Nordic Human Factors Guideline

Explanatory model for road user behaviour
Implications for the design of road and traffic Environment

Gabriel Helmers

January 2014

Trafitec
Scion-DTU
Diplomvej 376
2800 Kgs. Lyngby
www.trafitec.dk

Title: Nordic Human Factors Guideline.

Explanatory model for road user behavior.
Implicatins for the design of road and traffic environment

Author: Gabriel Helmers

Editor: Lene Herrstedt

Report date: January 2014

Language: English

No. of pages: 80

Client/financial source: Nordic Road Geometry Group

Project: Nordic Human Factors Guideline

Key words: road user behavior, human factors

The report is also available in Swedish

The report can be acquired from www.trafitec.dk.

Indhold

Introduction 5

1. Background 7

2. Basic ideas of the explanatory model 9
2.1 Road user behaviour in a developmental perspective 9
2.2 Man must learn practically everything 10
2.3 How do we perceive the environment surrounding us – a new perception theory 11
2.4 Driving is a skill – we perform skills without thinking about them 13
2.5 Driving is a ”self-paced task”, which is “perceptual” and performed automated 13
2.6 Operating a vehicle is primarily an automated activity while some tasks require perceptual assessments or symbolic understanding. 14
2.7 The driver’s ability to understand the symbolic information in the road environment 16
2.8 Drivers’ perception of the road – the ”self-explaining road” 17
2.9 Being well-oriented in one’s environment 18
2.10 Our expectations to the road and its continuation.................................... 19
2.11 The current visual impression and the memory of a familiar road 21

3. Explanatory model and our traditional way of thinking 23

4. A problem with the new model 25

5. A general principle for road user behaviour and road design 27

6. ”Ghost driving” 29
6.1 What is ghost driving? What is the problem? 29
6.2 ”Ghost driving” – Where does the problem occur? Where does the misconduct begin? 30
6.3 Understanding the causes of ”ghost driving” 31
6.3.1 Basic analysis of the problem 31
6.3.2 The road must provide the driver with a clear perception of how to drive on it 32
6.3.3 Interaction between physical road and symbolic contents of road signs 32
6.3.4 The driver must be well oriented in the traffic environment 33
6.3.5 Information on advance guidancesigns 33
6.3.6 Design of ramp connections – the ”fish trap principle” 34
6.4 Advice for designs at five points of trouble 35
6.4.1 ”Ghosts driving” at junctions – analysis and proposal for action 35

6.4.2 ”Ghost driving” at ”half” junctions – analysis and proposed measures 38
6.4.3 ”Ghost driving” at rest areas on motorways – analysis and proposed measures 39
6.4.4 ”Ghost driving” after U-turn on the motorway – analysis and proposed measures 41
6.4.5 ”Ghost driving” at change of design of road section 42
6.5 Analysis and general measures for reduction of ”ghost driving” on road sections 42

7. The driver’s choice of speed and basic conditions for a proper speed adjustment 49
7.1 Starting point 49
7.2 The driver’s choice of speed at unchanged road and traffic conditions 49
7.2.1 What does the explanatory model say? 49
7.2.2 The drivers choice of speed at unchanged road and traffic conditions 51
7.3 Driver speed adjustment upon unexpected reduction of passability 56
7.3.1 What does the explanatory model state? 56
7.3.2 Analysis with regards to driver speed adjustment upon unexpected reduction of passability 57
7.3.3 How should road and traffic environment be designed to meet driver expectations? 59
7.3.4 How to ”awaken” drivers going with false expectations? 60
7.4 Summary and conclusions 61

8. The drivers’s ability to read and understand road signs and road markings 63
8.1 Reading and understanding the meaning of road signs and road markings – can that constitute a problem? 63
8.2 Road signs and road markings are information carriers 63
8.3 Driver behaviour is perfermed at three ”levels” 65
8.4 The driver’s collection of information from the traffic environment in general 68
8.5 Correspondance between the ”natural” information of the road and traffic environment and the messages of road signs and guidance signs 69
8.6 Understanding messages on road signs and guidance signs 70
8.7 The message of each road sign must be immediately relevant to secure reading of it 71
8.8 Awakening the driver’s need for information from the road environment . 72
8.9 The driver’s collection of information on unfamiliar vs. well-known roads 74
8.10 Overall conclusion 75

9. Afterword 77

References 79

Introduction

Nordic Human factors Guideline is a Nordic collaborative project under the Nordic Road Geometry Group. The project covers road user demands to the design and construction of road systems based on existing knowledge of road users' physical and mental abilities.

The work is carried out by a Nordic research team represented by Lene Herrstedt (Civil Engineer, MSc., Ph.D., Trafitec, Denmark), Gabriel Helmers (Traffic Psychologist, Ph.D., Consultant, Sweden), and Fridulv Sagberg (Traffic Psychologist, Senior Researcher, TOI, Norway).

The project includes four sub-projects I, II, III, and IV:

I) *Collection of existing knowledge* based on comprehensive literature studies is presented in five thematic notes on road users' physical and mental abilities:
- Reaction time – break response time and resolution response time
- Eye level, reading distance, and reading time for drivers
- Walking speed
- Assessment of speed and distance
- Inattention and distraction

II) *Development of an explanatory model for road user behaviour* with the purpose of increasing the understanding of how drivers act in traffic and how our actions are influenced by road design and traffic environment. Conclusions from the model form the basis of "The self-explaining road".

III) *Execution of a number of case analyses* for verification of the applicability of the explanatory model as a tool for problem analysis and resolution of specific traffic problems in practice.

IV) *Three training sessions* encompassing three power point series with accompanying notes for the dissemination of the main findings of the project.

This report describes the results of sub-project II) Development of an explanatory model for road user behavior. The report is written in Swedish by Gabriel Helmers with the assistance of Lene Herrstedt and Fridulv Sagberg.

The report is also available as download in English from Trafitec's website www.trafitec.dk .All reports from the *Nordic Human Factors Guideline* project may be downloaded from www.nmfv.dk

1. Background

In order to design well-functioning road and street environments we need to have a good understanding of how we operate as road users. The challenges we meet when trying to understand road user behaviour, is very much influenced by our ingrained habits that tend to lead us astray. Using our traditional, philosophical approach, we automatically assume that the driver is conscious of his actions. This means that the driver will always hold the full (legal) responsibility for the adverse consequences of accidents sometimes caused by his actions. Should an accident occur in a technical system (e.g. road traffic), the individual road user (in this case the driver) will typically be found guilty in a legal sense. Only rarely is the formal legal responsibility that of the ”system owner”, which through its framework is responsible for the systems design, or on the road manager building and maintaining the road network or on the vehicle manufacturer who has developed and built the vehicle. This is very unfortunate because focus is often applied to the operator (driver) and his inability. Instead, attention should be paid to making the system user friendly and well-adapted to the qualifications of the driver and the other road users.

Consequently, there is a strong need to develop a good explanatory model for road behaviour. The model should provide a stable platform for instructions on how the road and traffic system should be designed and moreover should be easy to use. Such model must include a description of fundamental human behaviour with respect to moving around in the environment. Based on this description it should be possible to establish the general principles upon which testable hypotheses should be formulated for how different parts of the road system should be designed. The explanatory model must include realistic descriptions of various road user behaviours so as to accommodate the direct experiences we have as trained road users. Amongst others, the model should provide a good understanding of difficult vs. easy traffic conditions, and make up a good tool of analysis when it comes to understanding the causes of various problems.

In the next section we will try to formulate such fundamental properties of road behaviour. These properties must be well founded in behavioural theory and provide a clear conclusion of current knowledge. Consequently, our learnings will be summarised in a somewhat more universal and general way than what is usual praxis. Concluding the knowledge in more general terms is a necessary step in all knowledge and theory (See Brehmer).

A good theory or explanatory model is a prerequisite for a better understanding of road user behaviour. Based on the theory it must be possible to predict outcome of actual events. These must then be formulated as assertions (hypotheses which will have to be confirmed or falsified through empirical studies to test the theory. Each such empirically confirmed hypothesis reinforces the theory. In case the hypothesis is falsified, the theory must be adjusted. The aim of this work is to initiate a first step in the development of a practically useable explanatory model for road user behaviour.

After describing the explanatory model this will be used to analyse and explain current problems in the field. Suggestions for initiatives aiming to resolve such problems will be proposed. The following three areas of concern have been selected for analysis:

- ”Ghost driving” (Section 6)
- Selection of speed and conditions for appropriate speed adaption (Section 7)
- The driver’s ability to read and understand road signs and markings (Section 8)

2. Basic ideas of the explanatory model

2.1 Road user behaviour in a developmental perspective

In order to better understand how we act as road users we first turn to Charles Darwin's and J.J. Gibson's thoughts on how man has evolved during the evolution in interaction with our physical environment. Our description of driver behaviour is largely based on the 1938 classic article by Gibson and Crooks about how we function as drivers.

Darwin's thesis "survival of the fittest" makes up a useful starting point. The species and individuals best adjusted to the demands of society survive. During the evolution, our minds and brains have developed to more effectively perceive the most important information from society. Another prerequisite for survival has been that simultaneously we have developed at better ability to orientate ourselves and manoeuvre around in any given environment. Thus, individuals of the surviving species have successfully managed to satisfy their primary needs – eating, resting, protecting and reproducing.

During evolution, we have thus had to develop a more effective brain and a more efficient mind whilst at the same time improving our ability to move around and act (and manipulate) in society in general. Those species and individuals who – with as little effort as possible – have managed to acquire the largest "benefits", have survived. As such, this general cost/benefit principle, which we often use, has always played an active role in the evolutionary process that created man.

This "construction principle" has created a rational, efficient, and adaptive human - designed to move around in its physical environment whereby our minds, our brains, and our musculoskeletal system have developed to serve as an effective whole.

Moving around in our environment nowadays we tend to act rationally and effectively according to the principle "*maximum benefit at minimum cost*". We therefore try to avoid detours by choosing the shortest possible path without obstacles.

A first example: Poorly planned footpaths cause spontaneously created paths across lawns and even "holes" in hedges and plantings.

Another example: Bicycle paths not leading directly to the bicycle user's destination without causing an unnecessary detour will not be used as intended by the construction planner. The cyclist tends instead to choose the least strenuous and usually shortest route. This may involve cycling on streets which are primarily adapted for cars. The cyclist is often tempted to violate traffic rules (e.g. by cycling against the traffic on one-way streets, crossing on red, etc.)

Our behaviour is not always rational. An example: Cycling is the most energy efficient way of moving along paths. Why then, do we not go by bike on distances that are longer than comfortable walking distance and up to at least 5 km? Swedish studies have indicated that in most cases we choose to go by car even for such short trips. In fact half of all car trips are less than 1.5 km (!). The conclusion to be drawn is that we do not seem to fully acknowledge the true costs of a car trip in terms of expenses for infrastructure, vehicle, fuel, environment, and health.

Conclusion 1:
When moving we act rationally and effectively according to the principle ”maximum benefit through minimum effort”.

Conclusion 2:
Our choice of means of transport is often irrational. Through our choice we seem to accept high actual costs in order to fulfil our immediate need for comfort.

2.2 Man must learn practically everything

As soon as the baby bird is ready to leave the nest, it is able to fly. However, when a 1-year old human is physically mature to walk the child cannot just walk without first having learned how. The more developed a species, the greater the part of the behaviour must be learned, and the lesser a part is genetically programmed.

As the most developed species man is born virtually with no skills and will have to learn practically everything. One exception: We seem to have a genetic fear of heights and a natural understanding of the fact that we will hurt ourselves if falling. In contrast to this, we feel that the speed levels we uphold when driving are not particularly dangerous.

By operating in our environment, we receive feedback on our behaviour and thus learn which objects and characteristics of the environment affect our behaviour. Through such feedback we learn how to behave in order to qualify for the ”benefits” in our environment while avoiding the threats and dangers that are also present.

A new-born will even have to learn what belongs to its own body and what does not. By biting a finger or a toe the child will feel pain arising from the actual body part. The pain tells that “this is part of me”. When, however, the child bites into a piece of wood, the only feedback will come from its mouth. In this way, the child will learn to understand its own boundaries and what belongs to the surroundings.

How does a child learn how the surroundings work? The child wants to get its needs fulfilled, but - with the exception of the sucking reflex (when breastfeeding)

– it will not know how to behave. The only thing to do is try. Without knowledge, the behaviour is random. But if a child succeeds in behaving such that its needs are fulfilled, the behaviour will be reinforced. If the child fails, feedback from its surroundings will suggest that the child needs to change behaviour next time it tries.

This is a general principle for how we acquire knowledge about our surroundings and how we best act in it in order to meet our various needs and achieve our goals. To comply with the principle “maximum benefit at minimum cost” each individual will have to learn the limits of its own ability. The child will learn how to walk and run but will sometimes fall and hurt itself. After several attempts and failures the child will understand the limits of its own ability. By then, it has learned how to walk and run in a controlled manner and with increased confidence. This learning process is repeated as the older child learns how to bike, when the 15-year-old begins to drive a scooter, and when the almost grown man learns how to drive a vehicle.

And the learning process is repeated every time we learn a new skill. In traffic, the relevant skills are to move by means of various “transportation tools”: bike, scooter, motorcycle and car. Once we are comfortable with the vehicle, we experience it as an almost natural “extension of our arms and legs”. We receive feedback from the vehicle on the condition of both vehicle and road surface as well as the forces (various kinds of acceleration) required by the driver. Sometimes feedback from the vehicle is inadequate. One example is that the driver has great difficulty in correctly perceiving whether the road surface is slippery or not.

Accident statistics for debut cyclists, mopeds, motorbikers and drivers are dismaying. Furthermore, they confirm the above learning process with high risk of failure and injuries in the early stages and, that after significant practice and experience, security is finally acquired.

The number of accidents peaks in the debut year and then falls rapidly to finally stabilise at a low level after a few years. This is a fact which applies internationally. Different educational models for training have been attempted without any significant success in reducing the risks for debutants. In conclusion, many years of training and experience is required before road users have learned how to travel in a safe manner.

2.3 How do we perceive the environment surrounding us – a new perception theory

In their classic article from 1938, Gibson and Crooks prove that driving is a mainly perceptual task. Among other things, this means that road user behaviour for the most part is based on the user’s general experience of current road and traffic situation. Our overall experience is much more important to our behaviour than how we perceive the various sub-components in the traffic environment.

Gibson's new perception theory (1986) states that the information we require about our surroundings is already "out there" and that it therefore can be immediately registered by the brain through our senses. According to Gibson, the visual information is then "embedded" in the bundles of light rays, which after having been reflected in the faces and objects of the surroundings, meet the eye. The brain automatically registers the information content of the light rays. Without having to interpret these sensory impressions, we immediately experience how the environment around us looks and how it is constituted. Meanwhile, our perception of the situation in the moment is also predictive or "forward-looking". This means that we experience where we are going as we move into the surrounding environment. We even register what is about to happen in this environment before it occurs. As drivers we often run straight towards a pedestrian in the middle of the crosswalk because we "know" that the pedestrian will have reached the sidewalk before we cross. According to Gibson our minds and our brains have developed in interaction with the environment such that we are the most perceptive of the information we need the most. In this way, we get a valid and important perception of the reality around us through our senses.

Our senses contribute with contemporaneous information to the brain about the conditions around us. The brain records the information and provides an instantaneous and automatically best possible overall picture. The more detailed information we receive through our senses, the faster we will have a correct perception of the environment around us. In daylight, we have no problems but in the dark and in dark traffic our information is often inadequate and uncertain. This means that we are forced to make an interpretation based on insufficient "input" from the visual impressions. It will then take longer for us to obtain an accurate perception of the (road) environment. In worst case, we risk making a wrong interpretation and misunderstand the situation.

The traditional perception theory implies that all sensory input is interpreted in our brain. Once interpreted, we have obtained a perception of the outside surroundings. In contrast to Gibson (1986) the information is created in the brain. One of the difficulties of the old theory is that this does not explain how we without delay can have an immediate and accurate experience.

Conclusion:
Through our vision and other senses we obtain an immediate overall experience of our environment. We experience not only how the physical surroundings look but also what is about to happen around us. Our experience is therefore also dynamic. It cannot be compared to a photo but more to a short "video".

2.4 Driving is a skill – we perform skills without thinking about them

According to Gibson, effectively moving around in the environment is a fundamental skill of the human being as well as our mammal relatives. An example: Imagine the dog, chasing the hare at full speed over logs and stones through the forest. He will recognise the scent of the hare through his nose, any sound from the hare's escape he will hear, and he will see the terrain of the forest while following the trail of the hare. All of this must be recorded very quickly by the dog's brain providing him with an immediate complete picture of the actual situation and how it develops. The brain immediately sends impulses to the muscles on where to put his paws and move around without losing the track while dodging all obstacles and at the same time take advantage of all available opportunities to access more quickly. The dog performs this highly effective pattern of behaviour without thinking (which in fact he cannot).

In most situations when walking, biking or operating a vehicle we act just like the dog in the above example. Through our senses we get an immediate perception of the road environment and what is about to happen in this and we are unconsciously adapting our actions to the changes in the road and traffic conditions. According to Gibson and Crooks, walking, biking, and operating a vehicle are all similar perceptual-motoric skills obtained through long exercise (training). Walking, biking, and operating a vehicle are skills we mainly perform automated meaning without needing to think about what we do and how we are doing it.

