PART II: CRISIS SITUATIONS

In this part, we will discuss the human behaviour issues when encountering a crisis situation inside a tunnel. With crisis situation, we refer to anything from a car breakdown or an accident to a tunnel fire.

1 HUMAN BEHAVIOUR IN CRISIS SITUATIONS

1.1 Human behaviour in situations with fire, not associated with tunnels

It is important to realize how humans in general behave and react during a catastrophic situation in order to understand human behaviour during an emergency escape in a tunnel. It is clear that the human mind passes a number of stages from the occurrence of an accident until the situation is safe and back to normal again. If it is evident that an emergency escape must take place humans should be able to make this decision as early as possible in the process. It is also important to note that humans during critical situations always tend to fall back to what has been learnt before (Kecklund and Anderzén, 2005, **Fout! Verwijzingsbron niet gevonden.**).

A moderate level of stress can result in adequate human reactions in order to minimize danger or escape from a dangerous situation, e.g. in the mobilisation of extra energy or increased attention to handle a threatening situation. In terms of the Rasmussen terminology the person shows *knowledge based behaviour*. When the time is perceived to be too short for escaping an imminent danger, this can result in a state of *hyperactivity*. which is a high level of stress. This usually means that a person cannot make a correct judgement of the situation in order to evaluate different action alternatives or escape possibilities. This is the result of a decreased decision making capacity during a stressful state. Humans during critical situations tend to fall back to what has been learnt before and follow their first impulses. An example of this is when persons start running towards the entrance of the tunnel during a fire instead of looking for emergency exits.

On the other hand if an individual in a similar situation shows no or very little stress activation this may indicate a form of *denial* and *avoidance reaction* which can decrease the perception of danger and even obscures important signs of danger. Similar reactions can take the form of inattention, memory loss and actual distortion of the warning messages which may lead to *passivity* and not being able to take actions for self-protection (Kecklund and Anderzén, 2005,**Fout! Verwijzingsbron niet gevonden.**) .

Other typical human reactions in an emergency situation are an emotional denial of the emergency situation which could be looked upon as a kind of general shock reaction. This can also give rise to perceptual distortions in the timing of an event, i.e. that it is perceived in slow motion.

Even when there are indications of danger (like smoke), people may not be conscious of the severity of the situation, i.e. people may not perceive a threat from the environment as strong as to take any protective actions. Therefore, it might be more interesting to stay safely in the room, listen to music and wait instead of running out to start looking for the nearest emergency exit. The human response becomes more adequate first when the danger is obvious and is accepted by the person, however, the reaction still depends upon the person's state of activation and/or stress.

Many international reports about human behaviour in critical situations indicate that the most common reaction of human who experience a fire is a disbelief of the situation and an underestimation of the actual risk. This is evidently the case in the initial phase of a fire with little smoke and fire. At this point there are also very few individuals who are willing to evacuate.

Based upon experimental studies in addition to more realistic evacuation tests and exercises it has been shown that evacuating persons need approximately 5 to 15 minutes to decide whether they should do anything at all and finally what to do.

Other studies from earlier stages of an evacuations show a typical behaviour pattern characterized by uncertainty, confusion and inefficiency (Sime, 1980,**Fout! Verwijzingsbron niet gevonden.** ; Sime and Kimura, 1988, **Fout! Verwijzingsbron niet gevonden.**).

In stressful situations it is also very difficult to change the normal pattern of behaviour based upon previous experience and learning. To change behaviour in a more safe direction (if necessary) it is vital that new information is presented in a clear and understandable way in order to facilitate adequate decisions of how to react and behave in the critical situation.

The following is a copy from a paper presented by Noizet and Mourey (2005, **Fout! Verwijzingsbron niet gevonden.**) on some results of the ACTEURS project.

Except the remarkable studies of the TNO (2), very few analyse are dealing with crisis situations in a tunnel. Consequently, we enlarged our literature review with studies and analysis dealing with crisis in confined environments (buildings, theatres, underground parkings).

The review gathered 150 scientific references based on real crisis analysis. We then transposed what we learned from these studies on how people react and what kind of recurrent behaviours were observed to the tunnel environment and its specificities. This work led to a model of users egress in a tunnel in crisis situation.

3.2 How are psychological processes impacted by a crisis situation?

A crisis means time constraints and a potential high level of stress. These conditions impact the way people perceive, think, analyse, make a decision and react, and as such induces specific behaviours.

Under normal conditions, dealing with a situation implies to understand it and react according to the perceived risks, notably managing the risks inherent to the decision we make. In a tunnel these decisions mainly concern the driving activity taking into account the tunnel specificities and rules (speed control, distance with the preceding vehicle).

Under crisis conditions, the processes of decision making and risks management have different implications. Two main factors impact these psychological processes: the emotional state of the person experiencing an acknowledged risk (burn, smoke intoxication, death, etc.) and time pressure. By nature, an individual will always choose the best trade off between the maximisation of his/her profits (reach his/her goals while preserving his/her physical integrity) and the diminution of cognitive and psychological strain linked to making a decision under time pressure.

This trade off mechanism depends on several factors:

- The *initial knowledge* and/or the quality of the information locally provided to the user: To understand a situation, one uses both some existing initial knowledge as well as some information which is provided in real time. The better the understanding, the more appropriate the reaction of the user.
- *Psychological biases:* Under high stress and time constraints, some psychological mechanisms take place to enable the decision making and mitigate the effects of time pressure on it. In return (compensation), these mechanisms affect the environment perception, information processing, understanding and the results of the decision making. Also called psychological biases, they will result in natural tendencies such as:
  - Oversimplification, expedite reasoning and self-acknowledgement of the relevance of the decision made to avoid questioning it (3)
  - Minimising the risks which favours either the solutions one is familiar with or the first option from the top of one's head, like driving towards the entrance of the tunnel to get out of it (4).
  - Denying any solution with a negative connotation like not using the emergency exits because their access is usually forbidden ("don't enter except in case of emergency"), even if the prohibition only concerns normal situations (5).
  - Peer pressure and group dynamics can also influence decision making in crisis situation. Natural leadership can locally take place, organising and optimising the egress time of a group of people (6). Group conformity bias leads people to align their behaviour to the behaviour of other people.

To summarise, whatever the environment and the situation, **attention narrowing and focusing on a limited number of options are two characteristics of decision making under stress.** Additional information, giving a more accurate insight of the situation and its inherent risks, might help the understanding of the situation, hence ease the decision making process and optimise the reaction time (7).

A literature study by Steyvers e.a.(1999) gives the following reasons for many casualties due to fires;

A starting fire is not extinguished immediately. Often it can be extinguished with locally available extinguishers, but this requires effective acting by individuals, usually not trained in extinguishing. This means that the indication of available extinguishers must be clear.

Information about the fire is shared too late.

The message to leave the room is not accepted.

Evacuation routes are not used.

