Human behaviour influencing tunnel safety. (Durban 24 October 2003)

Human behaviour turns out to be a very important aspect in the total safety of a tunnel. This paper describes a framework for analysing and how human behaviour influences safety. The results of an extensive behavioural survey in the Netherlands are presented and based on that possibilities are given to influence human behaviour in order to get a higher safety level.

Ir. Evert Worm. Dutch Ministry of Transport, Public Works and Water Management. Tunnelling Department. Head of Centre for Tunnel Safety. Member of the PIARC C5 Committee. Member of the PIARC C5 working group 3: Human factors of road tunnel safety.

1. Framework.

Accidents do not come out of the blue. Frequently there is a relationship between what happened some time before the incident and the incident itself. One can outline it in a fault tree. After an incident several processes occur which together determine the eventual seriousness of the accident. We can outline it in an event tree.
The incident forms as it were the knot between the causes and effects, represented diagrammatically in the following bow tie model (Figure 1).

Left of the knot we find the accident causes which separately or jointly may lead to the incident; in the right half are the effects arising from the incident.
On both sides there are possibilities, at which the course of the process can be influenced by means of measures.
In outline these are measures in the areas of:

- pro-action (avoid unsafety)
- prevention (diminish chances and reduce consequences)
- correction (create opportunities for self rescue)
- repression (offer help from the emergency services)

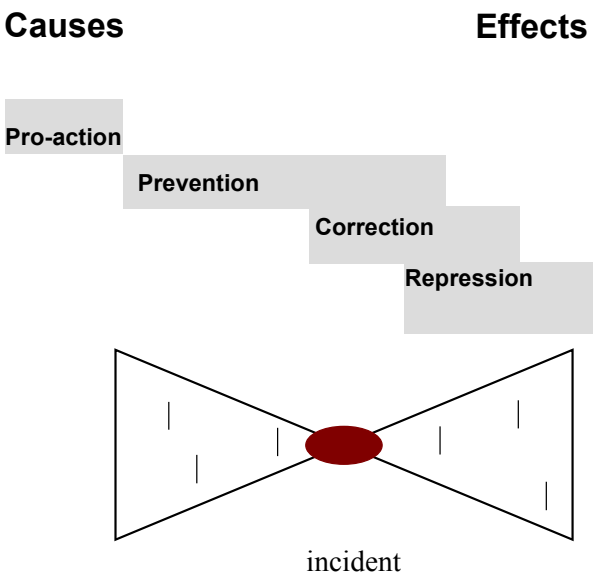

Figure 1: the bow tie model

In this *self-rescue* means:
- action of others present at the scene, immediately after occurrence of the incident
- bringing oneself and others out of danger without the aid of professional emergency services.

Emergency services include:
- actions taken by the tunnel manager
- actions taken by the police, fire brigade and ambulance services.

Measures can subsequently be targeted at the main components of the total system, namely:
- the infrastructure: the tunnel including all the technical systems and its approach roads
- the vehicles
- the users of the tunnel system
- the organisation; especially the operation of:
  - the tunnel operator, and
  - the emergency services

This results in the following table of possible measures, distinguished into process phasing and components of the traffic system:

Measures focusing on:	pro-action	prevention	correction (self rescue)	repression
infrastructure	x	x	x	x
vehicles		x	x	
tunnel users	x	x	x	
organisation: operator emergency services		x	x	x x

Table 1: Points of application for measures

In this lecture I will concentrate on human factors, that is on the last two rows in the table.
Despite all efforts aimed at the first two component systems (infrastructure and vehicles), serious accidents happen from time to time, at which 'the human factor' in particular gives evidence of points for improvement, both in the fault tree and in the event tree.
The following deals with this in greater detail, with the discussion being limited to *road tunnels*, although a number of items also apply to train and metro tunnels.
A further limitation is the concentration on tunnel users in particular, with the operational staff and the emergency services only being mentioned in passing. For the latter two the same approach is conceivable.
At first aspects of interest and experiences concerning human behaviour will be given (section 2) and then possibilities for influencing that (section 3).