Unlike the dog in the example above, humans have also developed a brain allowing them to think. However, this capacity does not help us walk, bike, or drive a vehicle in a better way. Our ability to think instead provides us with the ability to handle more complex tasks, which the dog (and our other close mammal relatives) lacks. The best example of this is the solving of tasks requiring use of language and symbols. This in turn is a prerequisite for logical thinking that we are able to remember what happened yesterday, and that we can plan what to do tomorrow. To humans this means that we do not just live in the moment like the dog, but that we also possess a time dimension of future and past.

Conclusion:
For experienced drivers, operating a vehicle is for the most part an automated action. This means that we do not consciously think about what we are doing and how we are driving. As a matter of fact, our thoughts are elsewhere during most of the drive.

2.5 Driving is a ”self-paced task”, which is “perceptual” and performed automated

Gibson and Crooks very early developed a nice explanatory model for driver behaviour. After failing to describe driver behaviour in traditional psychological terms, they conduct a study assuming that driving is essentially a “perceptual” task. According to the authors, the driver - based on his overall experience of the current traffic conditions and without having to think (unconsciously) – chooses speed and lateral position in pursuit of the most comfortable safety margin. Gibson and Crook claim that the driver will drive to his perceived “field of safe travel” where the zone in front of the vehicle is always longer than the corresponding experience of the vehicle’s “minimum stopping zone”. The extent of this zone is controlled by the driver primarily through change of speed. Similar descriptions of driving as a “self-paced task” have later been shown by Näätänen & Summula and Wilde et al.

It is noteworthy that the 70 year old study of Gibson and Crooks remains valid today. Results from recent research have confirmed the strength of the explanatory model. More recent researchers have tried to further develop the ideas and used alternative terms to describe the findings of Gibson and Crooks’ classic article.

Conclusion:
At automated driving, the driver’s choice of speed, position, and driving behaviour in general is directly related to his perceived safety margin, which again rests upon his overall experience of current road, road environment and traffic conditions.

<u>Note relating to perceived and true safety margin:</u>
The driver operates the vehicle with a safety margin perceived sufficient by him. This perception is subjective as there is a true but unknown safety margin. When a driver loses control of the vehicle he will have over-estimated the true margin of safety. Studies suggest, that it requires many years of driving experience to obtain a good correlation between perceived and true margin of safety (comparing crash risk of novice and experienced drivers).

2.6 Operating a vehicle is primarily an automated activity while some tasks require perceptual assessments or symbolic understanding.

The explanatory model of Gibson and Crooks summarised in the previous section, corresponds well to the “control behaviour” described in the study by Allen, Lunenfeld and Alexander (1971). In a later article a study is made of driver behaviour based on the information needed by the driver to perform his task. According to their study, the complexity of this necessary information varies along a continuum. The simplest and least complex information is used by the driver to keep the vehicle in the driving lane (“steering control”) and to adjust the speed (“speed control”). These are the two “control tasks” performed automated by the driver. They make up the essence of all driving because they must be performed continuously. The automated control of the driver can technically be described as follows: In a feedback loop the driver pays attention to and if necessary adjusts the vehicle position and speed thereby maintaining the safety margin continuously.

A significant characteristic for the automated behaviour is the fact that the driver has the capacity to do other tasks, such as thinking on other things, listening to the radio, or speaking to passengers. This excess capacity also provides the driver with a "broad field of attention" or a large functional field of vision which enables him to record what is happening on the road and the road's immediate surroundings in a broad angle ahead of the vehicle.

When it comes to performing different kinds of manoeuvres, such as change of lane or overtaking, the driver must make perceptual assessments to determine whether the current manoeuvre is suitable to perform in the current traffic situation or not. The writers use the term "guidance task" to describe this type of "tactical" manoeuvres allowing a quicker transport or adaptation to the other traffic.

Unlike the driver's broad field of attention when performing the control task, the perceptual assessments needed for the "guidance tasks" require a high degree of focus. As such the driver's entire capacity is used to perform the task. The functional field of vision shrinks so that traffic incidents registered at automated driving are now likely to be overlooked.

The most complex driving task has been given the term "navigation" by Allen and his associates. This task is the only problem solving type and requires both understanding of symbols and logical thinking. Reading and understanding symbols such as road signs, directions and road markings in the traffic environment is a "navigation task" as is planning and executing a trip from point A to B.

If the driver does not know the way to the destination the "navigation task" implies having to use the guidance of various kinds of road direction whilst simultaneously orientating in the road system by answering the following question: "Where am I?" At every routing point another question arises: "Which direction should I choose"?" The driver uses his previously acquired knowledge of the road and the symbolic information conveyed on road signs along the route as well as road maps and GPS inside the vehicle to determine his choice. As with the "guidance task" the "navigation task" also requires the driver's full attention and capacity.

After Allen, Lunenfeld and Alexander's article, other researchers have performed basically the same study but used a few other terms. Instead of "control", "guidance", and "navigation" the terms "operational", "tactical", and "strategic" have been used for the corresponding behaviours. In his study of operator behaviour in complex technical systems (nuclear power plants)", Rasmussen has used the term "skill-based", "rule-based", and "knowledge-based" behaviour.

In a couple of articles in 1977, Schneider & Shiffrin presents the results from a series of perceptual experiments supporting the study made by Allen, Lunenfeld and Alexander a few years earlier. The authors show that test persons solve the tasks in an experiment in two completely different ways. One method was performed in an automated process with a prerequisite that the stimuli were simple and law-abiding. If stimuli were more complex and difficult to predict, the full capacity of the test person was required. The first task was performed rapidly while the test person had the capacity to manage other tasks at the same time. This corresponds to the “control task” while driving. The second task, however, was performed during a long evaluation time and a high degree of concentration. The latter task corresponds to the driver’s “guidance task”.

Summary:
The control task is the simplest and involves control over the position and speed of the vehicle. It is carried out continuously and is automated. The task is therefore a priority while the driver has the capacity to other tasks. The “guidance task” on the other hand, requires the driver to make complex perceptual assessments and conscious choices. This happens when the driver is performing various manoeuvres such as change of lane and overtaking and requires the driver’s full capacity.

The most complex and less prioritised driving task is “navigation”. This is the only driving task requiring understanding of symbols, e.g. when reading road signs, and logical thinking and problem solving in order to reach the destination. Only during “navigation tasks” do we utilise the most recently matured parts of our brain.

2.7 The driver’s ability to understand the symbolic information in the road environment

In order for the driver to assimilate the information on road signs and road guidance signs he will have to function in “navigation mode” at lease for a short period of time. In case he continues the automated driving or performs any demanding manoeuvres he will not notice the traffic sign.

During automated driving the driver will be thinking about other things while managing a broad field of vision in the direction of traffic. The driver strives to maintain full control and notices (unconsciously) what is happening in the road sphere in front of him. As soon as the driver notices something different in the distance, his need for new information becomes obvious. He then “switches” to “guidance task” in order to be able to assess the situation and take the necessary measures. If the driver does not understand the situation he will instead start operating on “navigation mode” and read the road signs, which may contain relevant information.

When a driver is using a road for the first time he is “curious” about the appearance of the road and he will be more attentive and careful. The driver needs to identify early those dangerous passages, which can be found along the road. Such passages must be registered in a timely manner, and the driver needs to receive early information about these through road signs.

The driver must be able to assess a sharp curve at a certain distance at the same time as the road sign “Beware of sharp curve” must create a clear expectation with the driver ensuring that he is not surprised by the curve. There is good reason for the driver to read the road signs along the road. However, if the driver is driving on a road he knows very well, he will know how to drive and which speed to pursue along each section of the road. In these cases the road signs along the road do not contribute with new information but act more as a guide especially during night traffic. In the latter case, the driver has no need to read the road signs and therefore often does not notice them.

An example: For a long period of time, a good quality road has been sign-posted 90 km/h. Suddenly the sign is changed to 70 km/h without any changes in the physical design of the road. It can take quite some time before drivers using the road every day will discover that the speed limit has changed.

The only driving task which is problem solving is to plan and carry through a journey. Planning involves selecting the route and undertaking the journey involves following the road map by making the right choices in a number of intersections. The driver will need on time information prior to each major intersection in order to prepare to act by reading road signs and make timely decisions. Where am I? Where am I going? Which direction should I choose? The driver is also expecting certain city names to appear on the road guidance signs. When such directions are well readable he may find that the city name he expected to find did not appear on the signs. Then which direction should he choose? In such case geographical knowledge and a good understanding of the road net is required to select the right direction.

Conclusion 1:
Road signs will only be read if these fulfil an information need of the driver.

Conclusion 2:
Early warning before each major intersection and limiting the number of city names are required to provide good directions.

2.8 Drivers’ perception of the road – the ”self-explaining road”

Drivers perceive the road and the traffic conditions as a whole. This whole shapes the driving behaviour afterwards. This means that the various parts and components of the road and the traffic environment all must contribute to a clear and unambiguous portrayal of the traffic environment. This is a prerequisite for the road user to get a good sense of how to drive on the road. Should the design of the road, however, lack consistency by in one way or another being unclear, ambiguous, or contradictory, this will create problems.

Gibson argues that we immediately perceive which options we have in our environment in the shape of “benefits” and “threats” which we so to speak are offered to use or avoid (Gibson’s “affordance definition”). Some of the objects in our environment offer us (“afford us”) various kinds of benefits (=”positive affordances”). A chair offers us to sit. A path through dense forest offers a faster, more comfortable walk. A road offers fast movement. A better road standard offers drivers a faster drive while maintaining safety. A narrow curve is a “threat” to be avoided (=”negative affordance”). Our ability to immediately sense and relate to various “benefits” and “threats” in our environment contributes to a more effective adaptation.

A thought process akin to Gibson’s “affordance definition” is the idea of “the self-explaining road”. This refers to a road which is designed in such way that the driver immediately assimilates how to drive. This implies that all road users (pedestrians, cyclists, and motorists) directly and unconsciously assimilate how to act on the road.

A step towards the “self-explaining road” is a continued development towards standardised, consistent, and - for road users - easily distinguishable “design characteristics” of complete roads or sections of roads with different functionalities. This is also a prerequisite providing the road user with precise and correct expectations for the road. Such expectations not only arise from the design of the road ahead but also on potential future traffic situations.

Conclusion:
The development of “the self-explaining road” should be a long-term design goal for all road designs.

2.9 Being well-oriented in one’s environment

In order to be able to act rationally and exploit the opportunities of our environment we need to be well-oriented in this. A good orientation is also essential for us to identify the “benefits” and avoid the “threats” and dangers in the environment.

The requirement to orientate themselves generally applies to all beings having to visit different locations in their surroundings in order to satisfy their primary needs. Mother bird must find her way back to her hungry chicks in the nest. Migratory birds must be able to navigate back to Africa in the autumn. The male cat must get back home after hunting in the area. Similarly, humans must be well-oriented in their environment always knowing where they are. When we are not, problems occur. This sometimes happens. The migratory bird is flying in the wrong direction, the cat cannot find the way home, and we are lost in the forest and have great difficulties regaining orientation.

It is therefore important to be well-oriented in the environment in order to move where you want and choose the best route between locations. When operating a vehicle we need sufficient knowledge and information at each routing point in order to choose the right direction.

We have no challenge orienting ourselves in the well-known surrounding environment. As the distance increases and we find ourselves outside our known "territory" the basis for our orientation becomes increasingly uncertain. When driving on unfamiliar roads we use road maps. Bases on the accumulated knowledge and information we have, we create our own perception of the appearance of the road, the road network, and the landscape ahead. This perception or expectation may be equated to a "mental map" utilised to immediately orient ourselves along the road we are driving.

If we know that the road will be crossing a motorway in an intersection ahead and that we shall then continue on the motorway, we pay particular attention to the road guidance signs both before and after the intersection. If the intersection and the road guidance signs correspond to our expectations on its "design" and how to drive through it, we have no problems picking the right direction or how we may or must drive. But if it does not, problems arise. Is the road sign correct? Has anybody twisted the sign out of position? Or am I so sure of my faulty mental map that I do not read the sign?

Conclusion:
The road network should be designed in such way that road users know, where they are (landmarks) and how to orientate in this (simplicity).

2.10 Our expectations to the road and its continuation

The driver immediately obtains an overall experience of the road and the traffic conditions in front of the vehicle (see Section 2.3). But this does not help him much if he wants to gain knowledge about the road at a distance which is not visible to him. How do we make the best of this situation? Well, we people carry with us our experiences since childhood of how the environment around us looks and how we must adapt to the challenges it poses to us. Which is the most rational way of utilising this bank of experiences as a driver? Well, based on our previous experience on similar roads and traffic conditions we do so by creating quite certain expectations of how we should drive on the current road and the requirements it will probably set us.

Even before we enter a road for the first time, we have certain expectations as to how this looks. If the road is a national highway we expect the road standard to be relatively good. If the road is a local highway, our expectations are lower. If the road is a minor road in the countryside, we expect it to be small narrow and winding. Our "inner image" of such a road may be that of a narrow gravel road with tight curves but also that it may have better paved areas.

We have a natural curiosity about how the road looks the very first time we enter it. But already after a few kilometres on the completely unknown road, we have built up an expectation of what to expect of the road further ahead. The best estimate we can make is that the road will continue as it began. If the road worsens along the way, this suggests that it may get even worse. If we know that the road is approaching an urban area, we expect it to improve.

When exiting a motorway, we expect the exit to "grow out" from the right lane and that we need to go right. This expectation has been built through our experiences with the fact that motorway exits hardly ever differ from this general design principle.

When the road and the traffic conditions are in line with our expectations, no surprises occur. We then naturally have a high level of preparedness for the events and situations that we are expecting ahead. Correct expectations with respect to road design are therefore an important prerequisite for a well-adapted and traffic safe driving.

However, if the exit from the motorway deviates from the standard design by "growing out" from the motorway's left lane? – What happens then? There is a great risk that we discover much too late that the road is not consistent with our expectations. Automatically, we switch from our automated driving behaviour to making conscious assessments of the situation ("guidance task"). These assessments take relatively long time. First we need to re-orient ourselves in the traffic environment and quickly try to understand the function of the road ("navigation task") in order to have sufficient information to assess how to manoeuvre.

Then we need to assess whether it is possible to perform the necessary manoeuvre in the current traffic situation and use the exit. If surprised, this all happens under a significant time pressure, which implies a high risk of missing important information and making wrong decisions.

An important explanatory variable in the analysis of seemingly inexplicable and clearly irrational driver behaviour is therefore to investigate which expectations the driver has had on road design and functionality. The driver gets "confused" and surprised if experiencing that his expectations to road design and functionality do not correspond with the physical and functional design of the road. In a situation where prompt action is required, problems often occur because there is not enough time to take proper actions. Very often this will lead to human errors, which in turn can cause critical situations (lack of reaction, excessively long reaction times, sudden and unexpected manoeuvres, etc.).

Alexander & Lunenfeld use the term “positive guidance”. This term implies that roads should always be designed so that road user expectations to the road design and functionality are confirmed. The report provides several examples of road designs that confuse the road user by creating illusions and false expectations.

The writers describe two types of expectations: “a priori expectations” and “ad hoc expectations”. The first kind of expectations is created through learning the design principles of different types of roads, e.g. motorways. The report provides several examples of road design deviating from established design principles and thereby not corresponding to the driver’s “a priori expectations”. One such example is when the motorway exit is located in the left lane. Another is when the right lane in a junction leads away from the motorway (“lane drop”). In the latter case, the driver’s expectation is that exiting the motorway is done by merging onto an exit ramp. Deviations from an established design standard create problems.

According to Alexander & Lunenfeld a traffic safe road must be constructed such that the drivers “a priori expectations” are met. This means that the design of the road must have a well-standardised design in which no exceptions are made from the established design standard.

Alexander & Lunenfeld use the term “ad hoc expectations” about the other types of expectations. These expectations too are based on the road users’ previous experience with similar traffic conditions, which he/she transfers directly to the current road. The driver’s actual perception of the road and traffic conditions unconsciously and immediately create ”ad hoc expectations” of how the road and the traffic conditions will appear further ahead. The authors provide several examples of poor road design causing false expectations such as visual villas and illusions and incorrect visual guidance.

Conclusion 1:
Our experiences act as a bank of knowledge forming our expectations. The road must be designed to meet the road user’s expectations. Consequently, roads must have a clear and standardised design.

Conclusion 2:
If the road is designed so that it creates false expectations, this results in the driver being limited in his ability to meet the requirements of the road.

2.11 The current visual impression and the memory of a familiar road

According to Gibson through millions of years we have been “programmed with” the belief that our physical surroundings are stable and that change processes are very slow.

If the driver has taken the same road several times he has obtained a much better knowledge of the road and a strong expectation for the appearance of the road when passing it next. As such, the driver has two sources of information when it comes to the design of the familiar road, - partly the direct memory of the road, and partly the current visual impression. If the visibility is poor (dark, foggy, rainy or snowy), the visual information decreases and the memory of the road becomes more important as a source of information. If the road has been redesigned since the drivers' last visit, the two sources of information convey different information. This increases the risk of mistakes.

Now and then it happens that when hiking on a familiar path in the woods or when driving a familiar road in a vehicle suddenly you cannot orient yourself anymore. What has happened? Well, the path may have given the impression of having gone straight though in fact it turned slightly right or left. Actually you will have entered a side path without noticing. A 4-way intersection along the road may have been redesigned to a roundabout since the last passing. What happens when discovering the mistake? In fact, the driver will "immediately decouple" the memory of the old road and consciously tries to reorient in the current road environment. He does so by completely trusting his visual impressions. The problem is that the driver needs sufficient time to act in case the new road requires more adaptation (e.g. speed reduction). For the road authorities the task is to design the new road so that it provides drivers adequate time to notice that the road has changed.

