ERASER

SER and SER Approaches: State-of-the-art

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Executive summary

ERASER is an acronym of "**E**valuation to **R**ealise a common **A**pproach to **S**elf-**e**xplaining European **R**oads". This report is part of the ERASER project and serves as input for subsequent work-packages (WPs) within ERASER:

It guides research in WP 2 during which road user pilots will be conducted. Based on this report, prototypical locations and design alternatives will be selected.

Furthermore, it provides input for WP 3 which aims at developing a decision support tool for road authorities. This decision support tool is to provide road authorities with the necessary background to develop and implement self-explaining road (SER) categories. It will also incorporate a model to infer safe and credible speed limits. A feasibility check with road authority target groups to be conducted in WP 4 will ensure that this tool is accepted by the road authorities.

Self-explaining roads were developed to increase inherent road safety by taking into account the nature of human perception and information processing. However, to increase road safety, self-explaining roads per se are not enough. Additionally, the entire road categorization has to be self-explaining. With traditional road categorization being the result of historical developments and sometimes dating back to the time when traffic safety was no major concern, this will not always be the case.

In order to allow a common and modern state-of-the-art approach of self-explaining road categorization to be developed in Europe, the current practice of road categorization must be reviewed and compared with respect to their self-explaining properties. To achieve this aim, the report is structured into different parts.

First of all, the background of road categorization is described in the first chapter of the report.

This is followed by a second chapter which summarizes how road categorization impacts road design.

In chapter 4, a definition of self-explaining roads is given. We adopted the definition of Theeuwes and Godthelp:

> "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)

Because of the relationship of the SER approach and other approaches, chapter 5 is dedicated to explaining commonalities and differences between these approaches.

In order to understand how a road can be made self-explaining psychological concepts are introduced in chapter 6. In addition, a paragraph is exclusively dedicated to influencing speed behaviour.

After having explained SER principles for single roads, chapter 7 explains how an entire road network is made self-explaining. The crucial aspect is that road users correctly perceive the road category they are driving on and the behaviour expected from them on this category. Two principles were identified which support this aspect:

- homogeneity within and
- heterogeneity between road categories.

However, in order to decide whether these principles are met, criteria to do so were identified in chapter 8. In addition a methodology is proposed how these criteria can be applied in a practical evaluation of the SER quality of a given road and road network.

Before applying the first step of the methodology in chapters 10 and 11, an overview of the current practice of European road classifications is given in chapter 9. It was found that very few countries (The Netherlands, Denmark, Germany) actually apply or are developing SER approaches to road categorization. However, despite being largely in line with SER principles there are still weaknesses to be found. Whether such weaknesses in SER design affect behaviour will prototypically be tested in WP 2 of the ERASER project.

Based on the preceding chapters an attempt was made to develop and introduce an ideal self-explaining road categorisation. This ideal can serve as basis for the evaluation of existing approaches but can also be used to develop a coherent SER classification for Europe.

It is concluded that road categorizations differ widely in Europe and that only few countries are implementing or developing categorizations following SER standards. However, even those are at a starting point with none fully meeting SER criteria. It is thus concluded that additional empirical validations have to be performed in order to draw final conclusions. These empirical steps mainly have to deal with the question of whether designs which can formally be distinguished are also distinguishable by the road users – which is a prerequisite for a road categorization to become self-explaining.

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AADT	Average annual daily traffic
ADAS	Advanced driver assistance system
ESP	Electronic stability programme
SER	Self-explaining road

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1 Introduction

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

Indisputable, these aspects are important and essential for road network planning. However, the complex road categorization system has finally lead 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 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. 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.

2 Basics of road network structuring

The interaction of various areas of life such as living, working, educating, supplying, and recreation as well as the complex economical interactions require differentiated and adapted traffic systems. They should improve the general living conditions of humans and therefore, they have to be designed and realized in a safe, ecological, high-capacity, and economical way.

All over the world large parts of existing road networks are often the result of historical developments. Since humans need to transport goods and people, roads have been established between cultural and economical centres. Often, military aspects expedite the development at different places around the world, such as the Roman road network which had a total length of about 80,000 km. An important design value was always the travel time which influences the alignment and the section lengths depending on the means of transport (e. g. by foot, donkey, horse, coach).

Road networks are the result of traffic needs defined by the need to transport goods and people within and between existing or new locations and the territorial and geographical realities within the area to be covered. Nowadays, road networks are mainly structured according to two different aspects: road function and road hierarchy.

A functional structure allows designing parts of a road network with respect to their importance. By designing the infrastructure according to both traffic and local needs, road design and traffic coordination can be made flexible and efficient. This also minimises impacts on the environment.

A hierarchical structure has to be understood exclusively as a classification according to administrative jurisdiction. It mirrors the socio-political structure and is mainly used to clarify the responsibilities. Therefore, this way of categorisation does not meet any requirements of traffic science or road users. In most cases, roads of high importance belong to the national government whereas less important roads are administrated by local authorities.

Road network planning is based on the idea to connect urban areas and provide access to property. Urban areas are usually classified with respect to their importance. As an example, in the German guidelines RAS-N (FGSV, 1988) and RIN (FGSV, 2009) urban centres are classified as:

- Higher Order Centre (“Oberzentrum”)
- Medium Order Centre (“Mittelzentrum”), and
- Basic Centre (“Grundzentrum”).

These centre types are related to a different level of public and social services. Appropriate travel times have been defined which should not be exceeded in any region (Table 1).

	Higher Order Centre	Medium Order Centre	Basic Centre
Higher Order Centre	≤ 120 minutes		
Medium Order Centre		≤ 45 minutes	
Basic Centre			≤ 25 minutes
Residential Areas	≤ 60 minutes	≤ 30 minutes	≤ 20 minutes

Table 1 Appropriate travel times as proposed in German guidelines (FGSV, 1988, 2009).

Based on these or similar definitions the basic grid of a road network and different road categories are defined. In order to limit the maximum travel time to 120 minutes between Higher Order Centres which are often a long distance apart, a road category is required that provides road users with a direct and fast connection. In contrast to this long distance connection the relative travel time between Basic Centres and Residential Centres can be longer, thus allowing for – and requiring - lower order roads of another road category.

This general system is usually implemented in most road network planning approaches around the world with respective road categories being derived.

In general, three main functions are distinguished:

- Connecting:
    - connect important destinations,
    - allow fast traffic over long distances.

- Collecting:
    - link connecting roads to access roads,
    - help to avoid traffic disturbances,
    - act as buffers.
- Access:
    - provide access to private property, residential areas, commercial centres etc.

Considering travel time and travel distance the following connecting function types are differentiated:

- International and national connections
- Interregional and regional connections
- Subregional connections.

Besides the connecting function, access to private property or development of areas is another important function of roads. These roads ensure the distribution of traffic from connector roads to places of living, working, commercial centres, and recreation. Inhabitation is a function of roads that provide road users on the one hand with access to living areas and on the other hand with shared zones of traffic and pedestrians. Typical examples are roads in residential areas with a general speed limit of 30 km/h or less.

In addition to the function of a road also an administrative or hierarchical classification has been introduced to categorize roads. This is mainly done in order to take the administrative responsibility into account.

3 How road categorization impacts road design

As already mentioned the road category is mainly based on road function and administrative character and has a profound impact on road design. This is simply the result of the different requirements resulting from road function: direct and fast connection versus slow and flexible access.