2. Where can things go wrong with respect to human behaviour?

The tunnel user.
A car driver approaching a tunnel aims to drive through it under conditions as normal as possible and to continue his journey without inconvenience.
How does he approach the tunnel?

- fit or tired
- calm or stressed
- with or without a dangerous or not so dangerous cargo
- concentrating or occupied by other matters
- as a professional driver or otherwise
- under quiet traffic conditions or in heavy traffic
- under what weather conditions
- as a frequent user or a once-only user

The situation in which the road user is, also determines his driving.
He must:

- maintain his direction
- keep his distance to the vehicle in front
- maintain the correct speed
- pay attention to the signs
- pay attention to the other traffic

Subsequently he drives into the tunnel. Driving in tunnels has a number of special characteristics.
Apart from normal driving, a number of specific effects can be evoked:

- feelings of constriction or confinement
- fear of walls
- fear of getting stuck
- visibility reduced by the darkness
- monotonous visual surroundings
- lack of orientation
- lack of connection with the outside world

Infrastructural measures must prevent or limit these feelings as much as possible.
And then suddenly something goes wrong, with fire breaking out in the worst case.
This requires an enormous change in behaviour of the people involved. From one moment to the next the road user who is carrying out his driving task is required to change to a completely different desirable behaviour.
From ‘maintaining his direction’ to ‘warning, helping, extinguishing and escaping’. If this mental turnaround is not made adequately, valuable time is lost and wrong decisions are made with all the related disastrous consequences of that, as is unfortunately shown all too clearly by recent tunnel disasters.

In general, however, a fire will not develop to its maximum extent immediately. As long as there is little smoke development in the initial phase and also a certain degree of stratification occurs, there is the opportunity to extinguish the fire in its early stages, or to escape to a safer environment.
Depending on the situation, this available time, however, can be limited (see also Figure 2).

The time which passes from the moment of the fire breaking out until the people escaping have arrived at a safe environment can be divided into 3 phases:

- the detection phase: the time which passes between the fire breaking out and its detection
- the reaction phase: the time which passes between the moment of detection and that of action taken by the road user
- the evacuation phase: the time in which action is actually taken. (Here the need for escape might be minimised by a successful extinguishing action)

The total period must have been bridged before the climate in the tunnel becomes intolerable.