Conclusion:
Changes in the road environment posing increased demands on the driver, should be preceded by a road section design that does not appear familiar to the driver without him consciously beginning to reorient himself in the new road environment.

3. Explanatory model and our traditional way of thinking

In chapter 2 we have formulated a small set of basic ideas which collectively can constitute a new explanatory model for our behaviour as road users. We have chosen to call our previous traditional explanatory model "philosophical-legal" since it places the full responsibility for everything happening in the traffic solely on the road user.

When compared to our traditional way of thinking, the new model is able to explain how we as drivers behave in the traffic on a certain number of key points, which our traditional conceptual model is not. Through increased understanding of driver behaviour and problems a new explanatory model will hopefully be a useful tool for us to design roads and road environments which are better adapted to our natural qualifications to drive safely.

Before we move on we need to compare our previous "philosophical-legal" model of thought with the new "behavioural model" in order to show any significant differences with respect to the driver's conscious behaviour and decisions.

"The legal model" says: The driver is always conscious of his actions in the traffic. The driver's actions always rest on conscious decisions.
The driver reads all road signs and acquires all the necessary information from the current traffic situation.
If the driver misses a sign or other information in the traffic environment this is an expression of inattention (poor concentration, carelessness, fatigue, etc.).
In case of a traffic accident, the "legal" model of thought almost always blames the driver. (Compare the "general clause" of the Road Traffic Regulations: You must drive in such manner that no accidents occur).

"The behavioural model" says instead: The driver has three different tasks to perform. The most important one which is always applicable is "the control task". It is performed automated. The model implies that the driver's actions when performing the task are not based on conscious decisions but rather on automatic reactions to the current road and traffic conditions. Conscious decisions however, are taken by the driver when deciding to conduct various kinds of manoeuvres (guidance tasks) and choosing which way to go in order to reach the point of destination (navigation tasks).

To obtain information from road signs a conscious reading is required. To accommodate this, the road and the current traffic situation must be at a point where the driver's need for additional road sign information is evoked.

When an experienced driver makes a mistake leading to an accident – in spite driving with usual caution – the reason for the accident is often suspected to be a lack of interaction between driver, vehicle, and road. Since we cannot “redesign” the driver, we direct our attention to changing the vehicle, the road, and the traffic environment to enhance system components more tailored towards the driver’s competencies. As such, the “real” responsibility for this type of accidents is placed on the “system owner”.

Note:
Traffic accidents are often caused by reckless and risky behaviour. For this type of accidents the primary responsibility is of course that of the driver. A third type of accidents occurs due to inexperienced insecure drivers. There is an old saying “We all start out as children”. This indicates that it takes much time and requires a lot of practice before mastering a skill such as driving.

4. A problem with the new model

One of the basic thought processes behind the explanatory model is the following. The road and the road environment provide stimuli for the senses of the driver. To begin with the driver obtains a visual impression of the road and the actual developing traffic conditions. This experience forms the very basis of the driver's skill-based behaviour in the form of various measures, which directly aim to sufficiently and quickly respond to the demands of an ever changing traffic situation. In a way the driver's perception represents an "explanatory variable" between the physical condition of the road and the actual traffic environment – and the driver's reaction to these conditions.

The characteristics of the road and the traffic environment and the dynamics of the actual traffic situation can be objectively documented and described in different ways (e.g. through drawings, photos, video sequences, and measurements of various parameters). Likewise, the driver's behaviour in terms of observable actions and measures can be objectively described and measured partly through pedal and steering wheel movements and partly through changes in vehicle speed, direction, and position on the road.

Similarly, we would like to measure the driver's behaviour (i.e. the "explanatory variable") in an objective manner. The problem is that this variable is not directly and objectively measurable. Because experiences are subjective, they cannot be objectively described. If having been in a traffic situation and discovering that I acted wrongly; I will try to explain my mistake and find a reasonable cause. It then turns out that I will remember the spot on the road where I made my mistake for a very long time. However, I will have a hard time remembering how the exact traffic situation with all the other road users evolved as I made my mistake. What distracted me? Did I miss something I should have seen? I ask myself many questions without being able to give good answers. In case I acted wrongly but did not discover my mistake, of course I will not be able to remember having done anything wrong at all. The link back to my wrong behaviour is not established.

The conclusion to be drawn from this is that our "explanatory variable experience" cannot be directly used. However, this can be used indirectly as an indication of the fact that the road and the traffic environment do not function well.

A malfunctioning road and traffic environment is identified by the fact that drivers do not behave as intended by the road authorities. This may apply to a majority of drivers, who are not driving as intended. En example of this is the road where the speed limit is constantly violated. The problem may also apply to relatively few drivers who suddenly brake or turn or otherwise quickly change their driving. A large occurrence of deviant behaviour then indirectly shows that the drivers have misunderstood and were surprised by the actual conditions. In this case, it would be interesting to interview a selection of such drivers as quickly as possible on how they perceived the situation so as to arrive to a realistic road-related explanation for the deviant behaviour. Such an explanation is necessary in order to describe the problem and to select the appropriate actions to eliminate it. The problem may also occur in relatively seldom however very serious events such as "ghost driving" where the driver without discovering his mistake enters a lane of traffic in the opposite direction. In order for this to apply, the very design of the road and the road environment must have created conditions perceived wrongly by the driver as a direction on how he/she should drive.

In all these cases it is important to have sufficient measurements or indications proving that there is indeed a problem. If this is a reoccurring problem it will be easy to document through measurements, but when more rare, this will be difficult. In this context, it would be very effective if the road authorities had access to appropriate recording equipment to be installed at assumed areas of concern and thus able to document (e.g. through videos) such relatively rare or infrequent deviant behaviours. Such a method would fairly quickly be able to provide good data on the frequency of rare but serious deviant behaviours. By linking such data to current road and intersection designs in which they have been collected, one would obtain a systematic knowledge of which designs prove to have a minimum incident of abnormal behaviour.

In addition to documenting the problem, an independent study of the road and traffic environment should be performed. The study should be focused partly on evaluating which expectations the driver has to the road, and partly on the driver's overall experience of the road and how to drive on it. The work should lead to concrete suggestions in the form of framework solutions to the problem. A successful study must be based on the best possible explanatory model. The choice of model will have direct consequences on the measures to be proposed. A study according to the proposed model will always involve physical changes of the rod design. In comparison, an analysis based on the "philosophical-legal" explanatory model instead leads to measures such as further education, increased speed control, and longer sentences.

5. A general principle for road user behaviour and road design

The basic thinking explaining the behaviour of road users which is described in Section 2, leads to a general and comprehensive principle for how road user behaviour is created. This principle may be formulated as follows.

Road user behaviour is mainly determined by the driver's expectations and immediate perception of the actual road and traffic situation.

Note 1: The driver's expectations to the road and how to drive rest upon his/her overall experience of driving on different types of roads and traffic environments. In order to meet the driver's expectations as far as possible each such type of road and traffic environment must be easy to differentiate and recognize. This means that they must be designed in a consistent and standardised manner.

Note 2: We can influence the driver's immediate perception of the road space in front of the vehicle by shaping the road appropriately. The perception of how the traffic situation will develop should however to a great extent be based on the driver's previous experience with driving under similar conditions.

Note 3: Notes 1 and 2 indicate that a high degree of standardised road design and large experience with driving are two important prerequisites for safe traffic.

The general principle as described above is focused on road user behaviour and may even be reformulated as a target for road design. The principle could then be expressed as follows:

Roads must be designed in such way that road users immediately and correctly can assimilate how to drive on these.

6. ”Ghost driving”

6.1 What is ghost driving? What is the problem?

“Ghost driving” occurs when a driver, without noticing it, runs against the traffic on a one-way street. The driver does not discover his mistake but continues to drive against the traffic as if nothing is wrong. By all accounts, the “ghost driver” experiences that he is driving down a usual road with traffic in both directions. Oncoming drivers are not expecting to meet a vehicle in the wrong direction and thus are not prepared to act. It is therefore reasonable to expect that “ghost driving” poses considerable risks of a frontal impact – the type of accident with the most serious personal injuries.

On behalf of the Swedish National Road Administration, Sagberg conducted a study on how road design affects the driver behaviour in which “ghost driving” is discussed in Section 3. The report describes how the problem was studied early 1960s in the USA after initiating the Federal motorway network (The “Interstate” network). The report refers to several American studies and studies conducted in the Netherlands, Germany, Austria, and Japan. A few minor studies have also been carried out in Denmark and Sweden.

The literature shows that “ghost driving” is primarily a motorway problem. It also shows that “ghost driving” is a rare mistake causing relatively few accidents but that these accidents are very severe. According to the statement, 3-6% of all fatalities created by motorway accidents are caused by “ghost driving”.

Even if “ghost driving” leads to relatively few but serious accidents, it is an indication of a serious problem which should be addressed as soon as possible. It is namely, reasonable to assume that for each “ghost driving accident” a number of “ghost drivings” resulting in incidents (near-crashes) have occurred. For each of these incidents it is very likely that a large number of incidents that could have developed into “ghost driving” would have taken place should the driver had not discovered his mistake in due time.

According to the literature, the first evaluated measures against “ghost driving” have been the simplest and most inexpensive to implement, e.g. improved signage and road markings. Overall, results show that such measures have had some effect, but that the problem remains. This also applies to the use of such drastic measures as installation of large signs with text supplemented by both sound and light signals, which are activated by the “ghost driver”.

The referenced reports contain a few concrete suggestions for how roads and ramps should be physically designed to reduce the risk of “ghost driving”. However, there are only a few studies in which such suggestions are evaluated. The only design principle to be found of general nature is the following: The road/junction must physically be designed in such way that drivers are directed the right way, that is – accessing the entrance ramp must be made as simple as possible and accessing the exit ramp in the wrong direction must be made as difficult as possible (Gunnarsson).

Note 1:
The design principle must be concretized in order to be practically useful.

What characterises "ghost driving" according to the literature is the fact that older drivers and intoxicated drivers are overrepresented and that "ghost driving" more often occurs during off-peak hours under poor sight and visibility conditions (darkness and fog).

Note 2:
These characteristics have in common that the driver's visual function is reduced and that the visibility of the road and the visual directions is decreased compared with good daylight visibility. This suggests that a contributing factor to "ghost driving" may be that the driver's ability to orientate himself in the road environment and to perceive and understand the functionality of the road (i.e. how to drive on the road) is impaired.

6.2 "Ghost driving" – Where does the problem occur? Where does the misconduct begin?

A prerequisite for "ghost driving" is roads and lanes which are open to traffic in one direction only. The motorway is the only type of road, which is designed according to the principle "one roadway – one direction". Our remainder road network on the other hand, is built on the opposite principle, namely "one roadway – two directions". Every vehicle driver must be able to drive on both types of roads while knowing that problems may arise in their points of connection.

Consequently, an important question to ask is: "Where on the motorway does the driver make mistakes leading to "ghost driving"? This question can be answered by the literature (Sagberg), and the answer may be summarised in the following five "points of trouble":

- **At junctions**. The critical location in the junction is where every exit ramp from the motorway connects to the intersecting road in the secondary network (Section 6.4.1)

- **At "half" junctions.** The critical location is where the exit ramp from the motorway connects to the entrance ramp after which the exit and entrance ramp make out the lanes of a normal 2-lane road (Section 6.4.2)

- **At rest areas.** The critical location is where the exit ramp from the motorway opens into the rest area (Section 6.4.3)

- **On the motorway.** The critical location is the stretch of road (Section 6.4.4)

- **When the road design changes.** The critical locations are where a road without median barrier continues into a road with median barrier, and where two-lane roads turn into four-lane roads (Section 6.4.5).

Of the five "points of trouble" above the first four are related to the motorway. The fifth is a more general problem and applies to points along the road where the design changes. One such change is the point where the number of lanes increases. Another is where a road without median barrier turns into a road with median barrier.

We have described "ghost driving" as an accidental faulty act. The driver does not notice when he/she chooses the wrong road and therefore continues to drive against the direction as if nothing has happened. The most common cause of "ghost riding" is when drivers accidentally use an exit instead of an entrance to access the motorway. Another type of mistakes is when a driver on a motorway has a perception of driving on a regular road and turns around by making a U-turn.

6.3 Understanding the causes of ”ghost driving”

The following analysis of "ghost driving" and the proposed measures are based upon the explanatory model (Section 2) and its summary (Section 5). The purpose of this model is to provide a good tool to help us partly to understand the causes of ”ghost driving" and partly to explain "why the driver, who does the best he can, still makes fatal mistakes".

6.3.1 Basic analysis of the problem

The basic analysis of the problem rests upon the explanatory model and suggests that the driver's behaviour to a large extent is determined by the design of the road. In traffic environments where experienced drivers encounter problems and go the wrong way, our attention is therefore directed towards the design of the road and the traffic environment as main causes of mistakes. In these cases the road has failed to meet the principle laid down in Section 5: ***Roads must be designed in such way that road users immediately and correctly can assimilate how to drive on these.***

A first step towards the development of this principle is to try to design the road that ***"it will be easy to go the right way – and difficult to go the wrong way".*** Another principle is that: ***"if one has taken a wrong way, the road if possible shall be designed to allow a correction of the mistake".***

The proposed measures first of all require physical changes of the existing road as well as suggestions for design principles during the construction of new roads.

Note:
Obviously, criticism can be directed against the explanatory model and the measures suggested by the analysis. But what is the alternative? In our usual analysis (according to our traditional way of thinking) we point out the driver as the main cause of the problems. The measures suggested by the analysis are targeted at drivers of which most of us are experienced after several years of driving. Consequently, we are faced with the following choice: Should we direct our resources towards redesigning the road to make it better adapted to the qualifications of the road users, or should we instead reconstruct the road users to enable them to handle our traffic environments? We have knowledge and tools to cope with the first suggestion – but not at all with the latter one.

6.3.2 The road must provide the driver with a clear perception of how to drive on it

The physical design of the road and its various parts is the most important source of information to the driver. As a whole the road must therefore possess a clear design language in order for road users to perceive the nature of the road and its requirements. As such, the road should best possible provide the driver with an instant and accurate perception of how to drive on it.

When the road is designed in such way that the driver correctly and clearly perceives how to drive on it, this creates driver behaviour with little variation. If, despite good road design, the driver decides to violate a traffic law, this action is naturally conscious and wilful and therefore also punishable (in the strict legal sense). But in cases where the road is designed so that it misleads the driver, the "real" responsibility for any faulty action primarily belongs to the road authorities/systems owner and not the driver.

6.3.3 Interaction between physical road and symbolic contents of road signs

When at normal speed approaching parts of the road requiring large adaptation qualifications of the driver, information from the physical road is often not readable in due time. In such parts the road must be designed to evoke the driver's need for additional (symbolic) information. The driver will then consciously search for this information on road signs and guidance signs along the road. The "natural" information of the road (mediated by its physical design) and the symbolic information on road signs and guidance signs must therefore not contradict each other but must complement each other to convey a clear message to the driver. A road with a poor or even misleading physical design however, can never be supported satisfactorily using only road signs and guidance signs.

6.3.4 The driver must be well oriented in the traffic environment

We need to be well oriented in our surroundings and know where we are in order to move to a specific place. A clear orientation is essential for us to choose the best route between two points. If operating a vehicle, we need sufficient knowledge and information at each routing point in order to choose the right way.

At each routing point (junction, intersection), the road should be designed enabling the driver to know where he/she is. For drivers who already know the way, their orientation is mainly facilitated by the fact that the road and landscape are recognised by various "landmarks" (i.e. specific objects and details in the landscape). For drivers driving in the dark or using the road for the first time, the orientation is to a far greater extent based on road signs and guidance signs.

When driving on a secondary road, approaching a junction to a motorway, the driver has a certain expectation of (or a "mental map" of) how the junction will look and how he/she should go through it to get in the right direction. The mental map provides the driver with information also about the approximate direction to the destination. If the driver needs to access the motorway, he/she will therefore be expecting the entrance to the motorway to be located in the direction of the destination. This is a simple logic. For instance, when driving south it is reasonable to expect that the entrance ramp means taking off to the south followed by a ramp that continues to go south.

The mental map also provides the driver with an expectation of which entrance ramps to choose in order to get to the motorway. The ramp may be located just before the secondary road's crossing of the motorway or immediately after this, depending on the desired direction of travel. On the driver's "mental map" of the junction, the condition of the motorway therefore constitutes an important component to understanding and orienting oneself in the junction.

Once the driver has arrived at the junction he/she will need confirmation of which way to go in order to get to the destination. If the junction is designed to allow for an easy orientation this is a great advantage. Among other things, the motorway must not only be clearly visible (daylight) but also excellent in other situations (darkness) that the driver will always know on which side of the motorway he/she is. In order for the driver to be able to orientate himself in the junction without difficulties, he should also be able to see where both entrance ramps to the motorway begin. If not intending to take the first entrance, it is very helpful to simultaneously be able to see the other one. When the driver is able to see simultaneously the connection to the first entrance ramp, the motorway, and finally the entrance ramp on the other side of the motorway, he will have all the necessary information to understand the function of the junction and how to drive in it.