Since years, design guidelines exist which define permissible road designs depending on road function. Without explicitly being called self-explaining, existing guidelines often already incorporate aspects of SER design. This is for example the case with relational design guidelines which give permissible ranges of radii for curve sequences depending on the road function and the road characteristics. Subsequently, additional design parameters are listed for which guidelines usually exist depending on road category and road function:

- Acceptable minimum horizontal radius,
- Acceptable minimum vertical radius (crests),
- Acceptable maximum tangent length,
- Required minimum stopping sight distance,
- Required overtaking sight distance,
- Cross section design: Number of lanes, width of lanes, number of carriage ways
- General intersection design and location of intersections in sags

- Coordination of design element of horizontal and vertical elements in order to minimise the impact of optical distortion
- Coordination of consecutive horizontal curves concerning the radii (relation alignment).
- Safety Equipment (safety barriers, rail guards, road side design etc),
- Legal speed limits.

When describing and evaluating different road categorization approaches these elements have to be described. Existing guidelines need to be reviewed as they are supposed to provide a standardised alignment and design in order to make the road visible, perceptible, and comprehensible. Therefore, they can be elements of a self-explaining design.

4 Definition of Self-Explaining-Roads

The Self-Explaining Roads concept was introduced by Theeuwes and Godthelp (1995) who define the term self-explaining and self-explaining roads (SER) as:

“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).

Based on theories of attention and perception, such as depicted in Neisser´s perceptual cycle (Neisser, 1976), behaviour – when guided by perception – is guided both by top-down (driven by higher cognitive functions) and bottom-up (stimulus driven) processes. With respect to self-explaining roads this means that they are not only in line with expectations, but that they also elicit appropriate expectations and mental models.

5 What Self-Explaining-Roads are not: other related concepts

Imagine a driver’s behaviour is perfectly adapted to the road design. This will certainly prevent the majority of accidents from happening, but would this particular driver be protected from all accidents? Certainly not. There would still be accidents, caused for example by other drivers, objects on the road, extreme weather conditions etc. Thus, even if a road was perfectly self-explaining with respect to appropriate behaviour, accidents might still occur.

Further diminishing accident likelihood and also accident severity would require designing **forgiving roads**. These are roads and road environments which either prevent accidents from happening even if the driver behaved inappropriately or which reduce accident severity after an accident happened. An example of the former are safe hard shoulders which prevent the skidding of the car even if the driver left the carriageway. Whereas SER strive for influencing behaviour, forgiving roads aim at reducing negative consequences of wrong behaviour.

Technical measures preventing accidents from happening are usually termed **active safety** measures, whereby the term is usually applied to in-car devices such as advanced driver assistance systems (ADAS, of which an example is ESP). Measures diminishing accident severity are termed **passive safety** measures. An example of a passive measure is guardrails.

Another important concept is the **sustainable safety** concept applied in the Netherlands (Wegman & Aarts, 2006). Sustainable safety is a holistic concept which is based on five principles (see Table 2).

These principles are implemented by applying the 4-Es of traffic safety measures:

- Engineering
- Education
- Enforcement
- Economy or encouragement.

Table 2 Sustainable Safety Principles " (Wegman & Aarts, 2006).

Sustainable Safety Principle	Description
Functionality of roads	Monofunctionality of roads as either through roads, distributor roads, or access roads in a hierarchically structured road network
Homogeneity of mass and/or speed and direction	Equality of speed, direction, and mass at moderate and high speeds
Forgivingness of the environment and of road users	Injury limitation through a forgiving road environment and anticipation of road user behaviour
Predictability of road course and road user behaviour by a *recognizable* road design	Road environment and road user behaviour that support road user expectations through consistency and continuity of road design
State awareness by the road user	Ability to assess one's capacity to handle the driving task

In the sustainable safety concept, accident countermeasures attributable to one of the Es named above are all combined in order to reduce accident occurrence and accident severity.

Regarding these four Es, one could assume that self-explaining roads are an engineering measure. However, all 4 Es can – and sometimes have to – be applied to make a road self-explaining. Of course the road has to be constructed following self-explaining road principles (Engineering). However, not all engineering measures are self-explaining from the start. Sometimes specific cues have to be learnt by the road users in order to infer the expected and appropriate behaviour (Education). Furthermore, Enforcement itself is a principle which can be applied in order to make roads more self-explaining. An example would be rumble strips which provide the driver with immediate feedback in case the driver behaves inappropriate (leaving the lane). Roads making use of such principles are called **self-enforcing roads**. Finally, Economy or Encouragement are inherent principles in a self-explaining road network as behaving appropriately on these roads rewards the driver with safety and comfort. In order to be successful, the benefits of safety and comfort have to be higher than the costs associated with perceived slower travel times and a potential loss of thrill (for an overview of Sensation Seeking and driving, see Herzberg & Schlag, 2003; for an overview of human decision making, see Letho & Nah, 2006).

6 What makes a road self-explaining?

A road can be seen as any other everyday object humans are interacting with. Thus, in the first place, this chapter deals with generic design principles making objects self-explaining. The second part of this chapter sums up design elements applicable specifically to road design.

Different concepts are of use when designing self-explaining roads. All of these concepts make use of the nature of human perception and information processing:

- Cues and signals
- Affordances
- Optic flow
- Choice architecture including nudges
- Gestalt principles
- General principles of good design.

Cues (Posner, 1980) or signals (Hacker, 2005) are elements of the environment which – depending on the learning history of an individual – almost automatically result in a behavioural response. Road signs are an example of formal cues which act as integrated discriminative stimuli (Fuller, 1984). However, such formal signals have some inherent shortcomings:

- They might not be perceived due to physical, physiological or psychological filters (Rumar, 1985).
- They might not be understood.
- They might deliberately be ignored.

Therefore, warning signs are only the last resort in the classical hazard control hierarchy (Wogalter, 2006):

1. Design out/eliminate hazard.
2. Guard against hazard
3. Warn.

They should only be used in SER design when implicit measures are not applicable. In case formal cues are used, the message conveyed by them should be in line with the characteristics of the entire situation (Goldenbeld & van Schagen, 2007).

The behavioural implications provided by the characteristics of an entire situation or of a single object were termed affordances by Gibson (1986). Affordances convey a meaning to the onlooker in the sense of being ... – able. Stairs for example are "climbable" or a road is "drivable with a certain speed". These inherent object properties are perceived and evaluated by the onlooker and guide behaviour (for a summary of the concept of affordances see Jones, 2003).

Thaler & Sunstein (2008) recently developed the concept of nudges which implicitly makes use of the concept of affordances in combination with human decision making (for an overview of human decision making, see Letho & Nah, 2006). A nudge is an aspect in the environment “that alters people’s behaviour in a predictable way without forbidding any options or significantly changing their economic incentives” (p. 6).

Another important aspect of Gibson’s ecological approach to perception is the development of the concept of the optic flow and of perceptual invariants. These aspects can be purposefully used to influence speed behaviour (Weller, 2010).

Gestalt theory is a historic approach to perception. Gestalt theorists (Wertheimer, Koffka, Köhler) developed principles which describe how objects are perceived (a summary can be found in Goldstein, 2008).

These Gestalt principles can be combined with general principles of good design such as developed by Norman and being described in his book “The design of everyday things” (Norman, 1988, reprint 2002):

- (Natural) Mapping: design should follow cultural standards or physical analogies as stored in mental models[1].
- Conceptual model: where this mapping principle is not self-explaining a conceptual model has to be provided with the help of additional cues.
- Visibility: information has to be physically visible and mentally recognizable (see also Rumar, 1985).
- Feedback: has to be provided, communicating appropriateness of current behaviour and giving hints for learning.
- Affordances: objects should convey the behavioural possibilities associated with them (Gibson, 1986).
- Constraints: use natural and artificial constraints to reduce behavioural options to the appropriate one.
- Standardization: according to Norman, this principle should only be applied “when all else fails” (Norman, 1988, reprint 2002, p. 200). Standardized designs and the behaviour associated with them have to be learned.