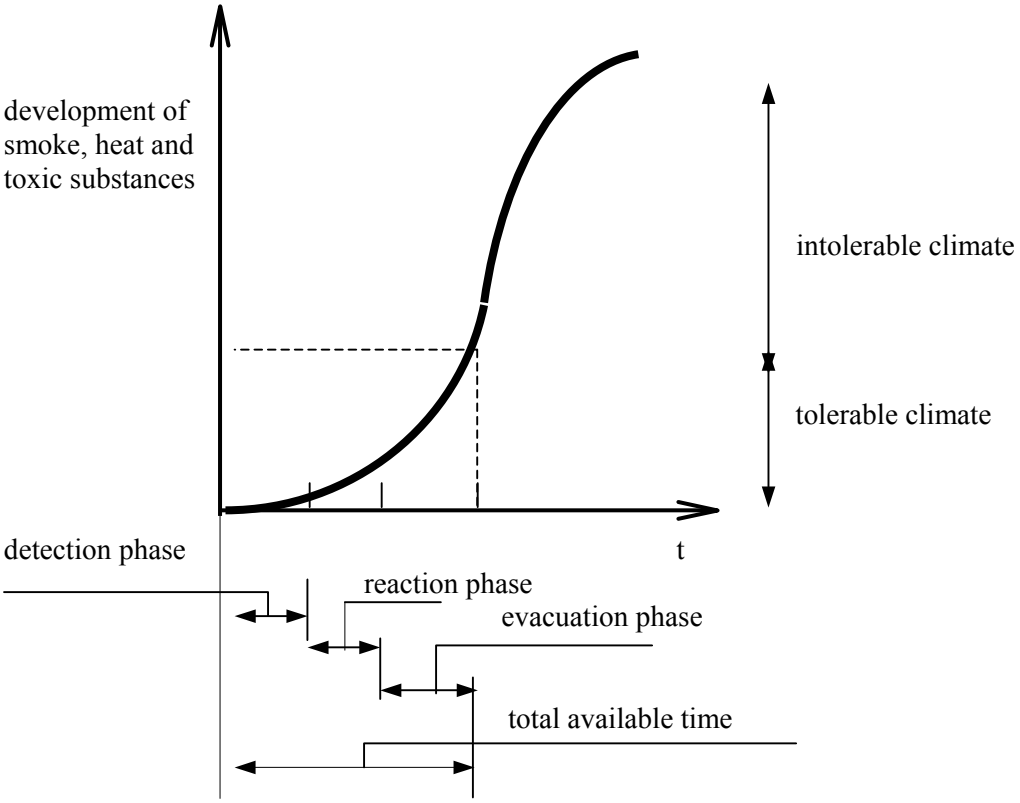

Figure 2: Fire development and available evacuation time

The mental turnaround must therefore take place as quickly as possible, in order to make the effective evacuation phase as long as possible.
The kind of behaviour that can actually be observed in this type of situation[1]:

- an initial response of disbelief
- people continuing their original behaviour as long as possible (turnaround gets under way slowly). After all, life-threatening situations, where people must get away immediately, are extremely rare
- people turn out not to like evacuating their vehicles (in several accidents it was shown that people died in their vehicles as a result of suffocation, although there must have been enough time to escape)
- the dangers of smoke, heat and toxic substances are evidently not perceived by the road users
- information comes over insufficiently and/or is not followed up immediately
- if people escape, they often look for the way along which they have come, whether in their vehicle or not
- escape facilities are often not recognized as such (ignorance and/or lack of clarity)

In addition, the literature[2] mentions several ancillary effects:

- frequently a fire is not detected immediately

[1] Common aspects on the use of tunnels and safety. COV 99-09. Literature study of the Dutch University of Groningen.
[2] Detailed information is also given in an article by the leader of working group 3of PIARC C5- committee: Human factors of road tunnel safety; behaviour of tunnel users. Dr. Ing Bernd Thamm. EU/DGTREN

- a fire in its early stages can often still be extinguished with fire-extinguishing equipment available on the spot. This, however, requires quick action with equipment, which must be very simple to use. Complicated directions for use turn out to be useless; in situations of stress they are of no use at all
- it regularly turns out that available fire-extinguishing equipment is not used
- information about fire is not always given immediately. People first wait for what is going to happen
- people do not want to leave their family and property unattended
- people are not familiar with the situation
- people are under time pressure and emotional pressure
- people get incomplete, incorrect or contradictory signals

An extensive behavioural survey, commissioned by the Centre for Tunnel Safety of the Tunnelling Department of the Dutch Ministry of Transport, Public Works and Water Management, was carried out in January 2002 among car drivers confronted with an incident in a tunnel[3]
This survey was divided in 4 parts:

Part 1:
An inventory among 115 car drivers at a petrol station in the neighbourhood of a tunnel entrance.

Purpose:
To get information on car drivers knowledge of safety measures in tunnels and his way of thinking on how to react in case of a fire.

Results:

Car drivers knowledge of safety measures:
- escape doors 71%
- extinguishers 60%
- telephones, emergency stations 50%
- not any 17%
- pictograms 5%

Thinking of own behaviour:
- try to flee 81%
- to stay in the car 6%
- emergency call 5%
- try to help/extinguish 4%

The way of fleeing:
- along the tunnel itself (road): 60%
- along the special escape route: 40%

[3] Executed by the Netherlands Organization for Applied Scientific Research. Report available on our website www.tunnelsafety.nl.