6.3.5 Information on advance guidancesigns

A driver driving on a secondary road and reaching a completely unfamiliar junction is in need of information to be able to orientate himself in the junction. The necessary information is conveyed by means of advance guidancesigns at the beginning of the junction. Advance guidancesigns must be designed so that they visualise how to drive according to the following: If continuing straight ahead on this secondary road, this leads to X, the first entrance to the motorway to your right leads to Y and the second entrance to your left leads in the opposite direction towards Z. This is a simple and easy to understand information.

Once the driver has passed the advance guidancesigns he must remember the message until having made his choice: continue straight ahead or turn into the first or second entrance to the motorway. This requires messages on the advance guidancesigns to be simple and unambiguous and therefore easy to remember. An advance guidancesigns which graphically displays which way to go in order to reach three destinations cannot be made much simpler.

However, if the advance guidancesigns contain too much or too complex information there is a great risk that the driver will be unable to recall this and misinterpret the message on the board. An example of an advance guidancesigns containing more and complex information is the type, which is not only showing the entrances (which you are allowed to use) but also the connections to the exits to the secondary road (which you are absolutely not allowed to use).
In this case the driver must remember not only where he is allowed to go, but also where he is not allowed to go without confusing the two messages. This memory task is significantly harder to handle. Consequently, there are strong reasons to limit the information on each advance guidancesigns to graphically show only the right ways to go in order to continue in three different directions, each with its stated destinations. The graphic description of the roads available to the vehicle must be simplified, yet perceived correctly by the driver. This means direct presentations of the roads in ordinary intersections and a circle sector with direct connections at roundabouts (see Figure 6.1).

The conclusion of the study is that both connections of the exit ramps to the secondary road should be left out on the advance guidancesigns located on the secondary road. Omitting the connections to the exit ramps to the secondary road is also in line with the analysis in the next Section (6.3.6).

6.3.6 Design of ramp connections – the ”fish trap principle”

This principle is based on Gibson’s affordance principle (Section 2.8). The entrance ramp (at the connection to a secondary road) shall have the same functionality as the entrance to a fish trap. It must be easy and inviting for the fish to enter. Similarly, the entrance to the motorway must be easy for drivers to enter. Once caught in the fish trap, the fish must not be able to get out. The exit is there but the fish does not “see” it. The exit ramp connections to the secondary road must be designed according to the same principle. The connections are there, but the driver on the secondary road does not “see” them and therefore does not care about them. They must be designed such that the driver on the secondary road feels that they have no function at all.

This principle implies that the driver entering the motorway must find the entrances inviting and welcoming and furthermore easy and comfortable to access. Also, these must be easy to locate from a distance (see Section 6.3.5) and have a distinct "character design" immediately perceived and identified by the drivers as entrance to a motorway.

The opposite accounts for the exit connections to the secondary road. Exits must be designed in such form that they are perceived as dismissive and obnoxious. One element of this is to make them difficult and awkward to access (e.g. narrow roads and wrong direction). The exit connections to the secondary road must be designed so that drivers on the secondary road do not notice them. They shall be designed so that they appear "hidden" and are perceived to be irrelevant and without functionality (exit ramps for example, should not be visible from the secondary road – this according to the principle: "what you can't see doesn't exist"). The visual line of the secondary road will naturally take road users past the exit.

6.4 Advice for designs at five points of trouble

In the previous section a set of general advice for designs were presented. In this section more specific advice is provided in relation to design of each point of trouble listed in Section 6.2. Each of these points is addressed in separate sections below.

6.4.1 "Ghosts driving" at junctions – analysis and proposal for action

The critical location is where every exit ramp connects to secondary road.

A. Diamond crossing: The usual design where entrances and exits from the one side of the motorway connect to the secondary road opposite each other allows for driving mistakes and therefore should be avoided. Instead, it is proposed that the exit connections to the secondary road are moved further away from the motorway. This means that the secondary road at the entrance connection should be shaped as a T-intersection with a function that is obvious to the driver (See Figure 6.2).

With this solution, drivers merging onto the motorway are not given any possibility of incorrectly selecting the exit ramp because this is no longer placed opposite the entrance ramp. The "ghost driver" might have reacted like this: "I need to go to A but the ramp incorrectly leads towards B and therefore the opposite ramp must lead to A."

Exit ramps opening on a somewhat larger distance from the motorway have no guidance which makes drivers on secondary roads perceive these as irrelevant and without function. Drivers on the secondary road are warned, however, about vehicles on exit ramp connections to the secondary road by means of the road sign

"Other danger" and the additional "Exit". The term "exit" contributes to making the ramp deterrent to enter. The ramp connection furthermore must he designed so that it is "hidden" for drivers on the secondary road. This can be done in different ways, whereby an effective way is to design the ramp to make its lanes invisible from the secondary road.

(The advance guidancesigns on the secondary road is designed in accordance with the analysis and proposed measures in Section 6.3.4. Principles for design of entrance and exit ramp connections to the secondary road are presented in Section 6.3.5).

B.Partial cloverleaf: The traditional design includes entrance and exit ramps for each driving direction on the motorway which are connected to the same side of the secondary road and right next to each other. This design is not appropriate because the ramps (especially during poor visibility and traffic conditions) can be confused. The design assumes that all road users (who are not used to driving in the junction) will always read the road signs at the beginning of the exit ramp ("no entrance"). This prerequisite is not met.

There are two alternative designs of ramp connections which are better suited to meet road user capabilities. These are described in the following.

Alternative 1: Two roundabouts are built on the secondary road – one on each side of the motorway. Traffic islands and lanes are given a clear "dynamic" design at both entrances and exits in the roundabout. At entrances this involves slow speed (small radius of curvature) and "acute" (tangential) connection to the roundabout. At exits a larger radius is needed inviting the driver to accelerate out of the roundabout (see Figure 6.3).

Entrance ramps to the motorway usually begin as normal exits from the roundabout while exit ramps from the motorway are represented by the upcoming lane. In this way, the connection of the exit ramp is "hidden" and its purpose becomes obvious to drivers in the roundabout.

The advance guidancesigns shows only how to drive in the roundabout and is designed in accordance with the analysis and proposed measures in Section 6.3.5. Principles for design of entrance and exit ramp connections to the roundabout are presented in Section 6.3.6.

Note:
First of all, Alternative1(See Figure 6.3) provides the physical design with a driving dynamic, which makes it difficult to directly merge onto the exit ramp from the roundabout, and secondly lets the exit ramp connection form an entrance to the roundabout thereby making it an unattractive possible choice. As a result the connection is perceived as "hidden". In case the driver misses the motorway entrance, this can be reached easily by running an extra lap in the roundabout.

Alternative 2: The proposed design consists of a more generally applied solution. The analysis upon which the general proposal is based is presented in Section 6.4.2. This section presents the design which is adapted to the junction.

The exit from and the entrance to the same side of the motorway consists of a conventional 2-lane road, which begins in a T-junction with traffic islands on the secondary road in the junction. After the traffic island the 2-lane road continues straight ahead for approximately 100 m after which the road splits in two. The right lane continues clearly visible to the driver straight ahead and represents an entrance to the motorway. The left lane, which is the exit from the motorway, takes off to the left in a long curve (about 180 degrees) before it connects to the motorway. On the secondary road there is a T-junction on each side of the motorway; one for entering and exiting in the one direction of the motorway, and the other for entering and exiting in the opposite direction (see Figure 6.4).

Drivers entering the motorway in a certain direction turn off the secondary road at that T-junction and then continue straight ahead on the 2-lane road. Their perception is that the road continues straight ahead and that the left lane for oncoming traffic turns left following a traffic divider board therefore making this "irrelevant" (i.e., it has no function for the driver).

The design is recommended in Sagberg's literature study (see Sections 3.4 and 3.5 in herein). Sagberg refers to Campell & Middlebrooks, who have reported good effects of a changed ramp design in junctions constructed according to this principle.

Advance guidancesigns on the secondary road show how to drive in the junction (Section 6.3.5). The road direction of the entrances is displayed on the secondary road and is repeated at each T-junction. The centre line on the 2-lane road is carried out as a solid line closest to the traffic island, then as a line of warning and finally as a stop line before the traffic divider board, which has been set up at the point where the road splits into two separate roadways. Road signs with "no entry/one-way traffic" have been set up in the left lane right after the point where the road splits.

The advantage of beginning the entry from the secondary road in a T-junction, which continues as a 2-lane road (for a short distance before the road splits up) is partly that the T-junction is easier to navigate in and partly that the single drivers who accidentally enter the wrong side of the traffic island immediately after passing this can make up for their mistake by shifting to the right lane.

Note: Alternative 2 is based on experience as well as evaluations showing that we spontaneously feel that we must continue to drive straight on a clearly visible road ahead of us. A road, which connects to the left side of the straight road, we perceive however as irrelevant for our onward journey (see also the analysis in the next Section 6.4.2).

6.4.2 "Ghost driving" at "half" junctions – analysis and proposed measures

"Half" junction means that exits are located only in the direction from an entrance towards one of the two long distance city names of the motorway. At "half" junctions the critical location for "ghost driving" is where the exit ramp from the motorway connects to an entrance ramp to the motorway after which entrance and exit ramps constitute the lane of a normal 2-lane road connected to the secondary road network at varying distances. Figure 6.5 shows a schematic ramp design for three possible options depending on the direction of the motorway's long distance city names.

The "half" junction provides a solid foundation for placing both entrance and exit ramps in elongated curves before they are merged to one joint roadway. This is rational as the design at the same time allows high speed and nice driving comfort (i.e. only small requirements for speed change).

The "half" junction with its two ramps is admirably simple but nonetheless causes "ghost driving". "Ghost driving" seems to be generated in some of these half junctions but not at other half junctions. How can this be explained? The starting point for this analysis is that there are two fundamentally different designs of entrances and exits, which are shown in Figure 6.5. One is afflicted with "ghost driving" (option 1) and the other is not (option 2). One is in danger of misleading the road user, the other is not.

In the analysis below, the term road space is used. This means the (3-dimensional) room, which consists of the road and its surroundings and which the driver will see, up to the point where the road disappears behind an obstruction of sight in the distance (curve, crest, etc.). This point often represents a minimum sight which then becomes a "gateway" to the next road space. A drive then includes having to move from one road space to another until reaching the destination.

The design, which is at risk of misleading the driver, is created as a generally straight and flat road (option 1). Once the driver enters the actual road space he will still see the road continuing straight ahead until it "disappears" behind an obstruction of sight. In Figure 6.5 the driver sees the road up to the crest of the viaduct over the motorway. The driver spontaneously perceives that this is the point far away on the road which he must pass. Getting quickly to the end of the road space and up to the "gate" to the next road space is rational driver behaviour. Focusing on and continuing towards this "gate" becomes a natural milestone.

So far the description fits well on an ordinary road with traffic in both directions. The problem is when the road "ahead" is no longer a path for traffic in both directions but represents the exit ramp from the motorway specifically designed for oncoming traffic. The one lane namely takes a right turn somewhere in the middle of the road space (see Figure 6.5, option 1). The driver's focus on the viaduct means that he risks not noticing that the ramp takes a right turn, but runs over the crest and becomes a "ghost driver".

In this case the driver has received an incorrect perception of the direction of the road he is taking. This incorrect perception of the road must be corrected in order for the driver to drive correctly. When the driver has received a clear but incorrect perception of the function of the road ahead of the vehicle, both strong and consistent information with new content is required to correct the incorrect perception and adjust it to the physical reality. In this case, it is particularly difficult for the driver to detect and understand that he should aim at a very different point in the road space. In this situation it is natural to perceive the road as continuing straight ahead while the lane taking off to the right can be perceived as an exit or a side road.

This problem, however, is not found in the second option (see Figure 6.5, option 2). The driver sees the road disappear over the crest at the end of the road space. He gets a correct perception telling him to run over the crest. He does so and goes the right way.

The solution to the problem is to set strict (geometric) requirements for the relative positions of the ramps enabling a correct perception in the driver in terms of how to drive on the road. Quite simple the road must not be about to mislead the driver. We can now conclude that option 2 (in Figure 6.5) works very well in this respect, but how should option 1 be designed to fulfil this requirement? The solution principle is shown as option 3 in Figure 6.5.

The characteristics of the "good" options 2 and 3 are the following:

- The driver on the entrance ramp must always continue driving on the road he sees disappearing far ahead

- On a straight, flat stretch somewhere in the road space the exit ramp must connect from the left side

6.4.3 "Ghost driving" at rest areas on motorways – analysis and proposed measures

Rest areas along the motorway can be connected to this in three different ways. Perhaps the most common solution in the Nordic countries is when rest areas are connected to a secondary road, which crosses the motorway in a junction. In this case there is a risk of "ghost driving" when driving in the junction itself. "Ghost driving" at junctions has been discussed in Section 6.4.1.

The second way of connecting a rest area to a motorway is to build a separate exit from the motorway. This exit then ends directly in the rest area. The same applies for the ramp leading directly from the rest area and back to the motorway again. This solution seems to be the design standard in Germany. Since exits from the motorway end directly in the rest area this represents a critical point in terms of “ghost driving”.

“Ghost driving” occurs when drivers at rest areas cannot find the entrance to the motorway but instead uses the exit from the motorway and thereby entering the motorway in the wrong direction. The driver does not discover his mistake but continues.

Previously, we stated that the driver has to be well oriented in his road environment in order to find his way (see Sections 2.9 and 6.2.3). This also applies to rest areas.

A general measure to reduce “ghost driving” from rest areas is to design the rest areas to facilitate driver orientation. This may be done in several ways. A general measure could be to build rest areas according to a standard which is simple and transparent, and which the driver can easily recognise.

A few comments and suggestions to facilitate the orientation; In case the rest area is located along the motorway the direction of travel from the motorway should be maintained also through the rest area from entering till exiting this. The road through the rest area should therefore be well defined and offer a good visual guidance. No asphalt surfaces without clear functions. Service shops at the rest area should be located along the internal road in a logical order to allow for the flow of vehicles going from the exit to the entrance ramp (e.g. exit and arrival, first fuel, then restrooms followed by serving and parking, finally departure and entrance). Parking for visiting vehicles (cars, busses, trucks) should take place on separate parking lots with parking boxes acing the direction of the entrance to the motorway.

Expectedly some of the drivers will return to the shop, which is located near the mouth of the exit ramps at the beginning of the rest area. To reduce the risk of “ghost driving” the area around the mouth should therefore be designed according to the “fish trap” principle (see Section 6.3.6). The driver must not be able to find the mouth. He will then look for signs directing him to the entrance ramp. Directions towards the ramp must be easily found, clear, and unambiguous.

Rest areas with direct connection to both directions of the motorway are particularly difficult for visiting drivers to orientate themselves in. This accounts specifically in cases where vehicles from both directions of the motorway are mixed in the rest area. This poses especially high demands on both road guidance signs and design of both exit and entrance ramps (Section 6.3.6).

The third type of connection from one direction of the motorway to the rest area is the design option suggested in Section 6.4.1 (see partial cloverleaf / Proposal 2) and which rests upon the analysis presented in Section 6.4.2. This type of connection may be particularly useful when the rest area is located some distance away from the motorway. The solution is shown in Figure 6.6.

6.4.4 ”Ghost driving” after U-turn on the motorway – analysis and proposed measures

It is reasonable to assume that the design of the motorway at a certain road stretch can be a contributing factor to U-turns, which often end as “ghost driving”.

One possible explanation to why drivers make a U-turn is that their thoughts drift away when driving and they “forget” that they are actually on a motorway thus perceiving that they are driving on a 2-lane road. In case the driver cannot see the opposite lane of the motorway or the traffic on this, the road environment is largely the same as for a 2-lane high-standard road.

Car driving is an automated action (see Section 2.3, 2.4, and 2.5). This applies in particular to off peak periods when “nothing is happening”. The driver is driving and thinking about other things. Suddenly, the driver feels that he is lost and tries to orientate himself on the road. “Where am I? I must have gone wrong. I have to turn”. The road environment is “lying” to the driver by signalling that “this is a 2-lane road”. The driver, doing the best he can, makes a U-turn and becomes a “ghost driver”.

The conclusions to be drawn by this analysis are that the motorway must be designed so that drivers are constantly reminded that they are driving on a motorway with one-way traffic in each lane. This information is best perceived by the driver if he sees with his own eyes the opposite roadway and the traffic flow on this. The distance between roadways should therefore not be particularly wide. In case of obstruction of sight in the area between the roadways, this should not be permanent but be broken with short insertions of visual eye contact with the opposite roadway. The problem of lacking oncoming traffic however, is more difficult to address. The analysis leads to the conclusion that there are strong reasons for giving the lanes/roadways on the motorway a specific “character design”, which clearly distinguishes them from roadways with traffic in both directions. The driver must unconsciously perceive that the roadway he is driving on is either part of a motorway or a two-way road.

Sweden has some experience with “ghost driving” after U-turns on the motorway. The problematic route was originally an expressway, which after a short while was extended to a motorway with large distances and no visual contact between the roadways (E18 at Ekolsund). The study performed after a number of “ghost drivings” demonstrated that a contributing factor for mistakes was the distance between the roadways, which was so large that it made visual contact with the traffic in the opposite direction impossible. Another contributing factor is being highlighted by the study. The stretch of road included a turning point for road maintenance vehicles. Such turning points invite drivers on the motorway to make a convenient U-turn. Turning points which offer and allow convenient U-turns should therefore only be located on stretches on the motorway with good visibility between the roadways.

