RECOMMENDATIONS ON TUNNEL DESIGN AND SIGNALLING WITH REGARD TO HUMAN BEHAVIOUR

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CONTENTS

PREFACE

Key Words

Nomenclature

Loudspeaker: PA (public address system)
Emergency doors: evacuation or exit doors
SOS-station: emergency niche

INTRODUCTION

This document is a product of PIARC WG 3.3 and 3.4. It focuses on knowledge, literature, experiments and guidelines related to the tunnel design elements that directly affect user behaviour, acceptance or comprehensibility. The main goal of this report is to summarise this knowledge and to come up with tunnel design recommendations and guidelines, specifically taking the tunnel user and human factors into account.

When referring to tunnel user behaviour two traffic conditions may be discerned: **normal traffic conditions** and **crisis conditions**. In both conditions tunnel users will have to be informed both on the road **approaching the tunnel** and **inside the tunnel**. This led to the main structure of the report:

Part I: Normal traffic conditions

1) The situation of the user driving on a road ***approaching a tunnel.*** Recommendations for this situation intend to help the user to approach the tunnel under optimal conditions.

2) The **"normal"** ***traffic situations*** (flowing traffic and traffic queues). Recommendations concern specific measures that can be taken to ensure safety under these circumstances.

Part II: Crisis conditions

3) The ***crisis situations*** which are the primary focus of the Working Group. The aim is to guarantee that the user – in case of an accident or a severe event, from small breakdowns and accidents to tunnels fires – is aware of the situation, leaves his vehicle, if appropriate calls from the emergency phone, alerts or helps other tunnel users, goes to the emergency exits, goes out of the tunnel via these exits or stays in the shelters waiting for the arrival of the emergency teams.

Both parts start with a description of what is known in general about human behaviour, proceed with observations and conclude with recommendations.

Part III presents an overview of instructions concerning the signs and signals actually in use

PART I: NORMAL TRAFFIC CONDITIONS

1 MODELS FOR HUMAN BEHAVIOUR

1.1 Models of Human Machine Interaction

One of the most famous models of the way people process information is the "Human information processing model" of Wickens (2000, **Fout! Verwijzingsbron niet gevonden.**). It is based on years of experimental work and general applicable to many aspects of Human Machine Interaction (ground transportation, aviation, etc.).

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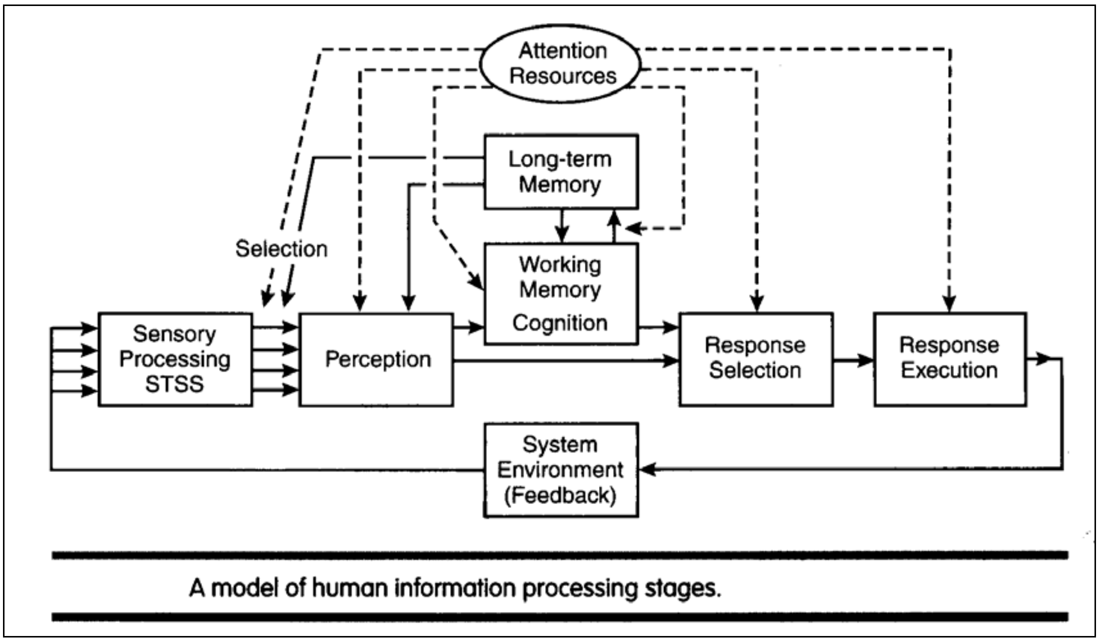


Figure 1: Human information processing model of a driver. (Wickens, 2000, ***Fout! Verwijzingsbron niet gevonden.****).*

Figure 1 gives an overview of the model, in which the process is illustrated by the arrows transferring information between different parts in the human central nervous system. A main factor in the model, that is also important when focussing on drivers in tunnels, is the *attention resource function* which in many respects determines the capacity and efficiency of the system i.e. in our case the human driver. If the mental resources decrease (e.g. due to distraction or fatigue) there will be an effect on one or more of the different parts described. For instance when a driver is tired has capacity to select information is reduced and also it becomes difficult to perceive the meaning of the information and to remember how to react on the information (perception and memory functions). For example: a driver with impaired attention capacity (due to stress or distraction) cannot select the relevant information or interpret the visual information correctly from the road (or tunnel) environment and thus will not react adequately

Steering is a good example of system - environment feedback based upon visual information from the vehicle itself and the environment. This information is being processed to form correct responses by turning the steering wheel through a feedback loop between the eyes and the hands.