Part 2:
An inventory among 69 car drivers, who had to stop in a tunnel for a fictitious fire with the instruction to bring themselves to safety. ***One part of the group got the explicit instruction to safe themselves along the escape doors****.*

Purpose:
To get information on car drivers individual behaviour in case of coming to a standstill near a fire in a tunnel and getting the instruction to flee.

Results:
- without extra instruction 75% fled along the escape doors
- with the explicit instruction to do so they were 95%

When fleeing along the escape doors into the escape tube:
- 70% followed the arrows in the escape route
- 18% followed their way against the arrow direction
- 12% came to a standstill and did not know any more what to do

More important results:
- only 35% had noticed the present of emergency stations
- 15% used the telephone
- comments on the little pictograms that mark the escape route
- comments on the insufficient marks and visibility of the escape doors
- comments on the few and little pictograms in the escape tube

Part 3:
An analysis of human behaviour in 9 traffic jams (40 to 50 cars each), caused by an unexpected (fictitious) fire in a truck.

Purpose:
To get information on car drivers group behaviour in case of coming to a standstill near a fire in a tunnel.

Results:
- in all the tests, except one, everyone stayed in his car! In one of the tests the first 10 cars even completely disappeared in the smoke, but no one came out.
- evacuation started, when after about 5 minutes it was announced to flee because of explosion danger
- evacuation then followed consequently along the escape doors

Part 4:
An analysis of individual human behaviour in dense smoke. (97 tests persons)

Purpose:
To get information on the behaviour of people in dense smoke in which in particular the question should be answered, whether people find the escape doors or not. During these tests acoustic systems[4] were tested. They consist of a kind of little loudspeakers, producing a hissing sound even to be heart above the sound of the mechanical ventilation.
The test persons were divided in three groups with the instruction:
Group 1: bring yourself in safety
Group 2: there are acoustic signals that might be helpful for your orientation
Group 3: there are acoustic signals from above the escape doors

[4] A development of Sound Alert Technology. UK.

Results:

- only in group 3 most of the test persons (69%) came through the escape doors in the escape tube.
- In all the other tests most of the test persons followed the road (test 1: 84%; test 2: 79%)

All the issues, passed until here, in my opinion lead to the key question *how to create a correct transfer of information to road users in order to get them moving in time and in the right direction in case of an emergency.*

The operator
To a certain extent, similar arguments apply to the operator.
In a normal working situation he monitors the flow of the traffic and in the case of disruptions he will take the necessary corrective measures using procedures described in advance.
And then suddenly something goes very wrong and a fire breaks out.
For the operator too this requires an enormous turnaround in behaviour. From one moment to the next he must switch over from routine action to 'emergency actions'. And although he may be expected to behave more decisively by reason of his occupation, this desired behaviour is by no means a matter of course.
Recent accidents show that operators are often not trained to deal with emergency procedures adequately, as they seldom if ever occur (compare this to training undergone by pilots time and again in flight simulators).

The emergency services.
The third subsystem, that of the professional assistance providers, is not considered here, as I would rather leave this to the experts in this field.

3. **Influencing people's behaviour.**

Clearly it is of vital importance that people should become aware as soon as possible that they are in a dangerous situation.
For this to be so, they must be aware of the risks involved in driving through tunnels.
As already stated, this awareness is not a matter of course and will therefore have to be imparted in an effective manner.
The resources available for this purpose are:

- information (general and for each tunnel)
- education (driver training)
- legislation
- enforcement

Of course those resources will not be the same for the different groups of human beings. The following table 2 indicates the possibilities.

	information	education	legislation	enforcement
tunnel user	x	x	x	x
operator	x	x	x	x
emergency services	x	x	x	x

Table 2: Resources for influencing human behaviour of different groups

As stated earlier this lecture concentrates on the tunnel user and the following especially concentrates on information and education aspects.

