cameras on particular spots can be a very effective method (e.g. Törnros, 1998). It does hardly disturb normal behaviour because it does nearly not affect the natural scene of the driver. This method is, however, only useful when the behaviour under study is overt, such as speed, and analysable from footage material. Other methods, such as putting cameras and other measurement aperture into a car, are mostly better able to measure more subtle behaviour. In general they are, however, also more intrusive, as they can be hardly made invisible for the driver. This method is these days often used in naturalistic driving studies. It has the advantage of being able to measure innumerable variables and connect them to scenarios that happen and the outside view. However, these field methods are less suitable for experimental manipulations of road designs to study.

## 1.4 *Current study*

This deliverable contains two studies that focus on driving speed and methods to measure speed in a valid way. The first study is a questionnaire study into the speed choice of drivers, related to the road design they are driving in. The second study is a field trial in which real driving speeds are measured by means of a camera. The results of both studies are combined to study validity. In order to get balanced results that can be linked to road categorisation and in order to avoid too much variables to be manipulated in a full experimental design, this study will be limited to rural (distributor) roads. Furthermore, rural (distributor) roads are known to be relatively unsafe, which is – at least partly - due to lack in forgiving and self-explaining design. Delivering knowledge that is better tuned to country specific characteristics can help improving driver-centred and safe road design.

# 2 Questionnaire study

## 2.1 *Background*

Although the amount of research about the effects of environmental elements, and road design in particular, influencing speed behaviour is becoming quite considerable, no studies are known that explicitly look at the combined effects of features and compare these effects between countries in a balanced experimental design. More knowledge about these aspects is also required to improve credibility heuristics that will be used for a decision-making tool to help road authorities making their roads more self-explaining for road users. This tool will be developed and tested in WP3 and WP4.

### 2.1.1 Research objectives

The objectives of this study are to:

- Demonstrate a method to determine main and combined effects of road design elements on speed behaviour
- Provide an indication of similarities and differences between European countries concerning their speed behaviour in terms of their reaction to the different road layout elements
- Provide input for the decision support tool to be developed in WP3.

As rural (distributor) roads are the roads under study, relevant variables to look at are:

- Road and lane width,
- Openness of the road environment,
- Number of lanes,
- Median treatment (.i.e: marking, physical treatment).

Other variables that might be relevant, such as horizontal and vertical lineation and road surface were not taken into account. The latter was not taken into account because surface has its most prominent effect by means of haptic feedback, which was not possible in a questionnaire study. Horizontal and vertical lineation and openness of the environment have in common that they provide more or less view on the follow-up of the road. As road environment is a more continuous feature, this was taken into account instead of the other sight-related variables.

## 2.2 *Method*

### 2.2.1 Materials

**Road Designs Used in the Questionnaire**

As was outlined in Deliverable 1 of ERASER discussing the state-of-the-art concerning Self-Explaining Road approaches, road width, road markings and environment all play a vital role in influencing driving behaviour and in designing self-explaining roads (Weller & Dietze, 2010). Thus, these three variables were selected as independent variables in the survey. In order not to have additional variations between countries, the stimuli presented in the survey had to be the same for each country. Thus, parameter values for each variable were established in a coordinated effort between all project partners by consulting the respective national guidelines and needs.

For road width, the matrix with the values finally used is shown in Table 1. As only a single value could be used for traffic lane width, the values for the right lane were chosen as values for all lanes in the 2 + 1 condition.

**Table 1 Minimum & maximum lane width per road type and country including the final lane widths selected for the stimuli.**

| | Lane width: Lanes in your direction (lanes in other direction) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 (1) | | 1 (2) | | 2a (1) overtaking lane | | 2b (1) right lane | | 2 (2) | |
| | min | max | min | max | min | max | min | max | min | max |
| Germany | 2.75 | 3.50 | 3.25 | 3.75 | 3.25 | 3.25 | 3.25 | 3.50 | 3.25 | 3.50 |
| Netherlands | 2.75 | 3.25 | 3.00 | 3.25 | 3.10 | 3.25 | 3.10 | 3.25 | 3.10 | 3.25 |
| Austria | 2.75 | 3.75 | 3.30 | 3.75 | 3.00 | 3.50 | 3.30 | 3.75 | 3.00 | 3.75 |
| | | | | | | | | | | |
| **Final** | **2.75** | **3.50** | **3.25** | **3.75** | **3.00** | **3.50** | **3.25** | **3.75** | **3.25** | **3.75** |

Similar to road width, a decision was made regarding road markings: A matrix, consisting of road marking type and number of lanes was drawn in a spread sheet. In this matrix, each participating country indicated whether a design was common or uncommon in the respective country. A pre-selection was made based on which ones were selected by the majority.

Finally, the environment was varied in two levels: wide and narrow. These levels were achieved by putting trees and bushes alongside the road.

**Table 2 Overview of variable combinations in stimuli included in the questionnaire ('x' indicates included stimulus).**

| Separation | Road Width | Environment | Number of Lanes in own driving direction + in other direction 2+2 | 2+1 | 1+2 | 1+1 |
|---|---|---|---|---|---|---|
| Physical (Phy) | Wide | Open | x | (x) | x | |
| | | Closed | x | (x) | x | |
| | Narrow | Open | x | (x) | x | |
| | | Closed | x | (x) | x | |
| Double white line (DWL) | Wide | Open | | x | x | x |
| | | Closed | | x | x | x |
| | Narrow | Open | | x | x | x |
| | | Closed | | x | x | x |
| Intermittent middel marking (IMM) | Wide | Open | | | | x |
| | | Closed | | | | x |
| | Narrow | Open | | | | x |
| | | Closed | | | | x |
| Additional designs for selected countries: | | | | | | |
| Cable barrier (Sweden) | Wide | Open | | | x | |
| | | Closed | | | x | |
| No middle markings (Germany) | Narrow | Open | | | | x |
| | | Closed | | | | x |

Additionally, two specific designs were used for Sweden and Germany: a cable barrier was used on a 2+1 road in Sweden with an open and closed environment and a narrow road with no middle markings was used in the German questionnaire, also with an open/closed variation. For Sweden, an additional design was included to provide a comparison to the real world data collected with the automatic video data analysis in Sweden (see Chapter 3). For Germany, the additional design was included because national guidelines strive to include this design in the near future. This resulted in the stimuli matrix shown in Table 2. The results of the additional German road designs are not included in this deliverable.

For the English version of the questionnaire, all pictures were presented from the driver's perspective on the left side. An overview of the stimuli can be found in Appendix A.

### Stimulus Preparation

The stimuli were designed in the simulation software STISIM Drive (Build 2.08.04; www.stisimdrive.com). The STISIM Drive software is a parameter based visualisation and simulation software with predefined commands. Each command has a variety of slots with predefined effects when being filled with the respective values. An example of the code used for the straight road sections for the stimuli can be found in Appendix B**.**

All pictures were taken from a perspective equalling a driver's line of sight. After the scripts were loaded in the simulation engine, screenshots were made. These screenshots were then reduced in size to 600×480 pixels. This was done in order to easily load the pictures to the questionnaire and to allow the questions to be shown below the pictures without too much scrolling.

### Item Selection

In general, items for the questionnaire were selected based on project needs formulated in the ERASER-DoW (Houtenbos & Eenink, 2009). However, in order for the large variety of pictures to be presented and to ensure that participants' concentration and willingness would not diminish, the number of items per picture had to be reduced to the most important ones needed for the project. Thus, based on the idea of credible speed limits that is applied in this project (e.g., Goldenbeld & van Schagen, 2007), the two items shown below were asked for each presented picture:

- If there was no speed limit, how fast would you drive on the road section shown? Please feel free to enter your speed as an unrounded number (e.g. "62" or "147").
- What speed limit do you think would be safe here?

The values for the first item could freely be chosen, for the second item predefined speed categories could be selected from a scale that ranged from 1 (30km/h) to 12 (no speed limit) using 10 km/h or mph increments. Similar to the difference in perspective for the pictures, the categories used depended on whether a metric (km/h) or English unit system (mph) was used. However, for data analysis, the English values were later recoded to metric ones. Figure 2 shows a screenshot of one picture as an example.

In addition to the picture-based items, demographic information was collected in a section prior to the picture section. The items used in the demographic section are shown in Appendix C).

Before the presentation of the demographic items, participants were given some general information and instructions (also in Appendix C).

After having completed the questionnaire, participants were asked for comments and whether they wanted to participate in the lottery (Appendix D).


road ERA net

10% completed

Please have a look at the picture below:

1. If there was no speed limit, how fast would you drive on the road section shown? Please feel free to enter your speed as an unrounded number (e.g. "62" or "147").

Speed mph

2. What speed limit do you think would be safe here?

[Please choose]
[Please choose]
20
30
40
50
60
70
80
no speed limit

Next

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**Figure 2 Screenshot of the questionnaire in the English version with the two questions used.**

## 2.2.2 **Procedure**

### Creating the Questionnaire for the Online Survey

In order to design the questionnaire along the needs outlined above and to present it online for the different countries, a powerful, reliable and cost efficient tool was needed. This tool was found in the software package oFB hosted by Soscisurvey (www.soscisurvey.de). Soscisurvey is free to use for non-commercial scientific organisation and allows using different internet addresses for different questionnaire versions in different languages. The language of the platform itself is German. A large selection of predefined answer formats and a graphical user interface allow most issues to be solved by laymen. For complex or specific needs, php and html code can be used. Participants' answers are saved online and can be downloaded in different formats, amongst which is the syntax format of the statistical package SPSS.

Unwanted effects caused by the order of picture-presentation were prevented by presenting pictures in randomized order. A combination of php and html scripts was used for this feature. Picture order and picture name were both saved as internal variables in the data.

All items were translated by the project partners in their respective language, resulting in four different versions: English (used for England and Ireland), Dutch, Swedish and German (with a slightly modified Austrian version).

E-mail addresses for those participants who wanted to take part in the lottery were stored separately from the survey data.

### Pretest conduction

Before participants were recruited, the survey was tested in each country. This resulted in some bugs being fixed.

### Recruitment

Although participant recruiting was done separately in each country, generally, the ways of recruitment were the same: Participants were recruited from colleagues, interested persons who subscribed to newsletters of the institutions, friends, family and students. In order to check for comparability between samples, several demographic variables were included in the questionnaire.

A stratification table was used for each country and participant characteristics (age and gender) were checked during selected times to check whether participant characteristics did not differ too much from the stratification table (Table 3). Details about how the stratification table (Table 3) relates to the actual distribution of participants (Table 4) are discussed in the next section.

**Table 3 Ideal stratification of respondents for gender and age group (per country)**

| **Age** | **Man** | **Women** | ***Total*** |
|---|---|---|---|
| 18-24 | 1 | 1 | *2* |
| 25-49 | 9 | 8 | *16* |
| 50+ | 8 | 4 | *12* |
| *Total* | *17* | *13* | ***30*** |

Besides some general information regarding the purpose of the experiment, the participation in a lottery was used as an incentive to take part. In each country, five vouchers of a large online bookstore a could be won by the participants.

**Survey conduction**

The survey was conducted between end of June and end of July 2011. After this period the link to the questionnaires provided the information that the survey was finished. After survey completion, data were downloaded and imported in SPSS with the syntax.

### 2.2.3 Participants

**Participant Characteristics**

Demographic characteristics of participants are given country-wise in Table 4.

**Table 4 Number of respondents per country, gender and age group**

| Gender | Age [years] | Country | | | | | | All |
|---|---|---|---|---|---|---|---|---|
| | | Austria | Germany | Netherlands | England | Ireland | Sweden | |
| Male | 18 to 24 | 1 | 3 | 2 | 3 | 0 | 1 | 10 |
| | 25 to 49 | 12 | 4 | 20 | 16 | 17 | 11 | 80 |
| | 50 ++ | 7 | 27 | 32 | 2 | 1 | 3 | 72 |
| | All male | 20 | 34 | 54 | 21 | 18 | 15 | 162 |
| Female | 18 to 24 | 2 | 1 | 9 | 5 | 0 | 0 | 17 |
| | 25 to 49 | 17 | 9 | 23 | 20 | 6 | 13 | 88 |
| | 50++ | 9 | 5 | 15 | 3 | 4 | 4 | 40 |
| | All female | 28 | 15 | 47 | 28 | 10 | 17 | 145 |
| All | | 48 | 49 | 101 | 49 | 28 | 32 | 307 |

The participants were selected to match the characteristics of the country-wise driver population.

Regarding the current driving practice, participants were asked how often they drive a car and how many miles (or the respective equivalent in kilometres) they drive each year. The results are shown in Figure 3 and Figure 4.

A part of the differences between countries shown in Figure 3 and Figure 4 might be attributable to the differences in mean age between the countries (see Figure 5 for the mean age per country). This was tested for question D206 ("How many kilometres do you typically drive a car each year"; see Figure 4) with a univariate ANOVA with country as factor and age as covariate. The results showed significant effects for both country and age. However, the country effect was still slightly stronger despite the significant age effect (country: $F(5, 300) = 3.14$, $p < .01$, $\eta^2=.05$; age: $F(1, 300) = 6.38$, $p < .05$, $\eta^2=.02$; although both effects would be considered small). The significant effect of country is mostly attributable to the British sample which reported the highest mileage and differed significantly from all other countries regarding the distance driven. The only other significant difference in reported mileage driven was between Germany and the Netherlands with the German sample reporting a lower mileage.

This exemplary test with variable D206 showed that there were indeed differences between countries in the selected samples. Despite the population having been carefully selected according to a stratification table, some of these effects were attributable to age. However, these differences are of minor importance as long as the ratings themselves are not influenced by demographic differences. This was also tested and is reported at the end of this chapter.

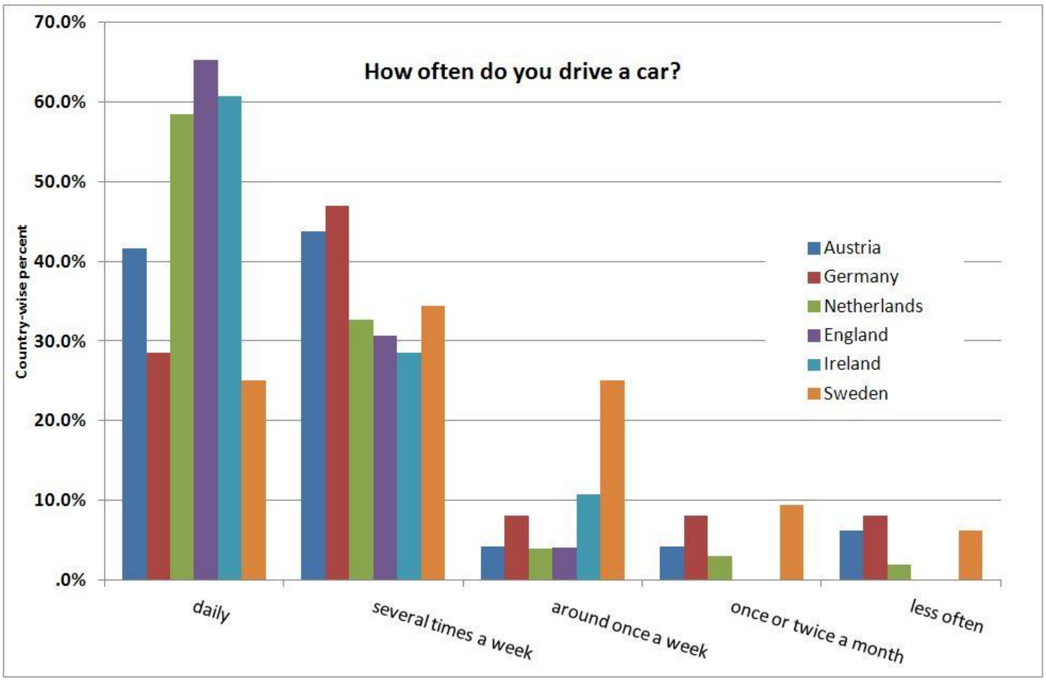



**Figure 3 Percentage of respondents per country indicating how often respondents drive a car.**

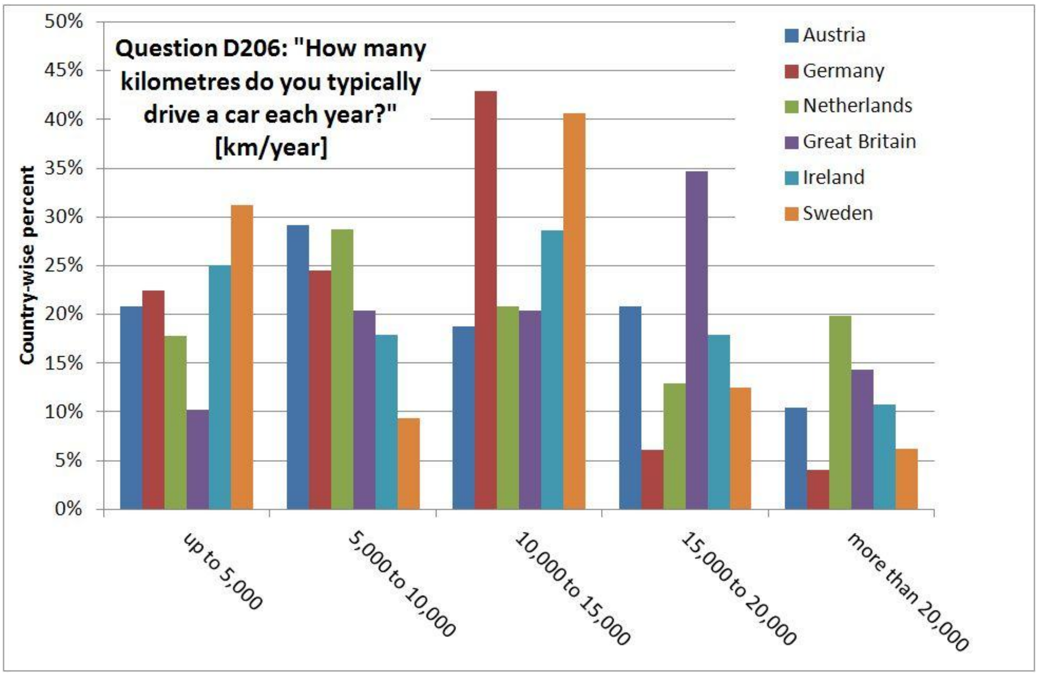



**Figure 4 Percentage of respondents per country indicating typical annual mileage (in km) Note: Values for GB were transformed from miles to kilometres**

The participants were further asked how they characterised their driving style. The answers were collected on a five-point Likert scale, ranging from “very calm” (coded 1) to “very sporty” (coded 5). However, as the extreme categories were underrepresented (“very calm” was selected 11 times, “very sporty” 2 times out of 307), they were recoded to the next less extreme category. This resulted in the country-wise distribution shown in Figure 5.