First relatives and personal belongings are gathered

1.2 Human behaviour in tunnels in crisis conditions

Car break downs

First of all it is important to note that in general people do not recognize dangerous situations or even are not willing to accept the possibility of a dangerous situation. Drivers have made up their mind to go from A to B (the *navigation level* of the drivers task) and often are only willing to respond to signs (the *guidance level*) that help them perform this task. It is well known that many drivers ignore red crosses, indicating the closing of a travelling lane when they do not see any reason. Also many drivers often do not stop for red traffic lights in front of a tunnel, either because they do not see the lights or they do not see any reason to stop when there is no queue in sight.
Also when stopped in a tunnel due to car breakdowns drivers tend to behave in the same way as they would do on a road in the open air.
The following examples on the A55 road tunnels in North Wales illustrate this tendency:

- After running out of petrol in the tunnel, a driver was observed to remove a spare fuel canister from the boot of his vehicle and attempt to refill the tank. The driver was not aware that if he had dropped the canister the petrol could have quickly evaporated in the heat of the tunnel and could form an explosive cloud of fuel vapour at high level in the tunnel.
- A car broke down in one of the A55 tunnels. The driver did not switch on hiss hazard lights but proceeded to release the bonnet catch on his vehicle and attempt to investigate the problem. The lane control signs were operated to close the lane, pending arrival of the emergency services. An approaching motorist collided with the rear of the broken down vehicle. The driver had failed to notice that the lane was closed and had also failed to notice that there was a stationary vehicle in his path. Owing to the momentum imparted to the broken down vehicle during the collision, the unfortunate driver of the broken down vehicle was run over by his own car.

Also at the *control level* drivers behave like on the road in the open air: this is illustrated by the small distances between the vehicles in queues in tunnels.
The observations above lead to the recommendation to make tunnel users aware of the special dangerous environment in tunnels and to attract as much attention to the danger signals as possible, giving also the reason for the closure of the tunnel or travelling lane. (BenR)

Fire

Noizet and Mourey (2005, **Fout! Verwijzingsbron niet gevonden.**) present the following psychological model of egress, based on a guide by the Society of Fire Protection Engineers (2002,).

Phase 0: Onset of a critical event in the tunnel

An abnormal occurrence activates alert systems and possibly functions and devices designed to stop the users inside the tunnel. At this stage, all users of the tunnel, except the one(s) directly involved in the event, are into their driving activity. None of them is prepared to face a crisis and all their resources are allocated to their main tasks (driving, personal concerns…).

Phase 1: The first direct signals appear (flames, smokes, flowing products…) as well as indirect signals (tunnel's alert system: message on a dynamic road sign, lights, siren, message on the radio, etc.).

The perception of these indirect signals is never immediate. Provided the intensity of these signals is sufficient, it requires first that users get enough free mental resources to be able to pay attention to the environment, perceive and correctly interpret them. As a matter of fact, most of indirect signals are firstly ignored by users usually focused on driving in the specific environment of the tunnel, hence ignoring a possible alert signal. Both multiplication of the modalities of the alert and high intensity signals increase the likelihood that alert signals will be perceived by the users (attention drawn). When perceived by users, the common first reaction is for the users to question the meaning of the alert signals. The appearance of alert signals generates ambiguity in users' perception and understanding of the situation. Every person facing an alert in whatever environment will first seek for further information on what causes the alert signals.

The credibility of the alert system is of utmost importance to trigger egress behaviours.

Phase 2: Evacuation decision making

1/ According to the literature, the first step of evacuation decision making consists for users in assessing the risks. To make up the decision that they need to stop, leave their vehicle and evacuate, the users first need to check whether the situation is really requiring it. Before starting to move, users analyse the situation on the basis of the information they perceive and gather, their beliefs and knowledge about the tunnel, its risks and the means of getting safe. They might share their interpretation with other people before making up their mind about the hazards reality. This analysis can lead to two opposite results: (i) denial, with users sticking to their initial main goal of crossing the tunnel or (ii) acknowledgment of the risks, with users searching for a solution to get safe.

At this stage, this is mainly the quality of information that matters to optimise the egress, whether it comes from users' initial knowledge or from the tunnel alert design and devices.

2/ It's only once the situation is acknowledged as critical by users that they will start to move in order to evacuate. They, in a way, "switch to an active getting safe mode" by first of all gathering their relatives and important belongings. Then, they get into "local" actions such as calling rescue, fighting against fire, accepting to leave their vehicle, etc. Once all local solutions are tested, they enlarge their scope of solution seeking.

At this stage, the key parameters are: the visibility of the safety devices, the quality of the initial knowledge about means of getting safe in a tunnel as well as the quality of information provided to users.

Phase 3: Evacuation

The behaviours related to getting oneself safe are thus happening quite late. Whether these behaviours will be adapted and efficient considering the situation will depend on what users understand of the situation and the safety means they recognize and locate inside the tunnel. If the only visible exit is the tunnel exit and if the users think they can do a u-turn, they will probably do it. Getting safe in such an environment is neither easy nor a reflex.

Table 1 summarizes the main factors that can potentially either trigger or delay the occurrence of egress behaviour according to the four phases of the model.

Experimental evidence

The UPTUN driving simulator study (Martens, 2005, **Fout! Verwijzingsbron niet gevonden.**) (more information about the study is necessary, BenR) showed that when brought in a fire situation (first traffic queue, then stopped traffic, then smoke) about 60% of the drivers switch off the engine spontaneously. When the drivers were informed by reading a leaflet on how to behave in tunnels this increased to 70%. Only after an oral warning by the operator this number rises to 100%. Also, the time needed to get out of the car after coming to a stop was longer if people had not read the leaflet and was shortest if people heard the operator’s voice. Only a few people use the radio to get additional information, not even after having read the leaflet. The most crucial action, that is getting out of the vehicle (or stating one would), is highly affected by the statement of the operator. Whereas 65% of the people indicated they would want or try to leave the vehicle, with 75% of the people who had read the leaflet, this number increases to 94% after the operator announcement. So reading the leaflet already improves the situation somewhat compared to not getting any additional information. However, with the help of an operators' voice, performance improves even more. This not only leads to more people doing the right thing, but also to do it more quickly.

	Main factors that can accelerate the occurrence of egress behaviours	Main factors that can delay the occurrence of egress behaviours
Phase 0: Onset of the event	Proximity of the source of hazard Initial knowledge about the tunnel, its equipment as well as about suitable behaviours in case of crisis To have already experienced a crisis situation	Distance to the source of hazard Level of personal concerns (for example, focus of drivers of large trucks on driving in the tunnel) Mistaken knowledge (beliefs) regarding the tunnel, le tunnel, its equipment as well as the suitable behaviours in case of a crisis
Phase 1: Perception and recognition of the alert signals	Proximity of the source of hazard Modalities and intensity of the alerts Clear and explicit messages about the risk level an its possible outcomes Credibility of the information given and perceived Collective move towards emergency exits	Distance to the source of hazard Absence of clear, informative and directive messages Radio not listened to Collective move against evacuation
Phase 2: To make a decision about hazards reality and to evacuation preparation	Clear and explicit messages about the risk level an its possible outcomes Directive information making clear the direction of emergency exits as well as the appropriate behaviours to adopt Credibility of the information given and perceived Presence/emergence of a leader organising and managing the evacuation Collective move towards evacuation High/good visibility of the emergency exits, of the safety devices, signs and displays	Absence of clear, informative and directive messages Radio not listened to Collective move against evacuation Low visibility or readability of emergency exits Low visibility or readability of safety devices, signs and displays
Phase 3: Move towards getting safe	Smoke well controlled Lighting High/good visibility of emergency exits, safety devices, signs and displays Directive information making clear the direction of emergency exits as well as appropriate behaviours to adopt	Presence of smoke, toxic gas Jam of road lines and tunnel paths Crowd density Low visibility or readability of emergency exits Low visibility or readability of safety devices, signs and displays

Table 1: Main factors that accelerate or delay occurrence of egress behaviours

Some people specifically mentioned that they planned to walk back to the entrance of the tunnel instead of using the emergency doors, which they were required to do, specifically people without any additional information. Since all subjects already drove the tunnel 3 times before and had a chance to see the exits inside the tunnel on ride 4 as well, apparently some people still want to use the tunnel entry as an exit. In the last group, in which it was specifically mentioned by the operator, nobody said to use the tunnel exit. This indicates that it is indeed a matter of receiving the appropriate information.