Information and education.
Recent inquiries in PIARC member countries on existing forms of information.[5] show that:

- except for Switzerland no country pays any attention to tunnel safety in its driving tests
- general written recommendations on desired behaviour in tunnels do not exist in any country
- with respect to heavy goods vehicles, regulations exist for the control and enforcement of traffic rules in most of the countries. Regulations for the training and testing of professional drivers with respect to their behaviour in road tunnels, however, are lacking in most countries

Based on this inventory and with the know-how already gained from research and literature quoted earlier, one can conclude that there is urgent need for:

- short and clear information for 'normal' drivers
- information for professional drivers
- information for driving schools
- general and easily accessible information on the infrastructure of tunnels

Developments in this field, recently organised by the European Commission, Directorate General for Energy and Transport, have been explained in an other lecture on the congress[6].

Other information can be provided by:

- general information leaflets about the layout of tunnels and the current safety systems in these tunnels
- specific leaflets for each tunnel.
  Many tunnel managers in many countries use information leaflets for their specific tunnel. Critics could say that such leaflets are of little use, because many put them aside unread. However, it is just like advertising: its power is in repetition. Continuous information increases the chance that when occasion arises exemplary behaviour is prompted which is followed by others.
- All these sources of information, however, do not in themselves guarantee that the message will be sufficiently disseminated. There is therefore a lot to be said for well-directed information campaigns drawing extra attention to this, for example via newspapers, radio and television. It is of great importance that they point out the specific dangers of fire, and that swift and adequate action in such situations is of vital importance.

With reference to the behavioural problems mentioned earlier, arising both from accident analyses and research, a special form of information transfer deserves attention. And that concerns indicating the escape route.
As stated earlier, the available evacuation time can be divided into the detection, reaction and escape phases. It is important to minimize the time required for the detection and reaction phases (detection systems and operator's actions), so that as much time as possible remains for the actual escape. This escape must subsequently be supported as effectively as possible.

In this respect recommendations made for the Western Scheldt tunnel in the Netherlands include the following:[7]

- provide large signs with the text: ALARM
- support the written ALARM auditively via a sound system and the radio
- provide escape doors with attention grabbers such as:

[5] The same inquiry also focused on some questions regarding operations and fire and rescue services. Full results of this inquiry have not yet been published.
[6] Human behaviour as a main factor of safety. (Joint results of PIARC, UNECE and EC) Session 13. Dr. Ing. B. Thamm. EU/DGTREN
[7] Groningen University /Netherlands Organization for Applied Scientific Research 'Vluchtwegen en vluchtwegaanduidingen Westerscheldetunnel' (Escape routes and escape signs in the Western Scheldt tunnel) of 26 January 2001

  - movement
  - light
  - sound
- ensure that escape doors give off more light relative to their surrounding area
- possibly add flashing light, which is only activated in an emergency
- provide large escape signs over the doors instead of the small standard pictograms
- also affix the flight pictograms to the escape doors in dimensions that are as large as possible
- apply a large arrow on the floor, at right angles to the direction of traffic, pointing to the door

The following could also be considered:
- orienting light lines on the step barrier or elsewhere low near the ground
- the sound beacons mentioned earlier, as they were tested in a Dutch tunnel and now are developed further in the Netherlands.

The above elements, completely or partially and in combination with each other, must form part of the infrastructure of a tunnel.
.

Legislation and enforcement.
The measures mentioned before are not enough. People are weak. They are taught and recommended so many things, but this does not mean that they therefore actually do them.
Elements not provided for by current legislation could therefore be made binding.[8]
And even that is not the whole story.
After all, people do not automatically abide by legislation, and it will therefore need to be enforced consistently.

[8] Legislation is currently being prepared in the Netherlands. In it rules will be laid down, inter alia, with respect to the processes relating to the construction and operation of tunnels, as well as requirements relating to measures in the areas of prevention, self-reliance and the provision of emergency assistance.