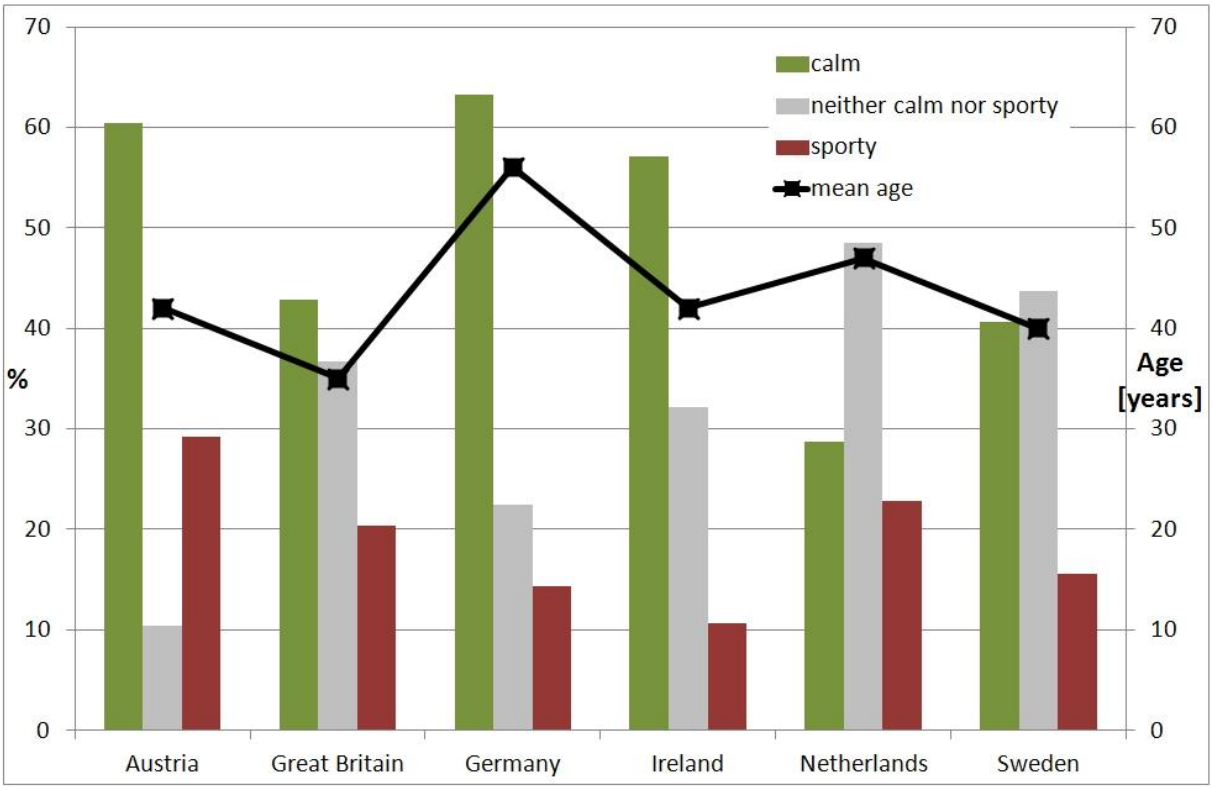



**Figure 5 Percentage of respondents per country indicating their normal driving style compared with age in years. For explanations regarding the effect of age, see text.**

The participants were asked for their driving style in order to have some control on whether individual driver characteristics play a role when rating the pictures. As can be seen in Figure 5, there are some differences in self-reported driving style between countries.

These differences were tested with a chi-square test, ran as a Monte-Carlo simulation. This test showed overall significant differences between countries with $X^2(10) = 34.59$, $p<.001$. The standardised residuals in the contingency table showed only few significant differences between the ratings of a single country and the overall ratings: Austria had significantly less drivers who reported to be “neither calm nor sporty” drivers ($p<.01$), the German sample comprised more drivers describing themselves as “calm” ($p<.05$) and The Netherlands had less drivers describing themselves as “calm” and more drivers describing themselves as “neither calm nor sporty” (both $p<.05$).

An additional test was conducted to test whether these differences might be attributable to differences in age (univariate Anova). The results again showed the significant country effect and an additional age effect (country: $F(5, 300) = 2.64$, $p < .05$, $\eta^2=.04$; age: $F(1, 300) = 8.16$, $p < .01$, $\eta^2=.03$).

When comparing these results with the results of the SARTRE study (Quimby, 2005, SARTRE, 2004), it becomes evident, that the sample of the study conducted here, differs in some respect from the more representative SARTRE study. This is not surprising given the relative small sample sizes of participants in the ERASER study.

However, for this report, these country-wise differences are only relevant in case of an interaction between driving style and country. To test this, all speed ratings (“How fast would you drive on the road section shown?") were averaged across all pictures and a univariate analysis of variance was calculated with driving style and country as factors. The results[1] showed two highly significant main effects of driving style ($F(2, 289) = 15.10$, $p < .001$, $\eta^2=.10$ (moderate effect)), with the sporty drivers giving higher speeds than both other groups, and of country ($F(5, 289) = 5.85$, $p < .001$, $\eta^2=.09$ (moderate effect), with most countries differing from one another. This effect of country will be analysed in more detail in picture-wise analyses in the main part of this report. However, the most important thing is that there is no significant interaction effect of driving style and country. This means that the subsequent country-wise analyses can be conducted without necessarily having to take into account driving style.

Whether countries differed regarding the self-reported speed preferences (Question D209: "How fast - or slowly - do you typically drive compared to the regular traffic flow?") was also tested statistically. A first look at the data revealed very small differences between countries. With categories ranging from 1 ("much more slowly") to 5 ("much faster") the median value was three for all countries. Small differences were only visible when values were averaged. The German sample showed the smallest average (2.92) and the Dutch sample the highest average (3.19). Because the most extreme categories were only selected once, they were recoded to the next less extreme value before the data were tested statistically. The subsequent chi-square test showed no significant differences between countries.

As has already been written, participants were selected according to a stratification table including age-group and sex. Although the requirements set by this table were met, participants could still differ regarding age as there were just three groups with the oldest one starting from the age of 55.

Thus, an ANOVA was carried out with country as factor and age (question D201_01) as dependent variable. Because the ANOVA is robust against smaller violation of its assumptions, this was done despite the data for Austria and Germany deviated significantly from the assumption of normally distributed data (significant KS-tests). The resulting ANOVA indicated highly significant overall differences between countries ($F(5, 301) = 10.77$, $p < .001$, $\eta^2= .152$).

Because Levene's test indicated highly significant deviances from the assumption of equal variances ($F(5, 301) = 12.15$, $p < .001$), the corrected statistics of Tamahane were used for the post-hoc tests. The most important thing here is that the German sample was the oldest one ($M$=56.2, $SD$=20.6) and differed significantly from all other samples, except for the Dutch sample ($M$=46.8, $SD$=15.8). The Dutch sample in turn was significantly older than the British sample which also was the youngest sample ($M$=35.3, $SD$=11.0). No other differences between countries were significant.

Because these differences in age could have consequences for the results, a similar test was conducted as for driving style: an ANOVA was calculated with the averaged speed values across all pictures per subject as dependent variable and with country as factor and age as covariate. The analysis showed a significant effect of country ($F(5, 300) = 7.21$, $p < .001$, $\eta^2=.107$) but no significant effect of age. This could indicate that the elder subjects in the entire sample belonged to a rather fit group within their peer group. At least for Germany, which showed these significant differences in age to the other countries, this could be the case: a part of the subjects was recruited from a rather fit sample of elderly drivers who performed a driving test in a preceding study. Because age was not significant, age does not necessarily have to be taken into account as an additional factor for the subsequent picture-wise analyses.

It can be summarized that there are indeed differences between countries in several driving

[1] Readers who are not familiar with statistical parameters such as F, $X^2$, the degrees of freedom or p-values can find more information in text books such as the one written by Field (2005)

relevant sample-characteristics. Whether these differences are due to actual differences between countries or are an effect related to the selection of the samples cannot be determined for sure. However, given the relatively small sample sizes of this study in comparison to studies using more representative samples (e.g. SARTRE, see above), the latter is more likely. However, the statistical analyses also showed that these differences likely do not affect the results for the country-wise analyses and thus do not endanger the main purpose of this study.

## 2.3 *Results*

### 2.3.1 Data analysis

Both variables Driving Speed as well as Speed Limit were treated as interval scale variables and GLM ANOVA Repeated Measures analyses were conducted accordingly. It should be noted, however, that some assumptions needed to be made concerning the variable Speed Limit, which, strictly speaking, was an ordinal scale due to the last point on the answer scale that referred to "no speed limit". To be able to transform the data to interval scale format, a recode was performed on the answer scale for Speed Limit, recoding all answers into the corresponding value for km/h where possible. The "no speed limit" point was recoded into 140 km/h to follow the 10 km/h increments from the previous scale point (130 km/h). Results should be carefully interpreted as we have no way of knowing if participants indeed would think a speed limit of 140 km/h would be appropriate or rather 160 km/h. The results for the Speed Limit variable are not presented separately as they indicated similar effects to the Driving Speed results. However, analyses was done using the difference between the (transformed) Speed Limit and Driving Speed. These are presented in Section 2.3.4.

**Three analyses**

Due to the unbalanced design, not all data could be included in one analysis. Therefore, three different subsets were defined that together included all data, and are individually as large as possible to still allow for comprehensible results. These subsets can be found in Table 5.

The "purple" analysis is the largest analysis and focuses on the differences between the 2+2/2+1 roads and the 1+2 roads and includes Separation with two levels (physical barrier versus double white line), Road Width with two levels (wide versus narrow), and environment with two levels (open versus closed). A dotted purple line in Table 5 indicates that the results of this analysis pertain to both 2+2 roads as well as 2+1 roads with a physical barrier, as the pictures created for these two types of roads could not be distinguished from each other with regards to the lane configuration. Due to the physical barrier blocking the view of the opposing lanes, the respondent could not tell whether there was just one or two lanes in the opposing direction (see in Appendix A the stimuli starting with "R22phy").

The "blue" analysis compares all 1+2 and 1+1 roads with a double white line as separation. Effects of Road Width (wide versus narrow) and Environment (open versus closed) are also assessed.

The "green" analysis compares all 1+1 roads that differ with respect to Separation (double white line versus intermittent middle marking), Road Width (wide versus narrow) and Environment (open versus closed).

**Presentation of results**

All results are described in words and complemented with the statistical information of the tests performed. For example, the ANOVA-test will be reported by mentioning the F-ratio, degrees of freedom, and the significance value "p", which generally needs to be smaller than

.05 to be considered significant. Also, to indicate effect size, rather than just reporting the level of significance, eta-squared is reported. In the interpretation of this effect size, .01 is generally considered a small effect, .06 moderate and .14 large. For more information on the statistical procedure, please refer to a statistical text book (e.g., Field, 2005).

Not all results are presented in a figure. Only significant results and/or results for which the interpretation is helped by presenting them in a figure, are presented in a figure.

**Table 5 Analysis scheme indicating the variable combinations in stimuli included in the "purple", "blue" and "green" analysis design respectively.**

| | | | Lanes | | | |
|---|---|---|---|---|---|---|
| **Separation** | **Width** | **Environment** | **2+2** | **2+1** | **1+2** | **1+1** |
| Physical (Phy) | Wide | Open | x | (x) | x | |
| | | Close | x | (x) | x | |
| | Narrow | Open | x | (x) | x | |
| | | Close | x | (x) | x | |
| Double white line (DWL) | Wide | Open | | x | x | x |
| | | Close | | x | x | x |
| | Narrow | Open | | x | x | x |
| | | Close | | x | x | x |
| Intermittent middel marking (IMM) | Wide | Open | | | | x |
| | | Close | | | | x |
| | Narrow | Open | | | | x |
| | | Close | | | | x |

### 2.3.2 **Driving Speed**

"Purple" analysis design, focusing on 2+2/2+1 roads versus 1+2 roads.

Lanes (2)

Separation (2)

Road Width (2)

Environment (2)

**Lanes**

There is a significant effect of number of lanes or should we say lane direction ($F(1,301)=338.18$; $p<.001$, $\eta^2=.53$ (large effect). Respondents in all countries reported considerably higher speeds on 2+2/2+1 roads than on 1+2 roads (Mean 2+x=101.78; Mean 1+2=90.98).

On roads with a double white line as separation, it matters less what the lane configuration is, than on roads with a physical barrier as separation ($F(1,301)=293.23$; $p<.001$, $\eta^2=.49$). The combination of a physical barrier and a 2+2/2+1 roads yields considerably higher speeds than all other combinations (see the figure below).

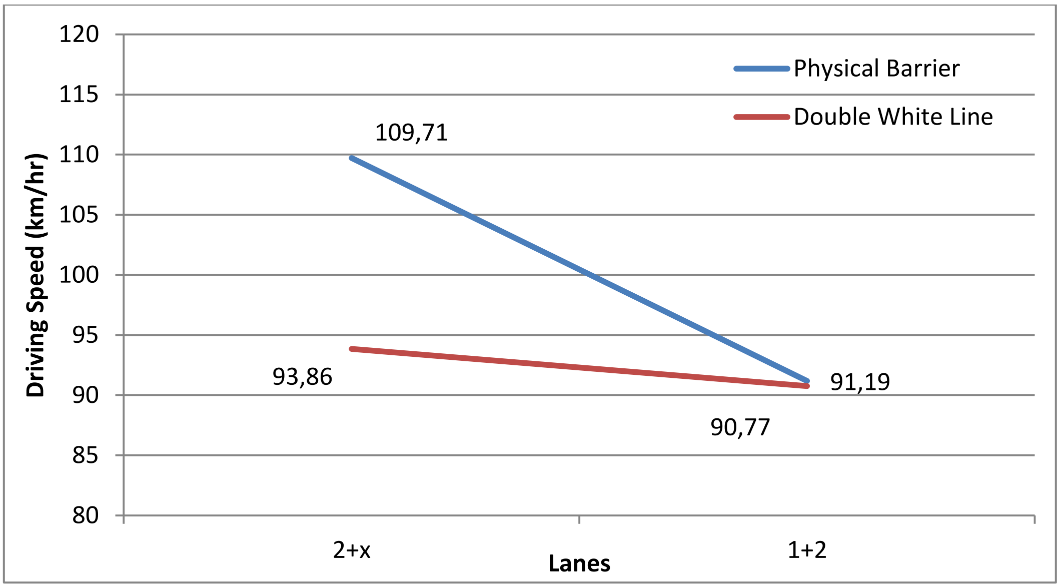



**Figure 6 Effects on reported Driving Speed of combinations of Lanes and Separation**

The speed increasing effect of the (open) environment was slightly larger on the 2+x road than on the 1+2 road: $F(1,301)=23.10$; $p<.001$, $\eta^2=.07$ (moderate effect).

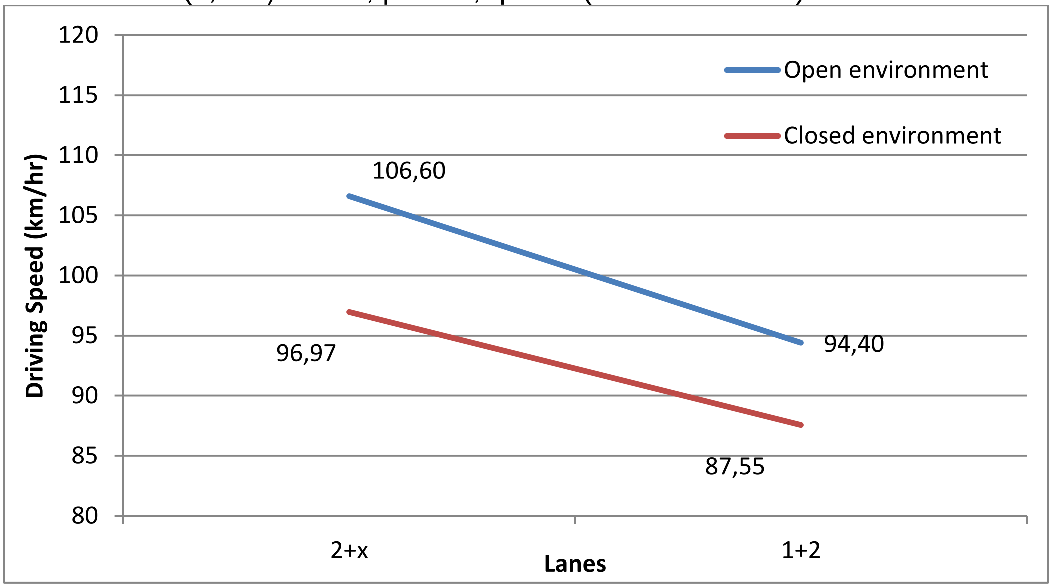



**Figure 7 Effects on reported Driving Speed of combinations of Lanes and Environment**

## Separation

Respondents reported considerably higher speeds (Mean difference =8.14 ) on roads with a physical barrier compared to the roads with a double white line as separation ($F(1,301)=182.43$; $p<.001$, $\eta^2= .38$ (large effect)). However, as can be seen in the figure below, this effect is not equally strong for each country ($F(5,301)=5.55$; $p<.001$, $\eta^2= .08$ (moderate effect)). The mean difference for Austria, the UK and Ireland, for example, is less than 5.5 , whereas the mean difference for Germany, the Netherlands and Sweden is more than 8.5. Also, on wider roads, the results show a slightly greater difference in reported speeds between roads with a physical barrier and roads with a double white line than on more narrow roads ($F(1,301)=4.88$; $p<.05$, $\eta^2= .02$ (small effect)) .

