IMPACT OF GROUP EFFECTS ON THE REACTION AND ESCAPE BEHAVIOUR OF USERS IN ROAD TUNNELS - RESULTS OF REALISTIC LARGE GROUP EXPERIMENTS

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ABSTRACT

The German Federal Highway and Transport Research Institute (BASt) initiated a research project that systematically investigated the influence of group effects on escape behaviour during self-rescue in road tunnels. As previous studies had shown that collective decision-making can delay the self-rescue process compared to a “single-person decision”, large-group tests were conducted.

The study took place in a highly realistic road tunnel environment at the “Zentrum am Berg (ZaB)” in Austria involving a total of 5 large group tests (73 test persons and 47 vehicles), as well as 7 individual reference tests of single drivers. The scenario considered was a vehicle collision leading to a lorry fire in a bi-directional traffic setting, which was realistically simulated by using gas burners and smoke. Participants drove into the tunnel in their own cars without any prior knowledge of what to expect. Their perceptions, decisions and behaviour upon first recognising the accident site, approaching it, getting out of the vehicle, finding their way in the tunnel and escaping were documented in detail via “on-scene” interviews in the tunnel, follow-up interviews and video recordings. The tests were analysed from a sociological perspective in order to determine types of behaviour and critical situations. Further analysis from an engineering perspective was executed in order to obtain relevant parameters such as reaction and escape times.

The paper points out the most significant results from the large group tests focusing on quantitative parameters such as reaction times and evacuation speed. The numbers found are higher than the reference values for the single-person test. However, these results remain within the range of the values commonly used in risk analyses, meaning no specific adjustments to the current regulations are required. In addition, selected results from the behavioural analyses are presented briefly.

Keywords: Road-Tunnel, Self-Rescue Phase, Experiment, Group-Dynamic, Risk-Analysis, Human Behaviour

1. MOTIVATION AND OBJECTIVES

The evaluation of real events and previous studies provided evidence for the assumption that people often make collectively supported escape decisions in extreme situations. As the influence of these group dynamic effects ("group effects") in the context of tunnel incidents had hardly been specifically investigated or quantified before, the German Federal Highway and Transport Research Institute (BASt) commissioned an interdisciplinary consortium of engineering and social sciences to conduct the research project "Analysis of Reaction and Escape Behaviour in Road Tunnels Considering Group Effects (FE 15.0703/2022/ERB)" in April 2023. The aim was to analyse sociological and engineering aspects in detail using realistic field trials with test participants This enables to check whether existing safety assessment procedures and the underlying regulations, which do not yet account for the effects of group dynamics on self-rescue, need to be adapted.

2. EXPERIMENT

2.1. Test Environment

As core-part of the project, trials with test subjects were carried out in the spring of 2024 at the "Zentrum am Berg" (ZaB) of the Montanuniversität Leoben (MUL) in Eisenerz, Styria, Austria. Built specifically for research and training purposes, this facility, corresponds to a real road tunnel in terms of dimensions and equipment. However, unlike tunnels with ongoing traffic, it allows for a flexible experimental environment without operational restrictions.

Figure 1: ZaB, north tube with road tunnel cross-section, perspective of the test participants approaching the accident scenario location, Source: STUVA

Along the designated route the test facility was equipped with original road signage for a speed limit of 50 km/h, indications of oncoming traffic tunnels, and no-overtaking signs. To allow the test subjects to get used to the situation, they drove along the route for as long as possible before reaching the accident site. The participants drove in their own vehicles in a loose convoy through a series of tunnels on the ZaB grounds. The first tunnel, consisting of the West tunnel tube and the South road tunnel, was about 715 metres long. The subjects then entered the second tunnel, which was designated as an oncoming traffic tunnel by signage and road markings. After about 270 metres, they reached a staged accident scenario.