6.4.5 ”Ghost driving” at change of design of road section

Examples of critical locations are where a road without median barrier continues into a road with median barrier, and where two-lane roads turn into four-lane roads with median barrier.

A general measure is to install a median barrier somewhere in the middle of an S-curve starting at the right side. The S-curve will then have a limited stretch of free visibility to discourage overtaking. The driver places the vehicle to the right in the lane during the first part of the S-curve where the barrier begins. The distance to the barrier is at its maximum and the risk of collision or driving on the wrong side of the barrier is minimised. The median barrier evokes a change of road without risk of “ghost driving”.

An S-curve with short stretch of free visibility is the gateway to the next road space. The driver coming out of the curve and into the new road space pays particular attention to the opportunities and risks of the new road space (“benefits” and “threats”). Thus it is appropriate to perform road changes right at the start of this space.

To prevent “ghost driving” at free visibility on road sections without barrier, see Section 6.5.

6.5 Analysis and general measures for reduction of ”ghost driving” on road sections

The driver sees the road ahead and does not only experience how the road and the road space look but also perceives how to drive onto it up to the obstruction of sight where the road disappears in the distance. In most cases, the driver’s perception of the road is entirely correct. But there are exceptions. The road design in some special cases misguides the driver.

At least one fairly common road design (on the motorway network) risks misleading the driver. In the current situation, the road design risks giving the driver the impression that he should continue straight ahead when in fact he should turn right. This is because the road straight ahead constitutes a lane for oncoming traffic. If the driver does not succeed in correcting his faulty perception, he becomes a “ghost driver”.

The solution to the problem lies in strict (geometric) demands on the roadway geometry and relative positions of the lanes. Sagberg (2003) also discusses whether a general rule to prevent “ghost driving” on road sections can be formulated. This rule would apply when the roadway with traffic in both directions at some point turns into a roadway with only oncoming traffic. If this is a general problem, the measures to remedy the problem could also be general.

In previous analysis we have used the term road space. By this we mean the (3-dimensional) space, which the driver sees and which consists of the road and its surroundings up to the point where the road disappears behind an obstruction of sight (curve, crest, etc.). This point is usually a sight limitation serving as the “gateway” to the next road space. A car drive involves moving from one road space to another until reaching the destination.

When the driver enters the current road space, he will see the road continue straight ahead until it “disappears” behind an obstruction of sight. The driver gets an immediate perception that this is the point along the road which he must pass. Getting quickly to the end of the road space and up to the “gateway” to the next road space is rational driver behaviour. Consequently, reaching the “gateway” to the next road space becomes a natural milestone on the journey.

So far the description fits well to an ordinary road with traffic in both directions. The problem occurs when the road “over there” is no longer a road for traffic in both directions but a roadway only for oncoming traffic. In fact, one of the lanes turns right halfway down the road space. This means that the driver has received an incorrect perception of which way the continuing road goes.

When the driver has misinterpreted how to drive, the perception needs to be corrected before he goes the wrong way. The problem is that once you have got a clear but inaccurate perception of the road ahead of the vehicle, strong and consistent information with new content is required in order to reject the first perception and reset this with a completely new perception of the function of the road corresponding to the physical reality.

In this case, it is easy for the driver to discover his mistake and instead perceive that he should drive towards an entirely different and closer point on the road. The continuing road namely turns to the right. In this instance it is natural to feel that the road continues straight ahead and that the lane going right is a side road.

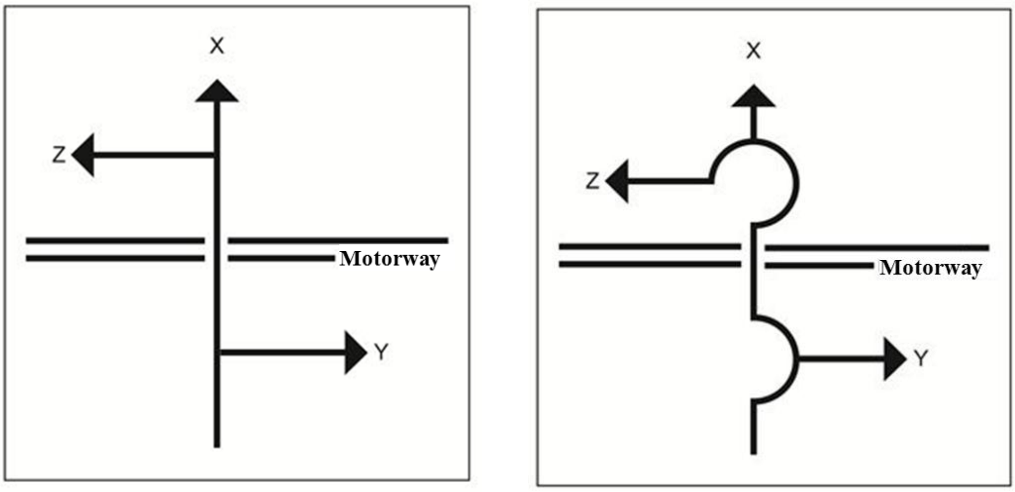
How should the road be designed in order not to mislead the driver but instead “guide” the driver in the right direction?
For road designs with barriers to prevent “ghost driving”, see Section 6.4.5.

Proposed general rule to prevent “ghost driving” in good visibility on the road section and without barriers:

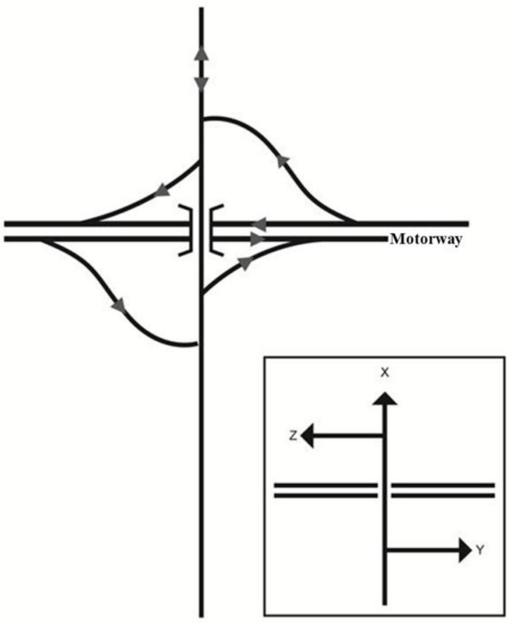
- A road which to the driver appears to be as going straight ahead, must *always* allow continued driving straight ahead.

The consequence of this rule is:

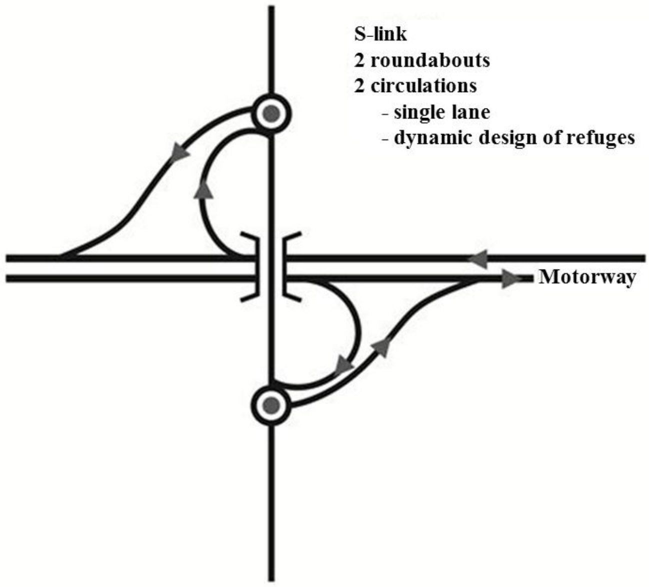
- If a lane turns off to the right from the road straight ahead, this should *always* be an exit from the main direction (straight ahead).



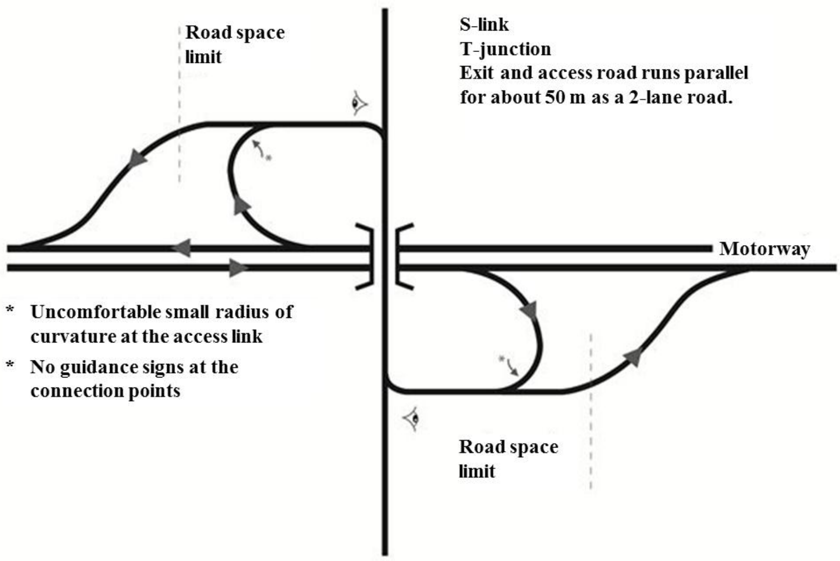
Figur 6.1



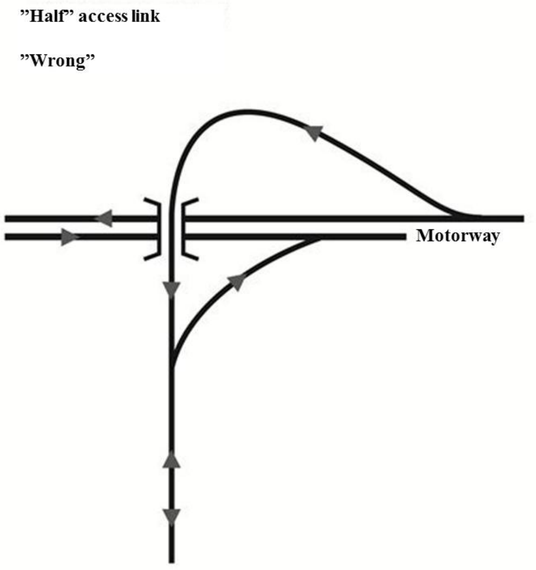
Figur 6.2

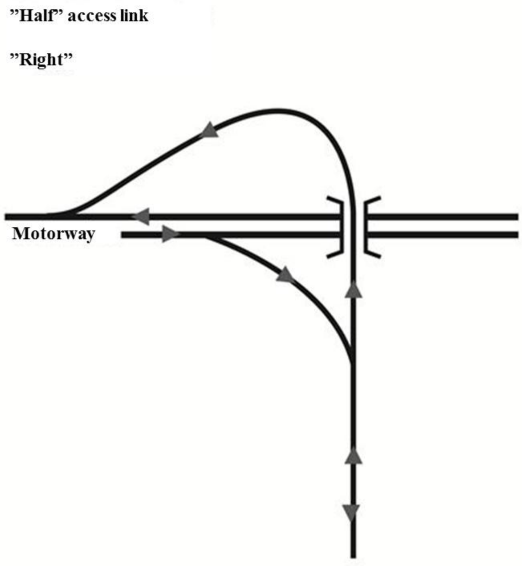


Figur 6.3

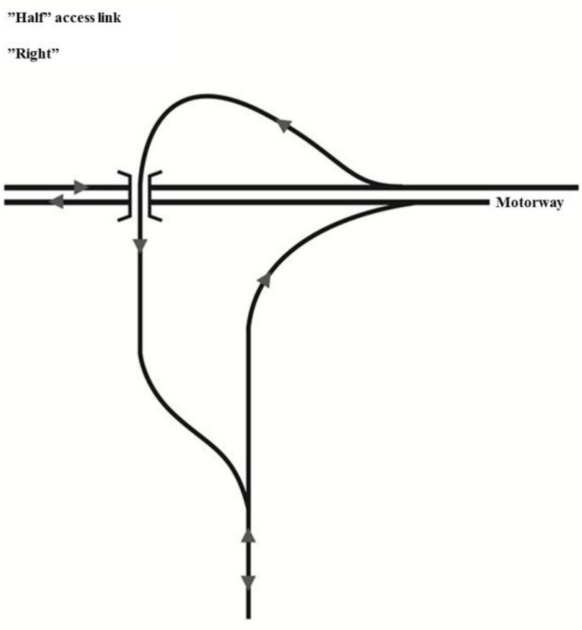


Figur 6.4



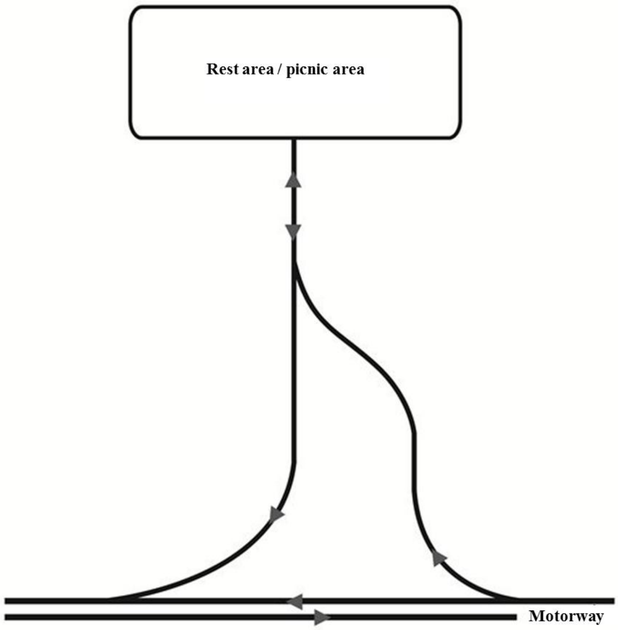


Option 1 *Option 2*



Option 3

Figur 6.5: *Three possible options for design of ”half” junctions. Option 1 may mislead the driver to “ghost driving”.*



Figur 6.6

7. The driver's choice of speed and basic conditions for a proper speed adjustment

7.1 Starting point

Analysis of the driver's choice of speed and the conditions for a proper speed adjustment will be made on the basis of the basic principle of the explanatory model (Section 2). The objective of the analyses is firstly, to provide a better understanding of how drivers act in terms of choice of speed and how they adjust their speed. Secondly, the analyses are intended to provide better tools and methods for influencing the driver's choice of speed and improve the conditions for a safe speed adjustment. The latter is especially important in situations where the passability is rapidly reduced.

Once the analyses have been completed, it is important to try and answer the question as to whether the explanatory model and the basic principles of this has contributed to meeting the objectives, i.e. providing us with a better understanding and more effective methods?

The title of this section contains two very different problems. The first problem is to describe how the driver chooses his speed when the road and traffic conditions along the road are almost unchanged. The other problem however, is to describe the conditions that with a high degree of probability will make the driver adjust his speed to a road section with significantly impaired passability.

In the following, we have chosen to discuss the two problems separately. The first analysis deals with the driver's choice of speed, and the second one with the conditions for proper speed adjustment on road sections where access is suddenly limited.

7.2 The driver's choice of speed at unchanged road and traffic conditions

7.2.1 What does the explanatory model say?

Before we begin our analysis, it may be appropriate to briefly repeat the main principles of the model (Section 2).

- **Man is a rational being when moving**
  During evolution man has developed according to Charles Darwin's principle "survival of the fittest". This principle means that we have been successful in satisfying our needs while avoiding threats and dangers. One of the conditions has been that we have been able to move around efficiently in our environment. We can reformulate Darwin's general principle to a -

for us - more up-to-date one but as a general principle for our behaviour. It reads “maximum benefit at minimum cost” (Section 2.1)

- **Man must learn practically everything**
  Through our behaviour we get feedback from our surroundings. In this way, we acknowledge the properties of the environment and the objects. We build up our experience and knowledge of how to act in order to satisfy our needs while avoiding the threats and dangers which are also present in our surroundings.

  But how do we know that our behaviour lives up to the demands of efficiency, “maximum benefit at minimum cost”? The only way this is possible is if we test the limits of our abilities. We do this by increasing the ambition level until we fail and lose control. Once the limit is sufficiently tested and defined we ”take a step back” and act based on the goal to maintain a certain safety margin to this limit (Section 2.2).

- **We receive an immediate overall experience of the environment surrounding us through our senses**
  The visual information is embedded in the rays of light, which reaches our eyes after having been reflected at various objects and surfaces in the environment. Eyes and brain record the information and in daylight we immediately perceive the 3-dimensional space always surrounding us. Because the information so to speak is not interpreted by our brains, but is common knowledge to everyone, this suggests that we as experienced drivers perceive the road and the traffic environment in a very similar way.

  Note:
  Our overall experience of the outside environment is to a great extent determined by our minds and our brains while the characteristics of this environment and the objects in it are something that we must learn. There is therefore no contradiction between this point and the previous.

- **We walk, we bike, we drive a vehicle without thinking about what we are doing**
  Walking, biking, and driving a vehicle are all skills we have learned after hours of training. Practicing a skill implies that the behaviour is based on automated learning patterns. These patterns of behaviour are rational and efficient while requiring little effort – i.e. maximum benefit at minimum cost.