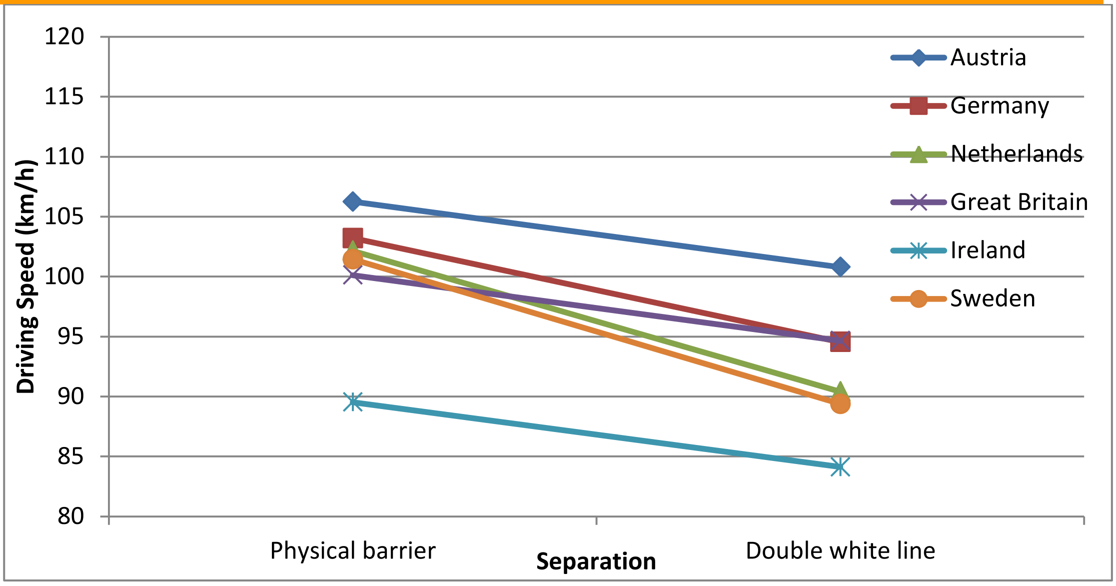



**Figure 8 Effects on reported Driving Speed of combinations of Separation and Country**

### Road Width

Reported driving speeds were slightly higher on the wider roads (Mean = 97.04) than on the narrower roads (Mean=95.72); (F(1,301)=28.06; p<.001, $\eta^2$= .09 (moderate effect)).

### Environment

Reported driving speeds were considerably higher on the roads with an open environment (Mean = 100.50) than on the roads with a more closed environment (Mean=92.26), (F(1,301)= 229.59; p<.001; $\eta^2$=.43 (large effect)).

### Country

The results indicated a significant difference between countries; (F(5,301)= 6.13; p<.001; $\eta^2$=.09 (moderate effect). Post Hoc tests revealed that Irish respondents reported a significantly lower speed (Mean Ireland = 86.82) than all other countries except for Sweden (Mean=95.41).

## "Blue" analysis design, focusing on 1+2 roads versus 1+1 roads. (Separation = Double White Line).

Lanes (2)

Road Width (2)

Environment (2)

### Lanes

Higher speeds were reported on 1+2 roads (Mean 90.77) than on 1+1 roads (Mean 88.72); (F(1,301)= 24.96; p<.001; $\eta^2$=.08 (moderate effect)). This effect appeared to slightly differ between countries; (F(5,301)= 2.71; p<.05; $\eta^2$=.04 (small effect)). In Austria and Germany, speeds didn't really differ between 1+2 roads and 1+1 roads. In other countries (the UK, the Netherlands, Sweden and Ireland), reported speeds were slightly lower for the 1+1 roads compared to the 1+2 roads.

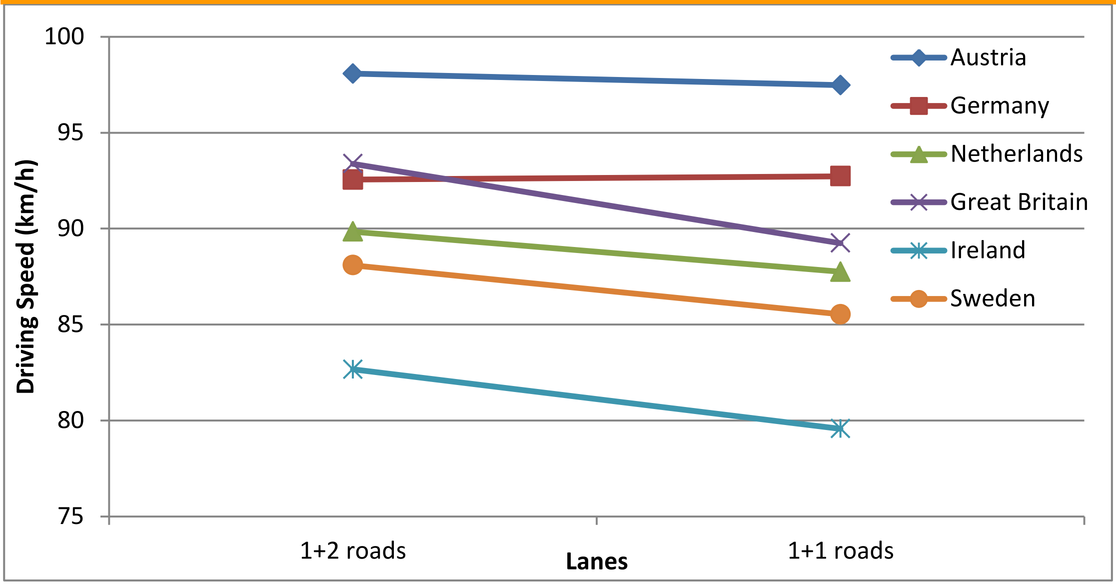



**Figure 9 Effects on reported Driving Speed of combinations of Lanes and Country**

## Road Width

Reported driving speeds were slightly higher on the wider roads (Mean = 90.75) than on the narrower roads (Mean=88.73); (F(1,301)=33.617; p<.001; $\eta^2$=.10 (moderate effect)). The speed increasing effect of a wider road seems to be slightly larger on the 1+1 roads than on the 1+2 roads (that are already relatively wide); (F(1,301)= 7.79; p<.01; $\eta^2$=.03 (small effect)).

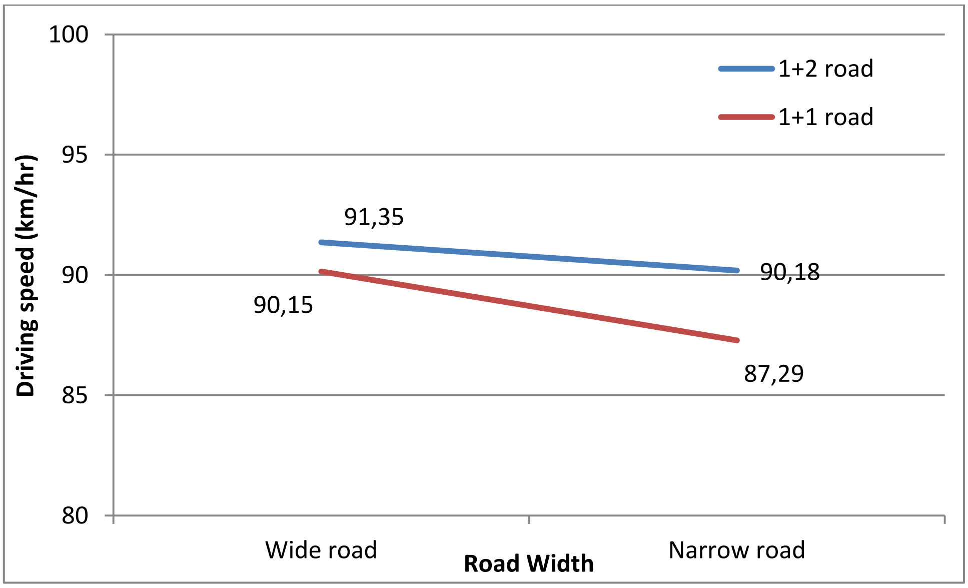



**Figure 10 Effects on reported Driving Speed of combinations of RoadWidth and Lanes**

## Environment

Reported driving speeds were considerably higher on the roads with an open environment (Mean = 93.31) road than on the roads with a more closed environment (Mean=86.17); (F(1,301)= 156.78; p<.001; $\eta^2$=.34 (large effect)).

### Country

Again, the results indicated a significant difference between countries; ($F(5,301)= 6.816$; $p<.001$; $\eta^2=.10$ (moderate effect)). Post Hoc tests revealed that Irish respondents reported a significantly lower speed (Mean Ireland = 81.12) than Austria, Germany and the UK. Dutch respondents reported lower driving speeds (Mean=88.80) than Austrian respondents (Mean =97.77). Respondents from Germany and the UK reported a Mean driving speed of 92.64 and 91.31 respectively).

**"Green" analysis design, focusing on 1+1 roads:**

- Separation (2: double white line vs. intermittent middle markings)
- Road Width (2)
- Environment (2)

### Separation

Overall, reported speeds on roads with a double white line as a separation between lanes do not differ from reported speeds on roads with intermittent middle markings. When we look at each country individually, we, however, do find differences between roads with these types of separation; $F(5,301)=563.86$; $p<.001$; $\eta^2=.08$ (moderate effect); Figure 11). In the Netherlands and Sweden, respondents reported lower speeds (2-3 km/h) on roads with intermittent middle markings compared to roads with a double white line. In other countries the opposite was found with the effect varying between 0.5 and 3 km/h.

A trend indicates that the speed increasing effect of an open environment might be slightly (1 km/h) higher on roads with intermittent middle markings than on roads with double white lines ($F=(1,301)=220.164$; $p<.10$; $\eta^2=.01$ (small effect)).

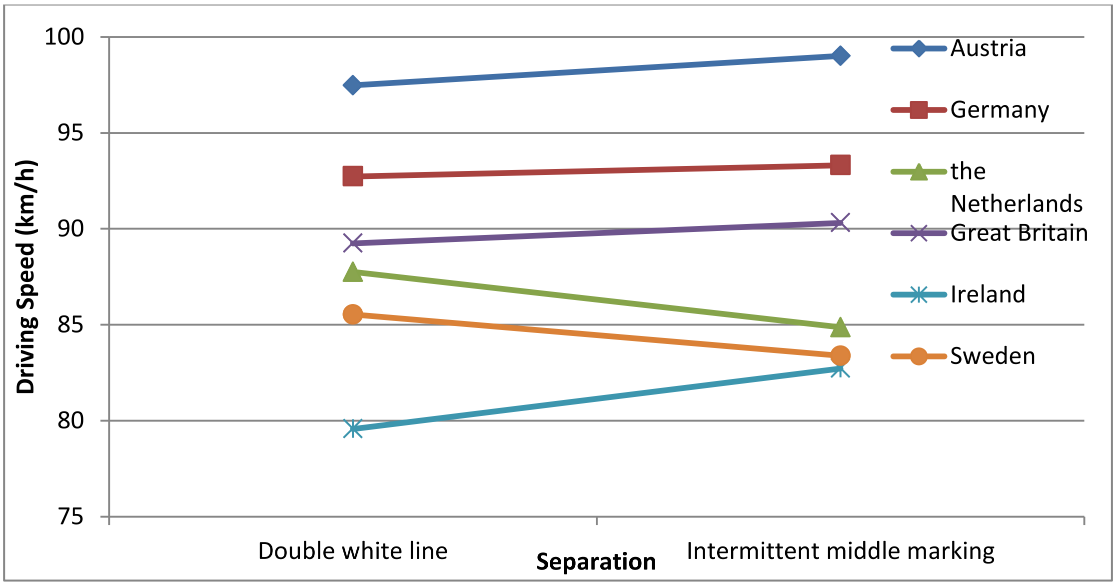



**Figure 11 Effects on reported Driving Speed of combinations of Separation and Country**

### Road Width

Reported driving speeds were considerably higher on the wider roads (Mean = 90.14) than on the narrower roads (Mean=87.51); $F(1,301)=53.56$; $p<.001$; $\eta^2=.15$ (large effect).

**Environment**

Reported driving speeds were considerably higher (ca. 8 km/h) on roads with an open environment (Mean = 92.91) than on roads with a more closed environment (Mean=84.75); $F(1,301)=197.84$; $p<.001$; $\eta^2=.40$ (large effect). Furthermore, a trend indicates that the speed increasing effect of an open environment might be slightly larger on the wider roads than on the narrow roads; $F(1,301)=3.52$; $p<.10$; $\eta^2=.01$ (small effect).

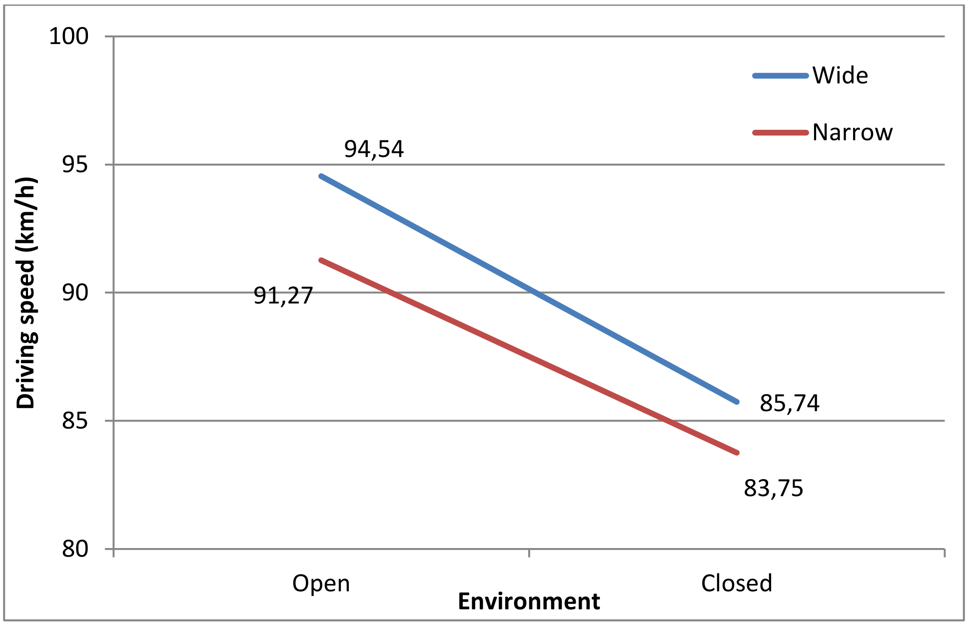



**Figure 9 Effects on reported Driving Speed of combinations of Environment and RoadWidth**

**Country**

The results indicated a significant difference between countries; $F(5,301)=10.00$; $p<.001$; $\eta2=.14$ (large effect). Post Hoc tests revealed that Austrian respondents reported a significantly higher speed (Mean Austria= 98.24) than all other countries except for Germany (Mean Germany = 93.02). The speeds reported in other countries ranged from 81.15 km/h (Ireland) to 89.78 km/h (Great Britain).

## 2.3.3 **Speed limit**

The results for Speed Limit were not analysed in the same way as the results for Driving Speed were as the results would show similar effects. Instead, to focus on the relationship between Speed Limit and Driving Speed, the differences were calculated and analysed. These results are reported in the Section 2.3.4. To help interpret the results within the context of each country's speed limit system, all countries were asked to provide the typical speed limits on the roads used in the questionnaire. The mean speed limits for the 2+2 and 2+1 roads with a physical barrier are the same due to the fact no distinction could be made between the pictures of the 2+2 versus 2+1 roads (see Section 2.3.1 for a more detailed explanation).

Table 8Table 6 through Table 11 provide a comparison of these typical speed limits and the mean speed limit mentioned for each particular road. In case of multiple speed limits, speed limits indicated in **bold** are generally the most typical speed limit. Speed limits in parentheses indicate what the speed limit might be on that road type if it were found in that country (which it is not).

