PART III: TECHNICAL SURVEY OF SIGNS AND SIGNALS CONCERNING TUNNELS

1 INTRODUCTION

In the preceding parts attention is focussed on theoretical schemes of human behaviour in tunnels and on ramps towards tunnels in normal and in crisis situations. Also a number of specific research studies after human behaviour in these situations is presented. In this third part of the report a survey is presented of the signs and signals that are actually recommended in various directives and guidelines concerning tunnel safety. Moreover some technical information will be presented concerning these signs and signals.

The signs and signals can be divided in two groups:

- Traffic signs and signals in normal driving situations and in crisis situations
- Signs and signals to promote self-help in tunnels

2 TRAFFIC SIGNS AND SIGNALS IN NORMAL DRIVING SITUATIONS AND IN CASE OF INCIDENTS

2.1 International traffic rules, signs and signals in normal situations and in case of incidents

At international level the following conventions and directive are relevant to the item of traffic signs and signals:

- The *Vienna Convention on Road Traffic* promotes international road traffic and road safety by agreeing upon uniform traffic rules.
- The *Vienna Convention on Road Signs and Signals* has the same scope by agreeing upon international uniformity of road signs, signals and symbols and of road markings.

Both conventions will be amended in view of tunnel safety.

- The *EU directive on tunnel safety* (Directive 2004/54/EG of April 29, 2004) also contains regulations about signs and signals to be used in front of and inside tunnels.

Here the articles concerning behaviour and signs and signals in tunnels are reproduced:

2.1.1 Signs on approaching a tunnel

The tunnel sign E,11[a]
Article 25 bis of t*he Vienna Convention on Road Traffic* reads:

Special regulations for tunnels indicated by special road signs

In tunnels indicated by the special road signs, the following rules shall apply:
1. All drivers are forbidden:
(a) to reverse
(b) to make a U-turn
(c) to stop or to park a vehicle except at the places indicated for that purpose.
2. Even if the tunnel is lit, all drivers must switch on the driving or passing lamps.
3. In case of a prolonged stoppage the driver must switch off the engine.

The Vienna Convention on Road Signs and Signals pays attention to special regulations signs to which category the tunnel sign E,11[a] belongs. Article 13 bis sub 2 bis reads :
Sign E,11[a] shall be used for tunnels of 1,000 m or more and in cases provided for by domestic legislation. For tunnels of 1,000 m or more the length shall be included either in the lower part of the sign, or on an additional panel H,2, as described in Annex 1, section H. The name of the tunnel may be indicated according to Article 8, paragraph 3 of this Convention

Figure 1: Sign E, 11[a]

In the Annex II to the Convention the sign is shown (see Figure 1). Annex I to the Convention gives more details about its application:
9. Signs notifying the entry to or exit from a tunnel where special rules apply.
(a) Sign E, 11[a] 'TUNNEL' indicates a section of road passing through a tunnel and on which special traffic rules apply. It is placed at the point from which these rules apply.
(b) In order to warn road users in advance, sign E, 11[a] may be placed in addition at a suitable distance before the point where the special rules apply; such sign shall show, either in its lower part, or on an additional panel H, 1, as described in section H of this Annex, the distance between the point at which it is set up and the point from which these special rules apply.

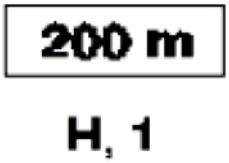

Figure 2: Additional panel H,1 indicating the distance to the entrance of the tunnel

So the sign shown in Figure 3 is in line with the Convention. It is not necessary to have the name of the tunnel on it. (The arrows to indicate bi-directional traffic is not prescribed, but very useful.) The signs may be placed at some distance from the entrance to the tunnel with the panel under it indicating the distance to the entrance.

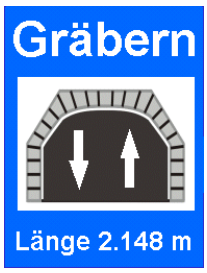

Figure 3: Example of application of the "tunnel sign"

The European Directive on Tunnel Safety prescribes the use of the tunnel sign E11,a for all tunnels in the Trans European Network longer than 500 m.
In view of the additional rules for traffic in tunnels desired by the European Directive (distance between vehicles) and the leaflets on how to behave in case of incidents and fire the use of the tunnel sign may be recommended for shorter tunnels as well.

Radio
In the case of tunnels in which users can receive information via their radio the European Directive on Tunnel Safety prescribes the use of appropriate signs before the entrance of the tunnel to inform users on how to receive information this information. The directive does not give examples of these signs and they are also not available from the Vienna Convention.

Regulatory signs
These signs are intended to inform road users of special obligations, restrictions or prohibitions with which they must comply. Examples (see Figure 4) which may be relevant for tunnels are: prohibition to overtake, speed limitations, closed traffic lanes etc. So this signs are applicable both in normal situations as in deviant situations. An important regulatory sign for tunnels is the prohibition to enter a tunnel for vehicles carrying dangerous goods, if applicable. This sign can be specified by an additional panel bearing one of the letters A,B,C,D. The meaning of these additional panels is described below.

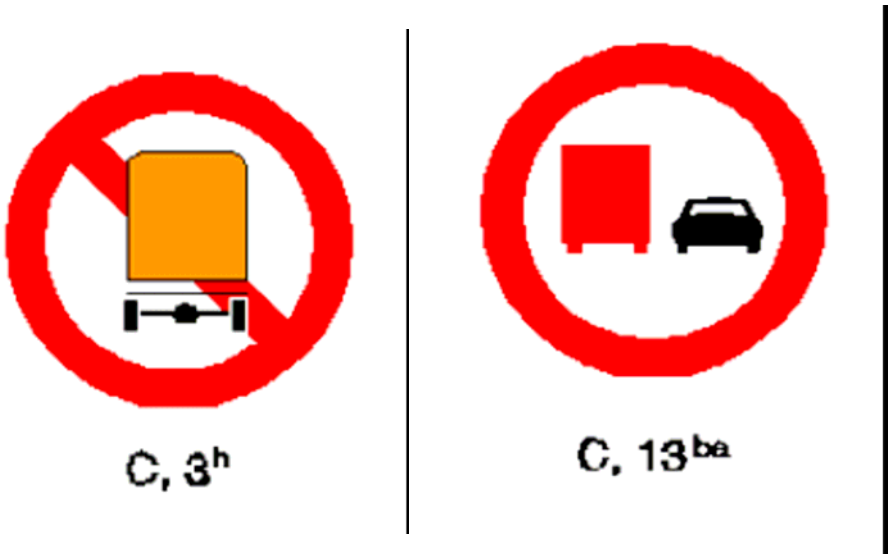

Figure 4: Examples of regulatory signs. Sign C,^{3h} indicates prohibition for vehicles carrying dangerous goods, Sign C, 13^{ba} indicates prohibition to overtake.