Whereas Wicken's model is quite detailed, a second model that is relevant for analysing behaviour of road (and tunnel) users is more general. "Rasmussen's model of human behaviour" puts us on a very general level and can also be directly applied to Figure 1. (Rasmussen (1986), **Fout! Verwijzingsbron niet gevonden.**). His model of human behaviour has three distinct levels; *knowledge-based, rule-based and skill-based behaviour*.

In the driving context, using the gears, steering wheel etc normally is a mental process on the *skill-based behaviour* level. Skill-based behaviour can also be called automatic behaviour, which is the result of a direct link between seeing or hearing something and responding, without the driver thinking about it. Skill-based behaviour is shown when specific behaviour is highly trained and does not appeal at all to mental resources. The problem with skill-based behaviour however is that drivers may still respond this automatic behaviour even if it is not appropriate anymore because of changed situations. For example, when you just drive into a tunnel every day, it might be that you do not see the lights indicating that the tunnel is closed for traffic, since there is a direct link between what you see (this very familiar tunnel) and what you do (drive into it).

Interpreting everyday situations and scenarios as well as traffic rules and regulations are on the *rule-based behaviour* level. Here, people know what

rule to apply when a certain situation is encountered. So here drivers would apply the rules : If I see this, then I will do that. Problems at the rule-based level may occur in case people apply the wrong rule to the situation, or misinterpret the situation and therefore select the rule that applies to the situation they think is at hand.
Encountering new situations or locations will usually put drivers on the *knowledge-based behaviour* level, which is the most taxing of the three. Here specific knowledge has to be applied to the situation at every moment, so it is a very conscious way of interpreting information and responding to this. Since it is so demanding, it may be that there is task overload and drivers may not have enough resources to apply all relevant knowledge to execute the task.

This description of skill-based, rule-based and knowledge-based behaviour applies to experienced drivers only. Novice drivers will tend to find themselves on the knowledge-based behavioural level most of the time which is very mentally demanding. Experienced drivers will tend to find themselves on the rule-based behaviour level most of the time (but here above and hereunder experienced driving is described as on the skill based level??). The rule-based behaviour is not just a matter of laws and formal regulations, but more so, a result of individual experiences gained through exposure to the transport system. This reliance on experience to tell us “how” to drive and “what” to expect, also creates expectations.
This model of human behaviour is obviously very important when understanding and developing the interfaces between the humans and the traffic system that they are operating in. Under normal driving conditions, skill based (or more automatic) behaviour will be involved, but under specific situations (see also later, in crisis situations) this skill based behaviour needs to be transferred into knowledge based behaviour. This transfer takes time and it is hard to break through automatic behaviour.

1.2 Models of human behaviour in driving situations

A frequently used conceptual model of the driving task consists of three hierarchically ordered levels, *navigation*, *guidance* and *control* (Allen et al., 1971, **Fout! Verwijzingsbron niet gevonden.**). Tasks at the navigation level refer to the activities related to planning and executing a trip from origin to destination. The need for processing information only occurs occasionally, with intervals ranging from a few minutes to hours. The guidance level refers to tasks dealing with the interaction with both environment (roadway, traffic signs, traffic signals) and other road users. Activity is required rather frequently with intervals of a few seconds to a few minutes.

At the control level the motion of the vehicle is controlled in longitudinal and lateral direction. Information has to be frequently processed, ranging from intermittent activities every few seconds to almost continuous control. Alexander and Lunenfeld (1986) visualised the relationship between the levels by a set of nested triangles (Figure 2), hierarchically ordered from a low to a high level with an increasing *complexity* and from high to low with an increasing urgency (*primacy)*. For example, a flat tire or being suddenly confronted with a heavy wind gust will immediately interrupt activities at the navigation level and put all attention to the control level, since getting lost has less severe consequences than running off the road.

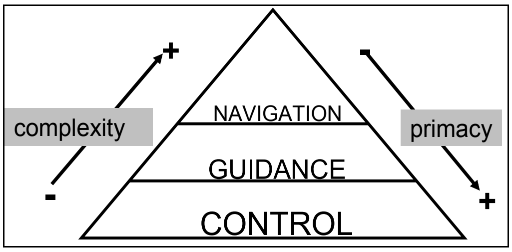


Figure 2: The three hierarchical levels of the driving task according to Alexander and Lunenfeld.

At each level of the driving task the successive steps of information processing (Figure 1), i.e. perception, processing and decision-making, and action occur. Moreover, the way a driver performs these tasks strongly depends on the routine one has developed in task performance (knowledge-based, rule-based, and skill-based). The choice of behaviour depends on interpretation and deductive reasoning. When a situation occurs frequently, then after some time a custom develops how to deal with that situation and recognising that situation leads to appropriate behaviour without a 'need' to understand exactly what is going on. Theeuwes (1993, **Fout! Verwijzingsbron niet gevonden.**) introduced a nice three-dimensional representation of the driving task as is given in Figure 3.