Also, the use of radio information is difficult, even though some people specifically mentioned that they knew they had to use the radio for specific messages, they forgot what frequency (a specific frequency is mentioned in the leaflet).

What remains an important area is that quite some people indicated they do not have any idea of how to handle in the given situation (even in the condition with leaflet and operator). This means that there is a lot of uncertainty in the case of accidents or incidents in tunnels. Even after hearing an operator voice, and even after having read the leaflet, people still were uncertain how to behave. This is something we have to be aware of in the near future: even though designers may think that all information needed is there, this may not be enough for the road users. **Information provided needs to be over-complete, with if possible a repetition of the messages.** Also, people with visible official status should be sent inside the tunnel (Is this realistic?? BenR) in order to help people make the right decisions. Also it is important if there are tunnel users with an exemplary behaviour, for instance professional drivers. Since these people drive tunnels more often than the average driver, their behaviour might influence other road users to do the same.

Almost all participants (over all categories an average of 83%) mentioned the smoke as an indicator for them to understand what had happened in the tunnel (independently of whether their understanding of the situation was correct). The fact that the smoke intensified or that it occurred in combination with a traffic jam was important for almost half of that group to determine what was going on. Since the traffic jam occurred earlier in time than the appearance of the smoke one can say that participants mentioning the traffic jam as a reason to understand what was going on were sooner concerned or alarmed than the participants merely mentioning the smoke. No major differences between Conditions ????? could be observed.

When people were asked what made them decide to take action (or why they did not take action), two participants in Condition 2 did not take action because of the smoke. One person said the smoke was too thick to approach the accident. The other person said the smoke was not very thick and that he therefore did not see any reason to go out of the car. This clearly shows that the interpretation of information is highly personal. Providing information such as: 'If the smoke gets thick, please leave the vehicle' would not make any sense since the definition of thick smoke varies from person to person. Even after reading the leaflet some persons mentioned that they were waiting for a signal or information on the radio to leave the car (even though the leaflet says: Smoke and fire can kill). Even if the operator informed road users, one person mentioned that it was unclear where to go and one person indicated to need more clarity of how to respond.

One of the good results of reading the leaflet may be that no one after reading the leaflet mentioned that they did not take any action because they waited for others to take action (3 people indicated this without reading the leaflet). One person specifically mentioned he knew what to do due to the leaflet. One person (without reading the leaflet) mentioned he felt safer in the car and one person (even after hearing the operator) simply mentioned that he wanted to get out but was afraid to do so.

The fact that a lot of people mentioned the smoke as the reason to take action indicates we have to be careful with getting the smoke completely out of the tunnel: this may enhance the delay in response time (This is nonsense, in longitudinally ventilated tunnels tunnel users upstream of the fire do not have to evacuate. BenR) . However, that reading the leaflet is not enough is shown by the people who said that they did not take any action (e.g. because they did not want to panic, did not see any panic, tried to stay calm, were looking for more information etc) even though they read the leaflet. There were only less people stating that is was not necessary to respond in the category where the operator stated what to do.

Even in the condition that an operator announced to switch off the engine and to go to the emergency exits, people though information was lacking. In general, remarks were made about the necessity to light emergency doors, warnings signs, information about what is going on, how serious it is and what to do, the need for information to be more extensive or information on the radio (this was only mentioned by people reading the leaflet, so apparently this is something they remembered without remembering the frequency). About a quarter of the people did not think any information was lacking.

2 CONTROLLING THE DEVELOPMENT OF INCIDENTS AND ACCIDENTS BY TUNNEL USERS

2.1 Introduction

This section describes experiences with the use of various systems incorporated in tunnels to control the development of incidents and accidents by tunnel users. The following processes are dealt with:

- communication with the control centre
- alerting traffic (not to enter or to stop)
- use of extinguishers
- emergency (S.O.S.) stations
- alerting tunnel users in case of fire.
- guidance towards emergency exits
- communication behind the emergency exits
- alarming tunnel users in the safe tunnel tube

The activation of the various processes depends on the kind of incident. In cases of car break downs only communication with the control centre and alerting traffic will be activated.

In case of a starting fire communication, alerting of traffic and use of extinguishers are important.

When the fire cannot be controlled every second counts. The sooner the operator is alarmed the sooner traffic can be stopped and tunnel users be alerted to get out of their cars and evacuate.

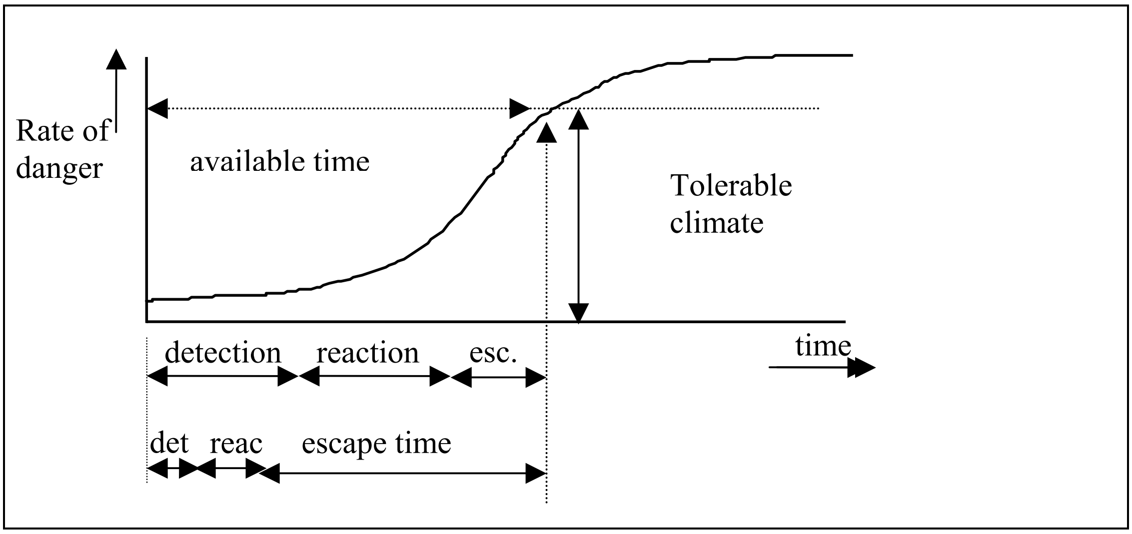


Figure 1: Importance of shortening detection and reaction times

The process of evacuation can be divided into three parts: *perception, decision/reaction and movement*. The total time of evacuation is the sum of these three. Figure 1 illustrates that the shorter the perception and reaction times, the more time is available for movement.