- With an additional panel bearing letter B: No entry for vehicles carrying dangerous goods presenting a very large explosion risk (Grouping B, tunnel codes B, B1000 or B1 according to 2.4 of Annex A of ADR), for which the orange-coloured plate marking according to 5.3.2 of Annex B of ADR is required;
- With an additional panel bearing letter C: No entry for vehicles carrying dangerous goods presenting a very large or large explosion risk or a risk of large toxic release (Groupings B and C, tunnel codes B, B1000, B1, C, C5000 or C1 according to 2.4 of Annex A of ADR), for which the orange-coloured plate marking according to 5.3.2 of Annex B of ADR is required;
- With an additional panel bearing letter D: No entry for vehicles carrying dangerous goods presenting a very large or large explosion risk, or a risk of large toxic release or a large fire risk (Groupings B, C and D, tunnel codes B, B1000, B1, C, C5000, C1, D or D1 according to 2.4 of Annex A of ADR), for which the orange-coloured plate marking according to 5.3.2 of Annex B of ADR is required;
- With no additional panel: No entry for vehicles carrying any type of dangerous goods, except class 6.2, UN No 3291, for which the orange-coloured plate marking according to 5.3.2 of Annex B of ADR is required.

* * *

Position of the signs

The tunnel signs mentioned here are placed not only at the entrance of the tunnel but also at reasonable distances in front of the entrance. According to the general Vienna Convention on Signs and Signals "signs shall be so placed that the drivers for whom they are intended can recognize them easily and in time. They shall normally be placed on the side of the road appropriate to the direction of traffic. they may however be placed or repeated above the carriageway. Any sign place on the side appropriate to the direction of traffic shall be repeated above or on the other side of the carriageway if local conditions are such that it might not be seen in time by he drivers for which it is intended."

Dimensions of the signs

According to the Vienna Convention on Signs and Signals it is recommended that domestic legislation should provide that the dimensions of danger warning signs and of regulatory signs (except special regulation signs) shall be standardized in the territory of each contracting party. As a general rule there shall be four sizes for each type of sign: small, normal, large and very large.

2.1.2 Signs in the tunnel

A. Horizontal markings

Visibility aspects

Concerning horizontal markings the provisions of the Vienna Convention for horizontal (longitudinal) markings apply.

The EU Directive prescribes the marking of edges of the carriageway. In tunnels with bi-directional traffic the division of the traffic direction must be made clearly visible.

B. Vertical signs and signals

Distance yet to be covered

The EU Directive on tunnel safety states that for tunnels longer then 3000 m the distance yet to be covered has to be indicated every 1000 m.

Indication of lay-bys

The Vienna Convention proposes the signs reproduced in Figure 5: These are more or less in accordance with the proposals in the EU directive on tunnel safety.

E, 17 [a] **E, 17 [b]**

Figure 5: Indication of lay-bays

Lane use indicators

The EU Directive gives the example of Figure 5

Figure 6: Lane use indicators

Direction signs

There are no international provisions for this item. The PIARC publication Lit. 6 gives useful information.

2.2 National rules, norms and guidelines concerning traffic signs and signals in normal driving situations and in case of incidents

At the moment of drafting this publication not all countries have adjusted their legislation and guidelines to the amended Vienna Conventions or to the EU-Directive. The aim of this section is to give examples of how countries try to maintain or to increase tunnel safety so as to learn from each other. Also comparisons can be made with the recommendations of parts I and II of this report.

2.2.1 Signs and signals on approaching a tunnel

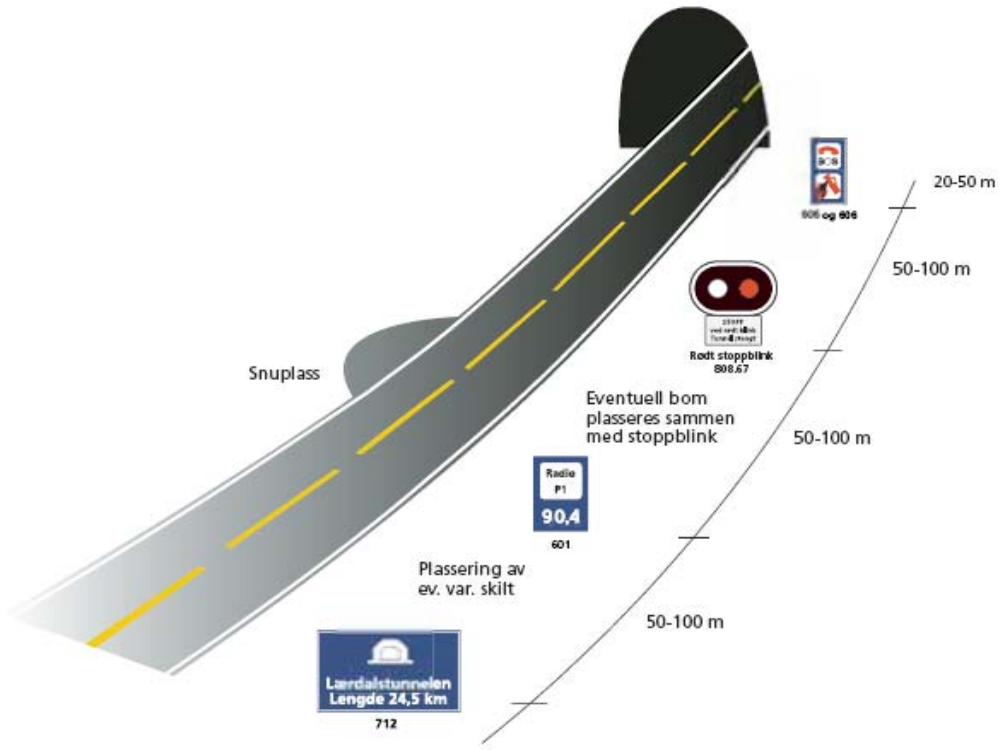

Figure 7: Norwegian example of signs on approaching a tunnel

Introduction

Figure 7 shows an example from Norway of the spacing of various signs on approaching a tunnel.

The distances between the signs are 50-100 m and the signs are presented one by one. This is in line with the observations on human perception. It is not necessary to repeat the signs because they are generally known (at least in Norway).