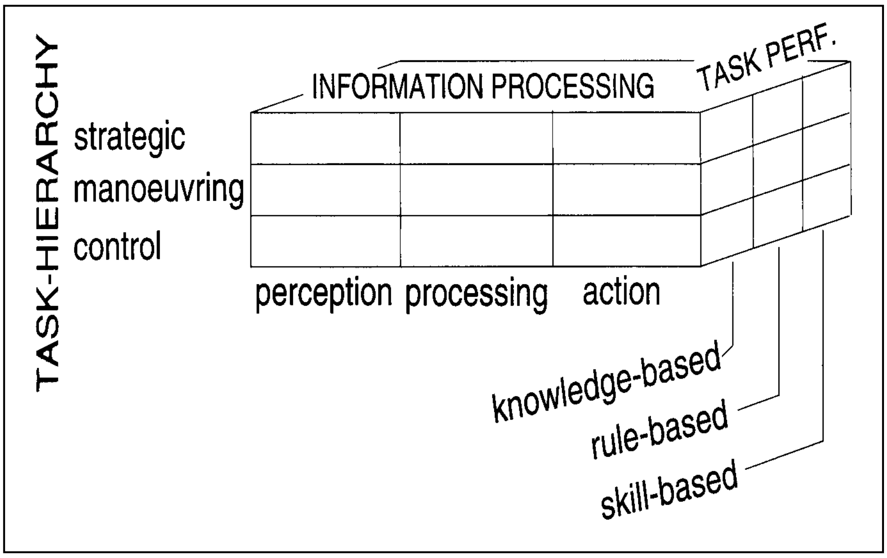


Figure 3: The driving task in three dimensions (Theeuwes, 1993).

It is obvious that also other aspects of the driver such as his intentions, attitudes, emotions and subjective norms play a role in modelling driver behaviour. One possible representation of this is given in Figure 4 .

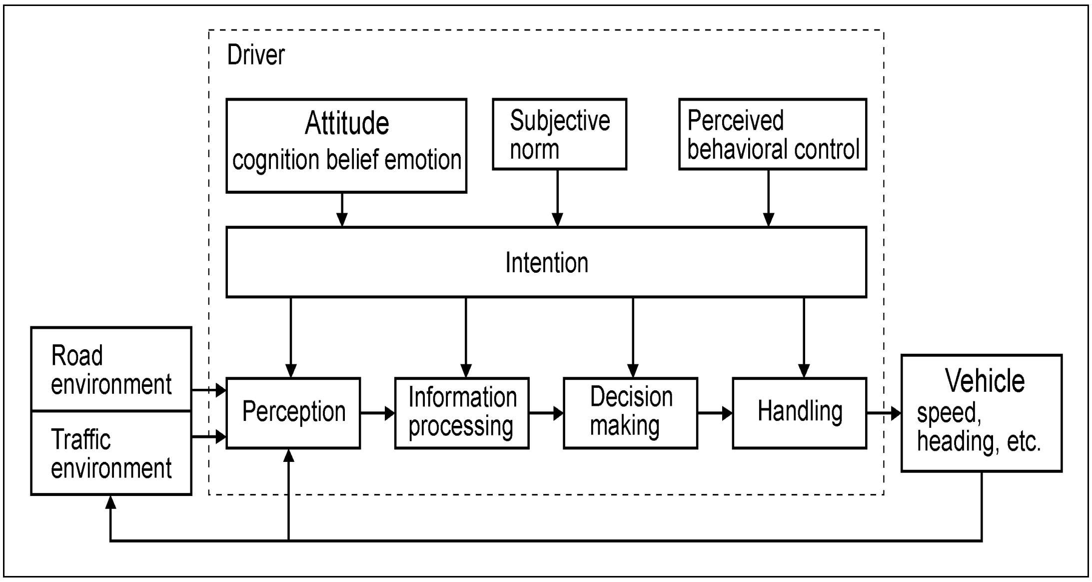


Figure 4: A driver behaviour model according to Van der Horst, (1998 ***Fout! Verwijzingsbron niet gevonden.****)*

1.3 Illustration: signposting panels

The process of finding one's way may illustrate the models. First of all when a driver has determined to go from A to B via a certain route, he will look for signs that will guide him to his goal.

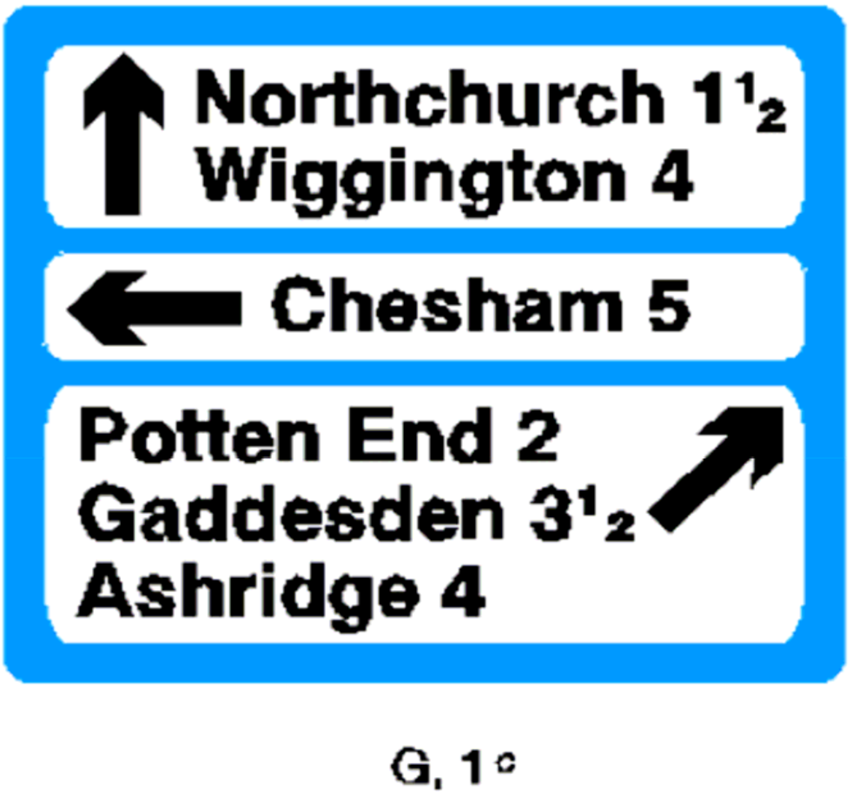


Figure 5: Example of Advance Direction Sign

That is why a number of direction signing panels have been developed:

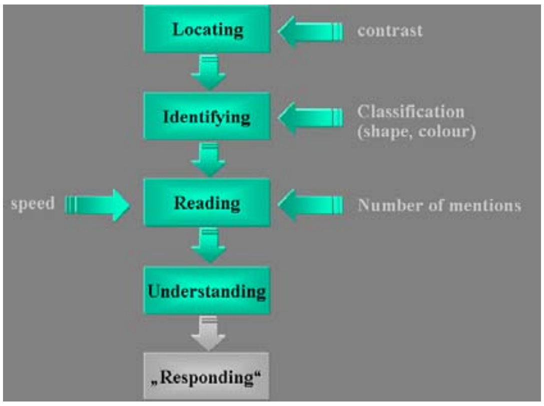
- Advance direction signs, to inform the driver about exits which might be of interest for him (see Figure 5). These signs are placed well before the point where the driver has to execute his decision in order to make up his mind. The signs may be even repeated.
- Direction signs (Figure 6) indicating the point where the action has to be taken,.
- Confirmatory signs (Figure 7) informing the driver about the direction of the road he is on.

Figure 6: Example of Direction Sign

Figure 7: Example of Confirmation Sign

But also the reading process of the panels themselves has to be taken account for.

Figure 8 is a copy of a figure presented in the PIARC publication on direction signing (PIARC 2006, **Fout! Verwijzingsbron niet gevonden.**) on a route associated with a tunnel.



In the first place a direction sign must be located, this means there should be contrast between the panel and its background; then the panel must be identified, i.e. classified according to its shape and colour; further the sign must be read, this means that the number of mentions on the panel should be limited depending on the driving speed; then the mentions have to be understood and finally the driver has to respond by choosing the right lane.

The PIARC publication on direction signing gives four principles see Figure 9:

It is advisable to take care that the same message is always conveyed by a panel of the same shape, same colour, and with the same symbols (principle of uniformity). Also, the same panel must always convey the same message and be reserved exclusively and everywhere to the same type of circumstance (principle of homogeneousness).

Regarding the installation of panels on the site, it is necessary that the users can easily identify the information they are aimed at (principle of concentration). Also, the users must be cared for permanently all along the route, thus implying a general signing schedule on an (inter)national level (principle of continuity).

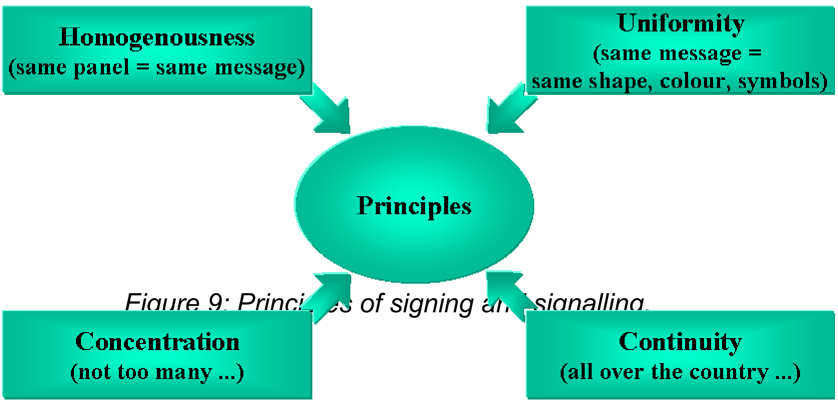


Figure 9: Principles of signing and signalling.

2 HUMAN BEHAVIOUR WHEN APPROACHING A TUNNEL

When approaching a tunnel there are several behavioural aspects involved. First of all, a driver has to decide whether he will actually continue on the route with the tunnel or whether he will choose a deviation in order to avoid the tunnel.

This is typically a decision that is not skill-based, but is knowledge based. (In the majority of cases it will be skill based. Only truckers carrying dangerous goods and people with tunnel fear, both not familiar with the tunnel will maybe puzzle, BenR.) If one knows the arguments for using the tunnel (e.g. shortest route, not too much traffic, only motorway) and the arguments for not using the tunnel (e.g. one is driving with goods that are forbidden inside the tunnel, one is afraid of tunnels), they are weighted along subjective standards and the outcome will either be continue (and use the tunnel) or use a deviation (and not use the tunnel).

Drivers who are not familiar with the tunnels in the they have to cover will have to pay much attention to the direction signing. As there generally is not enough space in the tunnel for the normal direction signs indications will be given in front of the tunnel.