2.2 Communication with the control centre

Intercom or emergency telephone

In many tunnels there are devices to alarm the control centre when a tunnel user needs help. Aspects that are of importance are: Do drivers know there are emergency phones? How can they find them? How far from each other they should be? How fast the connection is established? Can tunnel user and operator understand each other? There is not much known to answer these questions.
In Austria the telephones used to be installed only at the lay-bys (depending on the tunnel 100 – 850 m apart from each other). Recently in some tunnels additional telephones have been installed in SOS-stations in the tunnel walls in order to comply with the EU Directive on Tunnel Safety. Practice shows that only telephones at the lay-bys are used.
In the Netherlands the intercom has the shape of a "normal" telephone receiver and is one of many other items in the SOS-niche (fire extinguisher, fire hose, stand pipe, tank for foam). In a study, interviews were held with road users who were getting petrol at a petrol station right before entering a tunnel in Holland (Krul & Boer, 2001, **Fout! Verwijzingsbron niet gevonden.**). It was fairly well known that the tunnel had emergency stations, with 50 to 60% spontaneously mentioning things like fire extinguishers, telephones or emergency stations. 76% of the people think that they still have to dial the emergency number (112) from the telephones in the emergency stations. Therefore it is recommended to install self-explaining intercom devices like along motorways. Also it would help to recognize the intercom devices if they are painted in the same colours as those along motorways ??(BenR).

Mobile (cellular) phones

Fixed signage installed outside or inside the tunnel indicating telephone numbers for reporting incidents will increase the use of cellular telephones as a manual incident detection system. (Is this not contrary to the recommendation not to give too much information?, BenR) Some countries automatically direct all telephone emergency calls to the designated Emergency Control Centre to minimize the burden at the Control Centres that are responsible for the day-to-day operations of the tunnel. But in case of broken down vehicles and emergency the Tunnel Control Centre should know it first Are there experiences in this field??? BenR.

Loudspeakers

In many tunnels the tunnel control centre will be alarmed when a car stops. By means of CCTV the operator can immediately look what is happening in the surroundings of the stopped vehicle. When there is a loudspeaker system he can address the driver and instruct him what to do. There are ample positive experiences. Care has to be taken that the message only can be heard in a restricted section, so as not to disarrange other tunnel users. It does not seem favourable to address the driver having a breakdown with pre-recorded messages.

2.3 Alerting traffic to stop

It is well known that many drivers ignore red crosses, indicating the closing of a travelling lane when they do not see any reason. Also many drivers often do not stop for red traffic lights in front of a tunnel, either because they do not see the lights or they do not see any reason to stop when there is no queue in sight. Drivers have made up their mind to go from A to B (the *navigation level* of the drivers task) and often are only willing to respond to signs (the *guidance level*) that help them perform this task. So they need strong signals that there is really something wrong. This is very useful especially in case of car breakdowns and congestion. The following signals can be thought of:

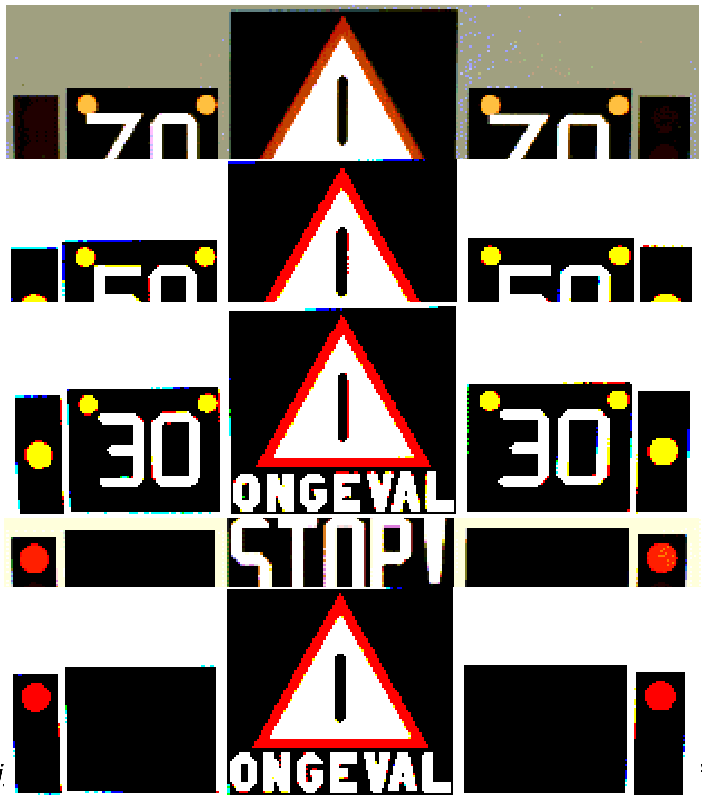
- On the road approaching the tunnel special traffic signs
- Inside the tunnel visual and audible alarms
- Radio messages

In 1998 TNO performed experiments with the driving simulator to investigate the reaction of drivers on stopping signs inside a long (6,5 km) tunnel (Martens et al, 1998, **Fout! Verwijzingsbron niet gevonden.**). The goal was to stop the traffic within one minute. Two strategies were set up: The Gradual stopping strategy and the Abrupt stopping strategy (See Figure 2).
In the gradual stopping strategy the matrix panels indicating a maximum speed of 70 km/h were shown (the speed limit in the tunnel was 80 km/h) during 10 seconds, In between the speed panels the general warning sign with the word “ACCIDENT” was shown, to give the reason for the speed limitation. Then the speed limit was reduced to 50 km/h and blinking yellow traffic lights were shown. Another 10 seconds later the speed limit was reduced to 30 km/h and the yellow traffic lights were kept constant. Finally the traffic lights were constant kept red and the sign “ACCIDENT” was alternated with the word “STOP!” .
In the abrupt stopping strategy no advised speeds were shown. First blinking yellow traffic lights were shown and in between them the general warning sign with the word “ACCIDENT”. After 10 seconds the yellow traffic lights were kept constant during

20 seconds and then the red stopping lights appeared and “ACCIDENT” was alternated with “STOP!” .

First the drivers made two runs without having to stop. In the third run they had to react. Then another three runs were done and in the 7th run another “accident” happened.

With the gradual stopping strategy in the 3rd run only 3 of the 16 test drivers stopped within one minute, with the abrupt stopping strategy there were only 2 of the 16 test drivers who stopped within one minute.



Fi helde tunnel (tests with driving simulator) with the Gradual Stopping Strategy. In the Abrupt Stopping Strategy the speed limitations did not show.