2.2. Scenario

The accident scenario involved a truck fire in the opposite lane. The fire was simulated using gas burners and a cold smoke system to create defined and thus comparable fire, smoke, visibility, and ventilation conditions for all test runs. This also kept the danger to the test subjects very low. Obscured vision in the subject’s area was undesireble and had to be avoided as much as possible for safety reasons (risk of collision). In all test runs the fans were controlled to move the non-hazardous, vaporised fog fluid as much as possible to the area behind the accident vehicle. Another truck and a car were positioned across the subjects' lane at the accident site in front of the burning truck mock-up, to act as an obstacle,

Figure 2: Truck mock-up, obstacles (cars and trucks), view opposite to direction of travel [1]

By the time the first test vehicle approached the accident site, there were already significant flames and smoke visible at the rear truck. The recognisability of the rear truck as a mock-up was hindered by the smoke. Due to the vehicle on the road, which was obviously involved in the accident with its hazard lights on, it was not possible to drive around or pass it. The test vehicles were forced to stop at a self-selected distance from the accident site. In the relevant area, there was a cross-passage with an emergency exit about 125 meters before the accident site and an emergency call niche about 20 meters before the fire site. Therefore, if they paid sufficient attention, the test subjects could see the burning truck, the emergency call niche, and the safe emergency exit. The driver and passenger doors of the two vehicles involved in the accident were open, making it clear that there were no injured or otherwise distressed people inside.

To standardise the test procedures, the "vehicle fire" operating program was started 60 seconds after the first vehicle came to a stop in front of the accident site. The jet fans in the test area were ramped up to 100% power accompanied by the corresponding noise. Simultaneously a pre-recorded loudspeaker announcement started, urging people to leave their vehicles. This voice announcement, characterised by a very clear and slow speech pattern, was played repeatedly with only short breaks of about 10 seconds.

2.3. Participants Trials

The core of the study consisted of test subject trials, including seven individual trials (as a reference) and five group trials. The test subjects were given only the most essential safety-related information. Communication between the subjects in advance was also prevented as far as possible. Test subjects were primarily recruited locally from communities around Eisenerz and Leoben through various digital and analogue channels. The aim was to recruit subjects from the "driving population"—that is, people who might actually find themselves in the situation under investigation—and to ensure representative age and gender distribution.

A total of seven individual trials and five group trials were conducted over two weekends in February and April 2024 with a total of 73 test subjects in 47 cars. The number of subjects in the group trials ranged from 12 to 14 people per trial run, distributed among seven to ten vehicles. This distribution aimed to replicate the different vehicle occupancy rates and structures of passenger groups (co-workers, friends, families, and so on) during either holiday or commuter traffic.

2.4. Procedure

The trials were divided into three phases: briefing, carrying out, and debriefing. Upon arrival at the test site, participations were briefed on the requirements for taking part (not having consumed alcohol, holding a driver's license, giving consent to GDPR), provided safety instructions, and were given the opportunity to familiarise themselves with driving on the test site by taking a test drive through the first tunnel section.

During the test subject trials, the vehicles were lined up in a random order, and the fire simulation was started. After around 2 minutes of driving, the first vehicle in the second tunnel section came into view of the fire site for the first time and stopped at a self-selected distance from the accident scenario. Sixty seconds later, the fire ventilation started, and the repetitive loudspeaker announcements began.

Continuous video recording was conducted throughout the trial using fixed and mobile cameras to document the participants' behaviour – such as their interactions or escape behaviour – in detail and chronologically. Figure 3 shows the different perspectives of these images. The subjects' behaviour was not influenced, only recorded. This included how long they stayed in the car, when they left the vehicle, whether they stayed near the vehicle, whether and how they communicated with other road users, whether they sought out the emergency call booth and placed a call, and when and at what speed they began to flee. Once the test subjects had reached the tunnel portal or the smoke-free parallel tube via the emergency exit, an exercise observer informed them that the trial had ended.