**Table 6: Austria: Typical and Mean speed limit per road**

| Austria | | | Lanes | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2+2 | | 2+1 | | 1+2 | | 1+1 | |
| | | | Typical | Mean | Typical | Mean | Typical | Mean | Typical | Mean |
| Phy | Wide | Open | 130/100 | 118 | 100 | 118 | 100 | 96 | | |
| | | Closed | 130/100 | 110 | 100 | 110 | 100 | 92 | | |
| | Narrow | Open | 130/100 | 116 | 100 | 116 | 100 | 96 | | |
| | | Closed | 130/100 | 110 | 100 | 110 | 100 | 91 | | |
| DWL | Wide | Open | | | 100 | 104 | 100 | 99 | 100 | 100 |
| | | Closed | | | 100 | 97 | 100 | 82 | 100 | 93 |
| | Narrow | Open | | | 100 | 103 | 100 | 98 | 100 | 97 |
| | | Closed | | | 100 | 97 | 100 | 91 | 100 | 90 |
| IMM | Wide | Open | | | | | | | 100 | 102 |
| | | Closed | | | | | | | 100 | 94 |
| | Narrow | Open | | | | | | | 100 | 99 |
| | | Closed | | | | | | | 100 | 91 |

*Note for all Tables: Phy = Physical Barrier, DWL=Double White Line, IMM = Intermittent Middle Marking*

**Table 7: Germany: Typical and Mean speed limit per road**

| Germany | | | Lanes | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2+2 | | 2+1 | | 1+2 | | 1+1 | |
| | | | Typical | Mean | Typical | Mean | Typical | Mean | Typical | Mean |
| Phy | Wide | Open | 120/100 | 121 | 100 | 121 | 100 | 104 | | |
| | | Closed | 120/100 | 109 | 100 | 109 | 100 | 91 | | |
| | Narrow | Open | 120/100 | 119 | 100 | 119 | 100 | 99 | | |
| | | Closed | 120/100 | 106 | 100 | 106 | 100 | 88 | | |
| DWL | Wide | Open | | | 100 | 106 | 100 | 98 | 100 | 99 |
| | | Closed | | | 100 | 95 | 100 | 91 | 100 | 90 |
| | Narrow | Open | | | 100 | 102 | 100 | 97 | 100 | 95 |
| | | Closed | | | 100 | 96 | 100 | 89 | 100 | 88 |
| IMM | Wide | Open | | | | | | | 100 | 104 |
| | | Closed | | | | | | | 100 | 90 |
| | Narrow | Open | | | | | | | 100 | 100 |
| | | Closed | | | | | | | 100 | 89 |

**Table 8: Netherlands: Typical and Mean speed limit per road**

| The Netherlands | | | Lanes | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2+2 | | 2+1 | | 1+2 | | 1+1 | |
| | | | Typical | Mean | Typical | Mean | Typical | Mean | Typical | Mean |
| Phy | Wide | Open | **130**/120/100 | 112 | **100**/80 | 112 | **100**/80 | 94 | | |
| | | Closed | **130**/120/100 | 103 | **100**/80 | 103 | **100**/80 | 88 | | |
| | Narrow | Open | 120/**100** | 112 | 100/**80** | 112 | 100/**80** | 93 | | |
| | | Closed | 120/**100** | 105 | 100/**80** | 105 | 100/**80** | 86 | | |
| DWL | Wide | Open | | | (80) | 91 | (80) | 91 | 80 | 90 |
| | | Closed | | | (80) | 84 | (80) | 85 | 80 | 83 |
| | Narrow | Open | | | (80) | 91 | (80) | 89 | 80 | 87 |
| | | Closed | | | (80) | 85 | (80) | 84 | 80 | 81 |
| IMM | Wide | Open | | | | | | | 80 | 87 |
| | | Closed | | | | | | | **80**/60 | 80 |
| | Narrow | Open | | | | | | | **80**/60 | 83 |
| | | Closed | | | | | | | 80/**60** | 78 |

**Table 9: Great Britain: Typical and Mean speed limit per road**

| Great Britain | | | Lanes | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2+2 | | 2+1 | | 1+2 | | 1+1 | |
| | | | Typical | Mean | Typical | Mean | Typical | Mean | Typical | Mean |
| Phy | Wide | Open | 110 | 111 | 110 | 111 | 110 | 94 | | |
| | | Closed | 110 | 105 | 110 | 105 | 110 | 85 | | |
| | Narrow | Open | 110 | 112 | 110 | 112 | 110 | 92 | | |
| | | Closed | 110 | 103 | 110 | 103 | 110 | 85 | | |
| DWL | Wide | Open | | | 100 | 99 | 100 | 96 | 100 | 92 |
| | | Closed | | | 100 | 91 | 100 | 87 | 100 | 84 |
| | Narrow | Open | | | 100 | 99 | 100 | 93 | 100 | 89 |
| | | Closed | | | 100 | 89 | 100 | 88 | 100 | 85 |
| IMM | Wide | Open | | | | | | | 100 | 96 |
| | | Closed | | | | | | | 100 | 88 |
| | Narrow | Open | | | | | | | 100 | 92 |
| | | Closed | | | | | | | 100 | 83 |

**Table 10: Ireland: Typical and Mean speed limit per road**

| Ireland | | | Lanes | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2+2 | | 2+1 | | 1+2 | | 1+1 | |
| | | | Typical | Mean | Typical | Mean | Typical | Mean | Typical | Mean |
| Phy | Wide | Open | **120**/100 | 107 | 100 | 107 | 100 | 89 | | |
| | | Closed | **120**/100 | 97 | 100 | 97 | 100 | 86 | | |
| | Narrow | Open | **120**/100 | 104 | 100 | 104 | 100 | 91 | | |
| | | Closed | **120**/100 | 96 | 100 | 96 | 100 | 84 | | |
| DWL | Wide | Open | | | 100 | 91 | 100 | 91 | 100/80 | 89 |
| | | Closed | | | 100 | 86 | 100 | 84 | 100/80 | 84 |
| | Narrow | Open | | | 100 | 92 | 100 | 87 | 100/80 | 87 |
| | | Closed | | | 100 | 90 | 100 | 84 | 100/80 | 77 |
| IMM | Wide | Open | | | | | | | 100/80 | 93 |
| | | Closed | | | | | | | 100/80 | 80 |
| | Narrow | Open | | | | | | | 100/80 | 89 |
| | | Closed | | | | | | | 100/80 | 81 |

**Table 11: Sweden: Typical and Mean speed limit per road**

| Sweden | | | Lanes | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2+2 | | 2+1 | | 1+2 | | 1+1 | |
| | | | Typical | Mean | Typical | Mean | Typical | Mean | Typical | Mean |
| Phy | Wide | Open | 120/**110** | 112 | 100 | 112 | 100 | 95 | | |
| | | Closed | 120/**110** | 97 | 100 | 97 | 100 | 88 | | |
| | Narrow | Open | 110 | 111 | 100 | 111 | 100 | 92 | | |
| | | Closed | 110 | 95 | 100 | 95 | 100 | 84 | | |
| DWL | Wide | Open | | | 100/**90** | 91 | 100/**90** | 88 | 100/**90** | 86 |
| | | Closed | | | 100/**90** | 83 | 100/**90** | 84 | 100/**90** | 81 |
| | Narrow | Open | | | 90 | 88 | 90 | 87 | 90 | 84 |
| | | Closed | | | 90 | 80 | 90 | 80 | 90 | 76 |
| IMM | Wide | Open | | | | | | | 70/80 | 83 |
| | | Closed | | | | | | | 70/80 | 76 |
| | Narrow | Open | | | | | | | 70 | 82 |
| | | Closed | | | | | | | 70 | 76 |

### 2.3.4 Differences between Speed Limit and Driving Speed[2]

"Purple" analysis design, focusing on 2+2/2+1 roads versus 1+2 roads.

Lanes (2)

Separation (2)

Road Width (2)

Environment (2)

**Lanes**

The difference between the selected speed limit and reported driving speed was generally slightly larger on 2+2/2+1 roads compared to 1+2 roads (-1.3 km/h vs. -0.7 km/h; $F(1,301)=6.05$; $p<.05$; $\eta^2=.02$ (small effect)). The negative difference indicates respondents reported higher driving speeds than the speed limit they selected.

An interaction effect with Separation indicates that the difference is largest on 2+2/2+1 roads with a physical barrier ($F(1,301)=10.61$; $p<.01$; $\eta^2=.03$ (small effect); Figure 12). No main effect of Separation was found. A trend also indicates that this effect might be slightly larger in Sweden ($F=2.00$; $p<.10$; $\eta^2=.03$ (small effect)).

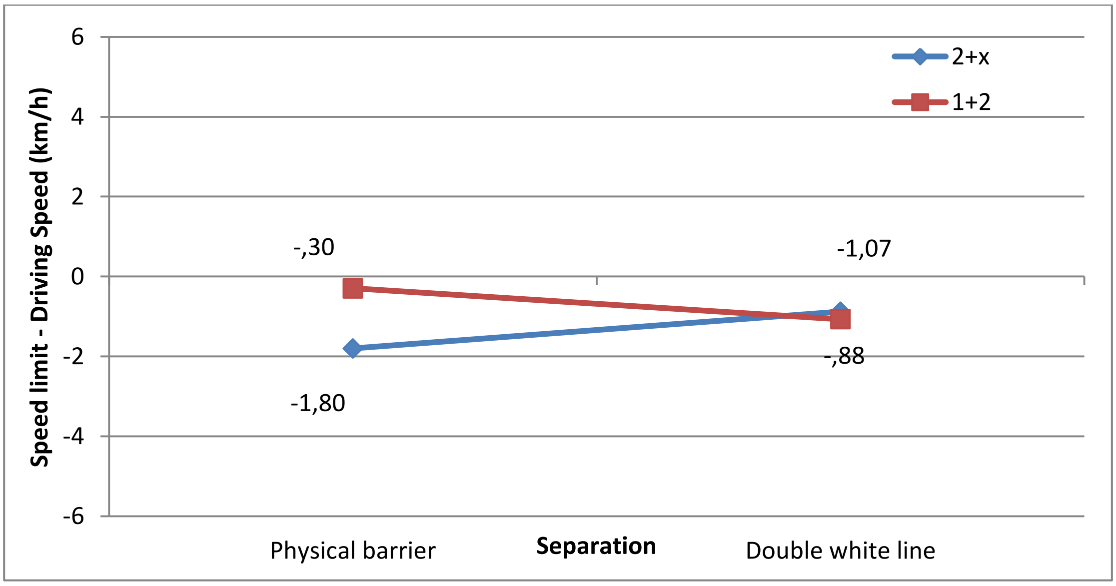



**Figure 12: Effects on the difference between reported Driving Speed and Speed Limit of combinations of Separation and Lanes**

**Environment**

The difference between the selected speed limit and reported driving speed was generally slightly larger on roads with a more open environment compared to roads with a more closed environment ($F(1,301)=6.38$; $p<.05$; $\eta^2=.02$ (small effect); Mean differences -1.4 km/h vs. -0.7 km/h). The interaction effect with Country indicates this effect is larger in Austria (Mean difference = -1.4 km/h) and Ireland (Mean difference = -2.6 km/h) than in other countries (Mean difference < |0.5|); ($F(5,301)= 2.57$; $p< .05$; $\eta2=.04$ (small effect); Figure 13). Another interaction effect indicates that the largest differences are found on 2+2/2+1 roads with an

[2] Differences were calculated by subtracting Driving Speed from Speed Limit. Hence, negative values indicate respondents generally reported higher driving speeds than the speed limit they selected.

open environment (F(1,301)=4.50; p<.05; η2=.02 (small effect)).

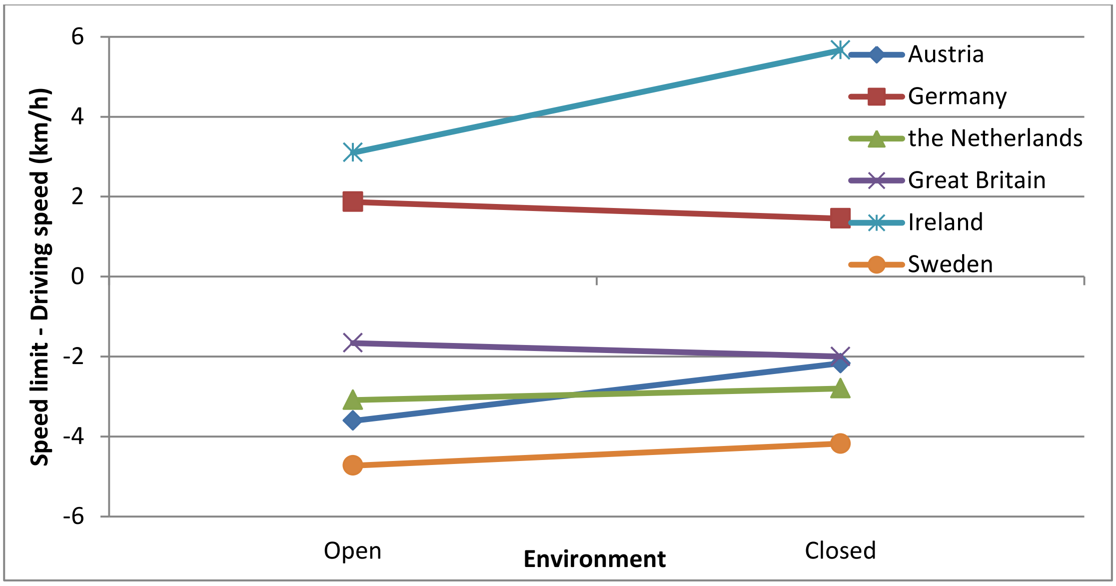



**Figure 13: Effects on the difference between reported Driving Speed and Speed Limit of combinations of Environment and Country**

### Road Width

An interaction effect of Road Width and Environment indicates that the greatest difference between speed limit and driving speed occurs on narrow roads in an open environment (F(1,301)=6.06; p<.05; $\eta^2$=.02 (small effect)). A trend interaction effect of Road Width and Separation indicates that the difference might be slightly larger on wide roads with a physical barrier (F(1,301)=3.06; p<.10; $\eta^2$=.01 (small effect)). No main effect of Road Width was found.

### Country

A moderate effect of Country was found (F(5,301)=6.92; p<.001; $\eta^2$=.10). Post hoc tests indicated that Ireland differs significantly from all other countries. The speed limits selected by Irish respondents are generally higher (Mean = 4.38 km/h) than their reported driving speeds. Only Germany shows the same effect, with a smaller difference of 1.66 km/h. All other countries generally reported higher driving speeds than the speed limit they thought would be appropriate there.

**"Blue" analysis design, focusing on 1+2 roads versus 1+1 roads. (Separation = Double White Line).**

Lanes (2)

Road Width (2)

Environment (2)

No effects were found for Lanes and Road Width.

### Environment:

A significant main effect of Environment indicates that on roads with an open environment, differences between the selected speed limit and reported driving speeds on roads with an open environment were slightly greater than on roads with a more closed environment ($F(1,301)=3.98$; $p<.05$; $\eta^2=.01$ (small effect)). Respondents generally indicated slightly higher driving speeds than the speed limit they selected. The interaction effect with Country indicates that this effect is not found equally for all countries ($F(5,301)=2.61$; $p<.05$; $\eta^2=.04$ (small effect); Figure 14). For example, in Ireland, the opposite effect was found. Respondents generally selected higher speed limits than driving speeds, and even more so on roads with a closed environment.

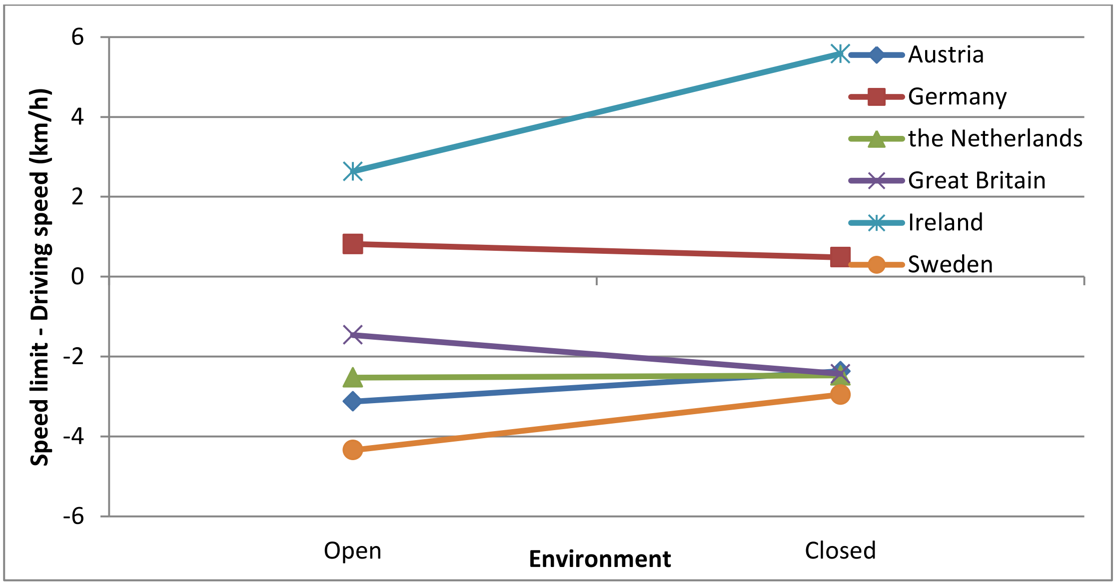



**Figure 14: Effects on the difference between reported Driving Speed and Speed Limit of combinations of Environment and Country**

**Country**:

A moderate effect of Country was found ($F(5,301)=5.30$; $p<.001$; $\eta^2=.08$ (moderate effect)). Post hoc tests indicate that Irish respondents showed significant greater differences (Mean difference = 4.11 km/h) than all other countries. Also, only Ireland (and Germany to a lesser extent) selected higher speed limits than reported driving speeds. All other countries, generally report higher driving speeds as compared to the speed limit they selected. For Germany, this might be explained by the relatively common option to have "no speed limit" on certain roads.

**"Green" analysis design, focusing on 1+1 roads:**

- Separation (2: double white line vs. intermittent middle markings)
- Road Width (2)
- Environment (2)

**Country**

A significant effect was found of Country ($F(5,301)=5.67$; $p<.01$; $\eta^2=.09$ (moderate effect)). Post hoc tests indicated a greater difference (Speed Limit > Driving Speed) in Ireland compared to all countries besides Germany and Great Britain. An interaction effect with Separation indicated that the difference between Speed limit and Driving speed per country also depends on the Separation ($F(5,301)=3.53$; $p<.01$; $\eta^2=.05$ (moderate effect); Figure 15). For example, in Germany and Great Britain, the difference is greater on roads with intermittent middle markings compared to roads with a double white line as separation. In Ireland, the opposite effect is found, and in all other countries, Separation did not seem to have that much of an effect.