In the 7th run these numbers were somewhat higher.
Most of the test drivers indicated that they expected to be able to continue driving at moderate speed until the end of a queue.
This shows that drivers only will stop when they see with their own eyes that there are obstacles like barriers

2.4 Use of extinguishers

Portable extinguishers

According to Merz e.a. (1999, **Fout! Verwijzingsbron niet gevonden.**) in about half the number of fires in the Gotthardtunnel the portable fire extinguishers (every 125 m) are used.
Traffic accidents in Norwegian road tunnels show that even if people's lives are lost (drivers trapped in smashed vehicles) the use of fire extinguishers suppresses fire and reduces the heat inside the tunnels.
In France, the detailed analysis of video pictures under fire conditions showed that the users generally do not succeed in extinguishing a vehicle fire. In one of these cases, the involved user – however accustomed to use the extinguishers – confirmed during an interview later on that it remains delusive to hope to extinguish a fire easily.

Do we have to promote this type of behaviour or must it be preferred only to install extinguishers without encouraging formally the users to use them systematically? In this event the strategy would be to let the users appreciate – according to the conditions – their ability to extinguish a fire (see special case of lorry users who, due

to their training in this field, are subject to conditions somewhat different from those for passenger cars users).
One opinion is that we should not encourage people to actually try and extinguish a fire. If the fire extinguishers are there, that is enough. The idea here is that if people who know how to use them will try to do that, but it is far more important that others bring themselves into safety. We do not want people to lose valuable time. Also, if we tell people (like in the Gotthard) at the signs inside the rescue shelter that they first have to extinguish the fire, there is a possible fear for liability that may drive people to go back in the dangerous tunnel because they do not want to be sued. A recommendation could be in this case to say: If you can, try to extinguish the fire. In this case you make clear that there are no liability issues.

The following text was presented by Norwegian delegates in the Needies Lessons Learnt Program on fire in tunnels;
"It is vital that the public may call for help using public emergency phones. Emergency phones must be installed frequently inside the tunnel. Together with the emergency phones there must be fire extinguishers. The removal of a fire extinguisher should give a signal at the Road Traffic Centres, and lead to immediate response. Combined with this automatic signal system attached to the fire extinguishers there must be other fire alarm systems".
From a Norwegian national fire prevention point of view it would be wrong to remove fire extinguishers from tunnels because one suspects that people can be trapped in smoke filled tunnels while trying to extinguish a fire. The fire extinguisher is one of several technical fire prevention measures in a tunnel. The technical fire prevention measures function as a chain of immediate response. Once a fire extinguisher is removed from its bracket it automatically gives a signal to the Road Traffic Centre. Together with alarm call phones it gives the tunnel operators the possibility to determine where the incident has occurred. In some tunnels it might also be verified by video surveillance.
Fire extinguishers must be installed within a limited distance from each other to encourage the use of them in emergency situations. A lot of tunnels are located outside rural areas and it might take time before the fire fighters arrive at the scene.

The conclusion is that fire extinguishers should be present in all road tunnels, preferably combined with automatic alarm signal systems that automatically alert the Road Traffic Centres when extinguishers are removed form their brackets. The extinguishers must be present in a number and with a distance between them that encourages people to use them. Combined with ventilation systems that automatically increase their power when a fire situation occurs, the use of fire extinguishers will often suppress fire in a vehicle and also contribute to the reduction of heat. In some cases it might be possible to put out the fire completely.
Therefore it is recommended that tunnel users be informed about the following behaviour in case of fire:

1. alarm the control room by using the intercom devices
2. try to extinguish the fire
3. if that is not possible escape as soon as possible

When the tunnel is provided with camera's and loudspeakers the tunnel staff can address the tunnel users according to this behaviour.

Fire hoses

In the Netherlands and in Austria fire hoses are installed in the tunnel. According to Weitenberg (2001, **Fout! Verwijzingsbron niet gevonden.**) the idea of the fire hose is not always understood: Some people think it is just for the fire fighters, or only for large or for small fires or only for fires close to the emergency station or only for fires further away. Some people think the hose is only for non-liquid fires. Most people did not notice the pictograms (????) on the mouth of the fire hose. If the pictogram is pointed out only half or the participants understands this has something to do with the shape of the foam or water coming out of the hose. If the fire extinguisher is removed from the emergency station to see if people would use the hose, about half of the people does not respond. One person turned open the partly hidden tap for the fire fighters. Using the fire hose goes fairly well, but properly holding the hose at the right pace does not always work and getting it all out from the emergency stations leads to small problems. Using the fire extinguisher does not lead to any problems, with quite some people reading the instructions on the extinguisher.

2.5 Emergency (S.O.S.) stations

In the Netherlands the SOS-stations contain many items (hand held fire extinguisher, fire hose, stand pipe, tank for foam, telephone). In a study, interviews were held with road users who were getting petrol at a petrol station right before entering a tunnel in Holland (Krul & Boer, 2001, **Fout! Verwijzingsbron niet gevonden.**). It was fairly well known that the tunnel had emergency provisions, with 50 to 60% spontaneously mentioning things like fire extinguishers, telephones or SOS-stations. The number of correct responses may also have been higher due to the way the questions were put ("along the walls there are emergency provisions, could you tell me which?").
The design of emergency stations inside a tunnel should be designed with human factors in mind, since people in an emergency situation may be at a high stress level and may not be thinking clearly. The use of these stations should be very easy and self-explaining. In an experimental study (Weitenberg, 2001), 60 persons of different ages participated, without anyone having experience with fire extinguishers. Some people indicate they think that the SOS-station is not meant for them. Some people also think that there will be first aid items in it such as oxygen, fire blankets, first aid stuff etc. In the conditions without a covering metal door in front of it, people best notice the fire hose, the manual fire extinguisher, the phone and the connection for the fire brigade. Also the tank with foam and the green button (delivered pressure) for the fire fighters are mentioned and some people thought this was an alarm button or an on/off button.

2.6 Alerting tunnel users in case of fire

Experimental evidence

A Dutch study (Boer, 2002 **Fout! Verwijzingsbron niet gevonden.**) was designed to look more into the process of evacuation without specifically informing people what was going on and without instructing them that they had to evacuate. In 7 tests groups of 50 individual drivers entered in their cars behind a truck. They knew something could happen since they were recruited for an experiment by TNO. In the middle of the tunnel the truck manoeuvred so that both traffic lanes were blocked and at the same time smoke was released from the truck.
That study showed long response times: Road users responded very passively, not doing anything for about 5 or 6 minutes. There was however some orientating behaviour, with people looking what was going on, and looking at other road users,

but no one evacuated. Interesting phenomenon here was that this passivity was also present when some of the cars were completely covered in smoke, people still remained seated in their car. In only one of the 7 tests, some people started to evacuate spontaneously (without warning by the operator), but in the 8 other tests this did not happen. This indicates that there **should always be an extra external cue** in order to start early evacuation. However, when the cars were completely covered in smoke, even the operator voice could not motivate these people to get out of their cars (probably afraid of the toxic smokes). One other important finding was what happened after the spontaneous evacuation in one test. After a while, people came back from the evacuation tube and just kept on hanging around the evacuation doors, with even groups of people waiting on the road. This could have been the result of people being curious about what will happen and their concern for their car.