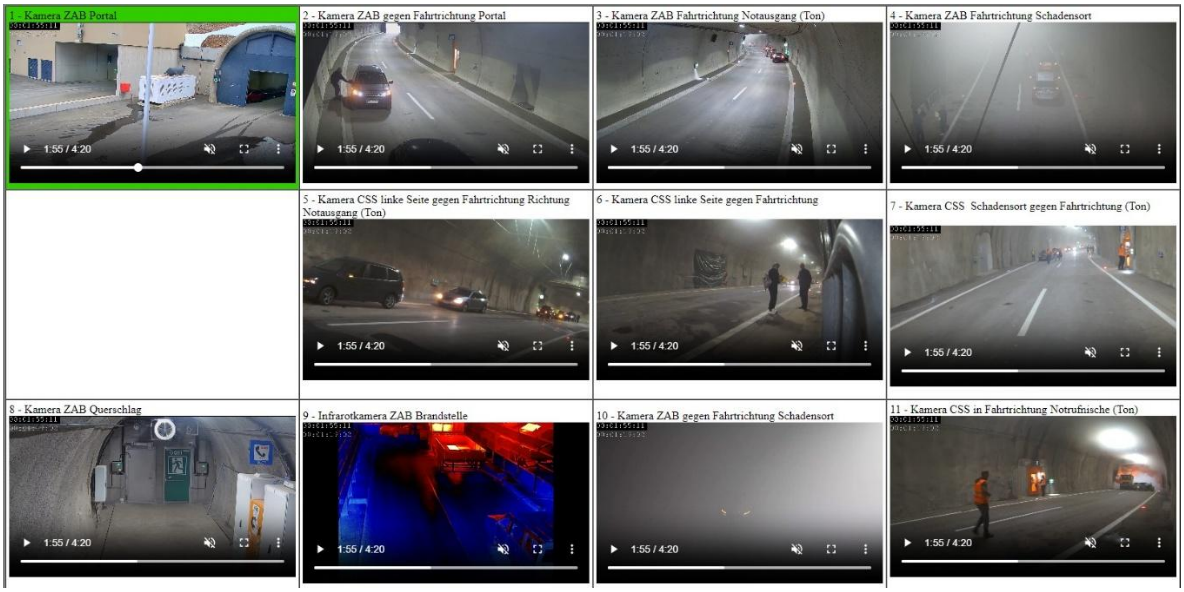

Figure 3: Synchronous display of camera views in the documentary [1]

The test subjects were interviewed in the tunnel immediately after the trials. The participants were asked to return to their vehicles. The occupants of the vehicles were asked about their perceptions, thoughts, decisions and alternative considerations, as well as their specific behaviour. The interviewers began the interview in the vehicle. The starting point for the descriptions was the entrance to the last section of the tunnel. A structured qualitative interview guide was used for this purpose. During the interview, the subjects' paths and stops were retraced together in the tunnel, and the interviews were recorded for analysis. Once back at the training building, a standardised survey was conducted using a questionnaire. Finally, the participants were informed about the project's purpose and given the opportunity to ask questions.

3. EVALUATION

3.1. Sociological Evaluation

The sociological analysis of the observed group effects revealed a complex and multifaceted picture. to support analysis and evaluation, relevant behaviours were classified into four categories ranging from positive to ambivalent/problematic, critical to even fatal behaviours.

Individual experiments can be classified into a scheme with the dimensions 'manifest behaviour' and 'patterns of reasoning and decision-making', with the latter divided into the subdimensions 'professional' and 'situational'. Observed manifest behaviours included (A) stopping, not getting out of the vehicle and turning the vehicle around as a continuous sequence of actions. (B) Stopping and exploring/making emergency calls/escaping on foot, often as a multiple sequence. (C) Attempting to drive past the accident site. 'Professional' reasoning and decision-making patterns are comprehensive courses of action that are shaped by previous experience or prior knowledge. Situational uncertain decision-makers make decisions in the moment, often multiple times, and give ambivalent or vague reasons. Situational confident subjects can give clear reasons and show little uncertainty when reflecting afterwards, but they do not have a comprehensive predetermined course of action. Although only seven individual trials were conducted, almost all combinations could be observed, even professional reasoning that lead to critical, potentially fatal behaviours.

In order to capture group effects, the behaviour and decisions during the group trials was analysed at three levels: individual, immediate 'neighbourhood' (vehicle crews and vehicles directly in front of or behind) and larger groupings. At all three levels, the experiments revealed a surprising range of initial reactions to the scenario and stopping the cars, up to and including the final route choices in the tunnel. "Group effects" can be expected either in the orientation of individuals towards others, within groups or through the formation or dissolution of groups (grouping effects). To give an example: the empirical analysis showed that the orientation towards other people at an individual level could be mapped onto six types:

(A) Guiding others, no orientation towards others
(B0) No or little orientation towards others, own course of action enforced
(B1) Orientation towards others and own course of action equally important
(B2) Strong orientation towards others despite having a personal course of action
(B3) Orientation towards others because of a lack of own course of action
(C) Act only upon explicit request

Overall, positive effects predominated: problematic or critical behaviour of individuals could be corrected by group dynamics. The actions of other road users at the front of the row, such as exiting the vehicle or starting to flee, made driver at the back aware of the danger, prompting them to react even if they did not perceive any direct danger. Potentially fatal behaviour, such as attempts to turn the car around or return from safe areas to the smoke-filled tunnel, was also prevented in some experiments.

