Fire Response Performance and Social Behavior in Tunnels Distinguishing from Buildings in Evacuation

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Abstract. The most decisive factor of tunnels' safety in the face of fire is the chance of evacuation safely. Immediate response and proper movement in evacuation from tunnels in fire is essential, which can largely improve the rescue efficiency and reduce the casualties. Tunnels, different from buildings, provide significantly different influence on evacuees due to its unique environment, layout, fire facilities etc. These external distinction not only affect the objective escape conditions directly, but also social behavior indirectly. Consequently, understanding how people behave in the case of fire is of great benefit to bring fire safety measures in line with their need and render valid escape guide in emergency. This paper makes a comparison of people's behavior affected by smoke accumulation, visibility, complexity of structure and fire safety facilities in tunnels and buildings according to available literature. Moreover, psychological comparison namely property attachment, affinity to the surroundings and influence by other evacuees are presented. The discrepancy between tunnels and buildings indicates that corresponding strategies should be applied on different scenarios in tunnel and there is a need to distinguish fire safety education separately.

Keywords: Fire response performance · Social behavior · Tunnel fire
Fire safety strategies

1 Introduction

With the increase in traffic volume, the chance of tunnel traffic accidents and associated fires have increased, which lead to great risk to human life and damage to property and the economy. Moreover, the trucks occupy a large portion of vehicles in tunnels which are much likely to trigger explosion and release much toxic gas. The burning gas and smoke, on one hand, is a vital threat to occupant's safety with the possibility of asphyxia and intoxication. On the other hand, it affects the visibility in tunnels which lowers the moving speed and lengthens the evacuation time finally.

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Many casualties are induced due to the fact that occupant stay still in their vehicles and don't take any steps escaping, for instance, where most of the victims were found inside their cars in the fire in the Mont Blanc tunnel (Kouabenan et al. 2005; Gandit et al. 2009). Different from buildings on the ground, the assistance of the professional emergency services like rescue it is much more difficult for fire brigades to extinguish tunnel fires since fire engine has trouble driving into the tunnel through traffic jam caused by fire and also the precise location of fire cannot guarantee underground. In such unclear situations, adequate self-evacuation can help occupants out of the danger or at least prolong survival time until the rescue. However, a large portion of people don't behave correctly: stop the vehicle distant from the fire source of 50 m or more on the side of carriageway, switch off the engine, switch on the hazard flasher, and leave the vehicle immediately while leaving the keys in the ignition lock. They should move to the nearest emergency exit as soon as possible (Egger 2012). Unfortunately, observations from various tunnel fires show that occupants do not evacuate immediately.

2 Evacuees' Reaction and Pre-movement Time

Evacuees' reaction and time to react determine the number of casualties since any delay and hesitation during a fire will shorten available time to escape. On the one hand, with strong social bonds between occupants involved in a fire, such as between family members, they tend to go and find their group at the very first time instead of escaping. On the other hand, task commitment which people cling to role patterns or expectations is in their first instance when unexpected events occur (Averill et al. 2005). This inhibits the recognition of danger and increases the processing time of information about the risks that a fire poses. People are often inclined to finish the job they are doing firstly before making their escape. And those who have organizational responsibilities for a building, by virtue of their roles or positions, such as waitresses and department managers, are also inclined to assume these duties during an emergency situation. Incident analyses have discovered that there is a connection between a delayed evacuation and a high number of fire deaths or injuries, particularly in residential buildings and hotels. Earlier evaluations, in particular those of the Beverly Hills Supper Club fire and the Cocoanut Grove Dance Hall fire, had already revealed that a delayed evacuation had resulted in a large number of fatalities. Since the tunnel is filled with a group of strangers, the delay resulting from role and social connection weakens. Occupants lack reliance on other people or their work, hence, they regard cars as the safest place and choose to hide in them. In the first few seconds, they stay still inside vehicles until further instructions or drive faster to rush out the fire zone as long as they believe they could survive through the rush, which would trigger server car accidents or crash with the possibility of fuel leakage. According to the handbook of tunnel fire safety, correct behavior is as followed in Table 1:

Table 1. Correct behavior for drivers in case of tunnel fire

1	Switch on warning lights	necessary
2	Switch off the engine	necessary
3	Leave your vehicle	necessary
4	Administer first-aid to injured people	unnecessary
5	Call for help from an emergency point	necessary

Among all the reaction, Sime, Proulx and Fahy have done the research which have revealed that pre-movement time is a more important element since required escape time is provided and movement to a safe place does not differ a lot. Though pre-movement time and pre-movement behavior are currently regarded as key aspects of the evacuation process, little document and research has put it into quantitated calculation, and less research in tunnels.

3 Movement Speed and Path

At the beginning of the 20th century, people firstly turned their attention to investigations of movement velocity and movement time, and now thousands of scientists from across the globe have conducted major research into this issue, including Fruin (USA), Pauls (USA), Predtetschenski and Milinski (Germany), Habicht and Braaksma (Canada) and Jin in particular. Several mainstream types of velocity in corresponding buildings and the time needed for movement purposes are relatively well documented. Among those, Paul and Fruin's investigations have been converted into calculation tools and are taken down in fire safety legislation and codes of practice. Jin discovered that walking in smoke behaves differently from that in previous study which focused on places without smoke. Also, some attention has been paid to the functionally impaired including young children and the elderly from the 1970s by Bpyce, Shields and Silcock, which proved to deviate from expectation and previous calculation. Two main experiments conducted by Jin and Frantzich and Nilsson. Jin investigated both irritant and non-irritant smoke and the results for irritant and non-irritant were 0.3 and 1 m/s and 0.5–1 m/s respectively. Experiments by Frantzich and Nilsson were devoted to a wider range of extinction coefficients and the obtained speed covered 0.2–0.8 m/s. Another factor is mobility which determines an individual's ability to move, distinguishing four levels, namely high, temporarily reduced, permanently reduced, and dependent mobility [lr38]. The average movement speed was relatively higher than that in buildings with less complicated engineered features like corners, stairs and obstacles, found to be approximately 0.9 m/s, independent of tunnel floor material examined. Moreover, during an experiment by Karl Fridolf and Enrico Ronchi etc., many participants walked with a crouched posture as shown in Figs. 1 and 2 due to an uncertainty about the tunnel height, improvement of the walking balance and an increase of perceived level of safety inside the tunnel.

Fig. 1. Walking with a crouched posture.

Fig. 2. Walking with the hands in front of the body.

4 Movement Speed and Path

Occupation density, the number of people in a building affects evacuation largely. High occupation density relates to a high probability of fatalities in the event of fire according to the literature. While congestion around the exit door or staircase is a huge problem in building evacuation, it troubles rather little in tunnels.

Shinji Emoto in Japan did an experiment and found congestion did not occur because the diagonal tunnel, constructed with a width of 8 m, had a large capacity for evacuees from one site to another (Emoto et al. 2016). According to many simulations via pathfinder and Building Exodus, people won't gather in front of either emergency doors or staircases normally, for its low occupation density and large size of tunnel installation. However, congestion at an emergency door was observed once because many participants arrived from both sides simultaneously. And there is possibility that people gather together in front of doors waiting others on their way to doors, which lead to serious congestion probably. Those situations are extremely hazardous with unimaginable damage to escapers once occur. It is expected to eliminate the congestion by guiding clearly and precisely with signage and some researchers are trying to guide and command occupants in emergency with artificial intelligence.

5 Safe Destination

Destination, referring to locations or areas that pedestrians move towards plays an important role in escaping for they move to their destination based on a shortest path algorithm according to distance potential maps in their mind. Thus, a clear destination brings about a quick reaction and a specific route (Sime 1999). In modelling, the behavior control moves the individual from one cell to another based on the shortest distance to a destination, supervising the waiting periods, and other behaviors such as overtaking or sidestepping. The method is usually based on "potential maps" which identifies a discrete approximation of the shortest path towards the destination and stores this information in the cells in order to achieve an efficient simulation and the path varies along with the destination.