The shape of the tunnel sign is somewhat differing from the sign E,11[a]. The Norwegian guideline forbids to use the additional panel H1 with the distance between the tunnel sign and the tunnel entrance, when the length of the tunnel is mentioned.

The reason obviously is that too much information might be given to the road user and in most cases it is evident for the driver where and when he enters the tunnel.

To indicate that a radio station can be received in the tunnel the panel F of the Vienna Convention is used. Alternating blinking traffic lights to stop traffic in special cases are placed at a suitable distance from the tunnel entrance as well. Finally information is given about the presence of telephones and fire extinguishers, also at some distance before the actual entrance of the tunnel. This arrangement is in good agreement with the recommendations. However it is noticed that tunnel drivers generally do not stop when the traffic lights are blinking.

Use of the tunnel sign

A comparison of guidelines of several countries on the use of the tunnel sign, E,11[a], shows that this sign is not generally used. Instead many countries use signs to make clear to drivers that they have to switch on their lights when entering the tunnels. These signs differ from country to country. One of the reasons is that until a short time ago it was left to domestic legislation whether or not to use the sign E,11[a] . As the sign indicates special traffic regulations and the only special traffic regulation in many countries is the obligation to switch on the lights the tunnel sign was not used. *Now that attention is paid on the due behaviour of road users in case of normal driving and fires the Technical Committee C3.3 recommends to use the tunnel sign in all countries. In this way the local signs for lights on are not needed any more and road users know how to behave in tunnels in all countries. In order not to give too much information at the same time the tunnel sign should be placed far in front of the tunnel entrance and before the other signs. Also the Technical Committee does not consider it necessary to indicate the distance till the tunnel entrance when the length of the tunnel is mentioned. The naming of the tunnel is only of interest to the road user if he wants to know where he is. When there are many short tunnels on the route he is not interested in all the names any more. So the Technical Committee C3.3 recommends to be sparing with reproducing the tunnels name on the panel.*

Radio

There is no uniform international sign to indicate the radio frequencies which can be received in tunnels. A sign that is used by some countries and which is in harmony with the UN-system of signs is shown in Figure 8, which is the general "F" sign with relevant information.

Figure 8: Application of the UN "F"-sign to indicate radio frequencies

From experience it appears that the effect of the announcement of special radio frequencies is rather poor. Reading the information and searching for the frequencies on the car radio requires a lot of attention. It is recommended that the sign for radio-frequencies is placed at considerable distances in front of the tunnel and repeated several times. Of course this has only sense if the radio concerned effectively can be received on the road from where the frequencies are indicated. **The placing of a sign for radio-frequencies just at the entrance is not recommended.**

When commercial broadcast stations want to be received in the tunnel as well it can be considered to agree that they allow for possible overruling the emission with messages meant for road users in the tunnel in special cases. The more stations agree the less it is necessary to indicate this on special signs.

Regulatory signs

The German RABT shows examples of the lay-out of signs and signals for different classes of tunnels. The RABT discerns four operation modes of tunnels:

- normal operation
- closing of traffic lanes
- closing of a traffic direction
- closing of the complete tunnel

On this page reproduction of Bild 15 of the RABT is welcome!

Figure 9: Signs and signals on approach ramps of long tunnels with high traffic intensities according to the German RABT

Here the signs to be used in the different modes for the highest class of tunnels are described (see Figure 9).
Normal operation and temporary speed limitation: Signs for (continuous) speed limitation and prohibition to overtake for trucks are placed at several hundreds of meters before the tunnel entrance and might be repeated. Just in front of the tunnel the signs for "lights on", "radio" and "limitation of height" are placed. *In view of the observations about human capacities to handle information it does not look likely that the information just in front of the tunnel is perceived.*
For cases where it is necessary to impose temporary speed limitation due to congestion, maintenance work etc. these speed limitation signs are given with variable message signs and the argument for the speed limitation is indicated as well. The first signs are given at a distance of 300 m before the tunnel entrance, a repetition of the signs is given a distance of 150 m before the tunnel entrance. The signs for speed limitation are repeated every 600 m inside the tunnel.

Closing of a traffic lane: Warning signs are placed at distances of 500 and 300 m before the actual point where the lane is closed. This point is situated at 300 m before the tunnel entrance and indicated by Variable Message Signs above the carriageway. These signs are repeated every 300 until 600 m also in the tunnel.

Closing of a traffic direction: Warnings by means of UN-signs A,17, indicating traffic lights at some distance, are placed at distances of 300 and 150 m before the tunnel entrance. If the traffic direction has to be closed lights mounted on top of the A,17 signs indicate the traffic lights blink. Additionally the sign indicating prohibition of all traffic is shown at 150 m before the tunnel entrance. The actual traffic lights are placed before the cross over through the centre shoulder to the other carriageway. If traffic has come to a stand still the operator closes the carriageway also with a physical barrier. (In case of fire alarm the physical barrier is closed automatically)

Closing of the complete tunnel: This mode will not be described here.

2.2.2 Horizontal markings in the tunnel

Visual guidance

Experience (e.g. the Netherlands, Japan) has shown that entering the tunnel is made easier and the road capacity is increased when: the lay-out of the carriageway is clear. This can be achieved by:

- good lighting system and clear walls
- sharp contrasts between road surface and lane markings, sidewalks or barriers

The EU Directive prescribes the marking of edges of the carriageway. In tunnels with bi-directional traffic the division of the traffic direction must be made clearly visible.

Examples of indicating this division of traffic directions are given in the PIARC publication Cross Section Design for Bi-Directional Tunnels.
Usually the traffic lanes are marked with white paint. Light reflecting paints can make the markings more visible as well as cat eyes. The course of the traffic lanes can additionally be made clear by longitudinal lighting.
Some guidelines prescribe the use of reflectors or LED's on the kerbs of the walkway along the normal travelling lane for better guidance (Figure 10). Other countries prefer to indicate the verges at both sides of the carriageway in this way. In this way also the course of roads in the open air is made clear when the road is not provided with lighting. Thus it follows that these reflectors of LED's might be of importance when the lighting in the tunnel is poor or absent. Unfortunately there is no uniformity in the use of the colours of the reflectors nor of the LED's. This goes so far that colours used to indicate the right hand side or the left hand side are opposite in some countries. *The Technical Committee C3.3 recommends that international agreement is reached on the colours to be used to indicate the verges of the roads.*

Another means to improve the guidance of the road is the permanent use of evacuation lighting (at a height of maximum 1.5 m), which is provided for by the EU-Directive on tunnel safety (Figure 11).

