MODELLING HUMAN BEHAVIOUR IN TUNNELS – EXPECTATIONS AND REALITY

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ABSTRACT

In case of tunnel accidents, the tunnel user, the tunnel operator and the rescue teams play a crucial role. In this paper we will focus on the first category, that is the tunnel user. In order to predict driver behaviour in case of tunnel incidents or accidents, more and more models are being developed. However, behaviour has shown to be quite unpredictable, with variations from person to person and from incident to incident. This paper describes the variability in behaviour and discusses the possibilities and difficulties to capture this behaviour in models.

Keywords: human behaviour, driving, tunnel, accident, safety, models.

1. INTRODUCTION

History has shown that road accidents in tunnels can result more easily into catastrophes than accidents in open landscapes, especially in case of tunnel fires. 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. Tunnel user behaviour was studied in the European UPTUN project and is described in this paper.

In case of accidents or incidents in tunnels, the tunnel user has to understand what is going on and act accordingly. But the question is whether tunnel users can understand what is going on. Since an accident or a fire is not directly visible for the traffic downstream, the driver can only guess what is going on. 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 the start of the actual evacuation process. When this period is long, the possibility for loss of lives increases. In order to predict human behaviour, many different models are being used.

2. TUNNEL USER BEHAVIOUR

A model is a (simplified) representation of what happens in the real world. Evacuation models allow designers and tunnel owners to get a better understanding of how people respond to different scenarios, including walking speeds, response to heat and fire, egress times, choice of emergency exit etc. A model allows the user of a model to vary specific input variables (e.g. distance between emergency doors) and see how that changes behaviour (what exit do people choose). Some examples of human evacuation models are CRISP, EVACS, Exodus, FIRESCAP, TRAFFIC, Wayout and many many more. Models about human behaviour all have specific assumption about how the user responds to situation A, B or C. Some models do have a large variability in the model output (behaviour), some models are very simple with less flexibility in output. The validity of a model (how well does the output of the model correspond with what would happen in real life) depends on the validity of the assumption that underly the model.
Some behavioural assumptions, used in evacuation models will be discussed here and will be compared to what is found in experimental studies in real life situations. Only by continuously updating models with new knowledge about human behaviour from experiments and real life accidents and fires, models will develop and become more and more useful.

2.1. Assumption 1:
In case of an accident or incident, people have a proper understanding of what is going on

In a driving simulator study, TNO studied how well drivers understand what is going on in case of a tunnel fire much further upstream (Martens, 2005). In this study, some of the drivers were already warned about what could happen since they read a EU instruction leaflet about how to behave in case of tunnels and tunnel calamities, including tunnel fires. The European leaflet is shown in Figure 1.

![Figure 1: The EU leaflet, shown to some subjects before driving in the driving simulator.](image)

In total, 58 subjects participated in the TNO driving simulator experiment. Participants completed 4 drives, 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 drive 4, participants were confronted with an accident with fire much more upstream (the fire itself was not visible). 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 a car fire about 1 kilometer downstream. The traffic signals 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. 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). This group 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 give a verbal protocol during all the rides, meaning that they had to speak out loud and name everything that they noticed.

We studied how tunnel users behave under these circumstances, and what they mention 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). In this paper we will mainly focus on getting out of the car.

What we found in this study is that in the scenario we presented, that is a simulated fire, it is hard for people to realise what is going on. When we specifically asked subjects to describe what they thought that happened, their answers were diverse, as is shown in Table 1. We did not test for any statistical differences between groups since none of the groups received any specific information about what was going on.

Table 1: Answers in percentages of participants per group and in total.

<table>
<thead>
<tr>
<th>Group</th>
<th>fire in car</th>
<th>fire in tunnel</th>
<th>smoke</th>
<th>accident</th>
<th>motor problems</th>
<th>explosion</th>
<th>traffic jam</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>55%</td>
<td>10%</td>
<td>20%</td>
<td>5%</td>
<td>5%</td>
<td>0%</td>
<td>5%</td>
</tr>
<tr>
<td>2</td>
<td>20%</td>
<td>30%</td>
<td>15%</td>
<td>5%</td>
<td>5%</td>
<td>15%</td>
<td>11%</td>
</tr>
<tr>
<td>3</td>
<td>28%</td>
<td>33%</td>
<td>17%</td>
<td>0%</td>
<td>11%</td>
<td>11%</td>
<td>0%</td>
</tr>
<tr>
<td>Total</td>
<td>35%</td>
<td>24%</td>
<td>17%</td>
<td>3%</td>
<td>7%</td>
<td>9%</td>
<td>5%</td>
</tr>
</tbody>
</table>