Loudspeakers and other audible and visual alarms

It has been demonstrated that loudspeakers are essential to convince tunnel users to get out of their cars and to evacuate. However care should be taken that tunnel users in the part of the tunnel, protected from smoke by ventilation, are given other information, because they do not have to leave. Another problem is to choose between pre-recorded messages and messages by the operator. In case of emergency is seems advisable to use pre-recorded messages since no time should be wasted if an operator has to think about what to say. Also, emotion in the voice is not advisable. On the other hand it is questionable whether tunnel users will be convinced by pre-recorded messages BenR.

It is important that the information provided by loudspeakers is simple and easy to understand. Words that are often used in everyday language are more easily understood than words that are seldom used. The ability to perceive and understand is often reduced due to the heightened emotional activation. When speech and text are used for information or instruction, it is recommended to use sentences that inform about desired behaviour. It is better to understand mandatory signs than prohibition signs, as it is easier, for example, to understand “turn right” than “do not turn left”. Instructions and orders should be given in the order the person should do them. This is very important especially for children. “Do A, then do B” is easier to understand than “Before you do B, you must do A”.

Radio

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 on 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. Therefore, it should be stimulated that people switch on the radio before entering the tunnel, and the best way to receive people is to broadcast not only on one channel, but interrupt all channels and override CD (like RDS) and increase the sound level in case of messages. Also, when broadcasting a message, it should be made really clear that the message is really for them (people tend to doubt if the information is really for them).

The project ACTEURS (reference??) in France showed that the 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 (reference??) 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)
It should be possible to differentiate general pre-recorded messages and messages adapted to a specific situation. Even a lot of messages for a special situation could be pre-recorded. This is advisable since no time should be wasted if an operator has to think about what to say. Also, emotion in the voice is not advisable.

2.7 Guidance towards emergency exits

Several investigations have been carried out into the familiarity of tunnel drivers with the presence of emergency exits.
A "forum" gathering the tunnel users of the Ile-de-France area showed that the users are not well aware of the emergency exits (reference??)
Eberl (2002, **Fout! Verwijzingsbron niet gevonden.**) reports that 50% of the test persons remembered the presence of escape doors.
In a Dutch study, interviews were held with road users at a petrol station right before entering a tunnel (the Benelux tunnel) in the Netherlands (Krul & Boer, 2001, **Fout! Verwijzingsbron niet gevonden.**). Most road users knew that in case of calamities, evacuation was the right thing (81% responded this). About 95% of the people who indicated they would evacuate would do this on foot. The presence of emergency exits was known by 75% of the people; 71% mentioned this spontaneously and after asking explicitly, 87% was aware of this. A weak point here is that only 40% of the road users actually indicated to use the doors in case of evacuation. The majority indicated to walk along the road. Although this is not always wrong (especially close to an entry or an exit), it is not the safe response most of the times. Also, it is known that people underestimate walking distances if they normally travel this distance by car, so evacuating via the route would than seem a fast way out whereas it would not be. The conclusion here is that knowledge about always using the emergency exits is far too low with 40%. Also, most people were not aware on which side the emergency exits were located. Only 40% gave the correct answer, but since there were only 2 possibilities (left or right) this is not above chance level. This is especially low since a lot of the interviewed persons used the tunnel regularly.

In a part of the Dutch evacuation studies (Boer, 2002, **Fout! Verwijzingsbron niet gevonden.**), the instruction to individual participants was that they were in a tunnel, a truck was on fire, the tunnel was filled with cars so they could not move their vehicle and they were supposed to go out of their car and bring themselves into safety. An interesting detail is that 43% if the participants actually used this tunnel on a daily basis and 35% used the tunnel at least once a week. The results showed that people got relatively quickly out of their car (remember they were instructed to do so), on average within 6½ seconds.
If participants did not get specific instructions to go to the emergency exits, 25% of the participants left the tunnel by walking via the road. This percentage was a lot lower than what people indicated they would be doing in the interviews (which was 60%). Only 1 out of every 5 participants noticed the signs indicating the emergency doors (they were located about 1.5 meters above the door).
Also, there was some confusion since the pictogram was pointing in two directions (to indicate it was actually there) and the more technical descriptions on the door lead to one person actually waiting in front of the door. After people actually entered the emergency exits, not everyone noticed the signs pointing to the right walking

direction. And of those who actually did notice preferred to walk against the direction, away from the danger. Some people wanted to enter the other tunnel tube instead of using the actual middle tube, which is a specific emergency evacuation tube.

That is why it is recommended in the first place to pay much attention to the design of the emergency doors so that tunnel users in normal situations will recognize the presence of the doors. Also it might be of use if tunnel users are acquainted with the presence of signs to indicate to way to the doors. In case of fire and smoke special visual and acoustical signals could be applied both to indicate the presence of the emergency doors and to help find the way from the vehicles to the emergency doors. For instance using strong, flashing lights by the floor or on the road so that they are visible through smoke (Jensen et al., 1997).

In some tunnels confusion between safety lay-bys and emergency exits may occur. In France for example, this occurred during a training exercise involving firemen. This confusion led to the decision to reduce the lighting inside the lay-bys. Also, signs indicating the emergency exits should always be lit in order to avoid any confusion. Also, a sign on the opposite side of the wall, indicating people have to cross might help people find the emergency exit .

The results of the Czech project OPTUN will be included in this report (is it already available?? BenR). The results could give some contribution to knowledge where to put the emergency signs inside the tunnel. From the notion we have got until now the smoke should not get below one's knees (if ventilation will not fail), so the people in tunnels should be instructed to low down as possible. From this point it would be good to take into account use of directional signs on the road/pavement.

Sound beacons

Possibilities for helping evacuation by means of auditory guidance have been a topic of research for over 10 years now. The firm Sound Alert makes these sound systems for evacuation and together with a university tests were performed to prove its efficacy (Withington, 2001, **Fout! Verwijzingsbron niet gevonden.**). However, these tests were always done with specific instructions in which the "shhussing" sound beacons were demonstrated and people were instructed that if they heard this sound, that this is where the emergency doors would be and that they were supposed to go there. A test of Boer and Withington (2004, **Fout! Verwijzingsbron niet gevonden.**) in a road tunnel (without the specific instruction) showed that less than one-fifth of the participants found the emergency exits without any specific instructions. People indicated at the end of the test that they thought it was a strange sound. It was therefore concluded that the particular sound did not suit the expectations, and that the system will only be effective if evacuees are informed in advance about the sound and its meaning.
Under contract with the Dutch Ministry of Transport, TNO developed a new sound beacon signal (Boer & Wijngaarden, 2003, **Fout! Verwijzingsbron niet gevonden.**). It consisted of the spoken message "exit here" preceded by dinner-bell sounds. The dinner-bell sound was a chime-like sequence of two harmonic bi-tonal complexes. Thereafter, the message "exit here" was played in 1200 ms followed by a silence of another 1200 ms. The spoken message was intended to suit the expectations of people in distress, who are looking for refuge: "There is an exit, and that exit is where you hear me calling". A suitable voice is important. A male voice was chosen, able

to convey determination and urgency, while avoiding threatening or casual undertones. The spoken text ensured localizability. A test was done with the new system in a tunnel filled with smoke. People left a bus one by one in the smoky tunnel (very poor visibility). Some were instructed very generally, that they had to find safety after they exited the bus. Some were instructed that there were sound beacons inside the tunnel to help them orient themselves, listen to the beacons. The remaining group was instructed that there would be sound beacons above the emergency exits, and that they had to go to these exits. The tests with the new system showed that the system was very effective, with more than 90% finding the exits under conditions of poor visibility, given that the sound used for guidance suits the expectations of the evacuees. Even without advance instruction, they offered help to test participants looking for refuge and a way out. In real calamities, one may assume that humans trapped in dense smoke will, similarly, be looking for refuge and the way out and that the self explaining sound used will suit the expectations as well. Additional testimony to the efficiency of the SE beacons was the observation that all participants except one went to the nearest emergency exit. This was 55% in the previous test with the beacon sound that was not self explanatory.