Figure 10: Red LED's indicating right hand kerb to guide traffic in Austrian tunnel

Figure 11: Permanent evacuation lighting used for road guidance in Spanish tunnel

In the Mont Blanc and Fréjus tunnels visual guidance is offered by yellow lights at a height of 1,5 m. at both sides of the tunnel.

<u>Audible guidance</u>

Lane markings executed as rumble strips warn drivers when they cross a lane marking. This can be considered as a corrective measure. It is warned that the noise may cause hindrance for the people living in the area.

Maintaining distance to other vehicles. If it is required to maintain distances in the tunnel drivers can be aided by means of chevrons or other symbols that are painted on the pavement at distances in accordance with the desired distances between the vehicles. Another means to aid drivers is employed in the Mont Blanc and Fréjus tunnels: every 150 m yellow light is replaced by a blue light. The distances to be maintained in the tunnel are150m for running traffic and 100m at stopping.

2.2.3 Vertical signs and signals in the tunnel

Signs indicating the distance yet to be covered in the tunnel
Fout! Verwijzingsbron niet gevonden. shows how "chrystal arcs" in the Laerdaltunnel indicate every km. In the Gotthardtunnel the distance to the end of the tunnel is clearly indicated. Fig. xx shows as an example how the distance to be covered in the Westerscheldetunnel is shown.

Signs to indicate lay-bys. The signs proposed by the Vienna Convention and the EU-directive (Figure 5) are generally used.

Deviant situations such as speed limitation, lane closure, warning for congestion can be indicated by VMS (Figure 6).

3 Signs and signals to promote self-help in tunnels

3.1 International regulations on signs and signals in tunnels to promote self-help

Car break down / emergency telephones
In case of car break down in a tunnel with lay–bys the Vienna Convention signs shown in Figure 5 have to be used. When the distances between lay-bys are too great these signs might be shown with the additional panel H,1 indicating the distance till the first lay-by on the way.

However most important is that the driver knows where it is possible to have contact with the tunnel operator using the emergency telephone. To this end the sign F,14, shown in Figure 12 is proposed by both the Vienna Convention and the EU Directive on tunnel safety.
In many cases of car break downs the driver cannot reach lay-bys nor the telephone.

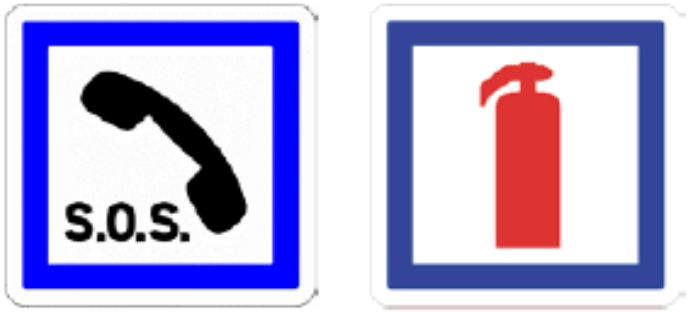

Figure 12: Signs F,14 and F,15 to indicate the presence of emergency telephone and fire extinguishers

Traffic accidents
In case of traffic incidents communication between drivers and the control centre only is possible when road users go the emergency telephones..

Fires
When a car has caught fire in a tunnel the car users or other road users have to contact the control centre as soon as possible and then, if possible, try to extinguish the fire with the available extinguishers. To this end road users have to be informed about where fire extinguisher is present. This can be done with the sign F,15 , shown in Figure 12 as proposed by both the Vienna Convention and the EU Directive.

If the fire cannot be extinguished and threatens to grow, all road users have to be alerted to leave their cars. The EU Directive only provides in *radio re-broadcasting*.

To inform road users who have decided to escape from the endangered tunnel tube about the distance to the escape doors signs G, 24 (Figure 13) are proposed by both the Vienna Convention and the EU Directive. They have to be placed every 25 m at a height between 1 and 1,5 m.

G, 24[a]

G, 24[b]

G, 24[c]

Figure 13: Signs G,24 to indicate direction and distance to escape doors

Finally the position of escape doors can be marked by the signs G,23 (Figure 14)

G, 23[a] **G, 23[b]**

Figure 14: Signs to indicate the position of the escape doors

3.2 National regulations on signs and signals to promote self-help in tunnels

The signs, mentioned in the preceding section are employed in most countries, be it that the symbols sometimes deviate by the addition of flames etc..

In this section additional means employed by some countries will be dealt with to share experience. The following additional means are described:

- communication with the control centre
- alerting traffic (not to enter or to stop)
- use of extinguishers
- SOS-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

3.2.1 communication with the control centre

Intercom or emergency telephone

The sign for intercom or emergency telephone as shown in Figure 12 is generally used.

Mobile (cellular) phones

Can anybody tell something is interesting? Is there a sign?? BenR

Loudspeakers

Many countries do not install loudspeakers because they think the messages cannot be heard. Yet loudspeakers can be of vital importance. In cases of car break down and accidents the drivers can immediately be told what to do (provided the traffic speed detection system alert the operator). That is why other countries do install loudspeakers.
The Dutch Rijkswaterstaat commissioned TNO to develop methods to improve the audibility of the loudspeakers because during exercises the loud-speaker systems didn´t work as well as expected. In the annex to this report the results are described.

The results were that the Speech Transmission Index could be improved from 0,28-0,35 before to 0,4 - 0,5 after. Work by TNO on further improving the STI is going on.

3.2.2 Alerting traffic (not to enter or to stop)

The following signals can be thought of:

- On the road approaching the tunnel traffic signs as shown in Figure 9, perhaps with an additional argumentation panel? In order to keep the traffic to a standstill a physical barrier might be necessary.
- Inside the tunnel visual alarms like red crosses and pre-recorded texts. It might be necessary to force the traffic to stop by means of barriers as applied in the Mt. Blanc tunnel.
- Radio messages

Figure 15:Pictograms indicating SOS-stations in Dutch tunnels

3.2.3 Signs to indicate extinguishers

The sign for extinguisher as shown in Figure 12 is generally used. In the Netherlands the pictograms as shown in Figure 15 will be used. According to research the pictogram with flames is better understood by the public.

It is recommended that tunnel users be informed about the following behaviour in case of fire:
alarm the control room by using the intercom devices
try to extinguish the fire
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.

3.2.4 SOS-stations

In case SOS-stations are separated from traffic noise by a door (Figure 16) the following recommendations apply :

Outside signing:

The outside signing is aimed at improving the apprehension of the system, so that the user can identify its equipment at the first sight. Then:

- The recess inside must be as clear as possible and the inside lighting must allow to distinguish the safety elements (emergency phone and extinguisher);
- The access doors to the recess – if any – must be glazed;

- A distinct colour must be used to emphasize the system and its closest environment (side walls, doors, ….). We suggest the orange colour that the users generally associate with the notion of emergency call stations generally available on the open roads.