Besides the sources given above, most of these concepts are described in more detail with respect to road design in Weller et al. (2006) and Weller (2010). Furthermore, applicable road design principles supporting SER are described in a PIARC report (PIARC, 2008).

Within the sustainable safety concept, Wegman & Aarts (2006) have summarized a hierarchy of measures applicable to ensure appropriate speeds. Given the importance of speed in accident causation and its direct influence on accident severity (Aarts & van Schagen, 2006; Elvik, 2009) these principles should also be considered for self-explaining roads. The principles are summarized by Wegman & Aarts (2006) as:

- Establishing safe speeds and safe speed limits: These are based on the mix of road users on a particular road and knowledge regarding risks for specific crashes in relation to biomechanical laws of injury risk and severity.
- Credible Speed Limits: Speed limits are credible when they are either in line with the safe speed associated by the users with the “look and feel” of a given road section or when specific cues are present providing explanations (e.g. a school or kindergarten at the roadside). Various methodologies and methods are available which allow the assessment of the effect of specific measures.

[1] Philip N. Johnson-Laird (Johnson-Laird, 2006, reprint 2008) defines a mental model as: “A representation of the world that is postulated to underlie human reasoning; a model represents what is true in one possibility, and so far as possible has an iconic structure. Mental models are the end result of perception and of understanding a description. Those of complex systems are a form of knowledge-representation in long-term memory.” (p. 428)

- Good information about speed limits: Because speed cannot always be inferred from the road, the road environment or external cues, the road user has to be provided with (formal) information regarding the speed limit. With the technical possibilities available today, there are several options apart from speed limit signs.
- Location and dimension of physical speed reducing measures: where necessary such measures (e.g. speed bumps) can be applied. Their application should be limited to locations where no other option is available.
- Credible Enforcement: if all other things fail, speed limits have to be enforced. Acceptance and acceptability has to be ensured.
- Making speed limits more dynamic: this would increase credibility and traffic.
- Finally, a completely dynamic, ISA (intelligent speed adaptation) supported speed limit system is proposed. In its least restrictive form, such ISA system would constantly provide the road user with the present speed limit.

It would be preferable if appropriate behaviour could be deduced from the mere "look and feel" of a road without prior knowledge. However, in reality there will always be road sections where this will not be the case. There, the road designer has to fall back on standardization. The meaning of a standardized design has to be learnt and it is often only understandable when seen in the context of all design variants. Thus, the self-explaining road concept requires not only local measures at particular road sections but a holistic approach for an entire self-explaining road network.

7 What makes a road network self-explaining?

Without explicitly naming self-explaining roads, Hale, Stoop & Hommels (1990) have deduced some design principles to reduce accidents based on the generic error modelling system (GEMS) of Reason (1990). These principles were further elaborated and specifically applied to self-explaining road networks by Theeuwes & Godthelp (1995) and Theeuwes (2000). They are summarized in Theeuwes (2000, p. 21) as:

- "Roads should consist of unique road elements (homogeneous within one category and different from all other categories).
- Roads should require unique behaviour for a specific category (homogeneous within one category and different from all other categories).
- Unique behaviour displayed on roads should be linked to unique road elements (e.g., woonerfs: obstacles—slow driving, freeway: smooth concrete—fast driving).
- The layout of crossings, road sections, and curves should be linked uniquely with the particular road category (e.g., a crossing on a highway should physically and behaviourally be completely different from a crossing on a rural road).
- One should choose road categories that are behaviourally relevant.
- There should be no fast transitions going from one road category to the next.
- When there is a transition in road category, the change should be marked clearly (e.g., with rumble strips).
- When teaching the different road categories, one should not only teach the name of, but also the behaviour required for, that type of road.
- Category-defining properties should be visible at night as well as in the day-time.

- The road design should reduce speed differences and differences in direction of movement.
- Road elements, marking, and signing should fulfil the standard visibility criteria."

Matena et al. (2006) and Aarts, Davidse, Louwerse, Mesken, & Brouwer (2006) have schematically depicted the basic ideas behind a self-explaining road network in the subsequent Figure 1.

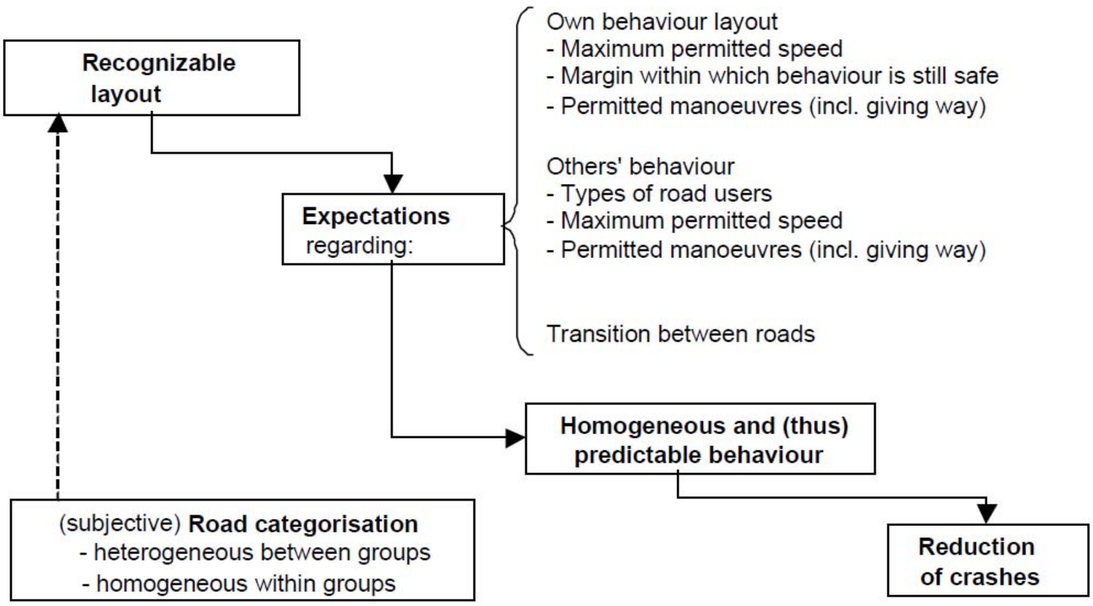

Figure 1 Chain of events regarding recognisable layout and predictable behaviour occurrences (Aarts et al., 2006; Matena et al., 2006).

The most important aspect for a self-explaining road categorization is that the road categorization has to be heterogeneous between and homogenous within groups and that this categorization has to be recognizable on a specific road section.

What elements of a road network can be used to increase the self-explaining nature of a road network? In principle, all elements of a road offer possibilities to increase the self-explaining nature of a particular road section or an entire road network. The subsequent list gives an overview of these road elements:

- Horizontal and vertical alignment
- Road width
- Road surface
- Road markings
- Cross-section design
- Design of crossroads
- Specific cues
- Roadside environment.

Weller et al. (2008) identified the subsequent criteria which were used by subjects to classify rural roads. The respective values are given in brackets:

- Surface (poor vs. good)
- Road width (very narrow vs. wide)
- Road markings (centre line yes vs. no)
- Sight distance (low vs. very high)
- Horizontal alignment (high vs. low CCR).

However, in reality, not all elements can be freely designed. This is because of restrictions given by the environment or legal aspects or because existing roads cannot be rebuilt due to a lack of resources. However, the nature of human perception also allows implementing perceptual designs. An example of such perceptual design would be to reduce road width by markings, instead of physically reducing road width.