However, problematic and critical group effects also occurred. A striking example of this was the phenomenon of passivity as a group behavior. Whereby the inactivity of test subjects in front of a vehicle resulted in a lack of or delayed danger awareness among those behind them. In one trial one person's call to approach the danger zone could have had potentially fatal consequences for others. In another trial, a small group of people formed and decided internally to conduct a search operation disregarding concerns within the group, thus exposing themselves to critical situations. In addition, ambivalent effects were identified, the impact of which depended heavily on the specific situation and the individuals involved. Many participants described their decisions as a conflict of objectives between saving themselves and saving others, whereby saving others could refer both to those directly affected by the accident and to the occupants of their own vehicle or people in the vicinity of their own vehicle or the “group” as a whole, i.e. all persons in the vehicles in the tunnel.

A detailed description of the complex relationships that could be traced based on the multilevel analysis can be found in the corresponding project report, Issue B 209 [1].

3.2. Quantitative Experimental Results

The goal of the quantitative engineering evaluation of the test subject trials was to derive reaction times and escape speeds from the (video) documentation of the escape behaviour. To this end, the individual escape paths and associated escape times of each subject were determined from the video recordings.

Reaction times were calculated as the sum of the time spent in the vehicle, any time spent exploring the situation, time taken to reach the emergency call niche, and the duration of placing a call. The individual behaviour of the test subjects and the paths they took were considered; not all subjects explored the situation, and only a few placed a call. Escape time was determined from the moment a person purposefully started moving towards a safe area until they reached it.

Figure 4 shows the statistical analysis of the time spent in the car—the time between stopping and leaving the vehicle—differentiated between individual and group trials. This included two individual drivers who turned their vehicles around, as the decision to become active and turn around is an escape decision in a broader sense. As a result, the median time spent in the vehicle was 24.5 seconds for individual trials and 44 seconds for group trials. The longer time spent in the vehicle during group trials is likely due to communication between the driver and passengers.

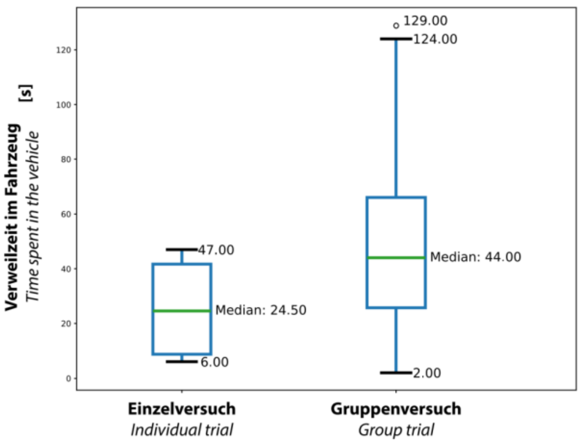

Figure 4: Time remained in the vehicle, differentiated between individual tests and group tests [1]

Figure 5 shows the statistical distribution of reaction times. In the individual trials, the median reaction time (for participants who did not place an emergency call) until they started to flee was 47 seconds. For people in the five group trials, this reaction time was significantly higher at 70 seconds. As with the time spent in the vehicle, this can be interpreted, as an indication that people in individual trials react faster because they do not wait for hints from others and do not spend time coordinating their approach.

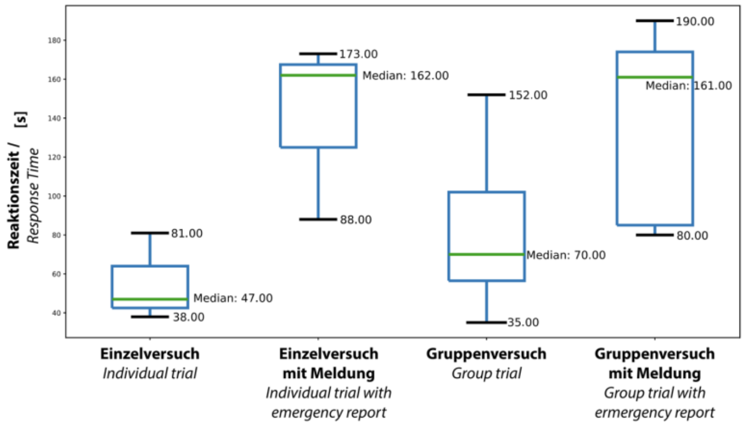

Figure 5: Statistical distribution of reaction times in individual and group trials [1]

