# HUMAN BEHAVIOUR IN TUNNEL ACCIDENTS: USERS, OPERATORS AND RESCUE TEAMS

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ABSTRACT

In case of tunnel accidents, the human plays a crucial role. In this, 'human' refers to the tunnel user, the tunnel operator and the emergency rescue teams. This paper touches upon all three human categories and provides an overview of some of the specific problems that arise in case of accidents. For tunnel users this means understanding the situation and getting to a safe area, for tunnel operators it is taking the right decisions for the specific incident and for the rescue teams it is getting to the tunnel as quickly as possible and try to limit the consequences.

## 1. INTRODUCTION

Past experience has shown that road accidents in tunnels can result more easily into catastrophes than accidents in open landscapes. Therefore, it is important to try to reduce the probability of incidents inside tunnels and to find measures to minimise the consequences of an accident when this occurs. The understanding of human behaviour could be a significant help, since people intervene in all phases of an accident; from the beginning (being responsible for causing an accident), ending as the receptor of the consequences up to the operators having to take appropriate measures and informing rescue teams to limit the consequences. WP3 of the European UPTUN project focused on these issues, related to human behaviour in tunnels. This paper could not have been written without all the good work being done in WP3. Although not all contributions could be included in this paper, the author wishes to thank all WP3 partners: Annemiek van Waterschoot (RWS, NL), Panos Papaioannou and George Georgiou (CERTH-HIT, GR), Jeremy Fraser-Mitchell (BRE, UK), Gunnar Jenssen, Moen Terje and Cato Bjorkli (SINTEF, N), David Brenkley, John Ellis and David Gibson (MRSL, UK), Tomaz Tolazzi and Vlasta Rodosec (University of Maribor, Si), Edvard Konrad, Marko Polic and Argio Sabadin (University of Ljubljana, Si, contributing via Maribor), Louis Boer, Sander van Wijngaarden, Jouke Rypkema, Anders Noren & Joel Winer (TNO Human Factors, NL), Jean-Christophe leCoze (INERIS, Fr), Paolo Fargione (SRS, It), Pieter van der Torn (WTTZ, NL) and Nils Peter Hoj (COWI, DK).

## 2. TUNNEL USER

In case of accidents or incidents in tunnels, the tunnel user has to understand what is going on. Especially in the beginning of an accident, the tunnel user will only have information from

what he sees around him, e.g. a car parked on the emergency lane or cars driving slowly. However this first period is very important, since there is still time to win.
In case of fires, significant time can be lost from the moment the fire starts until people understand that they are in mortal danger and start of the actual the evacuation process. When this period is long, the possibility for loss of lives increases. In a simulated tunnel fire Boer (2003) demonstrated that tunnels users waited over 5 minutes before considering evacuation. Amazingly, this included the ones who stood right behind the fire. The correct response—immediate evacuation—was observed only once out of seven tests.
Since the European committee also realised that the right human response is extremely important, they developed a leaflet on how to handle in normal tunnel situations and in case of incidents and accidents. However, the leaflet is based on the idea that tunnels users know what type of situation is going on. And it assumed that the information provided is easy to memorise and apply. In the UPTUN project TNO conducted a driving simulator study, in which this was tested. The leaflet is shown in Figure 1.

Figure 1. The EU leaflet that was tested in the driving simulator

In total, 58 subjects participated in the TNO driving simulator experiment. Participants completed 4 rides, all on a simulated motorway. All rides included a section with a tunnel, that participants entered (emergency escape doors inside as well as first aid posts with fire extinguishers, clearly marked as such). The first 3 drives were only to get used to driving in general and to get somewhat familiar with the tunnel. Nothing peculiar occurred. Other traffic was surrounding the subjects (on both lanes). However, in ride 4 participants were confronted with an accident. Just before entering the tunnel the traffic intensity would increase, leading the cars around the participant to slowly brake. This slowing down of traffic was the result of a simulated accident with two vehicles about 1 kilometer downstream. The traffic signalling above the driving lanes were activated and eventually the traffic came to a complete stop inside the tunnel.