Thus, van Schagen et al. (1999, cited in Matena et al., 2006) developed three criteria along which to identify applicable design elements. These criteria are as follows:

- Continuous visibility
- Practical applicability and feasibility
- No negative side effects.

Van Schagen et al. (1999, cited in Matena et al., 2006) applied these criteria to a number of potential design elements. The subsequent design elements fulfilled the requirements named above:

- Marking in the longitudinal direction
- Driving direction separation
- Width of lanes
- Adjacent cycle lanes
- Road surface/extent of roughness
- Characteristics of the shoulder (width, obstacle distance, reflector posts)
- Roadside environment (land use, for instance: urban characteristics such as buildings, parked cars, exits)
- Intersection and transition type (not continuously visible).

The specific values of these criteria do have an effect on behaviour and – subsequently - accident figures. These effects are summarized in Elvik et al. (2009) and are depicted in the subsequent Table 3, taken from Matena et al. (2006). A summary of effects for inner city streets can be found in Schüller (2010).

In order for a road to be self-explaining, the values of the criteria shown in Table 3 have to be in accordance with the intended effect for a certain road category. How these effects could be used to develop an ideal self-explaining road categorisation is shown in chapter 12.

Table 3 The effect of different road features on average speed, number of overtaking manoeuvres and lateral position (Matena et al., 2006).

		Average speed	Number of overtaking movements and % offenders	Lateral position (a = towards road axis r = towards roadside
Type of road surface	Rougher surface (e.g. cobble stones instead of asphalt)	-		
	Renewal of asphalt	+		
Separator	Larger physical hindrance (strips or flaps)		-	
	Double axis with reflectors and broken v. DR old	-	-	
	Strips between double axis	-	-	
Marking in the longitudinal direction	No marking			r
	Addition of axis line on an unmarked road	+		a
	Edge line	+/-		
	Axis line replaced by edge line	-		r
Width of driving lane	Marking in the lateral direction (split chevron)	-		
	Driving lane widths < 3m	-		
	Driving lane width > 3,75 + emergency lane	+		
Reflector posts		+/-***		a/r
(Non-compulsory) cycle lane	Urban area	o		r
	Rural area	o		a
Buildings		-*		
Roadside Vegetation	Continuous	+		r**
	Spread	-		
	Outside of bends	+**/-		a
	Inside of bends	-		
Obstacles/parked vehicles		-*		
Presence of other road users	Slow traffic	-		
	Oncoming vehicles			r

* The shorter the distance between building/obstacle and road, the slower the speed.
** except right-turn bends.
*** straights and left-turn bends slower / right-turn bends faster

8 Criteria to assess the self-explaining nature of a road classification approach

Two fundamental criteria have to be met by a self-explaining road classification:

- homogeneity within and
- heterogeneity between road categories.

This is mirrored by the three main criteria identified by Matena et al. (2006) and Matena & Weber (2009) along which different approaches can be compared. According to these criteria, SER have to be

- recognisable,
- distinguishable,
- interpretable and safe.

The safety criterion might well be named as a criterion of its own, thus resulting in four instead of three criteria. The reason to name safety as an extra criterion is its nature: safety could be seen as the outcome resulting from whether the preceding three criteria were met or not. Additionally, whether a road is recognisable, distinguishable and interpretable might preliminarily be assessed in a laboratory as was done by Riemersma (1988), Theeuwes (1998) or Weller et al. (2008). In contrast, assessing safety is much more complex and requires either to extrapolate from behaviour measured in the laboratory, the simulator or on the road or analysing existing accident data. Both methods have some shortcomings: For the transformation of behavioural data into accident likelihood reliable data are missing. The latter approach requires that roads were already built and enough accident data are available.

However, once safety criteria are specified, road design and road categorization can also be evaluated based on their

- effectiveness in achieving preset safety goals, and based on
- efficiency with regard to the resources spent.

A prerequisite for safety is that road and intersection design is

- in accordance with driving dynamic aspects and traffic flow parameters
- and with the mental models of the driver.

For the horizontal alignment this can amongst others be ensured by designed it according to relational design principles as for example described in the German RAS-L (FGSV, 1995) or in Lamm, Psarianos & Mailaender (1999). This will ensure that the drivers are not surprised by a sudden change in curvature.

An example for intersection design is that roundabouts cannot be used for high speed roads with high AADT. In order to be in line with mental models, the principle of visibility plays a crucial role in intersection design. In order to evoke the correct mental models:

- Intersections have to be visible.
- The right of way regulation at an intersection junction has to be perceptible.

- The right of way regulation has to be understandable, intelligible and consistent.

Last but not least, the implementation of an SER approach has to be

- practical, applicable and feasible.

Whereby this latter criterion was already named by van Schagen et al. (1999, cited in Matena et al., 2006, see preceding chapter) to select design elements applicable in SER design, it is here understood in a broader sense and refers to the categorization in its entirety.

One aspect related to practical applicability and efficiency is how long it takes or how effortful and resource consuming it is to redesign an existing road network. As a case study, the application of the SER approach within the Sustainable Safety approach in The Netherlands revealed that its implementation requires much effort and time (see Annex). The gradual implementation leads to a number of so-called grey roads which are roads not yet redesigned or roads which due to their nature cannot fully be integrated in the existing categorization system (see Annex). This leads to inconsistencies in the implementation process and has to be taken into account in the planning phase.

Another prerequisite for SER design is a

- functional classification

with connector, collector and access categories instead of a classification based on administrative responsibility (see also chapter 2).

Finally, like any scientific theory, road categorization should be

- diversified enough to meet traffic flow and transport functions, but at the same time
- categories should be reduced to a minimum in order to be distinguishable for the drivers.

How does one know that all these criteria are met by a given road design within a given road categorization approach? As already outlined above this can be done in different steps:

Firstly, road planning and design experts must ensure that “obvious” design errors are eliminated and formal design guidelines are applied appropriately. This refers to the consideration of driving dynamic and traffic flow aspects as described above. Table 3 can serve as another source of reference. For example, according to Table 3 the renewal of the asphalt will lead to an increase in speed. Thus, this measure is not appropriate for a redesign of lower order roads, without other measures being taken. Furthermore, the ideal self-explaining road classification developed in chapter 12 can serve as reference when deciding whether SER standards are met or not. It is especially important to ensure that unique design elements are solely applied within one category. This will ensure homogeneity within and heterogeneity between categories. Formally, this first step can be performed following road safety audit procedures as described in Matena et al. (2008).

Secondly, empirical research has to be carried out. This can be done as outlined above with laboratory, simulator or field studies. Each method has its own advantages and disadvantages. Besides safety considerations and the effort needed these can be summarized along the two dimensions internal and external validity. Usually, field studies require most effort but have the highest external validity. However, much effort has to be spent in order not to decrease their internal validity. With increasing experience in designing SER and with increasing knowledge how smaller deviations from the ideal SER design affect behaviour, this step might gradually be skipped and only be applied in cases where the environment requires unique deviations from the ideal SER design.

Finally, the effects on safety have to be continuously evaluated by accident analyses. A state-of-the-art approach on how to analyse accident data to identify hazardous locations is given in Elvik (2008).

9 Overview of current practices of road categorisations in Europe

In Matena et al. (2006) and Matena & Weber (2009) today's practice of road categorisation in Europe was investigated. The results showed that the way how road categories are defined is quite similar in most European countries. Usually, it is a combination of road function and road hierarchy that leads to a certain number of possible road categories which are characterized by more or less strict design rules.

Table 4 shows possible road categories for selected European countries, their function and their impacts on design and infrastructure parameters.

Table 4 Overview of the current practices of road categorization in European countries (based on Matena et al., 2006).