Figure 16The position of a SOS-station (safety recess) among other safety provisions

Inside signing:
If the user has to use the SOS-station, he will do it to inform that his vehicle is broken down or to fight against a beginning fire in a vehicle. Then the emergency phone and extinguisher box must be as easily accessible and clean as possible, so that the user can use them as spontaneously as possible. If no emergency phone is available, but replaced by a push-button, it would be preferred to have it of orange colour and displaying the SOS initials, so that there is no ambiguity about its purpose. In case of more severe fire, the user may deem, after having found refuge inside the recess, that this latter offers a sufficient protection against smoke and heat produced by the fire. To prevent any risk of confusion between the safety recess and the emergency exit, it is recommended to display inside the recess – and clearly visible as soon as entering into the recess – a board stating that the user is not protected and that he is recommended to proceed to an exit according to the arrows on the sidewalls.
This message could refer to the following text: « This room does not ensure a protection in case of fire – please go to an emergency exit following the signs on the walls ».

This room does not ensure any protection in case of fire. Please proceed to an emergency exit following the signs on the walls.

3.2.5 Alerting tunnel users in case of fire

The following signals can be thought of:

- On the road approaching the tunnel the traffic signs as shown in Figure 9, with an argumentation panel: FIRE (Are there any examples? BenR)
- Inside the tunnel visual and audible alarms
- Radio messages

Visual alarms

More and more countries employ variable messages to inform road users on open roads about closed lanes and recommended speeds. Sometimes it is also possible to mention by means of pictograms the reason for the traffic measure: queue caused by accident or fire. Also variable texts can be made. Pictograms can be considered as pre-recorded messages. Of course also texts can be pre-recorded. In the Westerschelde Tunnel in the Netherlands screens at eye-

height are placed at regular distances. In case tunnel users have to escape the text: “Alarm, get out” appears as a pre-recorded message. See Figure 17

Figure 17: Visual pre-recorded message to leave the car

Acoustical messages

Sirenes??? BenR

In case of fire, road users standing in a queue and not aware of any danger will not get out of their cars. The chance of being alerted by radio is small as only few persons will listen to the radio of the right frequencies. Even when road users see smoke a strong impulse is necessary to get them into action. That is another reason to install loudspeaker systems in tunnels.

The RABT prescribes the possibility of both direct and pre-recorded messages. In a chain of tunnels (Thüringen) pre-recorded messages are spoken in four languages. Experience showed that messages spoken with a high female voice were much better understandable than spoken with a low male voice.

In the Netherlands research has started to determine the sensibility of pre-recorded messages from a viewpoint of human reactions.

3.2.6 Guidance towards emergency exits

General

For the UPTUN project (Martens, 2005, Lit. 20), the Mines Rescue Service Limited (MRSL) reviewed literature regarding available guidance technologies. The conclusions are:

1. Passive rail and lifeline technologies provide the lowest cost approach to guidance. However there are limitations, viz.
    a) difficulty in providing continuous physical access to a handrail or a lifeline;
    b) possible directional ambiguity;
    c) not self-illuminating or self-revealing;
    d) strong tactile reliance.
2. Retroreflective signs have limited value in conditions of very low visibility and may require frequent cleaning. Self-powered emergency lighting strips using light

emitting diodes (LEDs) offer benefits of high relative efficiency, robustness and greater brightness compared with incandescent lamps. LED strip lighting has high cost implications.

3. Active guidance systems potentially offer an effective response to a variety of incident situations. (..) Any systems must have reasonable acquisition cost, relatively uncomplicated installation and should materially increase evacuation speed even in very low visibility conditions.

MSRL developed a simple-to-install novel fire detection/evacuation support system with some unique features. The main feature is the use of a single wire loop to provide power in a contact-less fashion to each beacon (outstation) via inductive power transfer. This avoids the overhead of local power supplies and the cabling and multi-pole connector problems associated with conventional approaches. The system design offers fail-safe behaviour, with each beacon activated when the charging line is broken or de-energised. The benefits of contact-less operation include; electrical isolation of individual units, guaranteed charge current sharing, the possibility of meeting high environmental protection standards (including submersed operation) and a key benefit – simplicity of installation and the opportunity for temporary deployment. Additionally, the same wire loop is used for data telemetry: the beacons can be interrogated and sensor data can be received from each unit by a central master controller. This offers a capability to monitor environmental conditions at each beacon location and to reassign the evacuation route.

The specific design features of the system can be summarised as follows. Each beacon is independently powered by an internal battery that is inductively charged from a line carrying a high frequency current, which couples in a contact-less fashion through each unit. There are no direct connections, each unit is isolated and significant cost and reliability benefits are anticipated from not having to use multicore cables and multipole connectors in the system. The single charging line, which can be kilometres in length, is also used to send and receive commands from individual units or groups of beacons. This provides a real-time facility to monitor environmental conditions and call alerts at each beacon, together with (potentially) a capacity to update direction information, responding to the development of a fire.

Figure 18: Prototype beacon, quiescent and arrow programmed in each direction.

Each unit is fitted with a precision temperature sensor and a dual range carbon monoxide (CO) sensor, providing an ability to detect fires and then subsequently monitor fire situations throughout the tunnel or structure. The use of a high fire withstand, ceramic clad wire is proposed for the charging line, which could in principle also provide tactile cues. The overall strategy has been to reduce beacon cost and installation complexity so as to allow beacons to be relatively closely spaced, and to provide a near continuous sequence of guidance cues, even where tunnel refuges or intermediate exits are relatively widely spaced. The system could also in principle provide an excellent platform to incorporate acoustic instruction and guidance information. With further commercial development, this proof-of-concept system is considered to have application potential across the generality of Europe's road, railway and metro tunnels. Figure 18 shows the prototype.
Unfortunately, there are no behaviour evaluations of using this system, so its direct effects on evacuation behaviour is not yet known.

Pictograms

The signs as shown in Figure 13 are generally used, be it with some variations. It is advised for unidirectional tunnel tubes to mount these pictograms at both wall of the tube.
It is recommended to mount on the wall opposite the emergency exit a panel with the wording "EXIT AT THE OTHER SIDE" as shown in Figure 19

Figure 19: Panel at the wall opposite emergency exit with the wording "EXIT AT THE OTHER SIDE"

Moreover on the carriageway arrows may be marked in the edge lane markings along the walls of the tunnel tube pointing to the direction of the emergency exits (Figure 20).

