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System for deterministic risk assessment in road tunnels

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Abstract

In this paper, a pragmatic and goal oriented system for risk analysis in road tunnels is described. It is particularly focusing on mortality risks in case of a road tunnel accident. It is a deterministic approach combining three major components: a) vehicle distribution in a tunnel; b) smoke propagation in case of a fire; and c) people evacuation (escape) component. The major improvement of this approach is in capturing the knowledge often provided only by experts into a robust and pragmatic system available to all decision makers. This is achieved through a large number of scenarios combining different configurations of road tunnels (e.g. different number of lanes, different speed limits) and the travel demand (e.g. different structure of the flow, different volumes of traffic) which were prepared and evaluated through microscopic traffic simulation. The resulting scenarios with the information about the number of vehicles in different tunnel sections were obtained. The results describe most of the existing tunnels and situations and can be used universally. Similarly, the people evacuation component can be evaluated in a general form. The results can be manually updated to suit any particular road tunnel which can differ for example by the availability or quality of warning and information systems. The remaining task is to create a physical model of the real tunnel and to model the smoke and fire propagation. All these components were combined into the CAPITA software that was developed as a part of the research project HADES (supported by the Technology Agency of the Czech Republic). The CAPITA software is presented in the last chapter of this paper. The scenarios available off-line are in fact a knowledge base available to experts as well as decision makers and lead to a higher level of comprehension of the developments in case of fire and significantly speed up preparation of a risk analysis.

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Keywords: road tunnel; risk analysis; deterministic model; CAPITA

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1. Introduction

This paper discusses the issue of "optimization" of technological safety systems used in road tunnels with the goal of providing adequate level of safety for the end user, in this case passing vehicles. There is always a moral dilemma on the side of the engineers and decision makers in general to find a compromise between the installed safety equipment and a safety level of a tunnel [1]. It is not possible to equip a tunnel with a safety equipment or a system to make it absolutely safe. On the other hand, installation of each additional safety equipment or system that is not needed to maintain a specific safety level, brings higher investment costs as well as (often disregarded) operational costs.

The design of the technological safety system is based on technical standards. There is a perception that a tunnel is safe when it is designed according to these technical standards. Such approach has certain limitations, since the tunnels are seldom identical, each tunnel has some unique features [2]. Even though the tunnel fulfils all requirements set in the technical standards, there is a residual risk that can be never specifically addressed. In many cases the real situation is different from the anticipations of the authors of the technical standards, which are often prepared over a lengthy period measured in years. This means that even when the technical standards are thoroughly applied, there is always a residual risk that cannot often be named or even known.

Since the term "safety" is difficult to define, it is often the case that the tunnels are designed strictly according to the technical standards while some additional safety equipment is added "just to be on the safe side". Such clearly formalistic approach may easily lead to increased construction costs. The general discussion on how to properly equip a tunnel with technological systems will probably never cease, however, based on the discussion on "Road Tunnel Operation" in the D.5 committee organized by the World Road Association PIARC it is possible to say that there is an increasing agreement on the need to optimize and lower costs of the equipment installed in tunnels, which leads to the approach combining the application of technical standards with risk analysis.

The following paragraphs briefly introduce the risk analysis model, which is available to the larger professional audience and that can be used along with the current prescriptive approach to tunnel design.

2. System approach to risk analysis

The Ministry of Transport of the Czech Republic and the Road and the Motorway Directorate of the Czech Republic paid much attention to research aimed at optimization of the safety equipment in road tunnels, which lead to a more holistic view of the safety standards covering not only tunnel design, but also tunnel operation. Risk assessment differs throughout the documentation preparation process depending on the stage that is currently elaborated [3].

2.1. Qualitative methods of risk assessment

Qualitative methods of risk assessment are methods that directly express the level of risk in the form of a numerical value indicating the number of affected people, economical losses, etc. Generally speaking, these methods are the most objective ones, since they are relatively well manageable. They are divided into methods working with statistics, which give us as an output in the form of a probability of a certain risk (for example death of people), and into the methods using transport simulation and physical models, which give us as a result in "hard" numbers such as the number of killed people. The key factor in a modern risk assessment is understanding that undesirable occurrences do not happen by themselves, but that they start with (often negligible) disruption of the normal operation that can unfold into several directions based on the reaction to the initial occurrence. This concept is known as the Bowtie Model and is shown in Fig. 1. The upper part of the figure shows the principle of the probabilistic method and the lower part of the figure shows the principle of the deterministic method called the Scenario Analysis Method, which is described later on as the software CAPITA.

The left side of the model is dealing with the cause of the undesirable occurrence such as fire, accident, traffic congestion or loss of freight. The occurrence, resp. estimation of its probability or frequency, is usually done using the Fault Tree Analysis (FTA). The FTA uses inputs such as traffic intensity, vehicle fleet composition, tunnel construction parameters, tunnel colour scheme, weather, etc.