Country	Road Category	Name	Function	Inter-sections	Number of hierarchical structure	Number of standard cross sections	Design speed	Speed limits
Austria	Motorways "A"	Autobahn	connector	grade-separated	2	9	≤100	130
	Expressway "S"	Schnellstraße	connector	grade-separated				100
	Federal roads "B"	Bundesstraßen	connector	[2]				100
	Roads outside urban areas „LB"	Landesstraße B	collector					100
	Roads outside urban areas „L"	Landesstraße	collector					100
Czech Republic	Motorways "D"	[3]	connector	grade-separated	3	9	n.a.	130
	Express roads "R"	1st class	connector	grade-separated			≤120	90
	Roads "S"	1st class	connector				n.a.	90
	Roads "S"	2nd class	connector				n.a.	90
	Roads "S"	3rd class	connector/ collector				n.a.	90
	Special-purpose road		access				n.a.	90

[2] Where not mentioned otherwise, blanks in this column indicate at-grade intersections.
[3] Blanks in this column indicate that either the same name is used as in the column "Road Category" or that no information regarding specific names was available.

Country	Road Category	Name	Function	Inter-sections	Number of hierarchical structure	Number of standard cross sections	Design speed	Speed limits
Denmark	Trough roads (high speed)	Gennemfartsvej XH	connector	grade-separated	n.a.	16	n.a.	120-130
	Trough roads (high speed)	Gennemfartsvej H	connector	grade-separated				90-110
	Trough roads (medium speed)	Gennemfartsvej XM	connector					80
	Trough roads (medium speed)	Gennemfartsvej M	collector					60-70
	Distributor roads (medium speed)	Gennemfartsvej/ Fordelingsvej M	collector					60-70
	Distributor roads (low speed)	Gennemfartsvej/ Fordelingsvej L	access					40-50
	Local road (low speed)	Localvej L	access					40-50
	Local road (low speed)	Localvej XL	access					30
France	Motorways "L"		connector	grade-separated	3	n.a.	n.a.	110-130
	Expressways "T"		connector	grade-separated				90
	Interurban major roads		connector					90
	Multifunctional "R"-class roads		collector					90 (110)
	Secondary rural roads		access					
Germany (current guideline)	AI	National highway	connector	grade-separated	3	9	80 -120	No speed limit – recommended speed 130
	AII	Interregional/ regional road	connector	grade-separated/ at grade			70-100	100
	AIII	Interurban road	connector				60-90	100
	AIV	Area access road	collector				50-70	100
	AV	Local road	collector/ access				50	100

Country	Road Category	Name	Function	Inter-sections	Number of hierarchical structure	Number of standard cross sections	Design speed	Speed limits
	AVI	Rural way	access				no	100
Germany (proposed new guidelines)	EKL1		connector	grade-separated	3	4	no design speed	110
	EKL2		connector/ collector	partially grade-separated				100
	EKL3		collector/ access					90
	EKL4		access					70
Greece	A I		connector		4	n.a.	n.a.	90-120
	A II		connector					90-110
	A III		connector/ collector					80-90
	A IV		collector					<80
	A V		access					<60
	A VI		access					<50
Hungary	Motorway		connector	grade-separated	2	10	110/140	130
	Motor road		connector				90/110	110
	1st categ. main road		connector				90/100	90
	2nd categ. main road		connector				60/70/90	90
	Connecting road		connector/ collector				50/70/80	90
	Access road		access				50/70/80	90
	Stations access road		access				50/70/80	90
Italy	Motorways		connector	grade-separated	3	10	no design speed	130
	Main		connector					90
	Secondary		connector/ collector					90
	Local		access					90

Country	Road Category	Name	Function	Inter-sections	Number of hierarchical structure	Number of standard cross sections	Design speed	Speed limits
The Netherlands	Through-road	stroomweg SW120	connector	[4]	3	8		120
	Through-road	stroomweg SW100	connector				100-120	100
	Distributor road (rural)	gebiedsontsluitingsweg GOW80	collector				80-100	80
	Access road (rural)	erftoegangsweg ETW60	access				60-80	60
	Distributor road (urban)	gebiedsontsluitingsweg GOW70	collector				70-80	70
	Distributor road (urban)	gebiedsontsluitingsweg GOW50	collector				50-70	50
	Access road (urban)	erftoegangsweg ETW30	access				30-50	30
Norway	Main Road	H1	connector		3	4	100-140	100
	Collector Road	S1	collector					80
	Access Road	A1	access					80
Portugal	IP roads		connector		2	13	80-140	80-140
	IC roads		connector				60-120	60-120
	EN roads		connector/ collector				60-100	60-100
	ER roads		collector/ access				n.a.	[5]
	EM roads		access				n.a.	

As shown in Table 4 the number of possible road categories differs between European countries. However, they have in common that they are all based on functionality. This is likely to be good from an SER point of view because road network functionality is supposed to mirror road user needs in functionality: On one hand road users need connections allowing for higher speeds to drive long distances within an appropriate travel time. On the other hand, road users require access roads in residential areas which provide a low level of noise and pollution and which allow entering and leaving the road at low speeds.

However, there are three aspects that threaten the SER nature of the existing categorisations described in Table 4:

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[4] Intersection and crossing designs vary depending on which roads are crossing (CROW, 1997; Matena & Weber, 2009; Matena et al., 2006; van Schagen & et al., 1999).
[5] No information available.

- The vast amount of different road categories within countries.
- The similarities between categories regarding both expected behaviour (same speed limits) and design (similar cross sections or intersection designs).
- The differences in design within the same category.

The first aspect increases the difficulties to find unique design elements which help drivers to perceive the road category they are driving on. Furthermore, it increases the likelihood that road categories and the associated behavioural expectations are mixed up. The second and third aspects violate the two essential principles of heterogeneity between categories and homogeneity within categories. Both are prerequisites for a self-explaining road network. Violating these principles results in road users having difficulties to perceive differences between categories. This subsequently leads to difficulties to adapt behaviour to the different requirements. This is further aggravated when the legal speed limit differs between categories which otherwise show no differences.

At this point a possible divergence between theory and practice has to be discussed. While this discrepancy applies to all road network designs, it is particularly relevant for SER approaches for which the look of the road plays a crucial role. Besides economic, geographical and local administrative circumstances, differences in traffic volume are the most critical aspect requiring deviance from SER principles. This is because different traffic volumes require a different road design in order to provide safe and economic travelling. This mainly affects cross section design which is chosen depending on traffic volume.

The crucial point with respect to SER is that even though a road has a constant network function traffic volumes can differ locally. Thus, roads of the same function must be allowed to differ in (cross section) design depending on AADT in order to take into account basic principles of safety, efficiency and economy. However, this could threaten the principle of homogeneity within categories. A solution would be to use other design elements than cross section as unique identifiers of road categories. Whether this is successful has to be tested.

It has to be concluded that throughout Europe the existing road categorisation approaches mainly consider the road network functions. Often, there is a high number of possible categories which are characterised by further design regulations regarding alignment, cross section type and intersections. Some of these design regulations have been applied for a long time and are already in line with SER principles. However, what is missing in traditional approaches is the explicit and direct implementation of driver needs and expectations regarding their driving behaviour. Another important weak point is that existing approaches resulted in a vast number of possible categories which have to be reduced. Thus, it is going to be difficult to redesign a whole network and adapt it to the requirements of an SER categorisation without major changes. However, sometimes hard engineering solutions could be replaced by soft psychological solutions by taking into account the nature of human perception. An example would be to perceptually narrow road width with the help of markings without physically changing the cross section.

10 Can the current approaches be termed self-explaining?

Based on the preceding chapters it can be stated that the various road categorizations do not include a holistic self-explaining road approach. Of course, single elements of self-explaining roads have been implemented. In general, the standardization of design categories and their design principles and parameters constitutes a first step.