Figure 20: Arrows on the carriageway in the edge lane markings along the walls of the tunnel tube pointing in the direction towards the emergency exit.

Visual guidance

Other means used in many countries (as prescribed by the EU-directive on tunnel safety) are evacuation lights like in Figure 11, be it that normally those lights only are lighting when there is a crisis situation.

Other suggestions (air plane solutions? BenR)

Acoustical guidance

In Switzerland ……

In the Netherlands the acoustical sound beacons discussed in part II will be installed in all tunnels of the national motorway network. They are mounted right above the emergency exits ( ).

Figure 21: Example of emergency exit with LED-frame (lighting only in case of emergency), permanent illuminated pictogram sound beacon above the exit. The Netherlands

Emergency exits

In most countries much attention is given to the design of emergency exits. They may be illuminated permanently so that tunnel users become acquainted with their presence. In case of fire there may be additional flashing lights or LED-frames to help find the exits through the smoke. Also sound beacons or sirens are employed.

3.2.7 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
- cross connections between tunnel tubes
- exit to an emergency gallery or mid-tunnel tube
- shelters with an escape route distinct from the tunnel tube.

Direct exits

Such facilities are galleries which allow the users to proceed directly to open areas via a corridor or stairs of various length.
Inside the tunnel, and if the way out to reach the exit is rather long, arrows can be marked to strengthen the users  to follow this direction, possibly indicating the distance still up to the exit.
Generally no ambiguous understanding is possible in this type of orientation. However, to comfort the user he/she made the right choice, the pictogram of the regulatory emergency exit sign could be repeated on the exit door (see Figure 14).
The evacuation galleries to outside should be lit. The use of photo-luminescent signs or luminous guidance signs (directional or not) allowing to ensure a lit continuous orientation may be proved to be useful in case of breakdown of the lighting of these evacuation galleries.

Cross connections between tunnel tubes

A connection gallery is a passage between two tubes of the same tunnel. In some configurations, e.g. many cut-and-covers, the connection gallery passes through a concrete thin wall separating the tubes. Then there is only a passage closed by a simple door. In other configurations – a frequent case in excavated tunnels – the tubes are separated by several metres, even several tens metres; then the connection gallery is a corridor closed on both ends by doors.

As mentioned previously signing in these facilities is always the same. But signage will depend on the local configuration:

If the two tubes are separated only by a simple concrete thin wall, the separating door must be anti-panic and opening in both directions. In this case the signage inside the connection gallery will be moved next to the tube separating door.

A connection gallery is likely to be passed through in any direction. Consequently the signage inside a connection gallery does not indicate any exit direction.

This is the reason why arrows are not recommend to indicate the walking direction inside a connection gallery. Instead of it photo-luminescent and self-adhesive dots can be used (see photograph opposite, with and without lighting).

The users must be encouraged to leave the connection gallery. Even if pressurized or provided with doors with a 2-hour resistance, the connection gallery generally is not designed to ensure safeguard of persons and is only a transit place to the safe tube.

The panel indicating the safe place should therefore not be used in the connection galleries, but the word EXIT will be marked on the back of each door. Its sizes must be adapted so that it can be read by a user at the maximal possible distance in the gallery. The use of photo-luminescent text on a green background or the word EXIT on a green background is recommended.

The connection galleries must be lit. The use of photo-luminescent marks or luminous studs (directional or not) allowing to ensure the luminous continuity of the walkway may prove useful in case of lighting breakdown in these inter-tube galleries.

In such a connection gallery between two tubes of the same tunnel, the users shunning the danger enter a corridor with two exits: the one guiding them back to the danger if turning back, and the other they would use more spontaneously and guiding them to the other tube. In this latter they hope they will not find the danger they are shunning. But this “safe” tube may still be trafficked when they enter it. Thus it is important that an adapted signage informs them on the potential danger they are shunning when going out rapidly into this tube. Obviously – and beyond such concerns – the operator must follow the instruction to stop traffic in the safe tube as soon as possible.

(pay attention to the traffic)

Exits through an emergency gallery

The dispositions proposed for direct exits from the tunnel to the outside will be adapted to the case of exit to an emergency gallery.

In ***mid-tunnel tubes*** in the Netherlands the following information is provided:

At the backsides of emergency exits the pictogram C,1[a] according to the Vienna Convention is applied. This is to indicate that opening of the doors from the evacuation gallery is not allowed.

Figure 22: Signs to be applied on the back side of emergency exits to prevent people entering the "safe" tunnel tube.

If for some reason there is only one way to get out of the evacuation tube signs shown in Figure 23 are applied from the ceiling of the evacuation tube. The signs are mounted every 50 m.

Figure 23: Signs indicating the recommended direction with distance to be covered to the exit from the evacuation tube and the forbidden direction.

At the end of the evacuation tube the sign:

is applied on the doors indicating the way to the open air.

Shelters are a special case. France recommends as follows.

Inside the shelters the users shunning a danger are in a closed room, the only exit of it brings them back to the danger. Therefore it is important to let them understand that their situation is safe, known, temporary, and that they must not come back to the tunnel.

Also, they must be informed about the various available elements they can use when they are in the shelter.

Lastly they must be reassured to avoid any panic impulse which could be detrimental to all those who took refuge inside the shelter.
An example of signage meeting such requirements is given below. This board (or boards if foreign users are assumed to pass through the tunnel) is installed at a height permitting several persons to read it at the same time.

KEEP COOL
YOU ARE HERE IN A SAFE PRESSURIZED AREA PROTECTED AGAINST SMOKE
DON'T GO BACK INTO THE TUNNEL
EMERGENCY AND RESCUE SERVICES ARE INFORMED
USE EMERGENCY PHONES.

A text could be displayed on the back of the access door to the tunnel with the pictogram opposite.

NE RETOURNEZ PAS
DANS LE TUNNEL !
VOUS ETES ICI A L'ABRI
MAINTENEZ LA PORTE FERMEE

Don't go back into the tunnel, you are safe here. Keep the door closed.

A handicapped person may be inside the shelter. Although this latter is designed so that it can be accessed to by everybody, a handicapped person may feel to be abandoned there.

Moreover, if an escape door of the shelter opens to a way that the handicapped cannot access to, he/she must stay there waiting for the rescue services which will assist him.

In order to reassure the handicapped person …it is recommended to display a pictogram similar to the enclosed one. This pictogram will be usefully complemented by a communication system allowing the handicapped person to communicate with the control room.

Acoustical communication

In all cases it is recommended to install loudspeakers in the evacuation ways to inform evacuees.