Though exit doors are regarded as destination generally, people would feel safe when they reach a place where they are familiar with. People in building fires aim to run out of the building and the surrounding outside is explicit and secure. In contrast, people escape with hesitation more or less due to the uncertainty outside the emergency door. The current three destinations in tunnels are namely refugee room, another adjacent tunnel or road surface all connecting with a cross aisle, which would bring less sense of security in escaping.

6 Property Attachment

According to research data in accidents before, the most two common actions drivers would take are to stop their cars and remain seated in the cars or to make a U-turn to the entrance of tunnels. The first would waste precious evacuation time on first stages of fire and lose the chance of running away. The second is more dangerous and detrimental since it may lead to traffic jam and accidents in tunnels and may hit evacuees badly. Admittedly, compared to the tunnel environment, drivers perceives relative safe inside their own vehicle is a main reason and reluctance to leave property behind is another undeniable cause of passivity. (Gandit et al. 2009; Ronchi et al. 2013). Similarly, property attachment has been shown to be a main account of non-evacuation in buildings in fire. This can be proved on the discrepancy of evacuation in home and office. Mostly, people at home cost longer time before taking action since they spend time gathering cash, jewelry and significant document. In contrast, the evacuation time is relatively short if task commitment, which means that people cling to role patterns or expectations, is neglected. This psychological tendency has no possibility to eliminate entirely but can only be overcome to some extent by announcement and instructions in tunnels. It is essential to distinguish various instruction ways including vocal message, signage and other ways and release effective information.

7 Affinity to the Surroundings

People's behavior towards surroundings is based on the acknowledgement and interpretation on it. The more familiar people are to the environment, the more effective and adequate measures they are tend to take. Affinity to the surroundings are the key to correctly and actively interpret what is happening around. It influences people's moving speed directly and disturb people mentally which would affect their react time and way finding choice indirectly. It can be divided into two aspects. On one hand, it is the basic surrounding that the structure provides including layout, dimensions, exit etc. On the other hand, it relies on the changeable parameters when an accident occurs such as the visibility and noise. Tunnels are unfamiliar from daily life and they are designed quite differently from normal buildings. Sometimes, even experienced drivers have had rare chance to move through tunnels without vehicles. Except from the lanes, other parts such as cross passages are black box especially when drivers are exposed to the dark surroundings. In contrast with tunnels, office and home are mostly alike with common structure, providing more sense of familiarity and security. Apart from the

natural characteristic, lights along the ceiling are obscured by dense and stratified smoke and fans for smoke ventilation will create much noise which would aggravate the horror in the dark. The change in illumination and huge noise would cause panic in a strange environment, which would worsen mobility and awareness. The perception of surroundings also plays a decisive role in fire response performance. It has been found that it is not the actual length of an escape route, but how it is perceived, which determines which way is chosen. Little affinity to surroundings increases the chance of misjudging distance when choosing exits.

8 Conclusion

It is widely agreed that clear and profound cognition towards human behavior is essential when meeting a fire in a compartment fire and research concerning to human response performance and social behavior has been conducted from the beginning of the 20th century. In contrast with masses of experiment and modelling focusing on fire in buildings, little attention has been paid to tunnel fires due to relatively less number of fire accidents in tunnel. Nevertheless, tunnel fires can never be taken too serious since its immeasurable destroy and large causalities usually companying with large explosion ignited by fuel tanks of vehicles. Though tunnel fires and building fires share quite a few in common in occupants' behavior facing emergency, tunnel fires differs a lot due to its weak illumination, relative confined space and unfamiliarity to occupants, containing some HGVs, which brings about various pressure and problem for evacuees. Currently, most investigations are based on building fires and the discrepancy between them lack thorough research with masses of modelling and experiments. New advanced technology like virtue reality provides convenience and facility and cuts down expense in both human and material resource, and thus should be put into use in quantity. Fire response performance is dependent upon the environment where an individual stands, the point should be stressed on the interaction between human and the features of tunnels. According, further research is demanded based on tunnel psychonomics in tunnel fires.

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