Especially roads of the highest category already implement important principles of self-explaining roads. The best examples are modern motorways. In most countries they are built as an own road category and their optical appearance is quite similar. Usually they are characterized by two carriage ways separated by median barriers, there are at least two traffic lanes per direction, intersections are grade-separated, there are limits regarding traffic participants (defined by a required minimum speed) and a fixed high speed limit. Thus, this road category likely meets the expectations of road users: How to behave on a motorway is well known, as it is known what roads users do have to expect. It is thus permissible to assume that motorways are at the moment the best example for self-explaining roads throughout Europe in terms of their practical realization. It seldom was a specific self-explaining road concept but rather the need to work on a high level of standardization for high speed roads which finally lead to these homogenous design standards.

Regarding the other road categories several aspects of the self-explaining road concept are realized but not comprehensively so. An example of its realization is the implementation of relation design between consecutive design elements such as horizontal curves. By designing roads in this way, road users' expectations are met because radii within a sequence of curves are all similar (see chapter 3).

Based on Matena et al. (2006) and Matena & Weber (2009) the only countries which already apply or are currently introducing self-explaining road principles to their road network are The Netherlands, Denmark and Germany with its new guidelines.

11 Preliminary comparison and evaluation of SER-approaches in Europe

The comparison of the European guidelines showed that the Netherlands, Denmark and Germany are furthest in planning (Denmark and Germany) and implementing (The Netherlands) self-explaining road concepts for rural roads (see Matena & Weber, 2009; Matena et al., 2006) (see also Table 4 and preceding chapter). These three approaches were selected for a closer comparison following Matena et al. (2006) and Matena & Weber (2009).

In the Netherlands self-explaining roads are part of a concept for sustainable road safety (see chapter 5) and thus started to develop about two decades ago. Even though the concept of self-explaining roads is, to some extent, related to the sustainable safety vision, there has not been an official implementation of the concept of self-explaining roads in itself. Based on a re-categorization of the whole Dutch road network three different categories (through roads, distributor roads, access roads) have been defined. Somewhat deviating from the original meaning of SER design, the Dutch concept assumes that the road user is acquainted with the different road categories of the road network. However, expected effects are the same: by easily recognizing and distinguishing road categories, behaviour is expected to mirror the road designers' intended behaviour.

In Denmark the road category depends on the road function within the network and on speed classes (see next chapter).

The German draft of the new rural road design guideline for rural roads "RAL" comprises four different design classes based on the road function. It is based on the experiences of the last decades of modern road design in Germany and is focused on the improvement of road safety and traffic service. The basic idea behind the RAL was not explicitly to realise an SER approach; rather it was intended to optimise the standardisation of rural road design and to minimise the number of possible road categories. However, this optimised road categorisation could be seen as resulting in an SER road design, even though partially defined design rules do not meet requirements of the theoretical SER approach at all times (see also next chapter). The different possible standard cross section types within one category are an example of this limitation. Here, the traffic needs (traffic volume) outweighed the SER principle of homogeneity. Thus, the new German guidelines are a compromise between a theoretical SER approach and its feasibility and the needs of traffic coordination.

The basis for the comparison is provided by the road function (see Matena & Weber, 2009; Matena et al., 2006). This is because a functional categorization with few categories is applied in all approaches which allowed the comparison to be made in the first place. Other parameters which could have been used differed between approaches thus not allowing a direct comparison.

To compare the three approaches four road types were used:

- Through roads
- Medium-speed through roads
- Regional/ distributer roads
- Local/ access roads.

In general, it must be mentioned that a comparison and especially the evaluation is difficult. On the one hand there are clear defined requirements and principles how to make roads self-explaining (see preceding chapters). On the other hand the feasibility of these requirements has also to be taken into account. Since road networks have historic roots it is unrealistic to apply new design principles for the entire road network. Therefore, requirements still have to be flexible to a certain extent in order to be applicable.

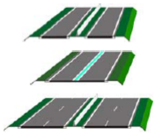
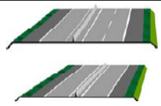
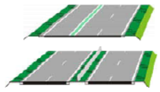
The comparison and evaluation which has been adopted here, is mainly based on the two important self-explaining principles:

- Homogeneity within one category
- Heterogeneity between categories.

The comparison and evaluation between countries is carried out for the above mentioned four different road categories. The description of the approaches is taken from Matena et al. (2006) and Matena & Weber (2009). The evaluation was carried out along the principles developed above. For the comparison between categories within countries, Table 4 is also taken into account.

Table 5 Comparison and evaluation of different SER approaches in Europe, Part I: Trough roads.

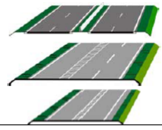
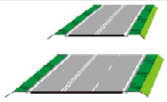
First road type: Through roads

	NL	DK	D
Name	Regional Flow Road Stroomweg	High Speed Through road Gennemfartsvej H	Design Class 1 EKL 1
Function	Mobility	Mobility	Mobility (long distance traffic)
Cross Sections			
Unique Identifier	Physical or coloured median barrier	Emergency lanes and physical median barrier	Physical or coloured median barrier
Crossings			
Regulation			
Speed limit			 *
Access to private properties	forbidden	forbidden	forbidden
Alignment			 generous
Remarks			* Generally the speed limit outside built-up areas is 100 km/h, 110 km/h is proposed for roads of EKL 1

		The Netherlands	Denmark	Germany
Cross Sections	positive		dual carriageways only	
	negative	dual and single carriageways different types of median barrier		dual and single carriageways
Crossings	positive	grade separated only	grade separated only	grade separated only
	negative			
Speed limit	positive	one speed limit		one speed limit
	negative		two different speed limits possible	
Alignment	positive			requirements
	negative	no requirements	no requirements	

Table 6 Comparison and evaluation of different SER approaches in Europe, Part II: Medium-Speed Through roads.

Second road type: Medium-Speed Through roads

	DK	D
Name	Medium Speed Through Road Gennemfartsvej XM	Design Class 2 EKL 2
Function	Mobility	Mobility (interregional traffic)
Cross Sections		
Unique Identifier	Broad centre marking	Alternating sections with 2 and 3 lanes, double axis line
Crossings	**Signals only if speed <=70, roundabouts, T-crossings <=50km/h**	 partially at-grade
Regulation	No agricultural traffic, 	
Speed limit		 *
Access to private properties	forbidden	forbidden
Alignment		 semi generous
Remarks		* Generally the speed limit outside built-up areas is 100 km/h, 100 km/h is proposed for roads of EKL 2 exceptional cases: intersections can be designed as crossings with traffic lights

		The Netherlands	Denmark	Germany
Cross Sections	positive	n.a.		single carriageways only
	negative	n.a.	dual and single carriageways	
Crossings	positive	n.a.	at grade only	partially at grade only
	negative	n.a.		
Speed limit	positive	n.a.	one speed limit	one speed limit
	negative	n.a.		
Alignment	positive	n.a.		requirements
	negative	n.a.	no requirements	

Table 7 Comparison and evaluation of different SER approaches in Europe, Part III: Regional / Distributor roads.