Hearing deficits are a natural limitation on the effectiveness of any sound beacon. About one fifth of the population has hearing problems in some degree (Shields & Boyce, 1995, **Fout! Verwijzingsbron niet gevonden.**). It is also known that the number of people with hearing deficits increases at old age (see ISO 7029, 1984). It is difficult to estimate from these data what proportion of people will be unable to hear sound beacons. These "deaf" people could perhaps let themselves be herded by others with adequate hearing. A limitation specific to beacons using natural language is insufficient mastery of that spoken language. The TNO system was a bi-lingual solution in which English and Dutch took turns. While increasing the proportion of the population that understands the beacons, this does not fully eliminate the limitation due to insufficient mastery of the language. Moreover, adding more languages increases the length of the total message (4 s for the current beacons) and beacons speaking (too) many languages may confuse the hearers.
Sound beacons will also be useful under conditions of good visibility. The continuous repetition "exit here" will help motorists to understand that they should leave their car and find refuge. The beacons can thus help to overcome the initial passivity of motorists surprised by a disaster.

Tactile Guidance systems

Experiments carried out in Sweden (Franzich and Nilsson, 2004, **Fout! Verwijzingsbron niet gevonden.**) tested guiding aid with sidewall markers and handles. It was shown that subjects in a confined space, under smoky conditions could guide themselves physically along the sidewalls to an emergency exit. (More info please, BenR)

2.8 Communication behind the emergency exits

There are various solutions to lead escaping people to a safe place after having passed the emergency doors.

- direct exits from the tunnel to the outside
- exit to an emergency gallery or mid-tunnel tube

- cross connections between tunnel tubes
- shelters with an escape route distinct from the tunnel tube.

It is of importance that tunnel users after having passed the emergency door are informed well how to proceed. This can be implicated by means of visual and audible messages. Information about how communication in these solutions is arranged is presented in part III. Only one study is known regarding human behaviour behind emergency doors.
Boer and Maarse (2004, **Fout! Verwijzingsbron niet gevonden.**) investigated the possibilities for a new sign for the 6.6 long Westerscheldetunnel in the Netherlands that would indicate the evacuation route and also warn for the presence of traffic in the other tunnel tube when leaving the evacuation cross passages. TNO tested the original design and the TNO design (see Figure 3).

The integrated design showed better response to the steps just after the door (29% compared to 11%). With the integrated design, there were less people that indicated they would open the door (77% compared to 94%). Although this may seem to be decreasing safety, this is only the case to a limited extent, since staying in the cross section is already safe, and the majority of the people would still open the doors, so this will also influence others. The danger of traffic directly behind the door was acknowledged to the same amount (over 30%).
Recommendations: The integrated design can be applied in combination with a loudspeaker message in the cross sections: “Follow the arrow to the other tunnel tube. Watch out for traffic”.

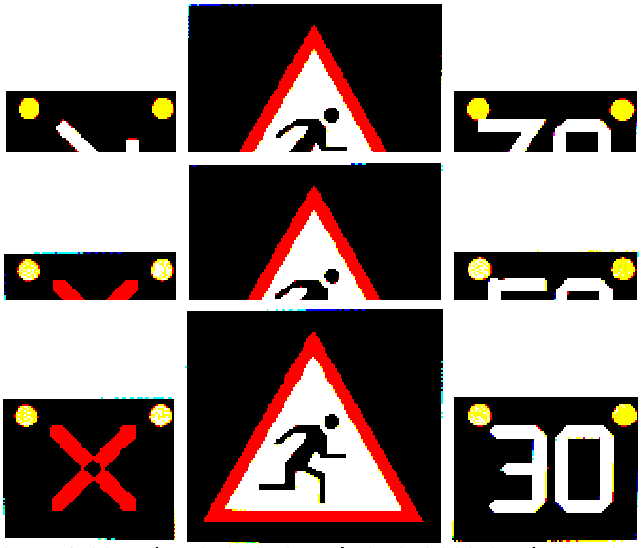
Figure 3: The TNO design to warn for traffic in the other tube.

2.9 Alarming tunnel users in the safe tunnel tube

In case of cross passages between two tunnel tubes escaping tunnel users have to enter the cross passages and have to stay there until the doors towards the safe tube can be opened. This is because when there are cars running in the safe tube other accidents could happen if escaping people suddenly appear on the overtaking lane. If the tunnel is long it may take a few minutes before all traffic has ridden out of the safe tube and no more cars enter into it. That is why for the Westerschelde tunnel a new strategy has been developed (see Figure 4).

Two variants of the Clearing Srategy were investigated in the TNO driving simulator: the Gradual Clearing Strategy and the Abrupt Clearing Strategy. The goal was to have cleared the overtaking (left) travelling lane within a minute.

In the Gradual Clearing Strategy first a clearing arrow above the left lane and a speed limitation 70 km/h (speed limit is 80 km/h) above the right travelling lane is shown during 10 seconds. In between these matrix panels another panel shows a red triangle with an escaping figure, coming from the left. This figure is copied from the general sign for emergency exit. Then the clearing arrow above the left travelling lane is substituted by a red arrow, whereas the speed on the right travelling lane is limited to 50 km/h during another 10 seconds. Finally the speed limit 30 km/h is shown constantly. Additionally the signs above the lanes were accompanied by alternating yellow lights in the angles up and down in the matrix panels to indicate the need to act fast.