The answers fall into seven categories. The first category: “fire in car”, includes only answers that include the remark that they thought there was a fire in a car. The second category includes answers in which the participants concluded there was a fire in the tunnel without referring to a car being on fire, but merely fire in general. The third category consists of answers that only include references to smoke, but not that the smoke was the result of a fire. The fourth category: “accident”, consists of answers that referred to the occurrence of an accident and no mention of a fire, smoke or an explosion. The category: ”motor problems” refers only to answers that include a reference to a boiling motor of a car as the source of the occurring smoke. Only two of the four answers included a reference to smoke. However these participants specifically mentioned that the smoke was white and thus had to originate from a boiling motor. The other two participants did not mention the smoke at all, only motor problems. The category: ‘explosion' consists of answers that refer to an explosion as the source of the occurring smoke. All answers in this category included a reference to smoke. In summary, the majority of participants thought that there was a fire, a total of 65% for condition 1, 50% for condition 2 (with leaflet) and 61% in condition 3 (leaflet and operator). In fact most people registered something was wrong and most participants concluded some sort of accident must have occurred. Only 5% of all participants (1 person in condition 1 and 2 in condition 2) were not sure what had happened (answer in the category “traffic jam”).
2.2. Assumption 2:

People in general know how they should behave in an emergency (incident or accident)

The question is whether it is true that people know how to respond in case of emergency situations in tunnels. In the same driving simulator study, some people read the leaflet how to respond just before starting the experiment, so this would be a so-called ideal situation.

However, the study showed that even though subjects already drove the tunnel three times before and had a chance to see the emergency exits inside the tunnel on drive 4 as well, some people still indicated wanting to use the tunnel entry to leave the tunnel. In the group that specifically got operator instructions to go to the emergency exits, 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 the leaflet and the operator help). 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 that tells them to go to the emergency exits 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 a repetition of the messages if possible. 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 exemplary behavioural function, for instance by means of training professional drivers.

In group 1 (not having read the leaflet), 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 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 to evacuate, 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. That reading the leaflet is not enough is shown by the people who said that they did not take 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 it was not necessary to respond in group 3, but even with the operator voice, not all people indicated to evacuate. Even in the condition that an operator announced switching off the engine and getting to the emergency exits, people thought information was lacking. In general, remarks were made about the necessity to light emergency exits, warning 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.

2.3. Assumption 3:

People do not start evacuation until they realise that they might be endangered = when the smoke approaches their position (that is the way how it is modelled)

As the driving simulator study showed, people do not always indicate they will evacuate, even when smoke approaches their position. In the first group, that received no operator help and did not read the leaflet, only 65% of the participants indicated that they would evacuate after the smoke appeared. This was 75% for the group that read the leaflet and 94% for the group with the leaflet and operator help. So even if they just read a leaflet about how to perform and there is an operator that tells them to evacuate, and there is smoke approaching and surrounding them, not everyone says they will evacuate. Since it was a driving simulator study, we could not study actual evacuation behaviour.
That not everyone evacuates as soon as smoke approached their position is confirmed by a large scale field test by Boer (2003). In this study, naïve participants (they were not aware of what would happen) were confronted with a truck that blocked the tunnel lanes inside a tunnel, with smoke coming from the truck. Behaviour of the drivers was recorded on tape, with some drivers being close to the smoke and others being further away from the truck and the smoke, being confronted only with stillstanding traffic. Several runs were made, with a new group of participants in each run. In one of the runs, not one driver responded, even after the smoke started to approach the cars and even surrounded the cars.

In the driving simulator study, some people even mentioned that smoke was the reason not to act. Two participants did not take action because of the smoke, that might be toxic. Some people closed the ventilation system of the car, closed the window and thought they would be safer in the car. One person said the smoke was too thick to approach the accident. The other person said the smoke was not very thick and that he therefore did not see any reason to go out of the car.

So even though smoke is a proper cue in many occasions, smoke is definitely not always a cue for people to evacuate (see also assumption 6).

2.4. Assumption 4:
As soon as they start evacuating, all people leave their cars immediately and go directly to the next emergency exit

This is also related to the group process as discussed in assumption 6. There is indeed a large group effect, as was shown in the evacuation studies of Boer (2003). As soon as some people start to evacuate, other people start to evacuate as well. That is, they start to leave their car based on other people starting to leave their car. However, in many cases this only happens after the operator warns for explosion danger. Also, people that spontaneously leave their car (before an operator voice warning for explosion danger), there is a large hesitation time. This means that people do not directly go to the emergency exits. Even in clear visibility, there is quite a large hesitation phase, with time passing between opening the car door and the moment the motorists begin walking.

Boer (2003) showed that many car drivers lost time between leaving their car and actually going to the emergency exits. Those reacting before the announcement of the operator hesitated much longer than those who reacted after the announcement. The hesitation time in the group that spontaneously evacuated (without operator announcement) was over 100 seconds in many occasions. From the 35 participants, only 3 left their car and walked to the emergency exits without hesitation. Of the group that only evacuated after the announcement (155 people), only 1 person showed a hesitation time of longer than 100 seconds.

These results show that assumption 4 is not right, since people may hesitate. If this occurs also depends on whether there is spontaneous evacuation or if evacuation takes place based on an operator voice. This also may very with what other people in the direct surroundings do.