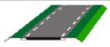
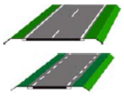
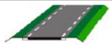
Third road type: Regional/ Distributor roads

	NL	DK	D
Name	Distributor Road	Medium Speed Road Gennemfartsvej / Fordelingsvej M	Design Class 3 EKL 3
Function	Distribution	Mobility / Distribution	Mobility (regional traffic)
Cross Sections			
Unique Identifier	Broken Edge Line Double Axis Marking / Median	-	Solid edge line together with single axis line
Crossings	at level	Signals only if speed <=70, roundabouts, T-crossings <=50km/h	at level
Regulation	Separate cycle lane always required	No agricultural traffic, Separate cycle lanes if AADT > 2000	Separate cycle lane if required
Speed limit	80	60 70	90 *
Access to private properties	limited	limited	limited
Alignment			semi adapted
Remark		Similarities between Medium Speed Through Roads and Medium Speed Distributor roads / -	* Generally the speed limit outside built-up areas is 100 km/h, 90 km/h is proposed for roads of EKL 3

		The Netherlands	Denmark	Germany
Cross Sections	positive			single carriageways only
	negative	dual and single carriageways	dual and single carriageways	
Crossings	positive	at level only	at level only	at level only
	negative			
Speed limit	positive	one speed limit		one speed limit
	negative		two different speed limits possible	
Alignment	positive			requirements
	negative	no requirements	no requirements	

Table 8 Comparison and evaluation of different SER approaches in Europe, Part IV: Local / Access roads.

Fourth road type: Local/ Access roads

	NL	DK	D
Name	Access Road	Low Speed Local Road Localvej L	Design Class 4 EKL 4
Function	Provide access to private properties	Local traffic	Local traffic
Cross Sections			
Unique Identifier	Single lane road with broken edge line	-	Single lane road with broken edge line
Similar to other Category / Identifier		Medium Speed Distributor Road, Extra Low Speed Local Road / Lane width	
Crossings	 at level	Roundabouts or T-crossings	 at level
Regulation	 allowed	 allowed	 allowed
Speed limit	 60	 40 50	 70 *
Access to private properties	allowed	allowed	allowed
Alignment			 adapted
			* currently 100 km/h, 70 km/h is proposed

		The Netherlands	Denmark	Germany
Cross Sections	positive	single carriageways only	single carriageways only	single carriageways only
	negative			
Crossings	positive	at level only	at level only	at level only
	negative			
Speed limit	positive	one speed limit		one speed limit
	negative		two different speed limits possible	
Alignment	positive			requirements
	negative	no requirements	no requirements	

The analysis of the road designs between categories within one country (see Table 4) and the comparison of designs within one category between countries (see the tables above) revealed the following results.

All approaches by The Netherlands, Denmark and the proposed German approach comprise self-explaining principles. In addition to the SER principles the road categorization is based on road functions, with Denmark additionally using speed classes to sub classify roads. Thus, all in all, feasible SER approaches were developed.

From the theoretical point of view it must be criticised that the homogeneity within one category as well as the heterogeneity between categories have not be adhered to. Especially the application of cross section designs is partly inconsequent: similar or equal cross sections are used for different categories (see first and second road type). Furthermore, different suggested speed limits within one category may lead to confusion. This aggravates a clear identification of the road category by the road user.

The case of different cross sections within one category was already discussed in the previous chapter: it is the result of a compromise between the strict application of the theoretical definition and the conditions imposed on road design by traffic reality, especially traffic volume. Various standard cross sections within one category are needed since the road design must meet the requirements of traffic structure and traffic volume (see chapter 9). As both can vary, it is sometimes appropriate to use a two carriageway cross section and sometimes a single carriageway cross section.

However, with respect to SER design, the relevant aspect is that road users perceive the different cross-sections as belonging to the same category. In this way, the driver will behave appropriately despite several cross sections are used for a single category. This might be achieved by using unique identifiers which do not depend on the cross section. An example of the effectiveness of this strategy is motorway design: by using emergency lanes and physical median barriers as unique identifiers, the actual number of lanes is of minor relevance for the driver's perception of the road category. Nevertheless, whether this is also the case for the cross sections described in the previous tables has to be evaluated empirically.

On the positive side the differing speed limits between the categories have to be named. Whether the speed limits are distinguishable by the drivers in reality must be further examined.

Another positive aspect is the design of crossings. Here, an explicit differentiation has been realised.

Even though influencing road user behaviour is an important objective of self-explaining road concepts the role of alignment design is subordinate in the approaches of The Netherlands and Denmark. Only the German approach defines general restrictions to the alignment for each road category.

Furthermore, it has to be taken into account that the practice of implementation will likely differ from theoretical classification approaches. The so called grey roads in the Netherlands are an example here (see Appendix).

Finally, when comparing the numerous criteria deduced from the literature (see preceding chapters), it is obvious that not all of these criteria can be applied for this comparison. This is because essential data are missing. This is for example the case for effectiveness or efficiency which can only be applied post-hoc. Another example is the evaluation based on whether roads are recognisable, interpretable and distinguishable. Whereas preliminary deductions can be drawn from psychological knowledge of perception and cognition, a final evaluation requires empirical data collected from road users.

However, despite these shortcomings which make the evaluation preliminary, it must already be stated that the current and proposed approaches are not entirely self-explaining: both the principle of homogeneity within and heterogeneity between categories is violated at least once within each approach. This will likely lead to formal signs being required to explain the road to the driver, and is thus essentially violating the self-explaining road ideal.

12 An ideal self-explaining road categorization

In the preceding chapters road categorizations were compared and evaluated. In this chapter, the principles derived in former chapters are prototypically applied for an ideal self-explaining road categorisation.

This is shown in

Table 9. Why the specific values were chosen is described in more detail below.

Location: A distinction is made between rural and urban roads following general principles in road categorization and accident analysis. Motorways are regarded as distinctive category outside urban areas.

Function: A functional classification approach was chosen instead of a hierarchical one based on general considerations made above.

Cross-section: The need to separate driving directions increases with speed, based on the function of the road, the speeds typically associated with these functions and the physical relationship between speed and accident severity and accident occurrence (Aarts & van Schagen, 2006; Elvik, 2009).

Alignment: the importance of alignment design decreases with decreasing driving speed (summary in Dietze et al., 2007).

Unique Identifier: The unique identifier has to be perceptible and dominant at first glance. The ones chosen are based on common sense and general principles of perception and cognition (summary in Weller, 2010).

Intersection design: The selection is based on safety and driving dynamic aspects.

Surface: Surface was shown to be one important distinctive element in subjective road classification (Weller et al., 2008). Whereby there will be few perceptible differences in higher order roads, low speed roads could easily be assessed by surface quality.

Regulations regarding other traffic participants: Based on safety considerations.

Speed limits: Based on safety considerations. Differences between categories were chosen in order to be clearly distinguishable by road users.

Table 9 Proposal of an idealised self-explaining road categorisation.

Location	Function	Cross-section width	Cross-section median separation	Alignment	Unique identifier	Inter-section design	Surface	Regulation (other traffic partici-pants)	Speed limit
Rural Motorway	Through I Motorway	Very wide	Physical median barrier. Emergency lane	Generous	Physical median barrier. Emergency lane	Grade-separated		No vulnerable road users	130
Rural	Through II Non-Motorway	Very wide	Physical median barrier. or broad coloured median marking	Semi-generous	Physical or broad coloured median and no emergency lane	At grade intersection with traffic regulation devices		Vulnerable road users only on separated lanes	100
	Rural Distributor	Wide	Median marking	Semi-adapted	Median marking	At grade intersection with traffic regulation devices		Vulnerable road users	80
	Rural Access	Narrow	Narrow cross section No median Left and right markings	Adapted	Narrow cross section No median Left and right markings	At grade intersection or roundabout		Vulnerable road users	60
Urban	Urban Distributor	Wide (urban)	Median markings		Median markings	At grade intersection or roundabout		Vulnerable road users on separated lanes	50
	Urban Access	Narrow (urban)	No median		No median	At grade intersection or roundabout		Vulnerable road users	30
	Residence		No physical separation between vehicles and vulnerable road users		Coloured or cobble-stone		Coloured or cobble-stone	Priority for vulnerable road users	7

13 Conclusions

It was shown that different road categorization approaches exist in Europe, some of which striving to put into practice self-explaining road principles. The latter approaches differ regarding the extent in which they are self-explaining. In fact, it was shown that none of these approaches is entirely self-explaining: both the principle of homogeneity within and heterogeneity between categories is violated at least once within each approach. Such inconsistencies likely require that they are explained to the driver in one or the other way, thus violating the basic self-explaining road ideal.