  When driving, most tasks are performed in an automated manner. This means that we quite spontaneously think about other things while driving. Only when solving problematic tasks, such as finding the right way or trying to understand ambiguous road signs, do we have to think while driving (Section 2.4).

Note:
The mind-set in the four points above leads to the following consequences in relation to the experienced driver's behaviour:

- **Driving is a perceptual task, which to a large extent is performed automated**
  This means that the driver's behaviour rests upon his overall experience of the road, the road environment and the actual traffic situation. Maintaining an appropriate speed and an appropriate lateral position are driving tasks that are usually performed entirely automated. The driver thus spontaneously chooses speed and lateral position to obtain full control of his driving. This in turn makes the driver constantly strive to maintain a certain margin of safety. If the margin is too small, the driver will find the speed unpleasantly high. If it is too big, he will find the driving extremely slow (Section 2.5).

7.2.2 The drivers choice of speed at unchanged road and traffic conditions

The importance of long-term driving experience
Together the first four sections above lead to the fifth and final point, which constitutes a general and comprehensive description of the reasons for driver behaviour.

That the experienced driver's task is primarily perceptual and automated means that the driver behaviour is more often a direct consequence of the driver's current and more importantly of his visual perception of the road, the traffic environment, and the current traffic situation. But this is not sufficient as basis for well-adapted driver behaviour. The driver also needs to directly perceive the demands requested by the traffic conditions to his driving skills through experiences about the consequences of various behaviours.

Here the experienced driver's accumulated experience finds it application in a sort of "experience bank". This holds information achieved by negative feedback from traffic environments during the driver's past mistakes. This information will then tell the driver how not to drive in similar situations in order to avoid repeating the mistakes. The bank also contains information from positive feedback advising the driver how to drive. The basis for this is the almost infinite number of traffic situations successfully managed by the driver under full (perceived) control.

The complete traffic experience of the driver makes up the knowledge base for his choice of speed and behaviour in general in every new traffic situation. A prerequisite for an appropriate speed adjustment is therefore an experienced driver.

Note:
Contrary to the experienced driver, the inexperienced driver has insufficient and inadequate knowledge in his "experience bank". This provides the new driver

with much poorer qualifications to be able to see and perceive the requirements of the current and the coming traffic environment. This manifests itself in the sense that the inexperienced driver generally has a poor speed adjustment as well as difficulties in correctly predict what is about to happen.

Experienced drivers' choice of speed in various traffic environments in urban areas

A study conducted by VTI in which experienced driver's choice of speed when running a public road in Linköping covering 38 road sections. Every section had a uniform road and traffic environment, whilst the variation between the sections was significant (Törnros, Dahlstedt & Helmers, 2006). The purpose of this study was to test the validity of some of the basic ideas of the explanatory model.

The model predicts that experienced drivers perceive traffic environments of various kinds and their requirements for the drivers in a similar way. Consequently, we can expect experienced drivers to spontaneously adjust their speed in different traffic environments in much the same way. The study also shows that the speed profiles of the drivers when crossing the various sections of the loop are much alike. The model is confirmed.

Two types of experienced drivers participated in the study. One group was from Linköping and had great driving skills in their hometown. The second group came from the almost equally big neighbouring town of Norrköping. The drivers from Norrköping had none or little experience of driving a vehicle in Linköping. The interesting question is whether the drivers from Linköping, having driven in their own town, had learned how to adjust their speed on the various subsections? In such case, they would have an advantage to the Norrköping drivers, who had not had this exposure?

The study was performed using an instrumented vehicle (Audi A6 Automatic) equipped to record speed and position (GPS). The driver, who was by himself in the vehicle, was continuously instructed about choices of directions along the drive – both verbally through loudspeakers and visually through a monitor. Before the experiment, the driver had been instructed to drive as usual. In order to enable the most spontaneous choice of speed, the vehicle's speedometer has been disconnected.

Results for both test groups showed that their speed profiles were virtually identical. The conclusion to be drawn from this is that experienced drivers have amassed a bank of experience and knowledge enabling them to adjust their speed to the road and traffic environment regardless of whether they are running in known or unknown traffic environments.

Of course individual variations are to be found amongst the drivers in terms of choice of speed. Some run a little faster – and others run a little slower. We can assume that this natural variation between drivers is dependent on numerous factors. It might be of interest to get an idea of how significant a part of the total variation (the variance) in the speed measurements in the study are dependent on the differences in the drivers compared to how much is dependent on the diversity of the different sub-sections of the loop.

Speed data were subjected to an analysis of variance. The difference in speed between the sub-sections explains 78% of the total variance in the material while the difference in speed between the drivers explained only 13%. The remainder of the variations, which cannot be explained, then constituted 9%. This so-called random variation is caused by disturbances of various kinds during the speed measurements, such as variations in other traffic, weather, and road conditions along with other uncontrolled events and conditions.

Note:
The result of the study above should be seen as an illustrative example of the fact that differences in the road environment have a large impact on the choice of speed. The relative impact (78%) of the traffic environment relative to the drivers (13%) is largely dependent on the variation and distribution of the road sections selected for the loop. The reported effects are therefore specific for this study and should not be generalised.

The results of the study are in accordance with the explanatory model. The explanatory model says that experienced drivers perceive different traffic environments in similar ways. As a consequence the drivers will also adjust their speed to these in a very similar manner, which the study empirically confirms. The choice of speed depends mainly of the design of the road and the traffic environment and only to a minor extent on individual differences in experienced drivers.

Individual differences in the choice of speed
As we have all experienced, there is a natural variation in driver behaviours. The choice of speed can be perceived as an expression of the driver's established habits and driving style. Some drivers drive a little faster and others a little slower. This is confirmed by the speed study referenced above. The main finding of the study is that drivers adjust their speed in the same way meaning that the driver speed profiles along the sub-sections are very similar and dependent on each driver's average speed.

Besides the road and traffic conditions the drivers also have difference in speed requirements depending on numerous factors such as the length and purpose of the journey and perceived time pressure. Also social motives influence the choice of speed, i.e. living up to a certain role, impressing one's surroundings, or avoiding attracting attention. An expression of the driver's current speed requirement is the cruise control speed selected by the driver.

Note:

As long as the driver's choice of speed and driving behaviour in general lie within the accepted limits of society, the individual driving style is not a problem. However, if the individual has established a (bad) habit of driving too fast very often or always this is something that can only be addressed through monitoring and sanctions.

Our senses provide us with relative and not absolute information
Our senses provide us with information about relative differences between stimuli of the same kind, but not on a physical (absolute) level. Through our vision we perceive light and colour differences between objects, and through our hearing we experience differences in pitch. *An example*: The piano tuner needs his tuning fork in order to adjust the tension of one of the strings on the piano to make this oscillate with a certain frequency (absolute level expressed as waves per second). All other notes on the piano are then adjusted based on the piano tuner's perception of each note's tune in relation to the keynote. Therefore, we have no problem perceiving the differences in the various tones. (There are people who have a perfect pitch; however, this is very unusual. In the case of the piano tuner perfect pitch would mean that he did not need a tuning fork, but that he would be able to hear exactly when the keynote was correct and all other notes correctly tuned).

The driver's assessment of his speed
The speed of the vehicle we are driving is a composite mass of distance travelled over time. We have a poor ability to make absolute assessments of both distance and time. This means that not only do we have great difficulties assessing our speed on an absolute level (i.e. in km/hour) but we also are very poor at assessing how much we reduced or increased our speed relative to our starting speed (i.e. our relative speed change). For instance, studies of speed blindness clearly show that, after a rapid reduction of speed, we perceive the speed to be much lower than it actually is.

All vehicles are equipped with a speedometer. The information from the speedometer is necessary for us to with any certainty determine how fast we are driving relative to the maximum speed permitted on the road as indicated on the road signs. In this way we try to control not going too fast. For this reason, we look at the speedometer very often; both when trying to maintain a constant and high cruising speed at constant maximum speed and when we change our speed relative to the lower or higher level sign-posted along the road.

Conclusion:
We are in great need of the speedometer to adjust our speed in accordance with the sign-posted maximum speed permitted along the road.

We attain the appropriate speed in relation to the requirements of the traffic environment
The results in the previously referenced speed study shows that drivers spontaneously and without information from the speedometer adjust their speed well to the

different urban environments they are exposed to and that they do so in a very similar way. On some routes, the speed is far below the sign-posted speed and on others far above. The study shows that the adjustment of speed happens with very little variation between the drivers. These results also verify one of the basic ideas of the explanatory model. Se Section 2.5.

Note:
We do not need information from the speedometer to adjust our speed to various traffic conditions in urban areas. However, we do need it to ensure that we do not exceed the sign-posted (maximum) speed.

How do we attain appropriate speed on motorways of high speed standards?
Modern vehicles are built to withstand speeds far above the maximum limits. At the same time, we build motorways with a geometric standard that under favourable conditions allow for speeds well above the maximum limit. How does an experienced driver behind the wheel of a new vehicle with good road handling and high speed capabilities choose to drive when the motorway he is taking offers high road standards, the traffic is low, the road is dry, and it is daylight? He will experience that the road and the traffic environment allows for a considerably higher speed than the sign-posted limits on the road allow while maintaining safety. Which speed does he choose?

Choice of speed from a cost/benefit perspective
The driver might perceive 140 km/hour to be an appropriate speed under the current conditions. He decides to run at this speed, thus exceeding the speed limit by 30 km/hour. He reaches his destination more quickly and thus saves travel time. The choice of speed puts the driver at risk of getting high speed tickets, but by using the cruise control he will not exceed the 140 km/hour which would put him at risk of losing his license. How much is the saved time worth? It depends on the circumstances. In this case the driver is running late and has to catch a flight to New York. In such case, every minute counts.

However, if the driver has ample time to reach his destination the shortening of travel time is not much worth. In his role as “loyal citizen” the driver might then choose to obey the speed norm and set the cruise control on 7 km/hour above the sign-posted limit (to compensate for the fact that the vehicle’s speedometer displays a speed which is at least 5 km too high). To the driver the longer travel time is compensated by the less stressed and more comfortable driving as well as the reduced fuel and vehicle costs.

The vehicle’s impact on choice of speed
Driver and vehicle can be considered integrated, holding one joint capacity. If the driver has invested in a new vehicle with good road handling capabilities and a strong motor, he will want “value for money” according to the principle “maximum benefit at minimum cost”. Part of the benefit may be that the new vehicle raises the owner’s social status in the eyes of the neighbours. Another might be to

utilise the better speed resources of the new vehicle by running a little faster and thereby arriving a little earlier. On the cost side, the investment in the vehicle has already been made and the slightly increased fuel costs are probably negligible in this context. The driver will take the risk of getting a speed ticket, thus choosing a speed well above the sign-posted one. However, the driver ensures that he does not over speed so much that he is at risk of losing his license.

If the driver on the other hand is running an old, worn out vehicle, the decision becomes different. He spontaneously chooses a lower speed and a more calm way of driving in order to reduce the strain on the vehicle with the purpose of avoiding a vehicle break down and instead extend the lifespan of the vehicle. The trip will take a little longer (increased cost of time) but the driver will find that this is off-set by the reduced vehicle and fuel costs.

General economic conditions and choice of speed
The same analysis can also be made on a collective and societal level. During financial booms, the economic outlook is positive. People are busy and have a hard time keeping up. Cost of time increases for all types of transport. This means that the average speed on the road network tends to increase. In this equation, the time saved is the benefit. Costs encompass increased driver effort and stress, increased fuel and vehicle costs, more accidents, and more severe accidents, which mean increased social costs.

During a recession, the opposite applies. Rather than a lack of time, time has become a surplus commodity. Short supplies are premium priced while surplus supplies are low priced. The cost of time decreases. People have a surplus of time and are more relaxed. Traffic is reduced. When the cost of time is decreased, speed on the roadways is lowered. By reducing the speed, the driving task becomes easier and the fuel and vehicle costs lower. Accident frequency and severity decreases and accident costs decrease.

7.3 Driver speed adjustment upon unexpected reduction of passability

7.3.1 What does the explanatory model state?

Section 7.2.1 refers to a number of essential basic ideas in the explanatory model (Section 2). These are still relevant but need to be supplemented with some additional ones for our further analysis. These ideas are referenced briefly below.

- **The road ”tells” the driver how fast he should run**
  Ideally the road should be designed to provide the driver with an immediate and unambiguous visual perception of how to drive. As such, the driver must perceive the function of the road as obvious. In such cases, the design of the road is self-explaning (Section 2.9). This means that the driver behaviour is largely determined by the driver's overall experience of the road itself.

- **The choice of speed is based on the driver's expectations to the road**
  The road evokes unconscious expectations in the driver as to how it continues a little further ahead as well as which traffic conditions will face him. The driver's ability to act rests upon these expectations. Consequently, it is important that the road meets the expectations it has created. One can say that "the road must deliver as promised" (Section 2.11).
  As a consequence also the driver behaviour is significantly determined by the driver's expectations to the design of the road and the traffic conditions a little further ahead.

- **Insufficient fulfilment of driver expectations causes problems**
  The driver may have difficulties detecting and adapting to unexpected situations. Such unexpected situations create great risks for poor adjustment of driver behaviour due to late reactions, long reaction times, and even missed or completely inappropriate reactions (Section 2.11).

If the driver's expectations are wrong, he must be "awakened" in due time. This is done by taking appropriate measures, all aimed at changing the driver's driving from automated to conscious. During conscious driving the driver actively seeks new and essential information about the road and the traffic conditions in order to obtain a correct indication of what is going to happen. Once this is done, the driver has the best condition to best adapt his speed and lateral position.

7.3.2 Analysis with regards to driver speed adjustment upon unexpected reduction of passability

The driver behaviour is based on two sources of information
The first source of information is the overall experience exposed to him by the road and the road environment through his senses. This experience is primarily visual, however complemented by other senses such as hearing (noise), feeling (vibration), and balance (g-force). The other source of information consists of the driver's expectations as to what will happen a little further down the road.

The driver's overall experience of the road and the traffic situation
The driver has to see the road and experience what is happening on this. This is a necessary condition for us to be able to drive a vehicle, which is obvious to everyone. (This is also a likely reason why a large part of the traffic research revolves around visibility problems in traffic).

The characteristic of the driver's primarily visual perception of the traffic is that it immediately provides him with the knowledge. The problem is that the quality of the visual information to the driver is rapidly deteriorating with the distance to the objects and events worth considering. As speed increases, the driver has to focus on traffic events much further ahead of the vehicle. Adversely, the driver's ability to accurately assess what is happening at this somewhat larger distance is affected because our visibility is insufficient.

An example: We see e.g. a vehicle in the far distance in our own lane on the motorway. Based on past experience, our expectation is that the vehicle ahead is running approximately about as fast as we do. We even believe that we can see that the distance to the vehicle does not change. This despite the fact that our visibility does not at all possess the capability needed (to falsify or verify the accuracy of our perception). After a few seconds we find that the distance is reduced. We feel that the vehicle is running slower than we are, but that the distance is still safe. Only when we come relatively close to the vehicle in front, we suddenly learn that this is stationary. Meanwhile, the left lane has become occupied with overtaking vehicles. “The heart jumps”, we brake in panic, and only barely succeed stopping behind the stationary vehicle.

Conclusion:
It is questionable whether the visual information received when driving fast is good enough to enable us correctly perceives what is happening in the relevant distance in front of our vehicle.

The driver’s experience, expectations, and ability to act
The experienced driver’s accumulated experience acquired through exposure to a large number of road environments and almost infinite number of traffic situations makes up an important base of knowledge for his behaviour. The driver is exposed to regularities and uncertainties in traffic and practices through feedback from the road and the traffic to obtain a better ability to predict in any situation the possible event outcomes, which are most likely to occur – thus choosing speed and acting in general has done successfully many times before in his past in similar occasions.

The road and the current traffic situation create expectations in the driver about what will happen a little further down the road. These expectations are then well grounded in real events. The expectations are functional for the driver in the sense that they create a state of readiness to act to adapt quickly to the most probable events and scenarios. Correct expectations are therefore an important prerequisite for well-adapted driver behaviour.

The driver’s expectations, however, will be dysfunctional in case he encounters an unexpected traffic situation. In this case, the driver has no or poor ability to act and will be surprised. A pore ability to act involves prolonged reaction times or at worst, no reaction at all or completely irrational driver behaviour.

However, in cases where the driver experiences that current situations are difficult to assess because they have developed in slightly different ways, this creates an uncertainty with the driver and an increased vigilance and ability to act to several different types of possible scenarios.

Conclusion 1:
The memory of the stretch of road just passed and the visual experience of the road and the current traffic environment together must create accurate expectations as to how the road will continue and which demands it will place.

Conclusion 2:
Well-adjusted driver behaviour requires that the driver's expectations on the road are met.

Conclusion 3:
In case the road and traffic environment do not meet the driver's expectations, he must be "awakened" in due time by means of various measures. This is to enable the driver to consciously acknowledge current and new necessary information in order to obtain a realistic idea of the situation.

7.3.3 How should road and traffic environment be designed to meet driver expectations?

An absolute condition to meet driver expectations is that the road and traffic environment is designed in a clear and unambiguous manner so that the driver will never be surprised. Therefore the road must be designed so that the driver feels that it has an obvious function. Both road and traffic events on this should as far as possible be law-abiding and predictable. This in turn requires a design which is highly standardised and thus predictable.

A curve, which the driver is approaching, shall in its visible part be designed to that the speed chosen appropriate by the driver in this part of the curve will also be appropriate in the hidden part of the curve.