2.5. Assumption 5:
Although the traffic lights at the tunnel portals show red, the traffic does not stop immediately (car drivers neglect the red traffic light for some time)

This is a type of behaviour that was shown in many real life situations. Tunnel operators were aware of an emergency inside the tunnel and switched on the red traffic lights. However, a problem is that this is an occasion that is hardly ever experienced by any driver in his or her driving career. With normal traffic lights at intersections, drivers encounter red traffic lights all the time. Therefore, a red traffic light is to be expected. In case of tunnels, this is not to be
expected. So even though there may be a red traffic light, this is not always interpreted as such, even if drivers were to fixate these red lights. In that case, red crosses above the driving lanes would need to be shown as well. However, even this is not strong enough, as was proven in the Westerschelde tunnel project (Martens, Koster & Lourens, 1998). In that case, drivers were confronted with two red crosses above the driving lanes inside a tunnel, but as long as other drivers continued to drive, participants in the study kept driving under the statement ‘everyone else kept on driving so I kept up with the traffic stream’. It is known from real life situations that the only countermeasure that gets people to stop in front of a tunnel entrance is the presence of physical barriers after the red light is being switched on. At the St Gotthard tunnel, emergency procedures worked properly as barriers automatically stopped more traffic entering the tunnel. At the Tauern tunnel on the other hand, many drivers simply passed the red lights and continued into the tunnel. A similar test was made some months later at another tunnel for a TV report and it also showed lots and lots of cars ignoring the traffic lights. Traffic lights present no physical obstacle, and also do not say why entry to the tunnel is not allowed. Without additional information, a prolonged red light may simply be taken for a malfunction, and once the first drivers ignore it, others will follow.

Only this physical barrier stops drivers from entering the tunnel. Therefore assumption 5 is true, but could be more firm: Drivers do not stop, instead of drivers do not stop immediately.

2.6. Assumption 6: 
In the evacuation process, there is no consideration of group dynamics

As was already discussed before, there is a large group effect, in two possible directions. This means a positive direction in the sense that if some people start to evacuate, other people will evacuate as well. Boer (2003) showed that as soon as action was taken by one person within a group, more people followed and started to react. Evidently people sat tight in their cars and prepared to react, but were unwilling to act until anybody else acted. On the other hand, he also showed a negative group effect. That is if some people wait in the door, or even go back into the tunnel to stay with their cars, other people start to do that as well. And, if other people stay in the car, people will not respond since others do not respond. This was also confirmed in the Martens (2003) driving simulator study, in which participants literally mentioned that they did not respond since no-one responded, and they therefore concluded that it would not be so bad.

As is often assumed, it is also not the case that social groups always stay together. In the Baku Metro fire one of the victims said: “I grabbed my two daughters and buried their faces into my chest, holding them close so they wouldn't breath the fumes… My daughters helped me off the train-I don't quite know how. They fell down from the train, when they tried to run they kept falling, tripping over bodies. The air was so bad, we were all coughing. It was so hard to breath. Then I collapsed and felt like I couldn't go on any more. I begged my daughters to go on without me, to make it to safety-to save themselves. As I lay there, people stumbled and fell over me. It was hell. People at the Depot finally rescued me.” This last statement is interesting because it shows the family group breaking up under extreme stress.
3. 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, and behaviour is very unpredictable and differs from condition to condition. Road users do not always know what is going on, and even if they know what is going on, they do not always know how to behave properly. Even though operator messages do help, they do certainly not overcome all problems. Since there is a large group effect as well, proper action of some people will help guide the behaviour of others, but wrong actions will also stimulate wrong actions in other people.

Models offer the opportunity to study how people respond in various situations. However these models are a simplified form of reality. However one should keep in mind that this is also the case for experimental studies. The only valid data we can get are data from real life accidents, but in most cases these data are only the verbal reports from the survivors. Human behaviour is the most complex and difficult aspect of evacuation to simulate, yet is crucial to get good results. A simple but useful approach is to consider what types of behaviour are considered rather than the details of the calculation. The simplest level (“egress only”) considers no other form of behaviour, apart from an abstract representation of “pre-movement” activities by a delay time for each occupant before they may start to move. The people may however be allowed some flexibility in exit choice. The intermediate level (“fixed”) covers models where the occupants may have a number of tasks to perform before they are allowed to commence evacuation. However these tasks are usually carried out in a deterministic sequence. The highest level (“adaptive”) also has occupants with a variety of tasks to perform, however the choice of task, and whether these are completed or replaced by alternative actions, is determined by the state of the environment, actions of other people encountered, etc. Adaptive behaviour models are potentially the most realistic, since the complexities of human behaviour are made explicit and amenable to users’ control (rather than reflecting the original program developer’s perceptions in a hard-wired algorithm). Although each person’s decision process is modelled separately, this does not preclude the option for co-operative or group behaviour. For example a person may have a task to rescue a dependent person; the dependant person may wait to be rescued. However when the rescuer meets the dependent, the task of both may change to “escape”, and the movement process modified to keep the pair together.

These adaptive behaviour models can offer designers an idea of the large variety of behaviour they can expect, the effect of interference or countermeasures and the effect of smoke, presence of emergency exits and the effect of group aspects. Even though one must keep in mind that the output of these models do not represent the exact outcome from real life scenarios, they can still be very valuable. Only by continuously updating these models with real life data and data from different kind of tunnel studies, these models will continue to improve their quality.

4. REFERENCES


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