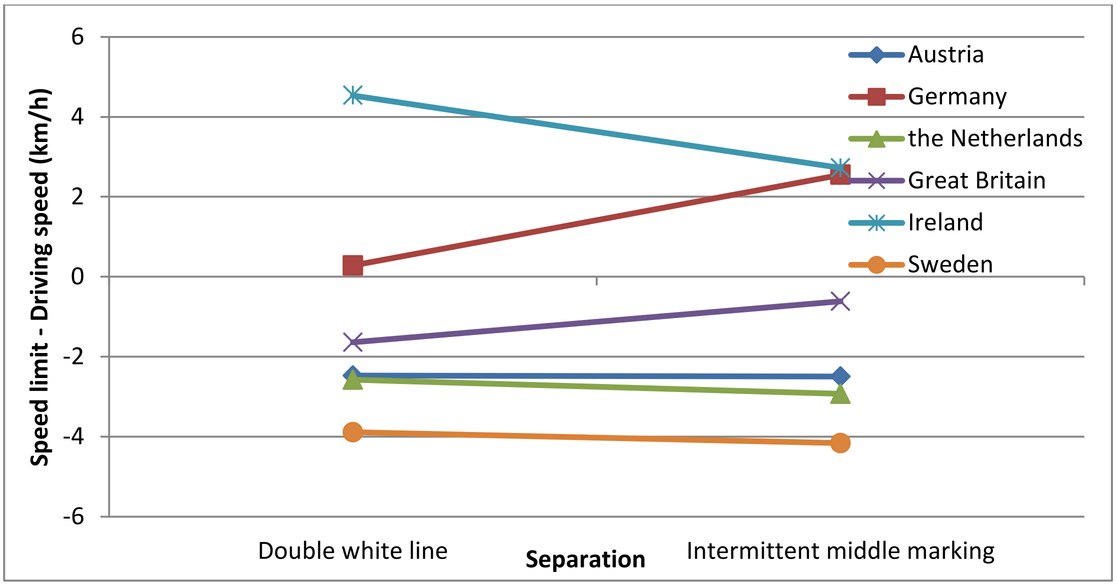



**Figure 15: Effects on the difference between reported Driving Speed and Speed Limit of combinations of Separation and Country**

## 2.4 *Discussion*

Although the amount of research about the effects of environmental elements, and road design in particular, influencing speed behaviour is becoming quite considerable, no studies were known that explicitly looked at the combined effects of features and compare these effects between countries in a balanced experimental design. More knowledge about these aspects was also required to improve the credibility heuristics that will be used for a decision-making tool to help road authorities making their roads more self-explaining for road users. This tool will be developed and tested in WP3 and WP4.

The objectives of this study were to:

1. Demonstrate a method to determine main and combined effects of road design elements on speed behaviour.
2. Provide an indication of similarities and differences between European countries concerning their speed behaviour in terms of their reaction to the different road layout elements.
3. Provide input for the decision support tool to be developed in WP3.

A brief discussion of the first and last objective can be found in Chapter 4. The discussion in this Chapter will focus on the second and main objective of this study and distinguishes between the effects on the reported driving speed and the effects on the differences between the reported driving speed and selected speed limit.

### 2.4.1 Key findings – Driving Speed

**Road width & environment**

The results found concerning road width and environment were all in the expected direction. Wider roads and roads with a more open environment elicited higher reported speeds than more narrow roads and roads with a more closed environment. The effect of the environment on speed was generally larger than the effect of road width.

The differences between countries do not occur for road width and environment, which implies that these aspects are relatively self-explaining.

**Country**

Differences between countries, however, did occur for lane treatment and the type of separation of driving directions, implying that these treatments are relatively less self-explaining and country specific.

**Lanes**

Although no differences were found between countries when comparing 2+2/2+1 roads with 1+2 roads, this was not the case when comparing 1+2 roads with 1+1 roads. In Netherlands, UK, Ireland and Sweden, 1+2 roads elicited at least 2 km/h higher speeds on average than 1+1 roads. Higher speeds on 1+2 roads as opposed to 1+1 roads were not found in Austria and Germany.

**Separation of driving directions**

The speed increasing effect of the physical barrier as opposed to the double white line as separation of driving directions is not equally strong for each country. The mean difference for Austria, the UK and Ireland for example was less than 5.5 km/h, whereas the mean difference for Germany, the Netherlands and Sweden was more than 8.5 km/h. When comparing roads with a double white line with roads with intermittent middle markings, the results indicate differences between countries as well. Dutch respondents reported lower speeds on roads with intermittent middle markings, whereas Irish and Austrian respondents show the opposite effect.

**Table 12: Overview of main results of the "purple" analysis for Driving Speed (see Table 5 for analysis design)**

| Measure | Effect | Mean difference |
|---|---|---|
| Lanes | 2+x > 1+2 | 10.80 km/h |
| Separation | Physical Barrier > Double White line | 8.14 km/h |
| Road Width | Wide > Narrow | 1.32 km/h |
| Environment | Open > Closed | 8.24 km/h |
| Country | Ireland generally reported lower speeds | |

**Table 13: Overview of main results of the "blue" analysis for Driving Speed (see Table 5 for analysis design)**

| Measure | Effect | Mean difference |
|---|---|---|
| Lanes | 1+2 > 1+1 | 2.05 km/h |
| Road Width | Wide > Narrow | 2.02 km/h |
| Environment | Open > Closed | 7.14 km/h |
| Country | Ireland generally reported lower speeds | |

**Table 14: Overview of main results of the "green" analysis for Driving Speed (see Table 5 for analysis design)**

| Measure | Effect | Mean difference |
|---|---|---|
| Separation | Double white line = Intermittent middle markings (but differences per country!) | 0 km/h |
| Road Width | Wide > Narrow | 2.63 km/h |
| Environment | Open > Closed | 8.16 km/h |
| Country | Ireland generally reported lowest speeds, Austria and Germany generally higher speeds | |

### Road width & environment

The results found concerning road width and environment were all in the expected direction. Wider roads and roads with a more open environment elicited higher reported speeds than more narrow roads and roads with a more closed environment. The effect of the environment on speed was generally larger than the effect of road width.

The differences between countries do not occur for road width and environment, which implies that these aspects are relatively self-explaining.

### Country

Differences between countries, however, did occur for lane treatment and the type of separation of driving directions, implying that these treatments are relatively less self-explaining and country specific.

### Lanes

Although no differences were found between countries when comparing 2+2/2+1 roads with 1+2 roads, this was not the case when comparing 1+2 roads with 1+1 roads. In Netherlands, UK, Ireland and Sweden, 1+2 roads elicited at least 2 km/h higher speeds on average than 1+1 roads. Higher speeds on 1+2 roads as opposed to 1+1 roads were not found in Austria and Germany.

### Separation of driving directions

The speed increasing effect of the physical barrier as opposed to the double white line as separation of driving directions is not equally strong for each country. The mean difference for Austria, the UK and Ireland for example was less than 5.5 km/h, whereas the mean difference for Germany, the Netherlands and Sweden was more than 8.5 km/h. When comparing roads with a double white line with roads with intermittent middle markings, the results indicate differences between countries as well. Dutch respondents reported lower speeds on roads with intermittent middle markings, whereas Irish and Austrian respondents show the opposite effect.

### 2.4.2 **Key findings – Difference between Speed Limit & Driving Speed**

As could be expected, less effects were found for the difference between Speed Limit and Driving Speed. The reported driving speed was quite often similar to the speed limit selected. However, some effects were found, suggesting that there are (combinations of) elements that can create a discrepancy between the speed limit people indicated as safe, and the speed they reported to be likely to drive there.

For example, the results suggested that on 2+x roads, respondents were inclined to report a relatively higher driving speed than the speed limit they selected as safe, compared to 1+2 roads. This is also found in combination with a physical barrier and an open environment. This implies that on a road that has a more "important" look (i.e. 2+1 roads, with a physical barrier and an open environment) people might be more likely to speed. It should be kept in mind, though, that the effects found are quite small, so the effect on speed behaviour might not be that noticeable.

**Table 15: Overview of main results of the "purple" analysis for the difference between Speed Limit and Driving Speed (see Table 5 for analysis design)**

| **Measure** | **Effect** | **Mean difference** |
|---|---|---|
| Lanes | 2+x ≥ 1+2 | - 0.6 km/h |
| Separation | Physical Barrier = Double White Line<br>N.B. 2+x & Physical barrier> all other combinations | - |
| Road Width | Wide = Narrow | - |
| Environment | Open ≥ Closed<br>N.B. 2+x & Open > all other combinations<br>N.B. Open & Narrow> all other combinations | - 0.6 km/h |
| Country | Ireland: speed limit is on average (4.38 km/h) higher than driving speed, more so than in all other countries, although Germany shows a similar effect (1.66 km/h).<br>In all other countries, speed limit < driving speed. | |

**Table 16: Overview of main results of the "blue" analysis for the difference between Speed Limit and Driving Speed (see Table 5 for analysis design)**

| Measure | Effect | Mean difference |
|---|---|---|
| Lanes | 1+2 = 1+1 | - |
| Road Width | Wide = Narrow | - |
| Environment | Open > Closed | - 0.6 km/h |
| Country | Ireland: speed limit is on average (4.11 km/h) higher than driving speed, more so than in all other countries, although Germany shows a similar, but smaller effect. In all other countries, speed limit < driving speed. | |

**Table 17: Overview of main results of the "green" analysis for the difference between Speed Limit and Driving Speed (see Table 5 for analysis design)**

| Measure | Effect | Mean difference |
|---|---|---|
| Separation | Double white line = Intermittent middle markings | - |
| Road Width | Wide = Narrow | - |
| Environment | Open = Closed | - |
| Country | Ireland generally reported the greatest difference between Speed Limit and driving Speed (followed by Germany and Great Britain). N.B. Germany/ GB & intermittent middle markings> all other combinations | |

# 3 Video recording and analysis of road user speed profiles

## 3.1 *Background*

Since 2004, Lund University has been developing an automated video analysis system that could handle road users in mixed traffic environments and extract their trajectories and speeds from video. So far, the system has been developed for, and thereby primarily tested in, urban conditions with relatively small area observed. To track road users in rural environment is in some way a simpler task since vehicles' direction of travel and orientation are more predictable and the distances between them are significantly larger.

However, the system had to be further developed and modified to meet the partly different demands in rural conditions. Higher vehicle speeds (compared to urban traffic) imply larger distances travelled in a short time and several cameras are necessary to cover the studied section. The cameras need to be synchronised in time and calibrated in a way that allows a seamless transfer of a tracked vehicle between the cameras. The detection and tracking algorithms must be modified to be able to handle a much higher share of heavy traffic and a much greater diversity regarding length among the heavy vehicles than is prevalent in urban conditions.

In this study, the video analysis system was used primarily to measure the travel speed of the free vehicles on a road section. It can be argued, that similar data could have been collected using more traditional methods like radar guns or by measuring travel time between two marked lines. In some way, this is true since the advantages of the system (primarily, the much higher degree of details in the data provided) did not really contribute to the quality of the final results. However, this test should be seen as the first try of the system in rural environment to explore its applicability and potential for making more advanced analysis of the road user behaviour (lane change manoeuvres, speed adjustments, interactions, etc.).

## 3.2 *Objectives*

The system development and the video recording study had four main objectives:

1. To modify the system to meet the demands in rural conditions
2. To test the modified video analysis system for collection of road user speed data in rural environment.
3. To compare actual speeds at two road sections with very similar design but different speed limits.
4. To compare the actual speeds at the studied road with the preferred speeds stated in the questionnaire responses and in this way get some indication of validity of the questionnaire study results.

## 3.3 *Method*

### 3.3.1 Site selection and filming

The video data for the experiment was collected at two sites on the road E65 in southern Sweden (Figure 16). This road is classified as having national importance for communication.

It is one of the main connectors to the Malmö airport Sturup and is also a recommended road for hazardous goods transportation. The highest allowed speed is 100 km/h, AADT is 10.000 vehicles per 24 hours.

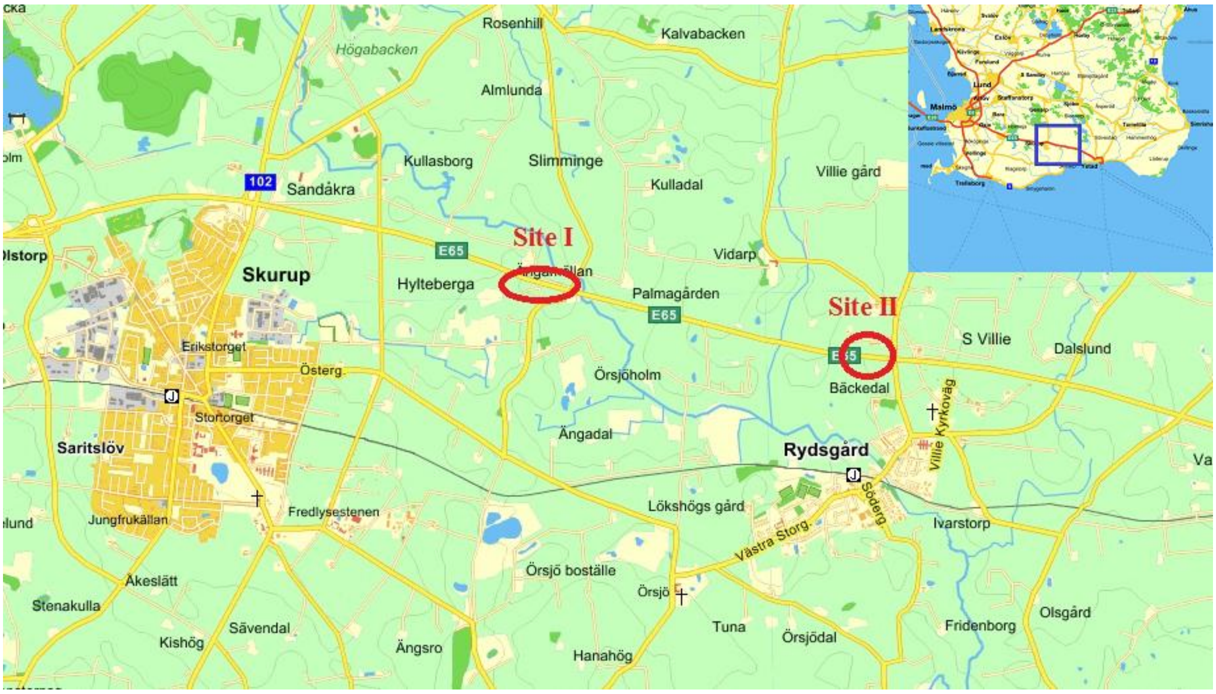



**Figure 16 The study sites on E65, southern Sweden.**

The road has 2+1 design, i.e. consists of two lanes in one direction and one lane in the other, alternating every few kilometres. The lanes going in the opposite directions are separated with a cable barrier. At intersections it is common to have one lane when entering the intersections and to have one or two lanes when exiting the intersection.

The sites were intentionally chosen close to each other to ensure similar traffic conditions. Each site is located close to an intersection with a local road. At Site I (a) the speed limit remains 100 km/h through the intersection and at Site II (b) the speed is reduced down to 80 km/h (Figure 17). Both at Site I and Site II, the sections entering the intersections have just one lane. At Site I there is one lane exiting the intersection while there are two exiting lanes at Site II. It was assumed, that the presence of a physical barrier makes the number of lanes on the other side of the barrier quite irrelevant for the drivers.


*a)* *b)*

**Figure 17 The views of the tests sites: a) Site I; b) Site II.**

The filming of the traffic was performed during October 2010. At Site I two mobile masts with totally five cameras installed were used (Figure 18). The mast heights were about 10 meters. Each camera was directed so that it covered a short road section with a small overlap with other cameras to allow for time synchronisation. The total observed section was about 200 meters. The equipment was powered by a set of car batteries that allowed recording for approximately 40 hours without interruptions.