Three and a half minutes after the virtual accident happened, smoke appeared in the tunnel coming from the front towards the participant in the car, getting thicker and thicker. The 58 subjects were split into 3 groups. Group 1 (control group, 20 participants) were not provided with any extra information. Group 2 (20 participants) had read the EU leaflet just before the start of the experiment. Group 3 (18 participants) had read the EU leaflet and received two specific instructional messages while inside the tunnel from a virtual tunnel operator (voice message). Group 3 received information from a virtual tunnel operator 1 minute before the smoke would appear ("Please turn off the engine. I repeat, please turn off the engine" (this was indicated in the EU leaflet as best behaviour) and 30 seconds after the smoke had appeared the operator voice would say: "Please go to the escape exits, I repeat, go to the escape exits". (this was also indicated in the EU leaflet as best behaviour). Participants were asked to perform a verbal protocol during all the rides, meaning that they had to speak out loud and name everything that they noticed.

We looked into how tunnel users behaved under the circumstances, and what they mentioned in the verbal reports and in the questionnaires. In this, we concentrated specifically on behaviour that was related to the required behaviour suggested in the EU leaflet (switching off the engine, putting on the radio, and getting out of the car).

The main results were that there were some differences between the groups. About 60% of the drivers switched off the engine spontaneously, after reading the leaflet this increased to 70%, only with the help of the operator this number rose to 100%. Not too many people used the radio to get additional information, not even after reading the leaflet (in which this was recommended). Some people wanted to use the radio but mentioned they had forgotten the frequency indicated in the leaflet. The most crucial action, that is getting out of the vehicle (or stating one would), was 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 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 operator voice, performance improves even more. This leads to more people doing the right thing, but also to getting into action more quickly.

Even though participants already drove the tunnel 3 times before and had a chance to see the exits inside the tunnel on ride 4 as well, some people still indicated wanting to use the tunnel entry to leave the tunnel. In the last group, in which it is specifically mentioned by the operator, no-one mentioned this. What was striking was that quite some people indicated they did not have an 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, and even though there is an operator voice and even though people read the leaflet. 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 in order to help people make the right decisions. Also, we need people with an exemplary behavioural function, for instance by means of training professional drivers.

In group 1, three people indicated to not have taken any action since they were waiting for other people to take action. One person indicated to feel safer in the car. Two participants in group 2 did not take any action because of the smoke, with one person indicating the smoke was too thick to get out and the other person saying the smoke was not very thick and he therefore saw no reason to leave the vehicle. Even if the operator informed road users, one

person mentioned he was afraid to get out of the car. Some others indicated it was unclear where to go and one person indicated to need more clarity of how to respond.
The fact 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 less people stating that is was not necessary to respond in the category where the operator stated what to do, but even with the operator voice, we did not succeed in convincing all people to evacuate. Even in the condition that an operator announced switching off the engine and getting to the emergency exits, people though information was lacking. In general, remarks were made about 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).

More information about tunnel user behaviour can be found in deliverable 3.3 of the UPTUN project.

## 3. TUNNEL OPERATOR

There is an important job for the tunnel operator in decreasing the time being lost in an incident. The operator needs to be stand-by in order to detect any incidents happening, to decide what is the proper action to be taken and he needs to provide other people with information (road users, emergency services, other operators etc.). Since the role of the operator is such an important one (overview of the situation, possibilities to communicate to several services etc), this role will be the subject of this chapter.
In the UPTUN project, an analysis was done of operator tasks and bottlenecks (based on literature reviews, a Dutch tunnel safety review and operators interviews). The tasks identified were:

- Monitoring the traffic flow and situation in the tunnel (and vicinity) using cameras, sensor readings and communication equipment. Note: constant vigilance is required.
- Preparation for effect reduction: education, training, exercises.
- Fast and correct detection of any event or disturbance likely to escalate into an incident.
- Closing the tunnel; switching equipment to 'emergency mode' (lights, ventilation, speed limits, escape doors, et cetera).
- Alerting other operators (where applicable), rescue services and tunnel users (instructing them for escape if necessary).
- Communicating with tunnel users to help them escape and to help them help others or correct the situation (for example: putting out a small fire).
- From the control room, assisting the rescue services in their rescue operation.
- Evaluating and registering the incident for the purpose of improvement

In the operator task, cognitive load is extremely important. The cognitive load model (Papaioannou & Georgiou, 2003; Rypkema et al, 2002) distinguishes three load factors that have a substantial effect on task performance and mental effort:

1. Percentage time occupied: the percentage of available time that the operator is occupied with his or her tasks. The higher this percentage is, the higher the cognitive load.
2. Level of information processing: relates to the complexity of tasks. This factor is based on the Skill-Rule-Knowledge framework of Rasmussen (1986), in which skill-based tasks demand the least cognitive effort and knowledge-based tasks the most.

3. Number of task-set switches: refers to the number of switches the operator has to make between different task-sets. The more switches, the higher the cognitive load.