3.2.8 Alarming tunnel users in the safe tunnel tube

In part II **Fout! Verwijzingsbron niet gevonden.** shows a possible means to clear the overtaking lane in case of possible escaping people entering the safe tube.

ANNEX: SPEECH TRANSMISSION INDEX (STI)

The content of this annex is based on a paper by Huijben (Lit. 41)
The noise levels caused by the jet fans in one Dutch tunnel with grouped jet fans were up to about 100 dB(A) and in another tunnel with distributed jet fans along the length up to 93 dB(A). This might cause several problems:

- Most people are not in panic due to the sight of smoke, but such high noise levels can cause a larger number of people in panic. People also loose their bearings not knowing where to go, and are reacting slower.
- In such high noise levels people can hardly understand each other even if they are in short distances to each other, which means that they are handicapped in warning and helping each other.
- Some rescue workers such as the fire brigade have helmets with sound attenuators but medical workers have not. That means that they have to work in a place with a high noise level causing remaining ear damage.

Figure 24 shows the main causes of disturbing noise: jet fans, traffic, and other sources. Also the loudspeakers themselves cause noise. The rate of noise is

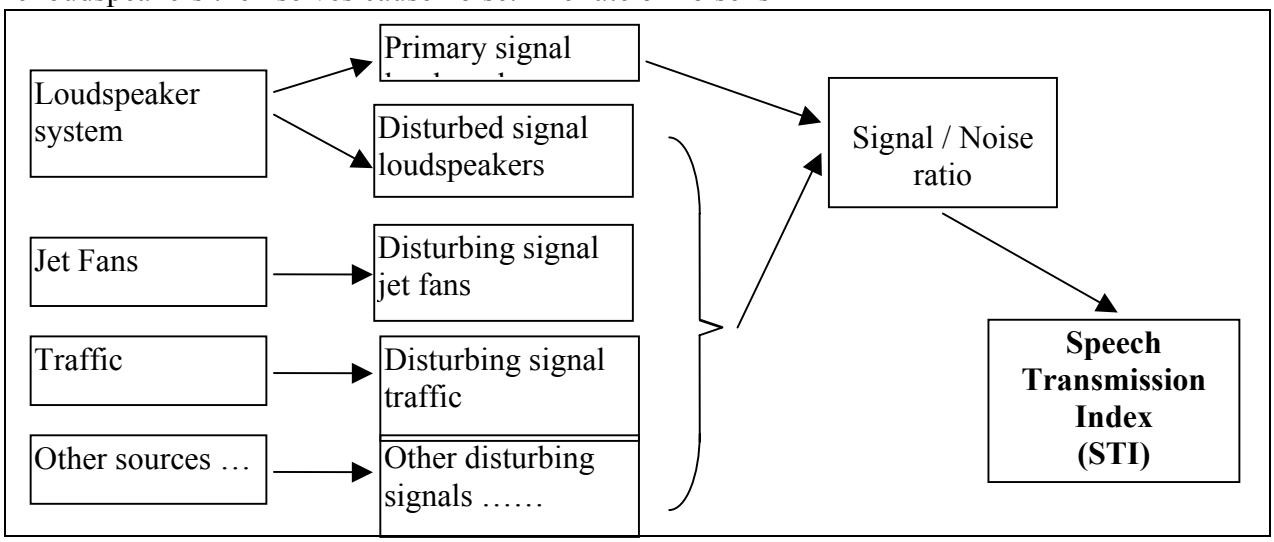

Figure 24: Analysis of the sources of noise

influenced by the high reverberation in tunnels: pavement, walls clad with tiles and heat resistant ceiling reflect many frequencies. The noise level of the primary signal of the loudspeakers has to be higher than the total noise level of disturbing noises.

For speech the frequency bands 1000 Hz, 2000 Hz and 4000 Hz and more or less also the 500 Hz bands are important, the bands 125 Hz, 250 Hz and 8000 Hz are supporting. The disturbing sound of jet fans also have high noise levels in the frequency bands 500, 1000, 2000 and 4000 Hz, whereas traffic noise has high noise levels in the frequency bands 1000 and 2000 Hz. This is illustrated in Figure 25 and Figure 26 for one of the tunnels before improving the STI.

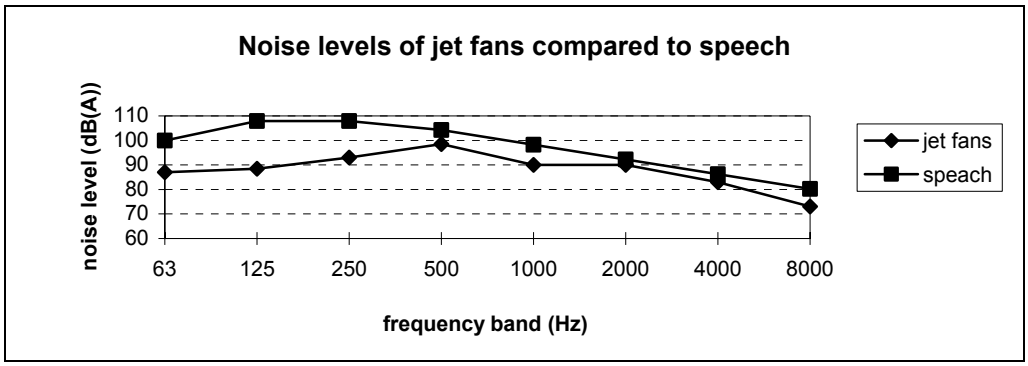

Figure 25 Noise levels of jet fans compared to speech

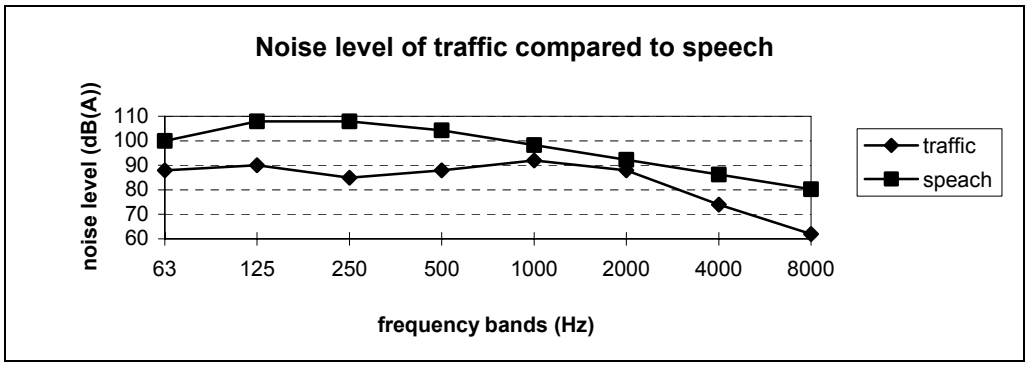

Figure 26: Noise level of traffic compared to speech

These figures illustrate that the Speech Transmission Index will be low because of the small difference between speech signal and noise signal.