In the individual trials the median escape speed of the test subjects was 1.27 metres per second. In the group trials, a slightly higher median speed of 1.43 metres per second was observed. This showed a considerable spread in individual speeds, which is attributable to different behaviors of the subjects, ranging from intensive communication during the escape to a running at a fast pace. These measured speed values generally align well with the assumptions used in common risk models for tunnel safety, such as the German model, which typically assumes an average escape speed of 1.3 meters per second. Furthermore, the empirical data underlines the general validity of the underlying escape model as a representative abstraction of human behavior within the risk assessment framework. Based on these results of the research project, there is no immediate need to fundamentally adapt the established methodology for the safety assessment of road tunnels in this respect.

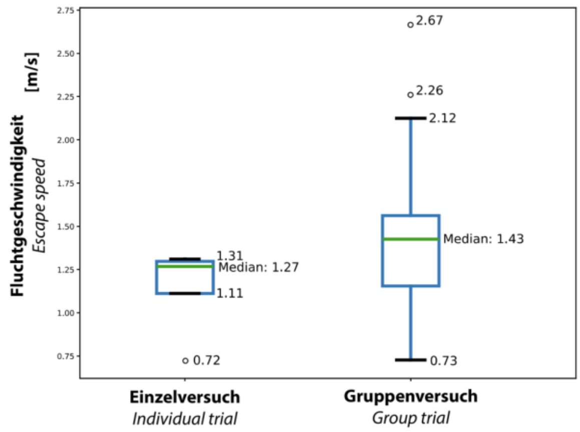

Figure 6: Statistical distribution of escape walking speed in individual and group experiments [1]

Table 1 summarises the parameters and shows that quantitatively, people in a group setting take a slightly longer to leave the vehicle and start fleeing but then seek a safe area at a faster walking speed. It should be noted that the result of the sociological analysis indicates a predominantly positive influence on self-rescue behaviour, but this cannot be reflected in the quantitative escape parameters. It is also worth noting that none of the individuals in the group trials remained sitting in the car.

Table 1: Overview of quantitative escape parameters comparing individual and group experiments

Parameter	Individual Trials	Group Trials
Median Time Spent in Vehicle	24.5 s	44.0 s
Median Reaction Time (without notification)	47.0 s	70. s
Median Escape Velocity	1.27 m/s	1.43 m/s

4. CONCLUSION AND OUTLOOK

The research project "Analysis of Reaction and Escape Behavior in Road Tunnels Considering Group Effects" has provided extensive insights into the influence of group dynamics on self-rescue in tunnel systems, based on sociological and engineering aspects. As part of the project, more than 70 test subjects were immersed in a highly realistic accident scenario with a fire in a road tunnel, and their behaviour during the self-rescue phase was analysed in detail. Numerous different behaviours were documented, and group effects were described.

However, when interpreting the results, it should be noted that the scenario still represented a relatively limited and ‘simple’ challenge in terms of tunnel length and accident scenario, the number of vehicles, the use of one lane only, the convoy length, path lengths, etc. These factors can be significantly more complex in other events. Restricting the test subjects to German speakers also represents a simplification.

The trials support the thesis that although group effects significantly expand the spectrum of escape behavior, they tend to improveself-rescue. However, negative grouping and group dynamic effects also occurred in the trials. It should be examined here whether and to what extent these can be addressed by safety concepts.

The engineering evaluation of the conducted trials, which determined the reaction times and resulting escape speeds for both group trials and individual reference persons, confirms the common assumptions of the basic parameters of risk models. Consequently, the results and data basis of the trials do not justifiy updating the regulations. However, due to the restriction to a single scenario and the limited total number of subjects, the transferability to general situations is limited.

Due to the extensive nature of the project’s fundamentals, results, and analyses, only a highly abbreviated form can be presented here. A detailed version can be found in the associated research report, which is part of the series "Reports of the Federal Highway and Transport Research Institute, Series B: Bridge and Civil Engineering" as Volume 209. This was published in April 2025 and is available for free download at: https://www.bast.de/DE/Publikationen/Berichte/unterreihe-b/2025-2023/b-209.html.

5. REFERENCES

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