Combination of these factors yields an indication of the operator's cognitive load, which is represented in Figure 2.

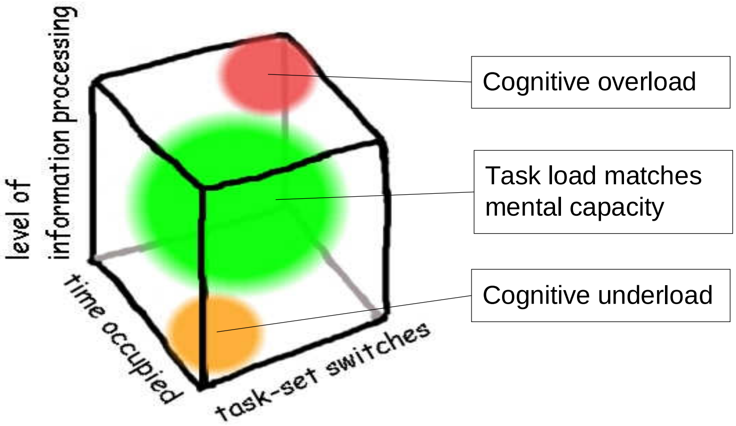


Figure 2. Schematic representation of the task load model

Cognitive *overload* (red area) can occur when the operator does not have enough time to finish the tasks, the operator tasks are too complicated or the operator has to perform too many tasks at the same time (or a combination of any of these elements). On the other hand, if all three elements are "low", cognitive *underload* can occur (orange area). Cognitive underload, just as overload, may lead to sub-optimal performance. Ideally, the task load matches the operator's mental capacity in a certain task setting (green area). Other identified bottlenecks (although this list does not include all bottlenecks identified) were:

- Vigilance problems during long periods of normal operation (related to underload)
- Unclear allocation of responsibilities and authority to personnel
- Insufficient skills due to lack of practice exercises, especially with the rescue services
- Overdue, incorrect or incomplete detection of incident due to combination of suboptimal cognitive load and suboptimal detection of risk factors in tunnel.
- Too many incoming signals, not all of which are relevant at this time (related to overload)
- Absence of or insufficient coordinated procedures between operators and rescue services
- Absence of adequate incident evaluating and registration procedures
- Mistake in incident is not evaluated or registered due to fear for career consequences.

After the tasks and bottlenecks were identified, the next step was to find solutions for the most important bottlenecks and designing an improvement strategy. Using a prioritized list of bottlenecks and general methods for influencing operator behaviour generates possible solutions for the most important bottlenecks. Possible solutions can be found in terms of:

1. recruitment (assess the proper criteria)
2. training and exercise (to improve skills, but also to test the effectivity of procedures)
3. personnel and organisation (number of people present, working method with time schedulres and organisational culture)
4. task support (such as procedures and guidelines)
5. control room and interface design (technical tools, such as one button to indicate a major accident, good tools to instruct the tunnel users)

What is most effective differs from tunnel to tunnel. An effective strategy should be a balanced mix, depending on which, and how many, bottlenecks are relevant to the situation, local circumstances, presence of other problems that need to be solved and the characteristics of the tunnel owner's organisation. After the strategy is implemented, its results should always be managed and it should be clear when and how the results will be evaluated. Evaluations should always include questioning the people involved and one should be prepared to change parts of the strategy if they do not turn out to be succesful.
In deliverable 3.3 of the UPTUN project, more detailed information is provided on how to improve the bottlenecks and a systematic strategy is provided for tunnel owners to improve operator performance.