Due to financial and technical constraints, the lateral clearance in tunnels and on the ramps towards them is often minimized to a degree that is generally considered unacceptable in open road design. Research findings (Blaauw and Leebeek (1974, **Fout! Verwijzingsbron niet gevonden.**), Blaauw and Van der Horst(1982, **Fout! Verwijzingsbron niet gevonden.**)) show that the proximity of the wall (of the ramp and tunnel) to the lane one is driving on, has an effect on perceived narrowness of the tunnel (not always on a conscious level), and consequently on driving behaviour. Drivers when approaching the tunnel portal increase the distance to the side wall of the tunnel entrance ramp. This is not observed when the emergency lane continues on the ramps and in the tunnel. Lateral displacement does not have to reduce traffic safety in itself, but it may decrease safety if, due to the limited space, traffic in the right lane moves to the left and traffic in the left lane moves to the right. This may lead to interference between traffic in adjacent driving lanes. Another effect of the reduction of the lateral clearance is a reduction of speed when entering the tunnel. (Theeuwes et al, 1995, **Fout! Verwijzingsbron niet gevonden.**)

On the other hand, the speed reduction can also be the result of the high amount of stimulation in the visual periphery. Research shows that too much stimulation in the visual periphery (about 30 degrees left and right of the fovea), is considered very unpleasant (Yamanaka & Kobayashi, 1970, **Fout! Verwijzingsbron niet gevonden.**). If the value of 2 rad/s of angular velocity is exceeded, drivers adapt their position and speed to avoid disturbing effects (Van der Horst & Riemersma, 1984, **Fout! Verwijzingsbron niet gevonden.**, Blaauw & Van der Horst, 1982 **Fout! Verwijzingsbron niet gevonden.**). A tunnel wall that is positioned close to the driving lane provides a relatively high amount of visual stimulation. Since changing lateral position does not solve the problem in single lane tubes, reducing speed is the only solution.

Research shows that road users focus their attention on the tunnel entrance some time before actually entering the tunnel (Narisada & Yoshikawa, 1974, **Fout! Verwijzingsbron niet gevonden.**, Verwey, 1995, **Fout! Verwijzingsbron niet gevonden.**). During the last 150 m before entering a tunnel, many drivers directed their eyes to its entrance, while the eye blink frequency decreases about 200m before the tunnel entrance. The drivers' attention is focussed on the tunnel entrance, and not to the environment in front of the tunnel, resulting in the loss of the information provided through signs and signals. On the other hand Eberl (2002, **Fout! Verwijzingsbron niet gevonden.**) reports about the assessment of different tunnel entrances in Austria, from which it becomes clear that the architecture of tunnel entrances influences the feelings (confining, dangerous,, good guiding properties, informative, slowing down effects) when approaching them. (BenR)
First results from a Czech study in the frame of the OPTUN project (optimisation of tunnels in Czech Republic) even show different EEG patterns in road users driving on open roads and those driving inside a tunnel. In the section when just entering the tunnel leads to the largest results, suggesting that this transition area from the open road to just inside the tunnel may be the most loading part. After having been in the tunnel for a longer period, the difference seems to decrease again. (This is in accordance with the observations earlier, BenR)

When approaching the tunnel entrance the sight on what is inside the tunnel almost never is clear. That is why often a reduction in speed is observed in area just in front of the tunnel portal. This is not only due to the great contrast of luminance between the surroundings of the entrance and the tunnel entrance itself, but also to the amount of stray light in the eyes of the driver.
Kayser and Pasderski (1991, **Fout! Verwijzingsbron niet gevonden.**) investigated the effect of different ratios of lighting levels inside and outside a tunnel on vehicle speed in a real life driving situation. They made a distinction between different tunnel parts, each with their own pattern of luminance. Despite a large range of differences between the luminance inside and outside the tunnel, no effect was found on driving speed. The distribution of speed differences was about the same for each class of luminance difference (difference in L_a/L_i ratio, where L_a is the luminance the eye is adapted to and L_i is the luminance inside the tunnel), which means that speed was found to be independent of lighting ratio. These observations allow the conclusion that under normal traffic circumstances, driving speed at tunnel entrances is not affected by the lighting ratio that characterizes the transition from light to dark.
However a Norwegian study (Amundsen & Ranes (1998, **Fout! Verwijzingsbron niet gevonden.**)) into the locations of accident revealed that tunnels without lighting most accidents happened in the section between 50 m in front of the tunnel entrance and 50 m after the tunnel entrance. After the installation of lighting in the tunnels the accident rate diminished considerably (BenR).
Moreover Japanese studies (Yonekawa, (1998, **Fout! Verwijzingsbron niet gevonden.**)) into the effect of brighter tunnel cladding and/or applying illuminating lane markings showed that the decrease in velocity around the tunnel entrances became less and the capacity of the tunnel in peak hours increased (BenR).

3 HUMAN BEHAVIOUR INSIDE TUNNELS

This chapter will focus only on driving in tunnels under normal condition, which means that nothing particular will happen (no accidents, no car breakdowns or fires). However, traffic queues are considered to be part of normal traffic and will therefore also be part of this chapter.

Psychological studies on tunnel safety performed in Austria (Eberl (2002, **Fout! Verwijzingsbron niet gevonden.**)) showed that quite some drivers perceive many of the tunnel characteristics extremely consciously (probably due to increased alertness) and that drivers respond quite differently to different tunnel designs in terms of driving behaviour. Tunnels that are assessed as positive by drivers, e.g. due to good lighting or good guiding properties by means of illuminated kerb reflectors, do not have a negative effect on driving behaviour.

Tunnel fear and estimating distance

Driving through tunnels may lead to increased uncertainty and fear. This fear is partly the result of the experienced threat of getting stuck inside the tunnel in case of possible traffic incident. In a driver interview on fear in tunnels, (Christensen et al., 1993, **Fout! Verwijzingsbron niet gevonden.**), two main drivers' anxieties were mentioned, the fear of hitting anything (e.g. an object, the tunnel wall or other vehicles) and the fear for dangerous situations (in case of a fire or a tunnel collapse). This second fear makes the underwater tunnels more fearful than others.

