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Integrating evacuation research in large infrastructure tunnel projects - Experiences from the Stockholm Bypass Project

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ABSTRACT

Large infrastructure projects often involve important decision about evacuation safety measures, e.g., emergency exit portals, alarm systems, etc, that need to be taken in spite of limited information and knowledge about the topic. This has been shown to sometimes lead to design mistakes, but these mistakes can potentially be avoided if research is linked to the project at an early stage. This paper discusses how research can be connected to large infrastructure tunnel projects, and illustrates the process using the Stockholm Bypass Project as an example. In addition, the results of a research project, which was linked to the Stockholm Bypass Project, are presented and relevant additional publications are given.

1. Introduction

Large infrastructure projects, such as road and rail tunnel projects, often involve major decisions that need to be made given very limited information and knowledge about the topic. Decisions often relate to issues that have not yet been fully explored in research. These decisions then need to be made based on the best available knowledge, but this can easily result in serious design mistakes [1].

There are many illustrative cases where evacuation safety measures have not worked entirely as intended. One example is the Traffic Information Signs (TIS) for tunnel evacuation in the Southern Link Tunnel in Stockholm [2], which is a twin tube tunnel with unidirectional traffic in each tube. The TISs were configured to display different messages, one of which was “evacuate tunnel” (in Swedish), see Fig. 1. Initially, this message was displayed in the affected tunnel section in case of fire and smoke, and the intent was that people should leave their vehicle and evacuate the tunnel on foot. However, real fire incidents have demonstrated that people interpret the message differently and some motorists instead drive out from the tunnel through thick smoke [2]. This type of behaviour is potentially dangerous in unidirectional tunnels due to the risk of running over people while driving through the smoke.

The Southern Link Tunnel example clearly illustrates that a particular design might not work as intended in spite of the best intentions. The simple evacuation message, i.e., “evacuate tunnel”, seems to make sense, since theory suggests that instructions should be kept simple in stressful situations due to the limitations of people's working memory [3]. However, a risk when making instructions simple is that the context can become more important for decision-making. In the Southern Link Tunnel example, the motorists were presumably in their vehicles with the engine on, and given this context it makes sense to evacuate the tunnel by driving out. This type of context dependent interpretation is arguably difficult for to predict, as it is not easy to adapt the mind-set of a tunnel user.

Incidents, like the one in the Southern Link Tunnel, are not in vain

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Fig. 1. Schematic representation of one of the TIS messages in the Southern Link Tunnel (left) and the Göta Tunnel (right) [translated from Swedish].

and it is important to learn from them. TIS messages in the Southern Link Tunnel have since been updated and alternative messages, e.g., “evacuate tunnel” or “stop engine, evacuate tunnel”, are now shown in different tunnel sections depending on fire and traffic conditions.

In another tunnel project, namely the Göta Tunnel in Göteborg, the TIS message “stop engine, evacuate tunnel” is shown in case of fire or smoke, see Fig. 1. This message, although simple, changes the context for which the message is interpreted. From the perspective of a motorist behind the wheel of their vehicle, it is not possible to drive out from the tunnel when the engine is stopped. Therefore, the remaining option is to evacuate on foot. Experiments have also indicated that the TIS design used in the Göta Tunnel performs well and is a much appreciated evacuation system [4].

It could be argued that well-trained experts is the way to avoid design mistakes, but experience shows that even experts are not able to predict the influence of the context on the interpretation of evacuation safety measures. This is illustrated by an experiment in a smoke filled tunnel, which was performed as part of the METRO project [5]. One of the objectives of the experiment was to study the effectiveness of different emergency exit portal designs. Fig. 2 shows one of the tested portal designs, which consisted of a green frame around the door, green and white lights at the bottom part of the frame, a back-lit emergency exit sign above the door and strong illumination on the portal. These features were chosen to resemble the design suggested in Swedish guidelines for tunnels.