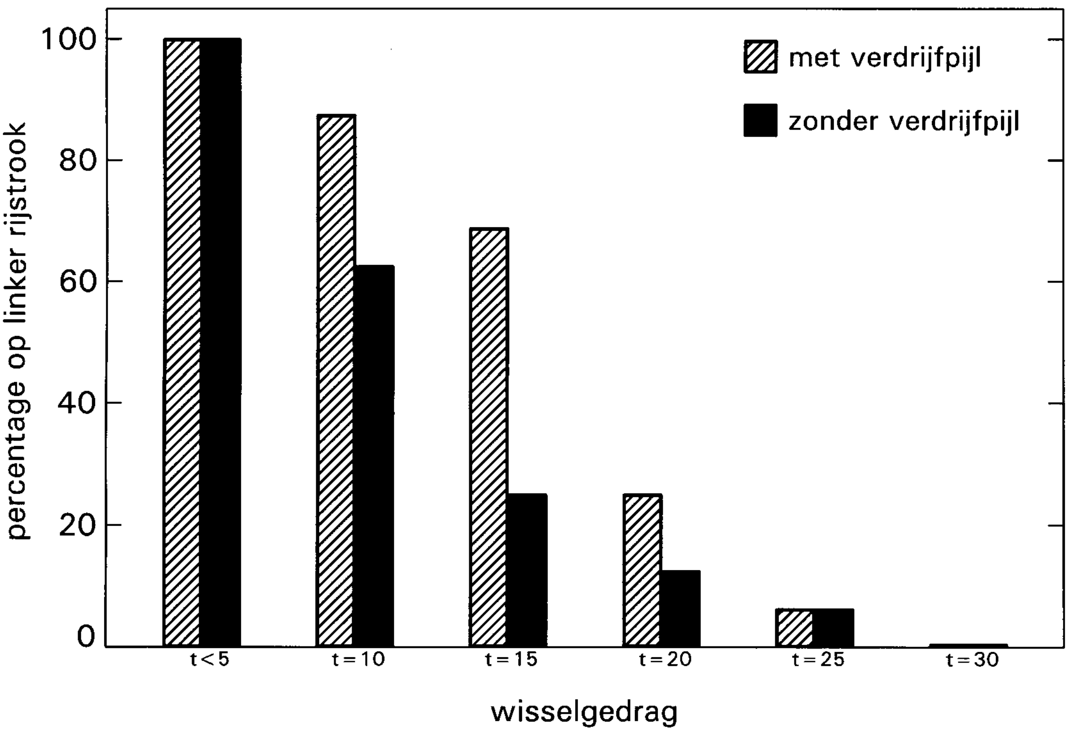


al Clearing Strategy. In the Abrupt Clearing Strategy the clearing arrow is substituted by a red cross.

In the Abrupt Clearing Strategy the red cross above the left travelling lane was shown immediately.

The results were that in both Clearing Strategies the left travelling lane was cleared of all traffic within 30 seconds. In the Abrupt Clearing Strategy more drivers had changed lanes within 15 seconds than in the Gradual Clearing Strategy (see Figure 5). 24 of the 32 test persons answered in the query sheets that they expected pedestrians on the travelling lane, for different reasons. One person indicated his first thought that he had to escape, but the fact that the speed limit on the right travelling lane remained 30 km/h persuaded him that this was not the case.

In the simulator tests after 1 minute an virtual escaping person appeared on the left travelling lane. 17 of the 32 test persons said they expected this of which 7 declared to have been frightened. There was no clear difference between the results of the query sheets after both Strategies. A number of drivers in the Abrupt Clearing Strategy indicated to have expected a clearing arrow before the red crosses.
As this is the normal procedure the Gradual Clearing Strategy is recommended.



3 RECOMMENDATIONS

General

- Just providing people with a leaflet on what to do is not enough. Information campaigns and driving lessons should pay more attention to the behaviour in tunnels in cases of incidents.
- People should be clearly guided in what to do. People want to know why they should do what is required.
- Messages have to be repeated.

Communication with the control centre

- Clearly indicate the presence of emergency telephones with understandable signs.
- The access doors to the recesses – if any – must be glazed;

- There should be an indication on the telephones that there is direct contact with the operator, eg by means of a sticker: "*Direct contact with operator room. Listen to the instructions".*
- Take care for fast reaction to the calls
- Take care of good speech understand ability of the telephone connection
- Mobile phones ???
- Look into the possibilities for a system that automatically localises 112 emergency calls on mobile phones and transfers them to the tunnel???BenR operator centre.
- If an emergency was already reported, the operator should tell people that they know there is an alarm (in order overload communication channels and waste time). A good option would be *The alarm has been reported, please do not call anymore.*
- Addressing the driver with a broken down vehicle by means of loudspeaker is the fastest way. Take care the message is restricted to surroundings of the driver involved only.

Alerting traffic (not to enter or to stop)

- Develop special signs to convince tunnel drivers they have to stop
- It should be possible to receive all radio stations in the region and to override them with alarm messages. But these messages only should be received on the approaching roads and in the tunnel.
- Inside the tunnel visual and audible alarms

Use of extinguishers

- Clearly indicate the presence of fire extinguishers with understandable signs
- Warn users to escape if it is not possible to extinguish the fire in a short time
- As soon as a fire extinguisher is removed, there should be an automatic call to the operator or fire fighting team.
- Make clear for the fire hose when to use this. Since there is more time available for extinguishing a fire, there should be a preference to use

them. Place a text: *“Water with foam, Can be used for all fires. Can be used everywhere in tunnel”.*

- Put the following text on the fire hose: “Water with foam. Limited fire extinguishing time”

Emergency (S.O.S.) stations

- Do not show tunnel users too much of the technical installations.
- Not based on experimental results: Put a red frame around the help posts and put the SOS sign immediately above the post.
- Give the background in the help posts a white colour so the elements inside can be properly seen.

Alerting tunnel users in case of fire

- Develop audible and visual alarm signals
- Emit voice messages via radio and loudspeakers
- It is also important the information to be simple and easy to understand. When speech and text are used for information or instruction, it is recommended to use sentences that inform about desired behaviour. It is better to understand mandatory signs than prohibition signs, as it is easier, for example, to understand “turn right” than “do not turn left”.
- Instructions and orders should be given in the order the person should do them. “Do A, then do B” is easier to understand than “Before you do B, you must do A”.
- Take care not to alarm tunnel drivers not endangered
- Investigate the sensibility of pre-recorded messages
- There should be a clear and authoritative operator voice indicating where to go and why. The best would be to have a men’s voice and to have prerecorded messages. Is that true?? BenR
- People with visible official status should be sent inside the tunnel in order to help people make the right decisions (Is this realistic??BenR)

Guidance towards emergency exits

- Clearly indicate the direction to the emergency exits with understandable signs
- A sign on the opposite side of the wall should indicate people they have to cross in order to find the emergency exit
- Clearly indicate the presence of emergency exits by good design
- In all cases the green colour will be favoured, because the users associate it to the notion of emergency exit
- Clearly indicate the presence of emergency exits with understandable signs
- In case of evacuation use visual and audible signals to find the emergency exits. In case of required evacuation, the green lights may be flashing. They should never be flashing in case of normal traffic conditions.
- There should be a clear indication on how to open the emergency doors.
- The access for handicapped persons should be ensured at least up to a safe zone, where they can wait for being supported by the rescue teams.
- Do not put any technical information on the doors (this will scare people off). In case it is required for the emergency services, make the information small, not in any colours and put them either very low or very high (not in a conspicuous place).

Communication behind the emergency exits

- Guide evacuees with visual and audible messages
- Once inside the emergency exit, there should be more indications on where to go and also clear instructions where not to go (e.g. No entry sign). Also people should be encouraged not to stay there but actually keep on moving
- If the emergency exit leads to the other tunnel tube with moving traffic, this should be clearly indicated. An integrated pictogram (like the one described in this paper with the integrated design) should be present in

combination with a loudspeaker message in the cross sections: “Follow the arrow to the other tunnel tube. Watch out for traffic”.

- Video cameras inside a shelter could provide the operator with images from the shelters to help decision about further actions for safety. The MRSL detection and evacuation system (What is that??BenR) can be installed to provide information about the conditions to the operator and to use this information to guide people to a safe haven.