## 4. RESCUE TEAMS

Once rescue teams (police, firemen and medical services) are informed about tunnel accidents, they have to act in order to reduce possible consequences. By collecting data from different countries, it was possible to analysis the rescue team tasks. The main important issue in the case of rescue teams seems to be 'what needs to be done' (functions) and 'who does it' (actors). In the UPTUN project, a new system approach is proposed that allows each country to perform a sensitivity analysis ("actors" vs. "function"), based on the comparison between/among countries that highlight the most relevant differences in terms of "who does what" or, better, "how many actors intervene in how many functions". The task analysis over different European counties showed that the organisational structure and the responsibility of tasks is different for the various countries. Also, there may be more than one party responsible for a specific task, which can make things complicated. One of the most important things that need to be avoided is conflicts during an accident scenario, for instance due to lack of communication (at different levels), interference in the mutual action fields or lack of agreements or operational procedures and of coordination.
In order to avoid or limit these conflicts, it is important for every rescue team member to know the other parties and colleagues involved, to anticipate possible emergency types, to have Operating Procedures available for emergency situations, and to be trained with all parties responsible by carrying out combined activities (about information, training and practice) with police, firemen, medical teams, tunnel operators and tunnel owners (and maybe even more).
A proposal has been done together with a Dutch fire department and TNO for a new team-training course. Current training objective are too general and evaluation sessions with rescue teams and the identified bottlenecks in the current way of training provided the opportunity to optimise training sessions. The structure of the training course is based on the assumption that the team members learn things at several levels, which they can use or apply while carrying out their job in the team. Five phases can be distinguished in which the team can gain experience: an instructional-, retraining-, training-, exercise and testing phase. These phases fit in a cyclic process for an instructional- or training course.
The determination of training goals is an essential part of the development process of training scenarios, as appears from the Event Based Approach to Training (EBAT, see Figure 3). EBAT is a method for the development of training, developed in the US at the Naval Air Warfare Centered Training Systems Devision in Orlando, Florida (Fowlkes, Dwyer, Oser & Salas, 1998; Oser, Gualtieri, Cannon-Bowers & Salas, 1999). EBAT focuses on scenario based training instead of reading or books. By means of a scenario the team that has to be trained is immersed in a (simulated) operational environment.

By using the EBAT method, it can be guaranteed that training possibilities are structured, training goals, exercise design, critical tasks, performance measurement and feedback are bound up with each other, and that training will result in an improved team performance. To optimise the exercises it is important to not only assess the final results but also the team processes that will lead to this result. Therefore a training method has been developed which can be used to formulate advice about the rest of the training course. Within the structure of this method the exercise phase has been worked out by:

- forming an exercise set up
- developing a checklist with starting requirements
- developing a method to log the development of scenarios
- developing a method to define the measurement points in the scenario
- developing tools to support the performance measurement

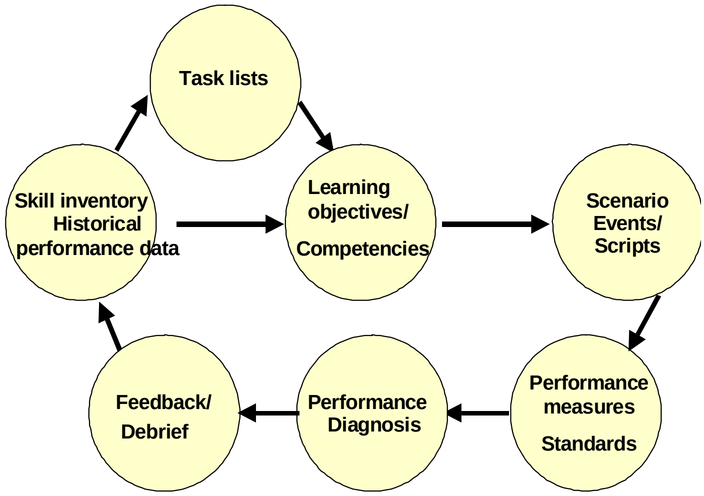


Figure 3. The ABAT methodology

More information on rescue teams can be found in deliverable 3.4 of the UPTUN project.

## 5. CONCLUSIONS

The human response is a very important factor in case of tunnel accidents. As we have seen there are a lot of factors that can prevent the human being from doing the right thing. If road users do not know how to behave properly, they may wait too long in their cars. If tunnel operators are not properly selected, trained or supported they may make the wrong decision and all different parties involved from the rescue services may falsely expect the other partner to respond or may not receive the right information.

The tunnel user should be provided with accurate, specific and timely information. The same type of information should be provided by different sources, such as radio, signals inside the tunnel, an operator voice and tunnel staff showing the right behaviour. Information provided needs to be over-complete, with if possible a repetition of the messages. People with visible official status should be sent inside the tunnel in order to help people make the right decisions. Also, we need people with an exemplary behavioural function, for instance by means of training professional drivers.

Even though this topic was not discussed in the current paper, evacuation behaviour in smoke has turned out to be improved by putting sound beacons above every emergency exit (Boer and van Wijngaarden, 2004; Boer and Withington, 2004) and within the UPTUN project, an innovative active evacuation system was made by MRSL.
Tunnel operators should be properly selected, trained and supported and bottlenecks should be identified in order to solve them. For rescue teams, standard operating procedures should be made and specific emphasis should be put on knowing the responsibilities and training with all parties involved. Only by focusing on all three human groups in tunnels, tunnel safety can be improved.

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