Various surveys were conducted in order to qualify the factors that influence the drivers' behaviour and their fear when driving through tunnels (Amundsen, (1992,**Fout! Verwijzingsbron niet gevonden.**) and Christensen et al., (1993, **Fout! Verwijzingsbron niet gevonden.**)). In these surveys, a small percentage of users reveal that the longer the tunnel the more fear they experience. This can be explained by the fact that if driving in tunnels is considered to be dangerous, driving in long tunnels leads to longer exposure to this dangerous situation. Although the percentage of people that is really scared is rather small, this small group can have severe implications for the homogeneity and safety of the entire traffic flow.

The problems experienced due to tunnel length also seem to depend on its design. A long tunnel becomes more acceptable for the majority of the road users, if its geometric characteristics are not designed in an extreme way (e.g. long stretches, curves, steep slopes downwards at the entrance and steep slopes upwards at the end of the tunnel, etc).

Extremely long tunnels should be avoided if possible. A possible solution could be to split the tunnel in smaller ones (a sequence of short tunnels), reducing the fear and keeping safety in acceptable levels. However, this solution in many cases will be impossible, or may generate problems to the users in terms of their sight adaptation. In that case, artificial solutions are also an option. SINTEF in Norway conducted a driving simulator study evaluating the effect of the selected interior design of the Lærdal tunnel on the main road between Oslo and Bergen. At 24.5 kilometres long it is the world's longest road tunnel. The purpose of the study was to evaluate four alternative interior tunnel designs and to investigate to what extent interior design solutions can increase safety and comfort as well as reduce anxiety and monotony. Sixteen subjects (???) were studied on a simulated road in open landscape, in excising (???) tunnel environments and in the simulated environments of the future tunnel. The results showed that speed, driving behaviour and subjective risk experience varied as a function of interior design. The interior design in the alternative of the "Rock Crystals" received the highest scores. In this alternative, artistic colouring and lighting was used in rock caverns (see Figure 10), strongly lit niches and lay-bys, a new distance sign concept, colour coding and use of two continuous hollow light tubes halfway down the tunnel wall to both sides.

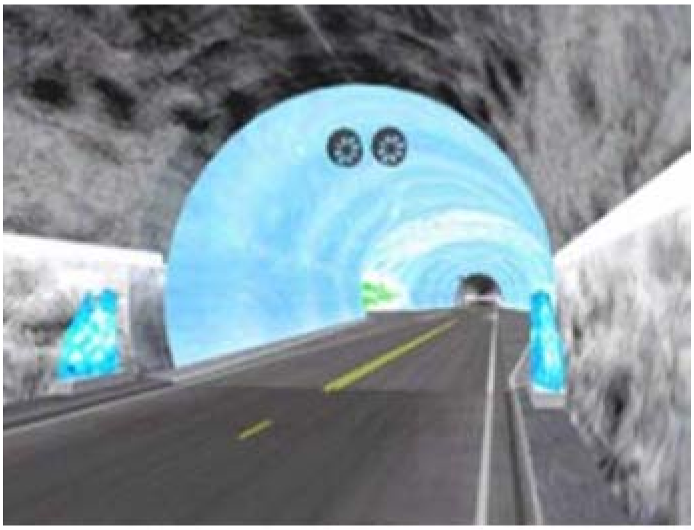


Figure 10: the Rock Crystal design in the Laerdal tunnel.

Figure 11: The Crystal arcs.

Crystal arcs were preferred as distance information by 63% of the drivers and it also received high scores for reducing monotony. Red and yellow colours can create an illusion of tunnel fire and should be avoided in tunnel interiors. Sudden large black unlit gaps (ventilation tunnels, off axis turnarounds etc) can be frightening and cause drivers to swerve. Continuous lighting with hollow light tubes reduce flicker and increase comfort. Continuous light tubes on both sides of the tunnel create a feeling of width. A double row of lights above the centre line on a two-lane road tunnel creates a feeling of height. Rock caverns with artistic interior design or projection of landscapes, trees etc can increase comfort and safety and reduce monotony in long tunnels. Rock caverns with grey concrete walls have minimal effect on speed, monotony, and subjective experience of safety and comfort. Drawing the light out in the mouth to both sides of a rock cavern extends the cavern (what does this mean??? BenR) and the experience of a break in the driving rhythm. SINTEF recommends that besides rock caverns every 6-km special measures should be used in extremely long tunnels in order to reduce monotony. For instance crystal arcs or strongly lit S.O.S-stations and lay-bys.

Road users perform poorly when they have to estimate how far they are inside the tunnel, as was shown in the SINTEF driving simulator study in the frame of the UPTUN project (Martens, 2005, **Fout! Verwijzingsbron niet gevonden.**). After a first drive through the virtual tunnel, drivers were asked to estimate the length of the tunnel. Further, following the second drive, the test persons were asked to estimate how far into the tunnel the accident (????) occurred. People thought they were further in the tunnel than they actually were. This means that this underestimation may lead people to walk towards the traffic exit or entrance if they think they are very near. An indication would therefore be useful (even though this may also cause some fear if people see they still have to drive 10 km longer inside a tunnel).