The portal design was seen by the involved researchers both with and without smoke before the experiment. Although a total of six experienced evacuation researchers examined the portal design, none of them were able to predict how it was going to be interpreted by participants. Post-experiment interviews revealed that some participants interpreted the portal as an oncoming train [5]. This was a surprise to the researchers, who had all failed to recognize the context in which the participants viewed and interpreted the portal. Participants had seen a film of a train ride in Stockholm Metro before they entered the smoke filled tunnel, which presumably made them believe that the focus of the experiment was on rail tunnel evacuation. Therefore, they were probably looking out for potential hazards in the tunnel, e.g., the electrified third rail, other trains, etc, which made them interpret the emergency exit portal as an oncoming train when seeing it through the thick smoke, see Fig. 2.

A potential way of minimising design mistakes is to analyse evacuation safety measures using a framework [1]. One such framework is the Theory of Affordances, which was proposed by Gibson [6] and further refined by Hartson [7]. According to Hartson [7] an object, e.g., an evacuation safety measure, can be interpreted in relation to what it offers the user in terms of (1) sensory, (2) cognitive, (3) physical, and (4) functional affordance. This approach is hence a way of considering the context for which an evacuation safety measure is perceived, interpreted and used. However, it has been argued that the Theory of Affordance is not a foolproof way to avoid mistakes, but that it should ideally be used mainly to rule out inappropriate designs at an early stage [8]. It is instead necessary to perform research aimed at testing different designs in realistic scenarios with representative participants before being installed in real tunnels. Failure to do this can lead to costly installations of evacuation safety measures, which only provide very limited benefit.

In order to avoid design mistakes, it can be useful to include research as a part of the initial stages of large infrastructure tunnel projects. One example of this is the Stockholm Bypass Project, where research was funded by the Swedish Transport Administration and the EU Trans-European Transport Network (TEN-T). In the following text, research related to design of evacuation safety measures in the 18 km long tunnel section is presented in order to illustrate how research can be used in the initial stages of large infrastructure projects to minimize the risk of design mistakes.

2. Project description

The Stockholm Bypass Project is an on-going large Swedish infrastructure project (budget: approximately € 3 billion). In the project, the E4 road will be lead around Stockholm, which involves the construction of 21 km of new road. A total of 18 of the 21 km will be located in tunnels, which in this paper is called the Bypass Tunnels. Construction, which was preceded by many years of planning and preparation, was initiated in August 2014 and will continue for another 10 years.

In 2012, the Stockholm Bypass Project applied for funding from the EU Trans-European Transport Network (TEN-T) for project related research. The funding lead to contacts being established with various

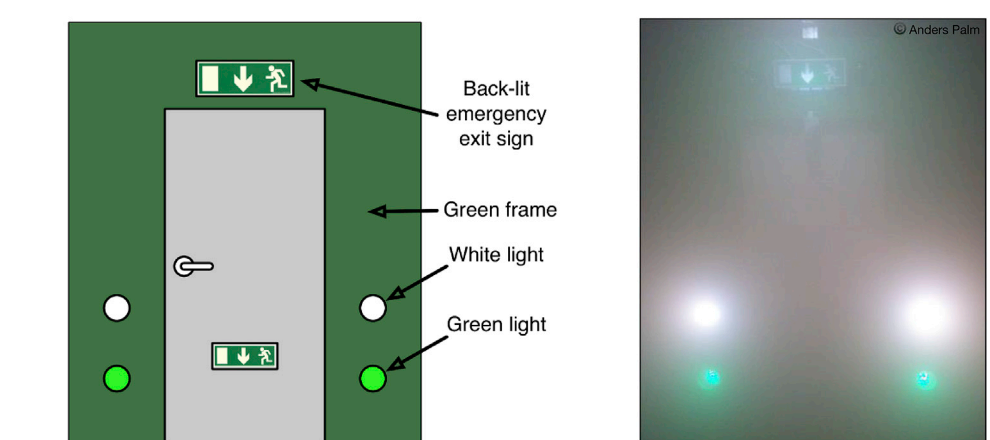

Fig. 2. Schematic representation of the emergency exit portal used in the experiment (left) and the actual exit in the smoke filled tunnel during the experiment (right).

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