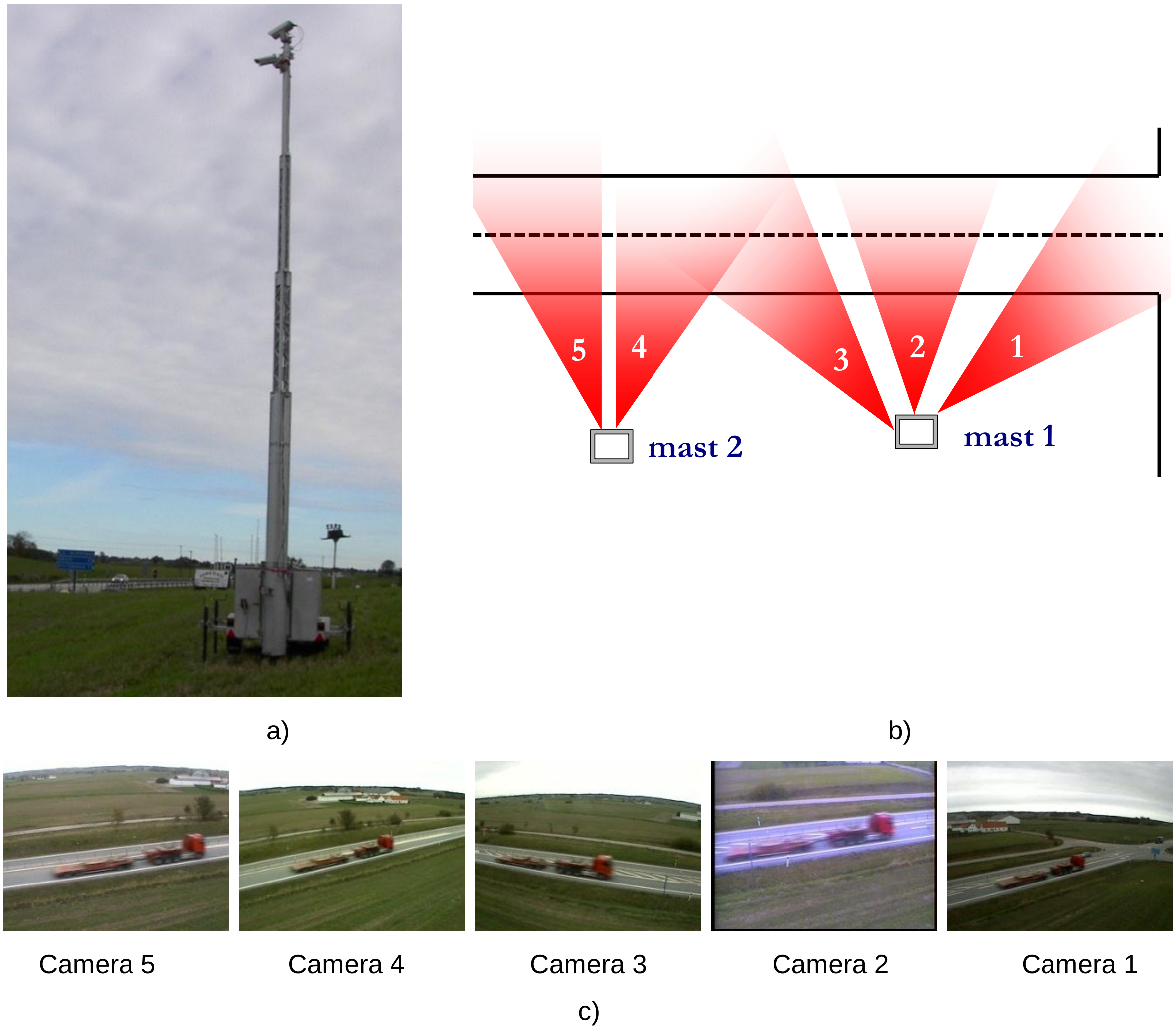
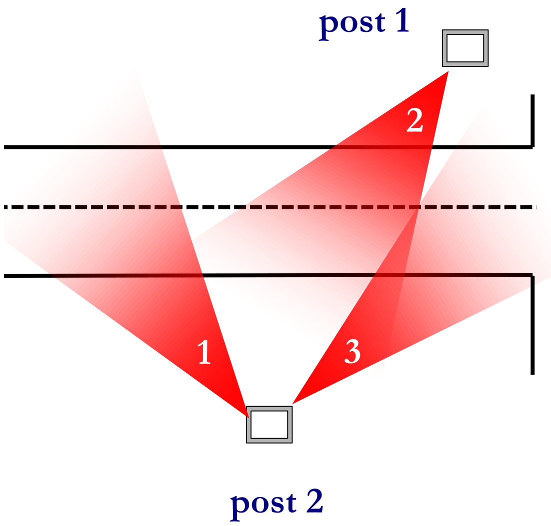



**Figure 18 Video recording at Site I: a) a mobile mast with several cameras installed; b) a schematic location of the masts and direction of the cameras; c) views from the five cameras, the same vehicle can be followed from one camera to the next one.**

At Site II it was not possible to use the masts since the fields on both sides of the road had been sowed (Figure 19). Instead, the cameras were installed on the lamp posts located near the intersection. Only three cameras were used, covering a section of about 100 meters. The cameras were mounted at approximately 7 meter height.




a) b)

**Figure 19 Video recording at Site II: a) lamp post used for camera mounting; b) schematic direction of the cameras.**

### 3.3.2 **Video processing algorithms**

The automated video analysis includes several steps:

- **Background/foreground segmentation** – detection of the image parts showing moving objects.
- **Scene modelling** – a model is created that describes the movement of the road users;
- **Calculation of model states likelihood** – the possible model states describing each frame are compared with actual background/foreground data.
- **Tracking –** the model is optimised to provide the most likely sequence of the model states that contain the trajectories of all road users.

**Background/foreground segmentation**

Background pixels are those that show the static background (e.g. pavement) while foreground pixels show the moving objects (road users). This segmentation is tricky because the static background is not really static. It varies not only due to noise in the video but also due to lighting variations. On a sunny day those variations are slow, but on a cloudy day a cloud passing by the sun will cast large shadows across the entire scene moving faster than the road users. To handle this the pixels of the input video is divided into small blocks (4x4 pixels) and those blocks are normalized with respect the lighting conditions (Ardö & Åström, 2009). From these normalized blocks a background image is estimated as a sliding temporal median. The expected variation of this background image is estimated as a sliding 25/75 percentiles.

Each input frame is then compared to the background image and by using the expected variation a probability can be estimated for each block in the frame to be showing foreground. Figure 20 illustrates results for single frame segmentation. White pixels are likely to be foreground while black pixels are likely to be background. Grey pixels indicate that the probabilities of them being a foreground or a background are close to 0.5, i.e. the situation is uncertain. This typically happens for blocks that are close to be uniformly coloured and it is not possible to distinguish a physical change from lighting variation. An example of such uniform region is the sky where the segmentation becomes uncertain.

a) b)

**Figure 20 Background/foreground segmentation example results: a) input frame; b) segmentation result, the probability of each 4x4 block in the input frame showing a moving object and not the static background.**

### Scene model

To explain the observed background/foreground segmentation in terms of road-user trajectories, a simplified model of the observed scene is constructed. It is assumed to consist of a flat ground plane on which all the road-users are standing. Each road user is modelled as a box of known fixed dimensions. However, there can be several road user types each having different box dimensions. Typically, there will be one car-sized box type, one bus-sized box, etc.

It turned out that in rural conditions the definition of a box set is a more difficult task compared to urban traffic. The challenge is that the share of heavy vehicles is quite high and their lengths vary between 6 – 25 meters without any clear breaking points. Therefore, one needs quite many boxes to be able to cover all possible truck sizes, which makes the model quite heavy for calculations and also increases the error risk when several smaller vehicles are classified as one big.

In this study the main focus lies on cars and some trade-off can be made. By defining just one big box for trucks, it is still possible to detect the presence of a large vehicle, while its position will be quite inaccurate due to mismatch of the box and the actual vehicles dimensions. This, however, makes the calculations much faster, while the task of distinguishing the cars from heavy vehicles and getting some indication of a time gap to the preceding vehicle is still fulfilled.

A discrete gird of points is placed on the ground plane. These points represent the allowed positions for a road user. The dynamics is modelled as a discrete state machine where the road user will appear at one of the grid points as it enters the scene and then jump from one point to another until it exits the scene again. Restrictions on the road user movements can be imposed by setting limits on where from its current position it is allowed to jump to. This is used to enforce that all road-users enter and leave at the borders of the scene and that they travel at reasonable speeds.

In this way, a state of a single road-user would be its type and position, and a state sequence would provide its trajectory. However, the scene might contain several road users and the number of road users in the scene might change as they enter and leave the scene. The model does not consider each road user individually. Instead, the state of the entire scene is considered and defined to be a configuration of road users at certain positions. The transactions between those scene states represent the motion of all road users as well as some of them exiting the scene and new ones entering. Considering those scene states, there will now only be a single state sequence representing all the road users and their trajectories. This is the state sequence that will be estimated from the observed background foreground segmentation. Working with those scene states it is also possible to impose restrictions involving more than one road user, such as limiting how close two road user can come to each other.

**Observations and scene state likelihoods**

The results of background/foreground segmentation for each single frame provide a set of observations that need to be explained in terms of the scene model.

Each frame is represented by a single scene state. Due to random factors such as noise, lighting variations, occlusions, etc. it is not possible to deterministically calculate the exact scene state from an observed frame. Instead, a probabilistic model has to be used that describes the likelihood of observing the given frame given a certain scene state.

Such likelihood can be constructed from a scene state by rendering an expected background/foreground segmentation image. This is done by projecting the boxes in the scene into the camera image. The interior of the projected boxes are expected to be foreground and the areas of the image not covered by any box are expected to contain background. This expected image is compared with the observed image produced by the segmentation algorithm in the first step. The likelihood that they are the same is calculated and this will be considered the observation likelihood of the scene having the specified scene state at this frame.

**Tracking**

The problem of generating trajectories for all road-users in the scene can be formulated as the task of finding the single scene state sequence that has the highest observation likelihood. To test all possible scene state sequences would be very time-consuming. That would require all possible sequences of configurations of objects to be tested. But by using online Viterbi optimization (Ardö, 2009) it is actually possible to find this scene state sequence with maximum likelihood without testing all possible sequences. Viterbi optimization, or dynamic programming, is a classical optimization algorithm that achieves this by recursively proving that entire sets of sequences can't contain the global maximum and does not have to be investigated further. In its classical formulation it is an offline algorithm that requires all observation to have been made prior to the optimization. It can however be generalized to work in an online fashion processing each frame as it is observed, see (Ardö, 2009). If the state-space is too large it might still not be plausible investigate all possibilities. However, it is in that case possible to only investigate the most likely states in each frame and thereby find and approximative solution. It also allows finding approximate solution in situations where the global optimum could not be found. This makes it plausible to use the described algorithm, at least in scenes that are not too big and do not contain too many objects.

### 3.3.3 **Trajectory analysis**

The described video processing algorithms provide pieces of road user trajectories that are seen in each camera. The next step is to connect the trajectory pieces belonging to the same vehicle into one long trajectory. To do this correctly, it is necessary to know the relation between the trajectory pieces in time and space.

The space connection is easily done at the stage of camera calibrations if the same map (and thus the same co-ordinate system) is used to calibrate all the cameras (the calibration process involves estimation of the parameters that describe the relative position of the camera towards the road plane).

The time synchronisation of the cameras can be done in several ways. Since each camera has an embedded clock, they were all synchronised before taken out to the sites against a desktop computer functioning as a time server. However, in the field each camera's clock operates autonomously and as the time goes the discrepancy between the time values in different cameras increases. Even though all the field work took relatively short time, at the end the difference between the camera time values varied between 3 to 5 seconds. This is still a sufficient accuracy to be able to match the video sequences from different cameras as belonging to the same time periods, but for connection of trajectory parts and calculation of speed this is not enough (in heavy traffic the gaps between the vehicles might be quite small and comparable with the time discrepancy size). Ideally, the cameras clocks should be adjusted regularly on a daily basis, for example, by having them all connected to a time server via Internet (not really feasible in case of field studies in rural environment) or by having GPS receivers that would provide the same time values for all the cameras.

In this study, since there was an overlap between the camera views, each camera pair was synchronised by finding the frames where a vehicle was seen in both cameras at the same location. Assuming that the difference in clocks' pace is a constant value, it is sufficient to find several such frames at the beginning of the recording period and at the end and then the synchronisation parameters can be found using a simple linear regression:

$\Delta t = t_0 + K_t \cdot t$, where

- $\Delta t$ – the time discrepancy between the clocks in two cameras;
- $t_0$ – the initial time discrepancy at the moment the recording started;
- $K_t$ – a linear coefficient describing the difference in clocks pace;
- $t$ – the time gone since the start of the recording.

Another problem is that even the frames are supposed to be taken at a constant rate, the actual time between the frames taken can also vary a little (between 0.03 and 0.1 seconds). In the video format that was used each frame had a time stamp, i.e. the system time value when the frame writing on disc was started. It was found that by using the time stamps values the synchronisation between the cameras can be improved even further.

Having both special and temporal co-ordination in place, connection of the trajectory parts is rather simple. Figure 21 shows several trajectory pieces extracted from different cameras plotted at the same time and space co-ordinates. It is very easy to interpret it as three separate road users as the trajectory pieces either overlap or can be extended by extrapolation until the start overlapping. By setting very simple criteria such as maximal discrepancy between the trajectory pieces at the overlapping areas the trajectory pieces belonging to the same road user can be joined together.

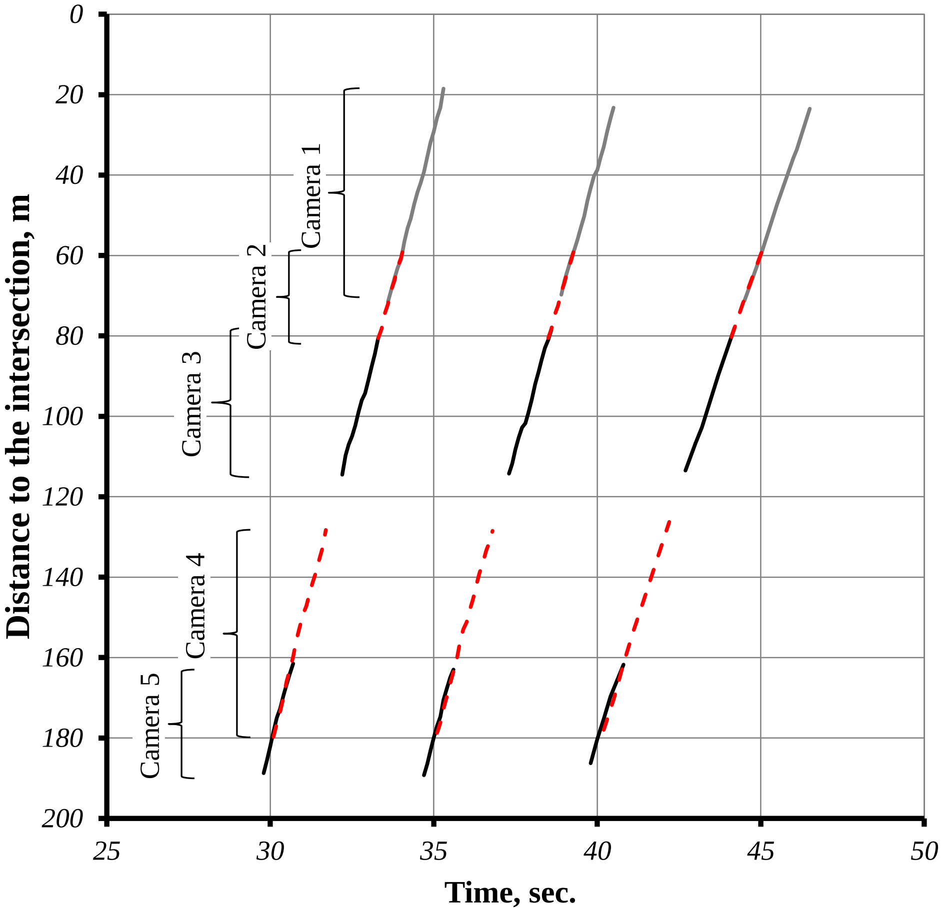



**Figure 21 Trajectory pieces produced by different cameras plotted in the same time and space co-ordinates.**

From the trajectory data, speed profiles of the road users can also be calculated. An example of speed profiles calculated for the Site I are shown in Figure 22. A certain systematic "turbulence" in the profile shapes can be noticed between 160 and 140 meters. As it is the place of transfer between cameras 4 and 5, some inaccuracy in calibration of these cameras might be suspected. This is not surprising since in the view of these cameras there are very few landmarks (except for the barrier posts in the middle) that can be used for camera calibration. However, even with this "turbulence", the profiles allow to calculate the travel speed over the section quite accurately, as well as to filter out "odd" profiles such as vehicles that slowdown in order to make a turn at the intersection or entering the road and accelerating from very low speed.

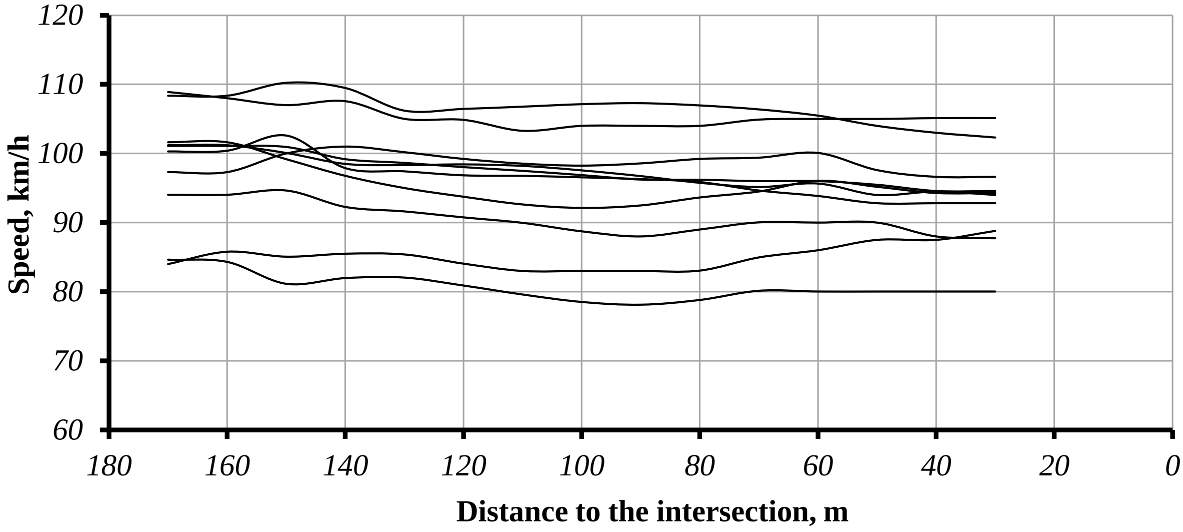


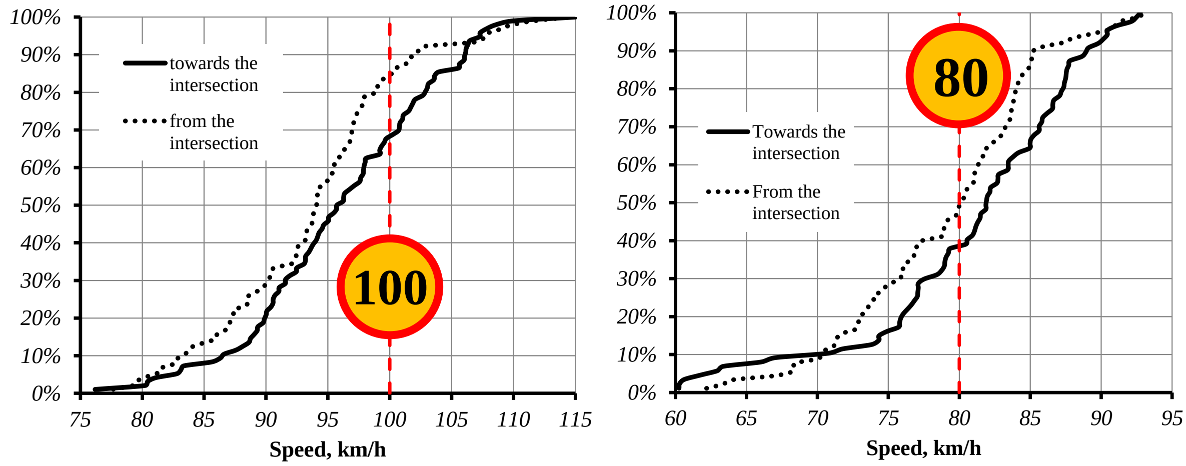

**Figure 22 Example of speed profiles calculated from the trajectory data (Site I).**

## 3.4 *Results*

### 3.4.1 **Speed measurements**

This study was a first attempt to use the video analysis system for speed data collection. Therefore, to ensure the data quality and to be able to discover detection and measurement errors, investigate and possibly remove the reasons for them, it was decided to manually check all the obtained results. This limited the length of the films analysed at each site to 1.5 hour. It was considered that the number of free vehicles during this period was quite representative for the purpose of the speed analysis and the main focus was put on adjustment of the system parameters to ensure robust detection and tracking.