Speed and keeping distance

Noizet and Mourey (2005, **Fout! Verwijzingsbron niet gevonden.**) report about a second WP1 study in the frame of the French ACTEURS project. The study was aimed at better understanding the actual tunnel users' behaviour and difficulties when driving in a tunnel under normal circumstances. Three methods were used: interviews with 10 drivers, a survey under 620 people at four rest areas just after having passed a tunnel and observations of 16 drivers in a short and in a long tunnel. Results suggest an overall lack of knowledge or inaccurate knowledge ("beliefs") of tunnel equipment and operation, specific driving rules and appropriate behaviour. Even professional drivers did know very little about tunnels.

It was also observed that most of the users had difficulties in perceiving information provided before and inside the tunnel. Users don't adjust immediately their behaviour to the specific tunnel environment. It takes a while: first, they focus on reaching the maximum authorized speed. Then they work on adjusting the distance to the forehead vehicle, not understanding the specific device (in the Mt. Blanc tunnel?? BenR) devoted to help measure the distance. Whatever the tunnel, it is only from the second third of the tunnel that users pay attention to the tunnel infrastructure, starting to notice signposts (=SOS-stations? BenR), emergency exits, etc.

Keeping distance to traffic ahead is considered of major importance for safe tunnels and at the same time a rule that is almost impossible to enforce.

Information derived from TNO and the UPTUN study (Martens, 2005, **Fout! Verwijzingsbron niet gevonden.**) indicates that even though people are informed about the fact that they should keep sufficient distance to the lead vehicle, they did not when coming to a stop.

Use of radio

If the radio stops playing or speaking when entering a tunnel this immediately creates a unpleasant atmosphere to the car driver and his passengers. On the other hand this (stopping of the radio) can increase the awareness of the driver of the special driving conditions and the related conduct. (BenR, agree??)

The original reason to enable radio reception in tunnels is to alarm tunnel users in case of accidents, especially fires. However this only was possible by overriding the radio broadcasting of a limited number of radio stations. This requires the mentioning of the relevant station before the entrance of the tunnel. This again deprives the driver from his favourite station and forces him to find the indicated frequencies which might endanger his steering performance.

More recently special radio frequencies are used to inform tunnel users continuously about the way how to conduct in the tunnel. In the Mt. Blanc tunnel there are even special frequencies for different languages.

In the UPTUN driving simulator study (Martens, 2005, **Fout! Verwijzingsbron niet gevonden.**) TNO found that even though people had just read a folder with the radio frequency in it, they either did not use the radio, or they wanted to use it but mentioned they forgot the frequency. Also, some people think they cannot receive any signal inside the tunnels.

When only tunnel broadcasting stations can be received in tunnels which constantly repeat the same message drivers will be induced to listen to other music. Moreover it is questionable whether the messages are understood well.

The ACTEURS project in France showed that professional drivers are seldom listening to the radio (comparison Mont-Blanc/Fréjus: the number of broadcast frequencies seems to affect the listening rate). Another project

DREIF (ref.???) showed that when there is a stake for the users and feedback as pertinent/adapted service, the users apply the technologies they are proposed to. (I do not understand this, BenR).

Signs

In order to obtain the right behaviour of the drivers it might be necessary to repeat signs given at the road leading to the tunnel. For instance speed limitation, keeping distance, prohibition to overtake. (Is there any literature about this item? BenR)

The ignorance of inexperienced drivers to drive properly in road sections with steep grades and tight curves, can lead to inappropriate braking patterns whereas time pressure can lead the professional and experienced drivers to accept unnecessary risks (Têtard & Roumegoux, 1993 **Fout! Verwijzingsbron niet gevonden.**).

Providing information about the presence of upcoming curves and gradients and indication of the most optimal driving behaviour, unsafe situations may be avoided. Besides indicating problems, signs may also designate the safety level inside the tunnel. People report that a sign indicating that the situation inside the tunnel is safe would reduce their anxiety, because the presence of this message would indicate that the tunnel is being monitored (Amundsen, 1992). This is not clear to me, BenR

Sometimes it is necessary to use road signs to mark a sharp curve or an upcoming exit.

Signs for self help

In the future more people will be informed about how to behave in tunnels in normal circumstances and in crisis situations. They will be informed about emergency stations and emergency exits. It will surely reassure tunnel users when they recognise these stations, emergency exits and signs leading to these exits when there is no crisis situation. Therefore it is recommended to clearly indicate the stations and emergency exits and the signs leading to the exits. For more information about this point we refer to part 2 of this report.

4 RECOMMENDATIONS FOR SAFE DRIVING TOWARDS AND INSIDE TUNNELS

Information to be provided before ramps leading towards a tunnel

When approaching a road section leading towards a tunnel sufficient information should be provided without an overload of information. Especially information about the regulations valid for the route through the tunnel should be provided in a proper way, allowing sufficient rerouting decision time.

The following information might be provided:

- Permitted height of the vehicles
- Tunnel category with respect to allowance of dangerous goods (e.g. no gas or no toxic gases)
- Tunnel length when the tunnel is more than 500 m long (so that people with fear of tunnels can decide to use another route)
- Toll regulations (if applicable)
- Route information in case of route choices inside the tunnel or just after the tunnel (See also PIARC publication on tunnels and road signing)
- Alternative route information (tunnel bypass route, if any)

Extra equipment, such as height detection systems may help human error. At various tunnels, these systems are applied and unfortunately they regularly have to come into action by means of the tunnel operator. Apparently truck drivers do not know they are too high or they do not respect the rules.