An example:
-*Road description:* The road is a road on the secondary road network. The surface of the road is relatively high-quality and the width of the road allows comfortable encounters between vehicles. At the end of a rather long and straight section of the road you can see this continue in a large radius curve. A line of forest prevents visibility of the latter part of the curve. There are no road signs along the road.
-*The driver's expectation and choice of speed:* The driver approaches the curve. He believes that he can comfortably run through it without slowing down and does so. He feels that the curve accommodates a steady speed through the whole curve (compare "the self-explaining road").
-*Resolution:* When the driver has passed the part of the curve visible to him at an early stage the radius of the curve suddenly gets smaller and smaller. The driver's expectations of the curve turn out to be completely wrong. This puts him in an unanticipated situation. The driver makes a controlled break to reduce speed whilst manoeuvring the vehicle through the sharp turn. This time he succeeds despite uncomfortably high lateral forces. But what would have happened had the road been slippery?

-Who owns the problem? Who can rectify the problem?
Problems caused by the road and the road environment creating false expectations with the driver can only be addressed by the road authorities.

7.3.4 How to ”awaken” drivers going with false expectations?

When the driver has false expectations of the road and the traffic conditions ahead, this means that he will have an image or idea of what is about to happen, which is not in conformity with the actual facts. This condition is hard to break. This can be compared with a driver having a filter in front of his eyes, making it difficult for him to see and discover the requirements that the traffic conditions suddenly lay down.

The driver is therefore at large risk of continuing his automated driving as if nothing happened. Only when the situation becomes critical the driver will suddenly “wake up” to discover his mistake (“like a bolt from the blue”). The driver then immediately switches from automated to conscious driving, thereby actively looking for new information to get an exact idea of what is about to happen. Simultaneously, he is forced to act quickly to “save the day”. In this critical situation, there is often no time for reflection and deliberate decisions and in these cases it is difficult to predict how the driver will act. The behaviour may vary from quick panic braking, over hasty manoeuvres, over action delayed by prolonged reaction times, and finally complete lack of action (that is paralysis).

It is therefore important to try to “wake up” the driver with the appropriate means. This should be done well in advance enabling him to reorient himself in the road environment and gain a correct perception of how the traffic situation will change further ahead. Only then does the driver have good conditions to adapt his speed according to the demands set by the “new” traffic environment.

A driver will be alert if he no longer recognises a traffic environment he usually knows very well. If, as an example, a 4-way intersection on a rural road has been rebuilt to a roundabout, it is advisable to also redesign the connections of the main road to this at a sufficient distance from the roundabout. When the driver uses the road for the first time after the rebuild, he will not recognise this. He then switches to conscious driving actively seeking new information and timely discovering the change and finally adapting his speed in a balanced manner before passing the roundabout.

One can even imagine that the connections to the roundabouts are designed in a unique and distinctive way making these self-explaining. This would require that the physical design of the connection should clearly state that the driver is approaching a roundabout.

Roadwork on motorways regularly involves that the driver’s expectations of an unchanged mobility is not consistent with reality. Meanwhile, this roadwork is more or less temporary. In order to obtain good speed adjustment during passage of roadwork on the motorway, certain conditions need to be met: The first condition is that the drivers have to be "awakened" in due time. This is done by various kinds of strong warning signals. When "awakened" the drivers switch from automated to conscious driving to be able to reorient themselves in the current situation by reading all road signs and road equipment leading up to the roadwork location. The other condition is that the designated lane just prior to and past the roadwork must be designed to set explicit requirements with respect to the speed which the driver should maintain at the passage. The third condition is that adequate provisions must be made blocking the line of sight past the roadwork forcing the drivers to act in a road space which is appropriately narrowed.

Drivers must perceive that all warning signals are strong, sudden, and unexpected in order to be effective. As such, these must be well adapted to the external conditions. Yellow flashes should be strong in daylight as well as in the dark. Consequently, they should be equipped with daylight and darkness levels that are as strong as possible without causing visibility damaging blinding.

The warning signal "noise contour lines" ("rumble strips") across the road are considered very efficient however this is not used very often. These lines are usually carried out as white markings of thermoplastic with a certain convenient height above the rest of the roadway. The sudden noise and the vibrations in the vehicle constitute the primary warning signal. The fact that the white line can be seen by the driver 1-2 seconds before the passage provides the driver with a visual pre-warning which should reduce the surprise effect. In order to provide the maximum warning effect these warnings should be composed of a material that cannot be seen by the drivers.

7.4 Summary and conclusions

In the introduction to this section (Section 7) it is stated that one of the purposes of the analyses was to improve our understanding of how drivers make their choice of speed. The other purpose was to obtain a well-grounded basis for more efficient measures resulting in an improved speed adaptation.

The study has shown that the explanatory model has provided a good basis for the analysis of the problem. The analyses have led to a deeper understanding of the driver's choice of speed and resulted in an improved understanding of the design of concrete measures.

The analyses have shown that the choice of speed to a large degree is determined by the physical design of the road and the traffic environment. The experienced driver unconsciously and with great precision perceives which speed is "the right one". At the same time, road environments provide a fiscal-administrative system with sign-posted maximum speed limits. In order to keep speed signs realistic and credible for the drivers whilst functional for society, these must not deviate very much from the speed perceived by the driver as the natural one. If the road authorities wish to reduce the speed on the road it will not be enough to post a lower speed limit without also implementing the necessary physical changes.

Whatever we do, we have expectations to what is going to happen in our surroundings. The analyses prove the need to design roads and traffic environments such that driver expectations are met and the traffic ahead will be as anticipated. If the expectations are not fulfilled we have no or poor ability to act and deal with unexpected situations. We get surprised and caught off guard leaving us with poor abilities to handle the situation.

In the event that the road does not meet driver expectations, the driver must be “awakened” in due time through strong, sudden, and unexpected stimuli. Once alert the driver will reorient himself in the traffic situation and adjust his speed and behaviour to this.

8. The drivers's ability to read and understand road signs and road markings

8.1 Reading and understanding the meaning of road signs and road markings – can that constitute a problem?

The road signs we pass along the road are mostly very visible. Despite this, we often fail to read them and consequently do not benefit from the information provided by these. This is a well-documented problem. To be able to change this, we need to find a good explanation to why we are missing the signs, but today we have no profound understanding of the problem.

Compared to road signs the road markings on the roadway usually have a much more varied visibility. If the road markings, however, provide an acceptable visibility we seem to catch the information they offer. How can this significant difference in the transfer of information from road signs and road markings be explained?

The purpose of this section (Section 8) is to perform an analysis with the help of the explanatory model, which will hopefully give us a better understanding of the problem. The analysis should also lead to well-founded suggestions (testable) for improving measures.

Road signs and road markings are two systems of information which are fundamentally very different. Section 8.2 describes this difference and the impact it has on the transfer of information to the driver. Section 8.3 deals with the driver behaviour based on the information he needs to fulfil his tasks.

8.2 Road signs and road markings are information carriers

In daylight our vision allows for receiving an immediate perception of the 3-dimensional space in front of us. We see the physical limits of the space and its furnishing with various objects. When actors are also available in this "space" we perceive what is about to happen. Our experience is perceptual, which means that it is immediate but does not need to be interpreted or understood – it is just there (see the explanatory model, Sections 2.3, 2.4, and 2.5). We continue to call this perceptual information which is based on the physical design of the space, its objects, and its actors for "natural"

Every road sign is a carrier of both "natural" as well as symbolic information. The "natural" information of a road sign is confined to the fact that it is a metal plate mounted on a pole or in a foundation. The metal plate is facing the driver. Road signs represent only one of several obstacles outside the roadway guardrails, light poles, trees, and large rocks, which the driver must avoid hitting if ending up in the ditch. The purpose of each road sign is to make this a carrier of relevant symbolic information needed by the driver. In order to assimilate the message of the road sign, the driver must actively read this. The prerequisite enabling drivers to read and understand road signs are discussed in the next section (8.3).

Also road markings are carriers of both "natural" as well as symbolic information. The road markings are mainly used to mark the road by means of edge and centre line markings, which will have a continuous extension along the road. When the edge lines are located on the roadway right inside the edge of the asphalt, these reinforce the often low contrast between the paved roadway and the gravel string against the ditch. The strong demarcation of the roadway from the ditch is the "natural" information of the edge line. Drivers also experience with high accuracy where the centre of the road is located. By adding a centre line in the middle of the roadway, it is made obvious to the driver exactly where the border to the oncoming traffic lane is located. The information provided by the centre line is very much "natural". The driver perceives that his lane, bounded by edge and centre line markings, forms a whole in the shape of a broad field (a "gestalt" in the gestalt psychological perspective), which extends forward in the direction of travel and which shows the driver which space he has at his disposal.

Only when the centre line is complemented by a solid line closest to the driver, this combined centreline becomes an information carrier of symbolic character. We will call this solid line in the middle of the road the "solid line". The symbolic meaning of the solid line is that this must not be violated by any wheel. Meanwhile, the driver will "naturally" perceive the solid line as a "fictional border" against the oncoming traffic lane. When the solid line is located on the far side of the centreline, this means that the restriction instead applies to oncoming vehicles. The driver has learned the purpose of the solid line and he must actively read this to understand what applies to him. At the same time drivers very rarely miss (visible) solid lines. From this it can be concluded that a solid line in combination with a centre line is not only a carrier of a symbolic message but also a substantial degree of "natural" information therefore immediately perceived.

A big difference between road signs and road markings is the fact that every road sign has a definite position on the road while the longitudinal road markings are either continuous or like the solid line positioned along a limited stretch of road. As a consequence, road signs can be read by the driver during a brief "distance and time window" just prior to passing the sign. Longitudinal road markings, on the contrary, require continuity in the information transfer. The information is clear and the content is unambiguous.

At intersections transverse road markings are used as stop line (solid line) and as yield line ("give way line"). These markings are drawn across the lane and perpendicular to the direction of travel. Drivers need to know what these two markings mean. As such, they carry a symbolic message that needs to be read and understood. The stop line means “stop and give way” while the yield line means “give way”. In Sweden the stop line is always used together with the road sign “STOP” and the yield line always together with the road sign “Give way”. In Denmark (with rare snow-covered roadways) stop and give way lines may sometimes be used without accompanying road signs.

Conclusion 1:
Road signs in general and transverse road markings at intersections have a significant symbolic content. At the same time road markings along the road seem to convey information which is highly evident to the driver and therefore perceptual.

In order for the driver to be able to trust that overtaking on a stretch of road with a centre line without a solid line is allowed (under normal conditions), the criterion for implementing a solid line on the stretch with free visibility must be adapted to overtaking and furthermore be standardised. Today this is not the case, which means that drivers especially in the dark often do not have sufficient information to assess whether it is appropriate to perform an overtaking.

On narrow roads solid lines are often not used but instead centrelines are replaced by a warning line on stretches with limited visibility in one or the other direction. Because the driver does not receive any information from the warning line as to which direction offers poor visibility, the warning line conveys an obvious unclear message. This is not good at all.

Longitudinal edge markings have the potential of conveying symbolic information, however this is not utilised today. A solid edge line on a two-lane road for instance means the same as an intermittent line.

Conclusion 2:
There is huge potential to improve the content of information of longitudinal road markings in order to offer the driver better information.

After above analysis we end the discussion of road markings due to their high degree of “natural” information. Instead the next section will be focusing on road marks and road markings with their significant symbolic content.

8.3 Driver behaviour is perfermed at three ”levels”

The driver model (Section 2.6) states that the different behaviour of drivers can be classified into three levels based on their need for information. These levels have been named “control”, “guidance”, and “navigation”. The driver needs the least information when operating in the control level. This level implies that the driver will have full control of the speed and lateral position of the vehicle, which is a continuous task (the driver can in this case be compared to a control unit in a control system, whose task is to keep the vehicle inside a suitable “ideal frame” for both speed and lateral position.

The driver performs the control task automated. He is capable of this and he uses his excess capacity for tasks not related to driving the vehicle, which means that he is entirely thinking of something else. For instance he may be listening to the news on the radio, be talking to other passengers in the vehicle, plan the day’s work, think of recent experiences, etc. Even if the driver is concentrating on the driving task, he cannot do so for very many seconds before spontaneously beginning to think of something else again.

The next information level (“guidance”) implies that the driver while performing the control task is carrying out “tactical” manoeuvres of various kinds to reach the destination more quickly or to adapt to the requirements of a complex traffic situation. Examples of manoeuvres are overtaking, change of lane in heavy traffic, crossing a main road. In order to perform various manoeuvres, the driver must often make difficult (perceptual) assessments as to whether the manoeuvre is appropriate in the current traffic situation or not. His excess capacity from the control level is now instead utilised to make these assessments and then performing the desirable or necessary manoeuvre. During complicated manoeuvres the entire capacity of the driver is being utilised. He will be fully focused on the task until successfully completed. The consequence of this is that the driver during the manoeuvre will completely miss the content of the news on the radio or that the conversation with the front seat passenger will stop. He will also have missed any road signs passed during the manoeuvre.

The driver’s perception of the current traffic situation and his previous experience with similar situations affects his decision on whether to carry out the manoeuvre or abstain until later. Afterwards the road user will not be able to explain how he arrived at his decision other than that he for example found that the manoeuvre could be carried out in a safe manner. This proves that the task was perceptual and that the decision rested on the road user’s overall experience of the current traffic situation.

Only at the third and most demanding level of information (”navigation”) our unique human ability is utilised for the driving task. Symbol processing is a prerequisite for us to be able to think, speak, plan, interpret, and understand symbolic contents and to solve logical tasks and problems. The road user needs to be working at the “navigation level” to be able to read and understand the messages of road signs and road guidance signs. When solving his tasks at this level, the road user will while performing the control task at the same time be using his excess capacity to handle the different symbol processing tasks he is faced with in traffic. Also in this case, the road user can neither assimilate radio news nor continue the conversation with his passengers while performing driving tasks of problematic character. Furthermore, the road user has no capacity to simultaneously carry out any manoeuvres.

Out of the three “levels” of road user behaviour described above, the control level is the prioritised one since it is carried out continuously. The next most important one is the “guidance level” at which the road user adapts his driving as soon as the current road and traffic conditions require this. The symbol processing task (”navigation level”) is placed in the bottom of this task hierarchy. During this, reading of road signs and road markings is not a particularly high priority.

At the same time, these three levels of road user behaviour are not considered strictly separate and distinct from each other but are seen as a continuum. Thus, the road user will not “jump” from one level to another but “slide” between the different levels depending on how complicated the current driving task is and which skills it requires.

An example: The road user is driving alone without having to hurry on an unfamiliar road. Road quality is good; traffic is little, and most of the time the road user is driving automated. The road use is thinking of something else while he has a need to obtain information about the road ahead as early as possible. He therefore has good reasons to read the road signs, which he passes. As soon as the road user notices a road sign, he therefore briefly switches to “symbol processing level”, reads the sign, and assesses whether this is relevant to him, and finally quickly returns to automated driving. Road signs which do not convey any (useful) information are “filtered out”. What happens if the driver instead has passengers in the vehicle, with whom he is involved in an interesting discussion? The driver’s excess capacity is now very much engaged by the discussion. As a result, it gets more difficult to switch to “symbol processing level” and he will miss many of the road signs, which he noticed in the first case.

Another example: When the same driver, this time listening to the news on the radio, approaches a city, traffic becomes heavier. For this reason he is more alert when meeting various traffic situations on the road. As soon as something occurs in a relevant distance in front of him, he “switches” to “manoeuvre level” in order to quickly make the necessary assessments of the situation, take decisions and then act in a sensible manner. As soon as the manoeuvre is completed and traffic is flowing normally again, the driver reverts to automated driving while again perceiving what is said on the radio. In case the driver receives a call from his boss when at automated level, such a call will to a large extent demand his excess capacity. If at the same time an event occurs in the traffic in front of him requiring his “manoeuvre level” there is no excess capacity to handle this. Since the driver is unable to handle both of these extra tasks simultaneously, the competition for his attention arises. A “hands-free phone does not provide much help.

Conclusion:
The driver performs the control task automated and continuously (control level). He has the mental capacity to perform other tasks. At automated driving the driver uses his excess capacity to think of other things.

When performing various manoeuvres ("guidance level"), he uses his mental excess capacity to make perceptual assessments, take decisions, and finally carry out the respective manoeuvre. This task is perceptual.

In order to assimilate information from road signs and road guidance signs and to some extent also from road markings symbolic comprehension and problem-solving skills ("navigation level") are required. Unlike the driver's immediate perception of the physical road space (based on "natural" perceptual information) he must actively read each symbol in the road environment to assimilate the message.

The driver's mental excess capacity is utilised to read and understand the symbolic information after which it is used to perform problem-solving driving tasks.

8.4 The driver's collection of information from the traffic environment in general

When driving along the road, the road user gets a basic visual perception of the road space he is travelling through. The road user sees the road and what is happening on this at near distance (perhaps up to about 100 m in daylight), however he receives increasingly inadequate visual information from the road as the distance grows. This has several reasons. The most important one is that our eyes are not designed to adequately perceive events at far distances required by today's high speed vehicles. Visibility changes in the various parts of the road and in the vehicles and road users traveling on the road are from a distance far too small to provide the road user with the necessary information. The acquirable information is furthermore deteriorated from a distance because the free visibility along the road completely or in part may be obscured by the road itself or by objects at the side of or on the road.