The distribution of the travel speeds over the studied sections at sites I and II are shown on Figure 23 and in Table 18. The dataset includes only “free” vehicles, i.e. the vehicles which drivers’ speed choice is not affected by other road users. This is done in order to make the results comparable with the questionnaire answers since the pictures given to respondents did not contain any traffic. A free vehicle was defined as the one having time headway more than 3 seconds (Vogel, 2002). Neither heavy vehicles were included in the data set, nor the cars that were slowing down in order to turn off the road or accelerating after coming on the road from a minor road.




a) b)

**Figure 23 Cumulative percentage of vehicles driving at a certain speed at Site I (*a*) and II (*b*)**

**Table 18 Speed measurement results per site and driving direction**

| | Site I | | Site II | |
|---|---|---|---|---|
| | towards intersection | *from intersection** | towards intersection | *from intersection** |
| **Number of measurements** | ***97*** | *90* | ***87*** | *91* |
| **Average (km/h)** | ***95.9*** | *93.8* | ***80.8*** | *79.1* |
| **Std. deviation (km/h)** | ***7.7*** | *7,3* | ***7.7*** | *6.6* |
| **85-percentile (km/h)** | ***103.9*** | *100.5* | ***87.5*** | *84.9* |
| **% above speed limit** | ***31%*** | *14%* | ***61%*** | *50%* |

** the speeds “from the intersection” are not directly comparable due to difference in the geometrical layout (one lane ate Site I and two lanes at Site II) and presented here merely to give a better understanding of the situation.*

The difference in average speed for the vehicles driving towards the intersection between the two sites is 15.0 km/h ($F(1,183)=175.53$; $p<.001$).

### 3.4.2 Comparison with the questionnaire answers

The design of Site I corresponds to the questionnaire picture with 2+1 layout, wide lane width and open environment. This layout was included only in Swedish version of the questionnaire, for this reason the number of respondents’ answers for analysis was limited (n=32).

The distribution of measured speeds (“towards the intersection”) and preferred speeds stated in the questionnaire is shown on Figure 24.

The respondents’ answers have much higher variation compared to the measured speeds ($\sigma^2_{reported}$ = 17.6 km/h vs. $\sigma^2_{measured}$ = 7.3 km/h) and have at least one very obvious outlier

(160 km/h). When the outlier is removed, the mean values for measured and stated speeds did not differ significantly (F(1,127)=3.31; p>.05).

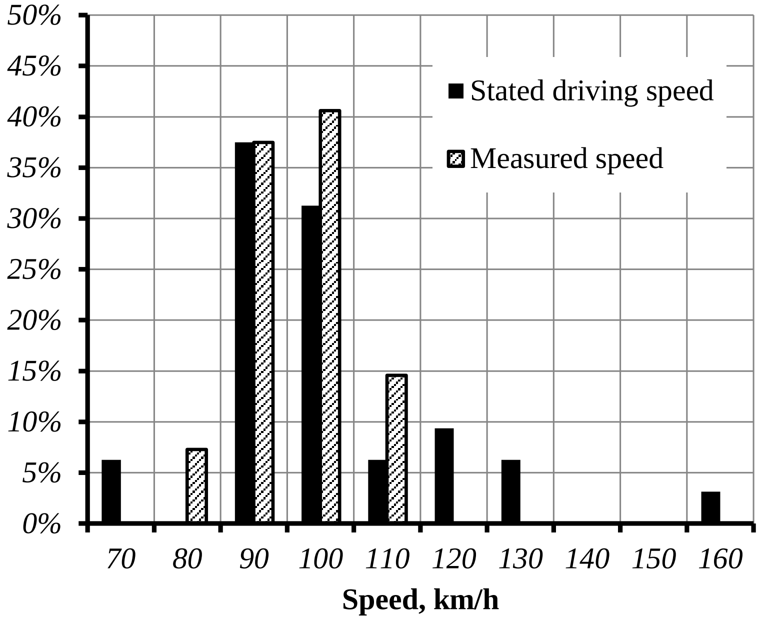



**Figure 24. Comparison of percentage of respondents per stated driving speed and measured speed on Site I, "towards the intersection"**

## 3.5 *Discussion*

After the modifications and adjustments to rural conditions, the video analysis system showed to be quite an efficient tool for collection of speed data. While it might be more cost-effective to measure spot-speeds using some other equipment (pneumatic tubes or radar guns), video analysis has certain advantages:

- A longer road section can be studied;
- Continuous speed data (speed profiles) can be collected, allowing for analysis of accelerations/decelerations and speed adjustments in relation to road geometry and presence of other road users;
- The vehicles to be included in the dataset can be automatically selected using a set of criteria (vehicle size, time headway, performed manoeuvre, etc.);
- Video recordings allow always to go back and to view the particular situation in detail.
- The price of the video data collection is mostly dependent on the initial installation costs, while recording one or two extra days does not add much to that. Therefore it is possible to make recordings over a longer period to cover various traffic conditions and then choose what time period to analyse. Even though in this particular study the analysed period was quite short, after all the parameters are adjusted, the automated analysis can be applied on much longer video sequences.

A specific challenge met at the rural conditions was a large variety in the vehicle dimensions that cannot be represented by a few pre-defined boxes in the model. Further efforts are necessary to address this problem, e.g. in a form of an additional module that will estimate the size for each detected vehicle individually.

Another problem discovered was a lack of the reference points ("landmarks") to be able to calibrate a camera against a drawing or a satellite photo of the road section. It might be a good strategy to put some temporary markings on the road shoulder to increase the number of reference points and thus improve the calibration quality.

Speed measurements at the two road sections with different speed limits but similar design showed that the difference in the actual driving speeds is less than the difference in the speed limits. This was to be expected as the similar results are reported in other studies (e.g., Nillson & Obrenovic, 2000, where the speed limit change from 110 km/h to 90 km/h resulted in only 6-8 km/h speed reduction). In some way, the observed difference in speeds was somewhat higher than expects (15 km/h vs. 6-8 km/h in Nillson & Obrenovic, 2000). A possible explanation might be that the drivers perceived the reduction of the speed limit as reasonable as it was introduced in the vicinity of an intersection with quite intensive crossing flow). Still, these observations indirectly supports the idea of having other means to affect the driving speeds (esp. by the road design) rather than simply changing the speed limit.

Comparison between the measured speeds and the answers by the questionnaire respondents shows quite good correspondence. This gives certain credibility for the conclusions based on the questionnaire results. It has to be taken into consideration, though, that the validation was done only for one road layout type and only in one country.

# 4 Discussion and conclusions

## 4.1 *Implications*

### 4.1.1 Implications for different countries

The results of the questionnaire imply that there are particular road features whose effects could be considered relatively self-explaining in the purest sense as they are similar for all countries. These features include road width and the vegetation of the roadside environment. When the road is wider, people tend to drive faster. The same goes for roads where there is relatively little vegetation on the side of the road; people tend to drive faster. Based on psychological literature and studies on visual speed reducers as described in Section 1.2.2, this could be expected.

Other road features, such as lane treatment and the type of separation of driving directions do show particular effects in particular directions, but these directions differ per country. So in one country a double white line might suggest to drivers a higher speed is possible whereas in another country the double white line might elicit lower driving speeds.

This implies that particularly these last features need extra attention. Road authorities should not assume they are as self-explaining as they might think and extra communication about the speed limit might be necessary. Also, by complementing a particular road design that is not self-explaining in the purest sense with elements that *are* self-explaining, might enhance the credibility of the road and nudge drivers towards the desired speed behaviour.

### 4.1.2 Implications for the methods used

There are different ways to determine the effects of design elements on behaviour. Road authorities particularly interested in the effects of new, not previously researched design elements can easily acquire an indication of effects through use of the questionnaire method. It would be helpful if such studies would also include road features of which the effects are known, to be able to compare the effects of the new design elements to the known effects.

## 4.2 *Limitations*

### 4.2.1 Questionnaire study

Although the use of pictures allowed for exact manipulation of different road features, this method does involve some limitations. The texture of the features (such as the road surface but in particular the trees and bushes) in real life was difficult to recreate in the pictures and consequently the pictures might not have been able to elicit the same feeling a real picture would have.

Other limitations involve the relatively low number of participants for Ireland (n=28) and Sweden (n=32). The fact that ERASER included Ireland as an extra country (outside of the partners) in the questionnaire, made it relatively difficult to recruit Irish participants as we had less contacts in our personal networks. The low numbers might also explain the rather strange results we found for Ireland. The timing of the questionnaire – during the summer holidays in Sweden – might explain the problems with getting higher numbers of participants in Sweden.

Another limitation is the way the environment, and to a lesser extent road width, was varied. For the openness of the environment, two extremes were compared: a situation with no trees or bushes whatsoever and a situation which was quite the opposite. It is likely that a more subtle difference wouldn't have elicited effects with the same magnitude as we found in this study. This presents a challenge for the translation of the results of the questionnaire to the heuristics of the tool to be developed in WP3.

Finally, the results for Great Britain were recoded from the imperial system to the metric system. For the results pertaining to driving speed, this shouldn't be a problem. However, it is possible that the interpretation of the effects that involved the difference between the Speed Limit variable and the Driving Speed Variable is slightly affected by this. Due to the mile system, the Speed Limit variable in Great Britain did not include as many scale points as the Speed Limit variable in other countries did (i.e. 20-80 mph vs. 30-130km/h). Thus, this not only complicates the comparison, but also, the British data might be less sensitive to differences in safe speed limits than the data for other countries.

### 4.2.2 **Video analysis**

Although the results of the video analysis study suggest the questionnaire approach yielded valid results, it should be kept in mind that this validation only included the Swedish 2+1 road with a cable barrier. Also, only one Swedish site was used for validation (i.e. the site with 100km/h speed limit). Including more sites in more countries would provide stronger support for the results.

## 4.3 ***Conclusions***

### 4.3.1 **Methods**

First of all, this study has demonstrated the use of different research methods that can be applied by people interested in the self-explaining nature of roads. The first method, the online questionnaire including pictures of virtual environments, demonstrates how you can get an idea of the effects of different road features and the way they might interact. It even allows you to get an indication of the effects of new features before they are implemented in real life. This presents a potential cost-effective solution to research on new road features.

The second method, the video recording and analysis, demonstrates how to get dynamic information on road user behaviour on a particular road. This can help to determine the level of self-explaining nature of a road (e.g. the credibility of the speed limit as a result of the combination of road features implemented). Several advantages of video analysis are pointed out: this analysis method allows a rather in-depth study of real, continuous and dynamic road user behaviour on longer road sections.

### 4.3.2 **Input to consecutive work in ERASER**

Second, the work done within WP2 of ERASER described within this deliverable has provided relevant input to be used in the next step towards a useful tool road authorities can use to assess the level of self-explaining nature of their roads. The results of the questionnaire will be directly integrated in the heuristics of the tool that is developed in WP3 of ERASER. More information on the development of the tool can be found in the deliverable of ERASER's WP3&4.

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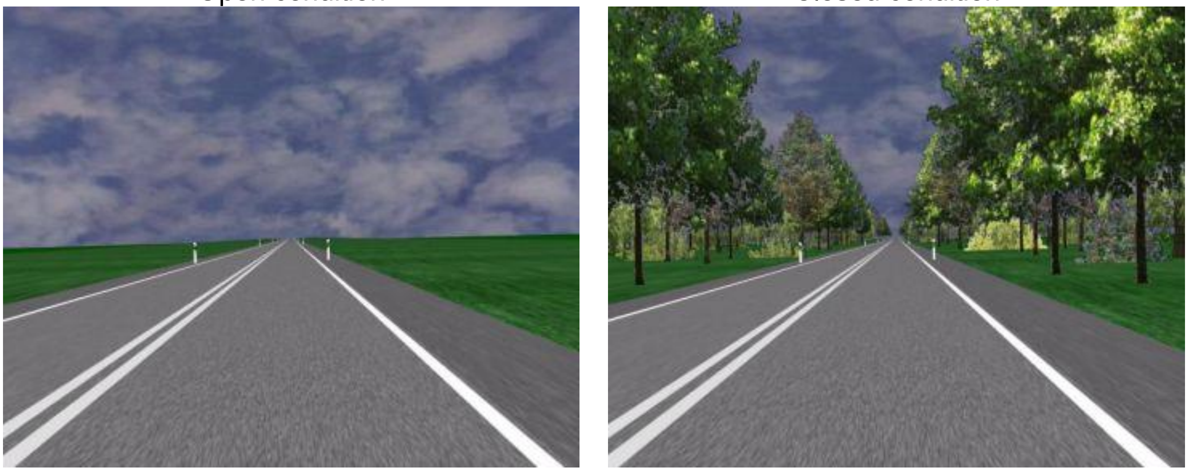
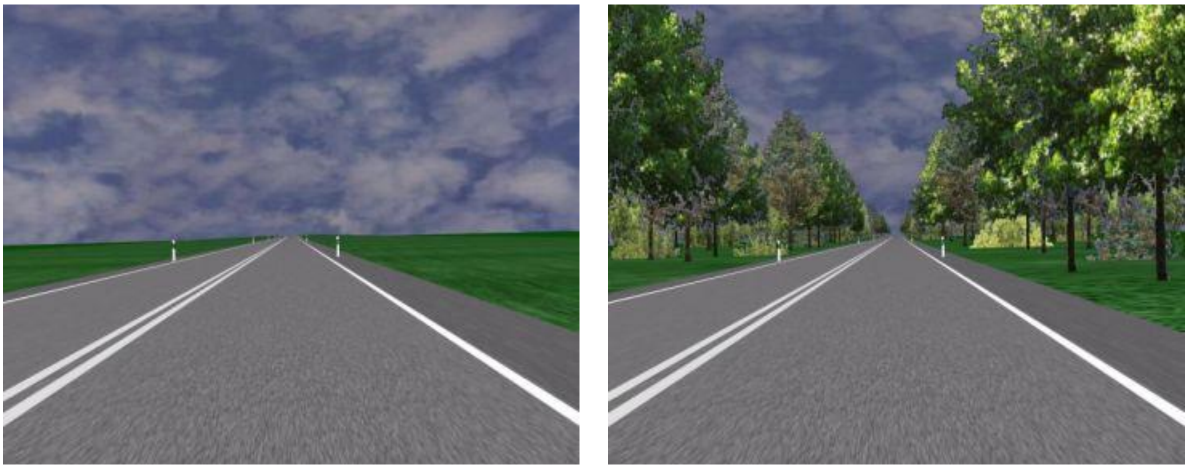
# Appendix A