However the signal/noise ratio is not the only parameter that determines the audibility. For instance consonants as the "k", the "s", the "t" can be heard better than other consonants, and also sometimes words can be understood by only hearing the consonants and not the vowels, or by hearing words partly. As an example the words ".. is fire, lea…. roo" from the sentence "there is a fire, leave the room" is maybe enough to understand. It is not easy to translate subjective perception to objective figures which represent audibility. From 1980 up to now Steeneken and Houtgast (Lit ???) developed a method to represent subjective speech in measurable figures. In this method a certain artificial speech signal is emitted by a loudspeaker and received by a microphone at some distance from the loudspeaker. Both signals are compared in the frequency bands which are relevant for speech. The comparison gives the ratio between the speech signal emitted and the number of words and sounds, received by persons, from which words can be derived, resulting in a percentage called the Speech Transmission Index. The STI is based in the standard IEC 60268-16 2nd edition (1998).This method yields much better results than only a comparison of the signal and noise. The level of the Speech Transmission Index is a measurement of the audibility of speech signals and can be understood as given in table 1.

Speech Transmission Index	Qualification
> 0,75	excellent
0,60 - 0,75	good

0,45 - 0,60	reasonable
0,30 - 0,45	moderate
< 0,30	bad

Table 1: Qualification of values of STI

To give an idea: If the STI is 0,35 then 50% of the sentences should be repeated for right understanding. If STI is 0,6 more as 75% of all words and sentences are to be understand, and if STI is 1 all speech can be heard clearly the first time.

From table 2 the following requirements are derived:
- on 90% of the road surface in a tunnel the STI should be higher than 0,45
- on the other 10% of the road surface the STI should be higher than 0,35
- a STI lower than 0,35 is not allowed

In tunnels the air muffles the noise at distances of 60 meters and more from the source, but the higher the frequency is the more the sound is muffled. This explains why in tunnels always the perceived noise is in the low frequency bands. This conflicts with the vowels in speech as the "u" and the "o" and that is another reason for the low Speech Transmission Index.

But defining a level for STI is not enough. The reaction of people on suddenly loud and unexpected sounds is fright, which leads to non-listening and losing the message, as was illustrated by interviews of the people participating in tests. Moreover sound pressure levels higher than 110 dB(A) are harmful to the ears even if the exposure time is shorter than 30 seconds and sudden sound levels higher than 105 dB(A) are not allowed because of the fright of the listener. This leads to an additional requirement:
- the maximum sound pressure level from loudspeakers should be lower than 105 dB(A) measured at 1,5 meter above road surface.

Until recently the STI-method was only based on measuring STI on existing installations. Rijkswaterstaat commissioned TNO to improve and predict the STI in tunnels by developing a calculation method. The results are presented in the next sections.

Improving the Speech Transmission Index

After knowing the problems with audibility of speech in a tunnel the improvement of the speech transmission index was handled departing from the following assumptions:
- reducing the noise level of the jet fans is possible by adding better attenuators
- traffic noise can not be lowered
- adding sound attenuating material to the ceiling or the walls is a very expensive solution which is not reasonable
- if the jet fans noise is at the same level as the traffic noise, the problem can further on be handled by improving the loudspeaker.

Reducing the noise level of the jet fans.

It was found that good results could be reached by lengthening the standard attenuators, and also a kernel inside the attenuator would help. A very important outcome was that sharp edges

and small holes inside the jet fans should be avoided as much as possible because with air velocities of about 30-40 m/s these edges and holes are sources of noise, mainly in the 2000 - 4000 Hz bands which are the important speech frequencies . Before the experiments with better attenuators the expectation was that the efficiency of the jet fan would be lower, but from the experiments it became clear that the efficiency stayed equal or became even better because of the improved streamline patterns upstream and downstream or the blade impeller. In tunnels with a rectangular cross section the jet fans are fixed just near the ceiling and deflection blades are used to turn the air stream away from the ceiling to improve the efficiency of the jet fan. But only simple blades in an air stream of 30-40 m/s produce high noise levels, mainly in the 2000 - 4000 Hz which are the important speech frequencies. An additional research has been done on the shape of deflection blades to lower the noise production, resulting in a special wing formed deflection blade.

The original tested jet fan, which was also used in both tunnels produced 102 dB(A) sound power level measured in a laboratory. The jet fan with the improved attenuators produced 90,5 dB(A), and with deflection blades 92-93 dB(A). This means in acoustical terms that the improved jet fan produces only 12,5% sound power of the original fan.

Improving the loudspeaker

From an investigation using ray-tracing techniques, which is a kind of simulating the sound travelling through a room, the conclusions for rectangular tunnels as used in the Netherlands are:

- The best type of loudspeakers are horn loudspeakers which can handle the high sound levels and are best proofed against the aggressive tunnel environment.
- The acoustical directivity (orientation?) of loudspeakers is not as important as was supposed. Mounting of 2 or 3 loudspeakers in a group together yields a good directivity (orientation).
- A far more important acoustical requirement to the loudspeakers is that they can handle the high sound levels without deformation. Also the amplifiers of the loudspeakers should be able to work without causing signal-deformation.
- Loudspeakers should give the main signal **against** the driving direction (in a one way tunnel) because otherwise trucks will function as a screen for the drivers.
- Mounting loudspeakers against the walls is a bad solution because of the high reflections against the other wall. The best place is above the driving lanes, and each lane should have its own loudspeaker group. Lengthwise the distance between loudspeaker groups above one lane should be not more than 60 meters and more likewise about 45 - 50 meters.
- The lengthwise successive loudspeaker sections should send their signal with a **time delay**. If all sections would send their signal on the same time they will destroy each others signals because of the time delay between a listener hears the signal from a near loudspeaker and he hears the same signal some parts of seconds later from loudspeakers further on
- It is worthwhile to intensify the speech signal in the frequency bands 500 - 1000 - 2000 - 4000 Hz using amplifiers between microphone and loudspeakers. In the Netherlands a microphone system in the tunnel measures the actual disturbing noise level. Based on this measurement the amplifiers adjust their speech sound signal to reach the right audibility

Employing these recommendations in a tunnel the Speech Transmission Index could be improved from 0,28-0,35 before to 0,4 - 0,5 after..

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