The road user tries to compensate for this lack of information from the road due to the long distance by using his previous experience from similar situations and the expectations they create on the continuing road and the development of the current traffic. But as soon as the driver notices something in the distance, which seems unusual and which he cannot identify or recognise his curiosity is aroused (urge to investigate) which eventually directs his attention to the "interesting" area. The driver actively searches for all the information he can get as the distance decreases until objects or events are completely identified and their consequences for his driving become obvious. This process includes assessment ("guidance"), interpretation, and understanding ("navigation").

Road markings often have a very good contrast against their background. They attract the driver's attention and can therefore be detected from a far distance.

This may be a contributing factor to why drivers read a road sign. The driver also needs to be fed with early information about the increased demands from the road ahead. The purpose of the warning signs is to provide early warning to the driver about conditions he is yet unable to see or assess but which are situated in a relevant distance. The driver reads the warning sign and assimilates the message provided that he perceives the message to be relevant to him here and now.
Example: “Beware of sharp curve”, “Railroad crossing”, “Narrow road”, etc. The warning sign alerts the driver of a particular change or risk, which means that the driver will have an increased ability to face and act upon the danger.

In cases where the driver is driving on a well-known road the warning signs do not convey any particularly relevant information other than they remind the driver exactly where along the road he is. The likelihood of the driver not noticing a road sign is therefore great. But if the warning sign is temporary or has been set up at a location along the road where previously there were no road sign the driver is far more likely to read it. Assuming that the driver perceives the warning to be relevant this will impact his driver behaviour, otherwise he will not care about it. Examples of warning signs which are often temporarily installed: “Road construction”, “Elk”, “Loose gravel”, “Traffic jam”, etc.

In general, the messages on warning signs are directed towards all types of drivers, while the message on many prohibition signs are aimed specifically at drivers of certain types of vehicles (e.g. heavy duty vehicles). Thus the messages on prohibition signs are often irrelevant to people operating a vehicle. Prohibition signs must therefore often be ignored. Other prohibition signs such as “No stopping” and “No parking” are only relevant in cases where the driver has an intention to stop or park. Otherwise, the driver does not need to see them. Signs that do not carry any relevant message must of course are ignored by drivers.

Conclusion:
The driver tries to acquire messages on road signs that he believes are relevant while ignoring road signs without useful information.

8.5 Correspondance between the ”natural” information of the road and traffic environment and the messages of road signs and guidance signs

Assimilating information from a road sign requires an understanding of the meaning of symbols but also that we understand the impact of the message on our behaviour in the current environment. The driver’s immediate overall experience of the current road and road space always constitutes the main source of information for his behaviour (see explanatory model Section 2.9). At automated driving the behaviour rests entirely on this “natural” information.

As such, the messages of road signs are simply to clarify and reinforce the information conveyed directly to the driver through the physical design of the road. Only to a limited extent do road signs affect the driver's spontaneous experience of which behaviour is correct and which is incorrect in the current road and traffic environment. Another consequence is that a poor and therefore also misleading design of the physical road environment can never be rectified by means of signage. Significant physical changes are always required.

In order for a message on a road sign to have an unambiguous meaning this has to correspond well to the spontaneous perception of the driver in relation to the function of the road and how to behave on it. In cases where the symbolic message of a prohibition sign conflicts with the "natural" information in the design of the road, this creates various kinds of problems. One is that the driver does not "see" the prohibition sign and therefore violates the ban without even knowing it. Another is that the driver does not understand how to drive without getting "confused", which can result in unpredictable manoeuvres.

Conclusion:
The messages on road signs and road guidance signs have to comply with the "natural" information conveyed directly to the driver through the physical design of the road.

8.6 Understanding messages on road signs and guidance signs

Information on road signs is conveyed to the road user by means of symbols. This means that the driver has to know the meaning of each symbol. But this is not enough. He also has to actively be able to read the road sign in order to acquire its message. The driver, at least momentarily, must function on "navigation level". Because the message of each warning sign is general, the driver must also "translate it" to apply to the current road and traffic situation.

An example: It is early spring. I am running on a motorway I know well and suddenly see a newly installed road sign which makes me "switch" to "symbol level". The warning sign says "Loose gravel". This produces a picture in my mind of asphalt work. I think to myself that this is too early in the season. What could the reason be? After a short distance, I see that a few "potholes" on the road have been repaired. I now understand the specific meaning of the sign. I get an alert that there may be loose gravel on the roadway but quickly assess that most of the stones will already have been removed and therefore do not reduce speed. The same road sign faces me several times during the trip and I now know exactly what it means.

The messages on prohibition signs and mandatory signs, however, are absolute. They are of the type "You may not" or "You should". The difficulty in this case is that the driver has to perceive each such message as credible in relation to the "natural" information of the road environment. As stated in Section 8.5 there must be "congruence" between the "natural" information on the road and the symbolic messages on road marks and road guidance signs.

An example: In case the driver feels that he is running on a road with good speed standards and then notices a sign which for no apparent reason states a maximum speed limit of 50 km/hour, - problems will arise. The driver perceives the signing not to be trustworthy. He may believe that the road authorities have made a mistake. The likely outcome is that the sign-posted unjustifiable low speed is not obeyed.

The driver solves his navigation task by trying to find the best path to the destination. This means that he has to make a number of choices during his travel. The driver has an idea of what the road network and the landscape he travels through will "look" like. This idea is similar to the "mental map". Before the driver's orientation along the road takes him to the destination, it is important that those locations as specified in the road guidance signs (city names) as far as possible are selected to comply with the driver's mental map. The driver maintains a good orientation of the route when meeting the expected geographical targets in the road guidance signs. In case he instead meets other and unexpected locations in the road guidance signs, his orientation along the route will be diminished.

Since we as drivers almost never experiences being burdened by a road sign which has no relevant content for us, we seem to be equipped with a well-developed "skip function". We glance at the road sign and immediately assess whether this is relevant or not. In the latter case it is "filtered away" immediately. However, we quite often experience that too many road signs in the same location makes it impossible for us to read them in time and understand their overall meaning. The same goes for road guidance boards with far too much and often irrelevant information.

Conclusion:
In order for a road sign to be obeyed, it is a requirement that the driver feels that this has a distinct meaning in the environment surrounding the road, and that the message has a high degree of credibility.

8.7 The message of each road sign must be immediately relevant to secure reading of it

In the driver model (see Sections 2.4-2.6) we have described driving as an essentially perceptual task. This means that the driver behaviour mainly rests on the driver's immediate perception of the current road and traffic situation. Simple tasks are run by the driver on automated mode. The task gets more difficult when the driver needs to make a manoeuvre of some kind; he will have to do a perceptual assessment as to whether the manoeuvre is possible.

The driver performs one necessary manoeuvre (“guidance task”) after the other an immediate consequence of the current developing traffic situation. As such, the driver avoids working on “navigation level”, which means that he does not use his ability to plan even for the very near future so as to handle the traffic situation following the current one.

An example: The driver must drive straight through an intersection. As the first vehicle at the red signal he has stopped and is now waiting for it to turn green. Along the road – just on the other side of the intersection which he has to pass – two highly visible and easily readable road signs are placed. But the driver is focused just on the closest task – passing the intersection. He looks at the red signal, he looks around, and he notices that vehicles are stopping in the crossing direction. The driver’s expectation increases for the signal to turn green. The signal turns green. The driver starts and runs into the intersection, checking as a precaution that there are no vehicles in the crossing directions. When the driver has passed the intersection he orients himself to the new road. The problem is that he fails to read the road signs, which he passes right after the intersection because these cannot be read once the driver has entered the new road and is in need of the information.

Conclusion 1:
The driver must have an immediate need for the message on a sign for it to have any meaning for him. To ensure that the road sign is read, it must be placed at a comfortable reading distance.

The priority road sign is an example of a sign which is not consistent with the principle of the above conclusion. Priority road signs are placed on highways after each intersection. The purpose of the sign is to inform the driver that the crossing traffic must give way. Since all traffic entering a road from an individual (private) road or a country road by law must generally give way there is no relevant crossing traffic to the driver until the next intersection. For this reason priority road signs lack meaningful information. The drivers’ need for information on the other hand rises as soon as he approaches an intersection in which case he is informed by alternative road signs.

Conclusion:
Priority road signs are widely used even if in most cases they do not convey any relevant information. Drivers very likely do not “see” the sign.

8.8 Awakening the driver’s need for information from the road environment

Basically, there are two different ways of awakening the driver’s need for information. In traffic, the most important method is when the need arises because the design of the road and the traffic environment does not provide the driver with sufficient information with respect to how it looks and which requirements it will impose. The driver will then actively have to search for new and complementary information to establish an accurate idea of the road and the traffic further ahead.

The other method is initiated by the driver's personal needs. *An example*: The driver notices a shortness of fuel in the tank and he will soon have to refuel. If the driver is not familiar with the road and knows where the nearest gas station is, this means that he will actively start looking for gas station signs. If he does not find any he might try to solve the problem in an alternative way by reading road guidance signs to gain knowledge about the road and the distance to the nearest town.

Good advertising along the road does not only expose a brand but also points out where road users can have their everyday needs satisfied. When fuel runs low the gas station sign points out where the nearest suitable place to fuel is located. If the driver and his passengers are hungry, restaurant signs will tell them where they can eat. Company logos on signs are often also information for road users presenting the choices between different service stations, restaurant chains, etc.

Conclusion 1:
If the driver feels that he needs more information about the road and how to run, he seeks such information in the road environment. The driver will most probably read potential road signs in case these contain useful information.

For the driver to pay attention to a "problematic situation" along the road at a sufficient distance, this must be very visible in both daylight as well as in the dark and in poor visibility. Dark conditions are especially difficult because the insufficient visual information may cause the driver to spontaneously perceive the situation completely incorrect (visual illusion). Signage in the dark is therefore particularly important as this must not be misinterpreted.

Despite the high visibility there is a risk that the driver does not pay attention to a problematic situation because he has "focused his attention" on the road area behind this. An example is when a driver runs over a weak crest focusing all his attention on the next crest along the way thereby failing to see the intersection with clear markings, which becomes visible in the darkness behind the nearest ridge.

It is therefore an important principle to design the road so that a driver approaching the "problematic situation" cannot see the continuing road behind this. Such limitation of visibility along the road forces the driver to focus his attention to the "problematic situation" at the end of the road space. Only when the problematic section has been passed, the continuing stretch of road should "open up" to the driver.

Note: Our knowledge about how we direct our attention to various conditions and events in the road environment is deficient. Crests along the road seem to act as “trigger stimuli” for our attention. There are other designs with corresponding “trigger features”.

Another approach may be to change the “old” and “habitual” road e.g. before a newly constructed roundabout (in rural areas) in such a way that drivers no longer “know where they are”. The driver then switches from automated driving to consciously reorienting himself in the “new” road environment. The driver reads all the necessary symbols (road signs and road guidance signs) as “natural” information (physical design).

Conclusion 2:
The design of the road to a large extent controls the driver’s attention and ability to read the road signs and markings.

8.9 The driver’s collection of information on unfamiliar vs. well-known roads

The first time a driver is driving on a road, he is curious about how this will look and he will have a need to explore it. He is particularly attentive to detect potential threats and dangers along the road (e.g. unexpected curves). When the driver notices a curve in the distance, he tries to assess how sharp it is. At the same time he is actively looking for the warning sign “Sharp curve”. If the sign is there, he chooses a lower speed than he would otherwise have done. By being attentive to the design of the road like this while reading the road signs along the road the driver tries to gather all the information he needs.

Already after the first time on the road, the driver will have gained a useful picture of this which will be helpful during his next drive. A driver who on the other hand runs the road very often knows this in detail and knows exactly how to run it. Road signs and road guidance along the road are no longer the carriers of meaningful information.

Consequently, one cannot expect a driver to read a road sign along the road when he might have crossed that stretch of road hundreds of times. In case the road authorities change the speed limit signs by replacing the 90 km/h speed limit signs for the corresponding 70 km/h signs along a stretch of road without also having made an appreciable change in the physical design of the road, the road authorities have made it very difficult for the driver to detect the change.

An example: It took a driver several months to discover that the speed limit on his road to and from work had been lowered from 90 to 70 km/hour.

Conclusion 1:
When a driver is running on a road he does not know, he tries to acquire all the necessary information. There is a high probability that the driver will read all the information on road signs that is relevant to him. However, if the driver knows the road well, he has gained a good knowledge of the road and its requirements. Then there is no obvious reason to read the road signs.

If the driver is running in an unknown and complex traffic environment with heavy traffic (e.g. urban traffic) he must make an effort to operate the vehicle in a safe manner. He must constantly adapt to changes in the road and the traffic situation by performing various manoeuvres ("guidance level"). The task that remains is to read road signs and road guidance signs and make the correct choices to reach the goal.

The various tasks of the driver can be ranked in a hierarchy of tasks, from the most important to the least important task. Reading road signs and road guidance signs is the least important task to conduct a safe drive. This is because the driver often does not have time to read the symbolic information in the road environment. His capabilities simply do not suffice. Despite so, complicated traffic environments seem to function reasonably well. The explanation is probably that our most complex traffic environments require that drivers have learned how to drive in these after years of exposure.

Conclusion 2:
In order to obtain information from road signs and road guidance signs, the driver must have time for this after performing the preliminary driving task, which for safety reasons must be given top priority. This time is often not available in particularly "information dense" environments.

8.10 Overall conclusion

The analysis in this section shows that the traffic environments are often poorly adapted to our abilities and natural behaviours as drivers. This very much affects how well we succeed in discovering, reading, and understanding the symbolic content of road signs and road markings. The analysis leads to the general conclusion that there is great potential for improvement. This applies both to regulations for the design of roads and traffic environments in total but also specifically for how the regulations for road signs, road guidance, and road markings are designed.

9. Afterword

The work on the explanatory model and its application to the three problems "ghost driving", "speed adaptation", and "understanding of road signs and road markings" has served to increase our knowledge and understanding of how we as humans act as drivers or operators in the complex technical system, constituted by the road system. By better understanding how we function as operators, we can change the system in such way that we can perform the task better.

The aim of our explanatory model has not been that it should serve as the "truth" but that it should be better than the often unspoken (implicit) models of explanation and traditional habits of thought which continue to permeate our culture. The explanatory model is a summary of the behavioural theory which is relevant for driving, complemented by both empirical results and a long experience of driving.

From the general explanatory model, conclusions have been drawn with respect to possible improvements within the three areas of concern. These conclusions are often formulated in a clear and concise manner while in most cases having a lack of empirical foundation. Consequently, they are certainly not to be considered as "truths" but rather as possible hypotheses in future empirical studies. Many of the findings need to be confirmed before they can form the basis for revised design rules.

The work in part II of this project (See *Introduction* in p.5) has served to derive outcomes based on theoretical foundations that subsequently should be subjected to empirical testing. The results of such tests (case analysis part III) could then be used to improve the theory. Only through the development of theory supported empirical findings in a scientific process can we achieve increased and more general knowledge of how our road and traffic environments can be adapted to our abilities as drivers and road users.

References

Alexander, G.J. & Lunenfeld, H. (1986): *Driver Expectancy in Highway Design and Traffic Operations.* Report No. FHWA-TO-86-1, U.S. Department of Transportation, Federal Highway Administration, Office of Traffic Operations, Washington, D.C. 20590

Allen, T.M., Lunenfeld, H. & Alexander, G.J. (1971): *Driver information needs.* Highway Research Record, Number 366, pp102-115.

Brehmer, B. (1993): *Vad är det för fel på transportforskningen.* TF-nytt 3-93.

Campbell, B.E. & Middlebrooks, P.B. (1988): *Wrong-way movements on partial cloverleaf ramps.* Final report, Federal Highway Administration, Washington, D.C.

Darwin, Charles R. (1859): *"The Origin of Species".*

Gibson, J. J. (1986): "*An Ecological Approach to Visual Perception."* Lawrence Erlbaum, Hillsdale, NJ.

Gibson, J. J. and Crooks, L. E. (1938): *"A theoretical field-analysis of automobile-driving."* The American Journal of Psychology. Vol. 51 No.3, pp. 453-471.

Gunnarsson, S.O.(2000): *Felkörning på motorvägar ("spökkörning").* CHART Rapport 2000:1. Chalmers University of Technology, Dept. of Road and Traffic Planning, Göteborg.

Näätänen, R. & Summala, H. (1974): *A model for the role of motivational factors in drivers´ decision-making.* Accident Analysis and Prevention, No 6, 243-261.

Rasmussen, J. (1986): *Information processing and human-machine interaction: An approach to cognitive engineering.* North-Holland. New York.

Sagberg, F. (2003): *Påvirkning av bilførere gjennom utformingen av vegsystemet. DelIII: Spøkelsesbilister" – i feil kjøreretning.* Transportøkonomisk institutt, SM/1480/2003, Oslo.

Schneider, W. & Shiffrin, R.M. (1977): *Controlled and automatic human information processing: I. Detection, search and attention.* Psychological Review, Vol. 84, No. 1,
pp.1-66.

Törnros, J., Dahlstedt, S. & Helmers, G. (2006): *Spontant hastighetsval i olika trafikmiljöer i tätort.* VTI notat 9-2006, www.vti.se/publikationer, Linköping.

Wilde, G.J. (1982*): The theory of risk homeostasis: implications for safety and health.* Risk Analysis, Vol 2, pp 209-225.