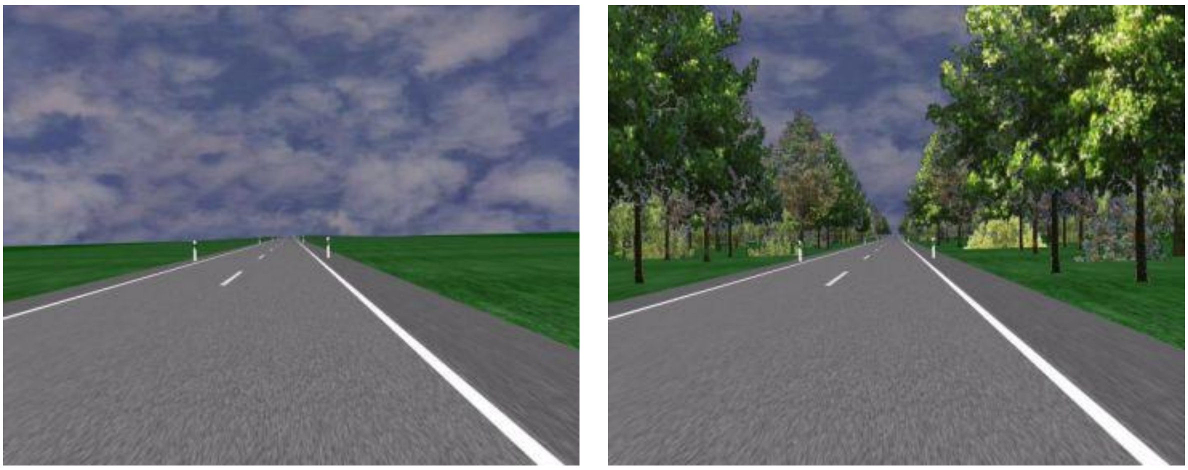
Open condition | Closed condition



R11dwl_n
Narrow condition

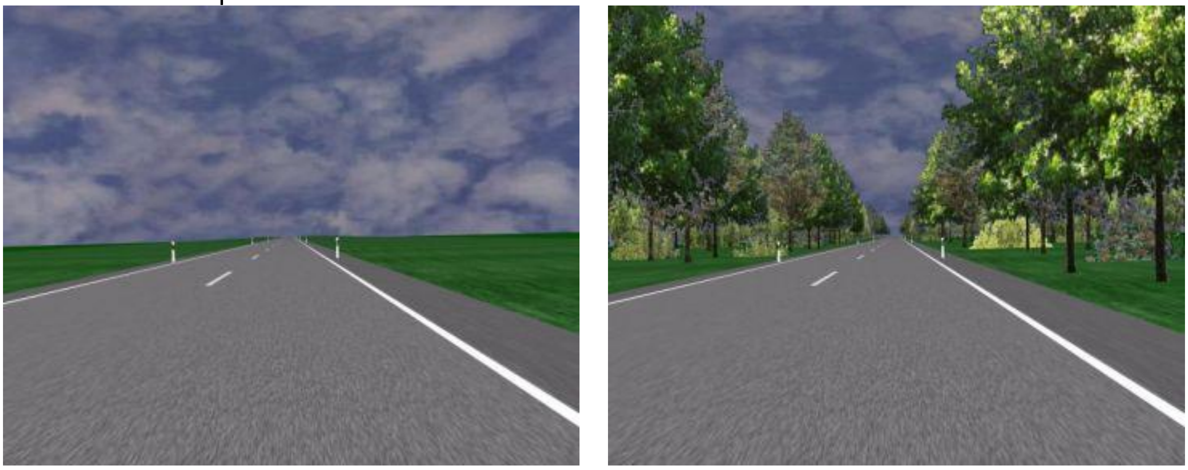


R11dwl_w
Wide condition



R11imm_n_c.jpg
Narrow condition

Open condition | Closed condition



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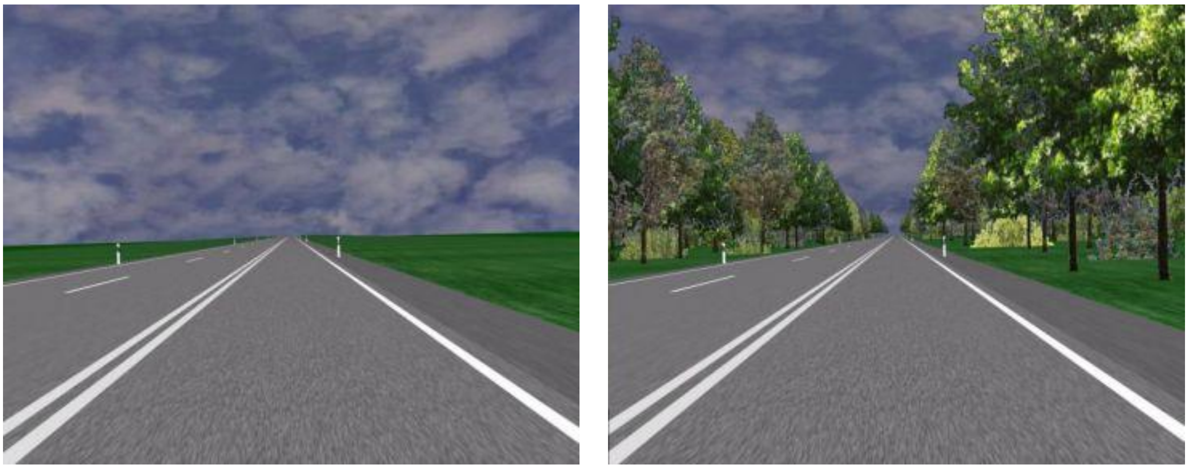
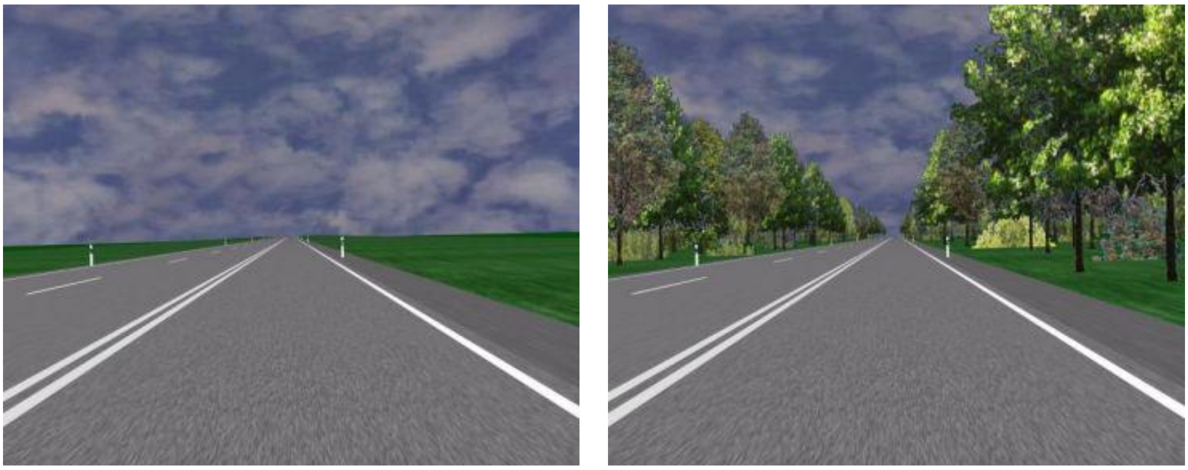
Wide condition



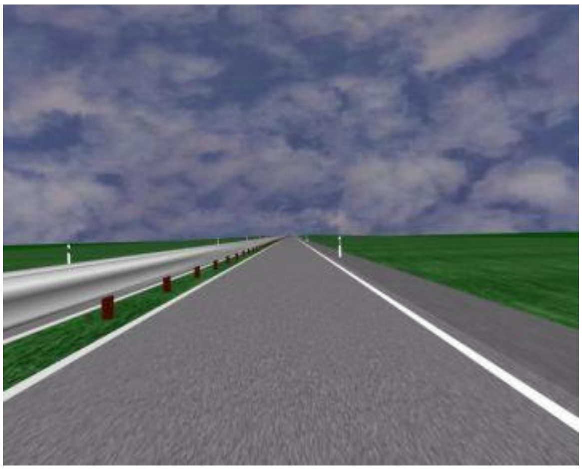
R12dwl_n_c.jpg
Narrow condition



R12dwl_w_c.jpg
Wide condition

Open condition | Closed condition

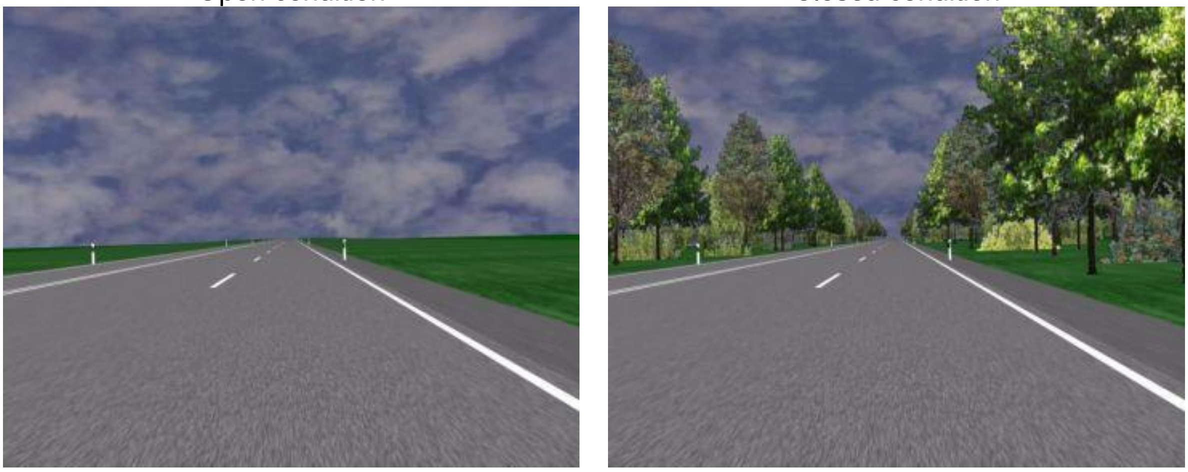

R12phy_n_c.jpg
Narrow condition



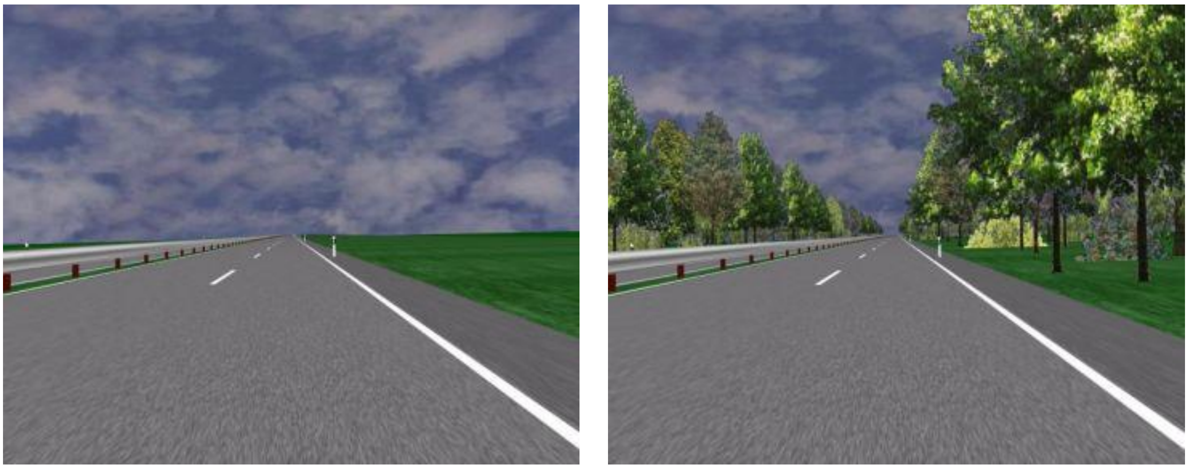

R12phy_w_c.jpg
Wide condition


R21dwl_n_c.jpg
Narrow condition

Open condition Closed condition



R21dwl_w_c.jpg
Wide condition



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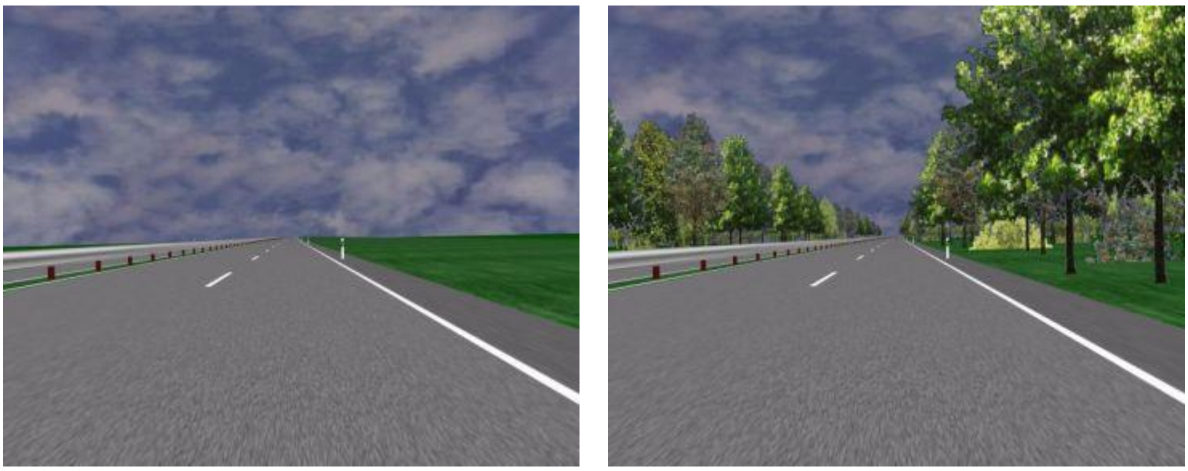
Narrow condition

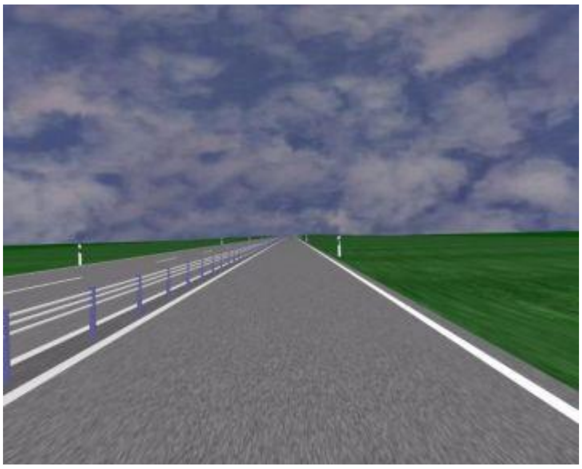


R22phy_w_c.jpg
Wide condition

Open condition

Closed condition

R01nmm_n
Narrow condition



R12cab_w_c.jpg
Wide condition

Example of left hand drive picture
R11imm_n_ol.jpg

Example of left hand drive picture
R12dwl_n_cl.jpg

# Appendix B

Example of the STISIM code used to create the stimuli for this questionnaire study:

For the "simple" straight road section needed for the pictures, the code for a road without trees looks like the following:

"metric

0,ROAD,2.75,2,1,2,0.2,4,8,0.12,0.12,0,-2.5,-2.5,0,0,0,0,-6,1.5,-6,1.5,0,C:\STISIM\Data\Textures\Road03.jpg,3,C:\STISIM\Data\Textures\Road03.jpg,1,C:\STISIM\Data\Textures\Road01.jpg,1.8288,C:\STISIM\Data\Textures\Grass11.jpg,7,C:\STISIM\Data\Textures\Road03.jpg,2

0,SOBJ,0,3.25,0,0,0,0,C:\STISIM\Data\Barriers\Leitpfosten.3ds,1000,50

0,SOBJ,0,-3.25,0,190,0,0,C:\STISIM\Data\Barriers\Leitpfosten.3ds,1000,50".

"Leitpfosten.3ds" is a 3d-model of roadside marker posts used in all pictures. Textures used in the first line of command denote textures used for the road and environment surfaces. Using the same command lines ensured that all pictures differed only in the values of the experimental variation.

# Appendix C

0% completed

## Welcome

**to this questionnaire which deals with driving behaviour on rural roads.**

We assure you that all details given by you in the following sections will be analysed anonymously, will be used only for research purposes and will not be passed on to third parties.

Taking part is worthwhile as participants can win one of **five Amazon gift-certificates worth £17.50 each.**

The questionnaire is restricted to people aged 18 or over who hold a valid driving licence and who regularly drive a car.

If you fulfil these conditions, please click **Next**.

This survey is conducted within ERASER. ERASER stands for "Evaluations to Realise a common Approach to Self-explaining European Roads" and is a research project administered by ERA-NET Road and funded by the European Commission under the 7th framework programme. ERASER is a joint research program of SWOV Institute for Road Safety Research, Technische Universität Dresden (TUD), Kuratorium für Verkehrssicherheit (KfV), Transport Research Laboratory (TRL) and Lund University.

Next

3% completed

**Before starting, we need some information about you.**

**1. How old are you?**

Age in years: ______

**2. Are you ...?**

- ○ male
- ○ female

**3. When did you get your driving licence? (Please enter the year)**

in ______

**4. Do you own a car?**

- ○ Yes, I do.
- ○ I do not own a car but have regular access to a car.

**5. How often do you use a car?**

- ○ daily
- ○ several times a week
- ○ around once a week
- ○ once or twice a month
- ○ less often

**6. How many miles do you typically drive a car each year?**

- ○ up to 3,000 miles/year
- ○ 3,000 to 6,000 miles/year
- ○ 6,000 to 9,000 miles/year
- ○ 9,000 to 12,000 miles/year
- ○ more than 12,000 miles/year

**7. How would you characterise your normal driving style?**

| ○ | ○ | ○ | ○ | ○ |
|---|---|---|---|---|
| very calm | calm | neither calm nor sporty | sporty | very sporty |

**8. How fast – or slowly – do you typically drive compared to the regular traffic flow?**

| ○ | ○ | ○ | ○ | ○ |
|---|---|---|---|---|
| much more slowly | more slowly | at a similar speed | faster | much faster |

**9. Where do you usually drive?**

*Select more than one option if appropriate*

- ☐ in urban (built up) areas
- ☐ on rural roads
- ☐ on motorways

**10. How safe do you feel when driving ...**

| | very unsafe | unsafe | safe | very safe |
|---|---|---|---|---|
| ... in urban (built up) areas? | ○ | ○ | ○ | ○ |
| ... on rural roads? | ○ | ○ | ○ | ○ |
| ... on motorways? | ○ | ○ | ○ | ○ |

Next

# Appendix D

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93% completed

**Would you like to participate in the lottery in which you can win one of five Amazon gift certificates worth £17.50 each? (If not, click 'Next'.)**

☑ I would like to participate in the lottery. I consent to my e-mail address being saved until the winners are drawn. My interview will remain anonymous and my e-mail address will not be passed on to third parties.

☐ I am interested in **the results of this study**. Please send me an abstract by e-mail

E-mail:

Next

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97% completed

**1. Please enter any questions or comments you have about this survey below, then click "Next".**

Please, enter your comments.

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## Thank you for your participation!

We would like to thank you for your assistance!

Close window