To compare and evaluate differences between approaches several criteria were identified and applied. However, it was also found that several of these criteria have high requirements regarding data. One important requirement is how road users actually perceive the roads and how they behave on them. Such criteria have to be evaluated in additional empirical steps. This will partly be carried out in subsequent ERASER work-packages.

Sources

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Annex

Case Study: the State of Redesigning Roads in The Netherlands

The Sustainable Safety vision points out that in order to increase the recognizability of the various road types a consistent categorization of the network is essential. Nearly the whole Dutch road network has been categorized on the basis of the functionality of its roads. Nevertheless, the extent to which these roads comply with the Sustainable Safety requirements is still limited.

A survey study by Weijermars & Doumen (2009) investigated to what extent the Dutch road network is categorized according to the Road Safety Manual and also to what extent the roads are designed according to the EHK guidelines. The results of the survey suggest that an estimate of 90 percent of the municipalities has already categorized the road network and 62 percent of them did it according to the Road Design Manual from CROW (CROW, 1997). The municipalities that did not perform the categorization according to the manual gave varied reasons for this. Some responded that they were not aware of the manual, others that it is not feasible in practice, or that it was too costly and a few claimed to disagree with the manual.

The EHK guidelines have been in an implementation phase for some years already and because of feasibility constraints, these guidelines allow for a phased implementation. This implies that many roads are not fully redesigned with EHK and have therefore, neither the traditional layout nor the one corresponding to the EHK guidelines. Moreover, there are many road authorities that simply do not agree with the EHK guidelines and develop the infrastructure according to their own ideas. These issues undermine the recognizability of the roads.

The study by Weijermars & Doumen (2009) revealed that 75 percent of the rural access roads (60km/h) and about 40 percent of the rural distributor roads contain the 'Essential Recognizability Characteristics'. Another survey study performed among the Dutch road authorities investigated to what extent they employ the existing guidelines and recommendations (Boer, Grimmius, & Schoenmakers, 2008). Three types of road authorities participated in the survey; 64 percent of the Dutch municipalities, 83 percent of the provinces and 83 percent of the water control authorities. The survey revealed that road authorities are more likely to employ the EHK guidelines outside urban areas than inside them. According to the road authorities, on rural distributor roads (80km/h) the EHK guidelines are always (or when possible) employed, which for these roads are double axis marking (or median) and broken edge marking.

For rural access roads (60km/h), 85 percent of the road authorities stated that they follow the EHK guidelines whenever it is possible. They argue that the lack of space is the main reason they do not fully comply with the design guidelines.

There are, however, roads that have not been yet redesigned according to the guidelines. Road authorities seem more willing to modify distributor roads according to the guidelines than access roads, at least in the near future.

In urban areas the EHK guidelines are not often followed on distributor roads (50 or 70 km/h), which are managed by the municipalities. According to the road authorities it is usually not feasible to apply the guidelines, mainly because of lack of space. They consider moreover, that applying the guidelines does not contribute to increasing safety in the area. The road authorities that do follow the guidelines stated that they plan to redesign the existing roads in the future in order to make them comply with the guidelines.

Case Study: Grey roads

When the road categorization began, which was carried out according to the 'Startprogramma Duurzaam Veilig", it was found that certain roads are difficult to assign to one distinct category, as stipulated by the Sustainable Safety vision. Certain roads, mainly in urban areas, were very busy and had both an access function as well as a flow function. This 'double function' implies that the road can not be categorized as either 'access road' or 'distributor road'. These roads were called therefore, 'grey roads'.

Later, several more detailed definitions have been suggested but all of them have in common the fact that a grey road fulfils two different functions.

Road authorities deal with this problem of the grey roads in varied ways and many of the adopted solutions that have been implemented are not in line with the Sustainable Safety principles. In urban areas for instance, in cases where the traffic function has a predominant role and vulnerable road users should be somehow separated from the motorized traffic, some road authorities have chosen to create space by implementing the 'non-compulsory lane' (Kroeze, 2004). The non-compulsory lane (fiets suggestiestrook in Dutch) is like a bike lane but it is not reserved to cyclists 'only'. Studies showed that this option is less safe for bikes than any other facility for bikes. Bicycle lanes, bicycle paths or a shared lane with cars, for example, are safer than the 'non-compulsory lane'.

There are several examples of conflicts between theory and practice. An example of how road authorities cope with grey roads in urban areas can be found in Delft. Delft is one of the typical old Dutch cities which has many canals and historical buildings, narrow roads, and a high population density. The application of the EHK guidelines in the Delft road network in certain situations led to complex design assignments because of space requirements and competing concerns (Breider, de Groot, & Nederveen, 2006), specifically on old roads that now have an important flow and also access function. The municipality found that one of the shortcomings of bringing the theory of Sustainable Safety into practice was that the tension between the access and flow function is very large. On the one hand, there is often no alternative route to offer to the traffic and on the other hand, diminishing the access function is not desirable. That is why the municipality of Delft finally chose to create a fourth road category which has a distributor function but pays more attention to safety and to the requirements of the surroundings. The new road category is called 'wijkontsluitingweg' (major distributor road) and Figure 2 shows an example of such a road type in Delft. The major distributor roads have an adapted road design focused on a speed limit of 40km/h but with a formal speed limit of 50. The desired adapted speed limit is pursued with a combination of measures such as a narrower driving strip and a special median slightly elevated.

One of the many examples of grey roads in rural areas is a road named Geestdorp which is located in the province of Utrecht (Grontmij, 2010). This road has an important flow function but it also has an access function provided by the several property accesses along the road, on both sides. Agricultural vehicles are allowed on this road and there are at-grade crossing facilities for slow traffic. The horizontal alignment is very tight.

In order to cope with this double function of the road one possibility was to convert the road into a 60km/h access road but the flow intensity is too high for such a road. Another solution was to straighten the road alignment but it is not feasible given the high costs it involves. The authorities chose to convert the road into a 60km/h distributor road (instead of 80km/h as the standard). This solution includes the prohibition to overtake and bicycle facilities along the complete road stretch in order to avoid frequent crossing of slow traffic.

Figure 2: Grey urban road in Delft - Ruys de Beerenbrouckstraat.

Figure 3: Grey rural road in the province of Utrecht - Geestdorp (Grontmij, 2010).

According to SWOV (Dijkstra, Eenink, & Wegman, 2007) the solutions to grey roads adopted by various road authorities present shortcomings in relation to the Sustainable Safety principles. SWOV states, for instance, that the introduction of the fourth road category by the municipality of Delft is not a suitable option because it involves unsafe speeds, particularly related to conflicts between non-motorized and motorized traffic.

In order to provide a solution to the problem that grey roads entail and based on studies about crash safety, SWOV proposed a ‘safe speeds’ concept. The idea is that depending on the potential conflict types existing on intersections or roads sections there is a maximum speed that should be allowed in order to avoid serious crashes. One of the main points is that cyclists and pedestrians should not end up in conflict situations with motor vehicles travelling faster than 30 km/h.

CROW is currently working on an updated version of the Road Design Manual which includes grey roads and how to deal with them.