Information to be provided at the ramps approaching a tunnel

According to the *Human information processing model* it is often the case that the environment causes an information overload which should be avoided by the system provider. Do not use too many signs and design the signs and the surrounding to make it easy to find the way and “self-explainable” as much as possible. Thus, there is a fine line between information overload and the necessary amount of information (signs) to assist the driver to feel both safe and comfortable. The following guidelines may be given:

1. It is recommended in the first place to present the information at great distances before the tunnel entrance (at least 200 m).
2. Do not provide too much information on a sign.
3. As the drivers attention can be diverted or information can be hidden by other traffic the signs should be placed at both sides of the road.
4. When the required conduct is very much differing from the conduct that is normal on the road (for instance speed reduction) the attention of the driver might be attracted by blinking signs.
5. Also the driver might not give much attention to the signs (due to fatigue for instance). Therefore it is recommended to repeat the most important signs, depending on the amount of traffic and its composition (e.g. many strangers) and the characteristics of the tunnel.
6. Finally it is recommended that all requirements in the tunnel be valid already from the point where the information is given. For instance: speed limitation, keeping distance, turning on the radio (this requires the radio signal can be received also outside of the tunnel)

The following information might be provided:

- The tunnel sign, speed reduction, keeping distance to vehicles ahead, prohibition for trucks to overtake
- Warning for section speed control
- Radio frequencies, if any
- Safety information (emergency telephones, emergency exits etc.) <u>???In my opinion here signs and signals indicating queues, the closure of traffic lanes or total closure of the tunnel has **utmost** priority. BenR.</u>
- The name of the tunnel (only when it is deemed essential)
- <u>In case of a road section with many tunnels closely one after another it is not necessary to repeat all the information</u>. (BenR)

To restrict the amount of information provided when approaching a tunnel entrance, priority should be given to information in direct relation with safety. More specific information, e.g. there could be a case where the conditions inside the tunnel are more uncomfortable than outside, there could be prewarnings preparing road users for conditions inside the tunnel. This could for example be the case if there is a low sun, which does not cause any glare inside the tunnel but does so when driving out. Another possibility is the situation that there is dry road surface inside the tunnel and wet outside the tunnel, which often happens in case of rain.

Lateral clearance of approaching ramps and in tunnels

The ideal situation would be if lateral clearance on approaching ramps and within tunnels would not differ from that on open roads. However, if for some reason the design of a tunnel requires limitation of dimensions in some way, there should be enough time for drivers to get used to the new dimensions to avoid any radical changes in driving behaviour. A smooth transition should be provided between the standard open road, the road part approaching the tunnel and the tunnel entrance, without any sudden narrowing. It is yet unclear to what extent reduced road width in tunnels is acceptable. Anticipation of the road lay-out seems necessary to prevent uncertainty about the available manoeuvring space and lane width should be sufficient (3.30 m - 3.60 m) to avoid interfering actions from passing cars and to improve the driving conditions for heavy vehicles. For more information about the geometry of tunnels reference is made to PIARC publications on Cross Section Geometry in Unidirectional Road Tunnels (2001, **Fout! Verwijzingsbron niet gevonden.**) and Cross Section Design for Bi-Directional Road Tunnels (2004, **Fout! Verwijzingsbron niet gevonden.**).

If the lateral clearance has to remain reduced due to financial or other constraints compensating measures like speed reduction, reflectors or LED's, should be taken.

Design of tunnel entrances and of tunnels

It is recommended to pay utmost attention to the architecture (design) of tunnel entrances and of the tunnels themselves. Experience has shown that simulator studies can help choose the best designs.

In these studies also attention should be paid to light conditions at the tunnel portals in order to prevent blinding or too less contrast when entering the tunnel.

Light and painted patterns at the walls can contribute to break the feelings of an endless tunnel and moreover provide information for better orientation of the driver

Lighting and Guidance of traffic

For a safe driving conduct it is of utmost importance to have a good lighting system in the tunnel. More information is available in national and international directives and handbooks.

Other means to help drivers are well visible or audible traffic lane markings as well as visual guidance of walkways or barriers (reflectors of LED's).

Information to be provided inside the tunnel

The special rules for the specific tunnel might be repeated several times to confirm the required conduct.

Signs to indicate great gradients or sharp curves

For long tunnels inform tunnel users about the distance yet to be covered.

Clearly indicate the stations and emergency exits and the signs leading to the exits.

Speed

The speed (especially the maximum allowed speed) is information of primary importance to all users, it is objective information, and it should be easy for everybody to see the information. It would be advised not to change the speed limit in front of tunnel, but to change this speed limit (if required) about 2 km in front of the tunnel. In that case behavioural changes have already taken place when one enters the tunnel. In case of excessive speeds, trajectory speed control would be a good solution, as long as it is well indicated that there is trajectory speed control. Having a speed camera would lead to sudden changes in speed, and especially large speed variance in front of tunnels does negatively affect traffic safety.

Keeping distance

Inform tunnel users about the reasons to keep enough distance by means of information campaigns. When approaching a tunnel a sign or message could be developed to remind tunnel users and in the tunnel signs and signals can help to keep the distance. Possible future developments may be ACC-type of systems that automatically keep distance to a lead vehicle in tunnels.

The studies under progress on the development of Advanced Driver Assistance Systems significantly help the users to keep their distance in the future.

Radio

In order to provide road users with the most updated information (about what??, not crisis situations), the optimal solution is to broadcast radio messages on all radio frequencies inside the tunnel. In long tunnels, connecting areas with different radio stations, special tunnel radio in various languages might be provided. BenR

The RDS-type broadcasts should only be received in the specific tunnel one is referring to and the very near surrounding. Otherwise, the message could be misinterpreted and lead to improper responses in other tunnels.