Tunnelling and Underground Space Technology 26 (2011) 71–82

Contents lists available at ScienceDirect

Tunnelling and Underground Space Technology

journal homepage: www.elsevier.com/locate/tust

Probabilistic risk assessment of highway tunnels

Ondřej Nývlt, Samuel Prívara, Lukáš Ferkl *

Department of Control Engineering, Faculty of Electrical Engineering, Czech Technical University in Prague, Technická 2, 166 27 Praha 6, Czech Republic

ARTICLE INFO

Article history:
Received 11 January 2010
Received in revised form 21 June 2010
Accepted 29 June 2010
Available online 31 July 2010

Keywords:
Risk management
Risk analysis
Road tunnel
Costs effectiveness
Economic optimization

ABSTRACT

Many approaches to risk analysis in tunnels have been proposed by both international and national authorities over the last few years. Many safety problems have been discussed and a large number of important risk factors and hazards in tunnels have been identified. The concept of risk analysis in the scope of tunnel risks is, however, still under development; particularly an overall idea about the risk management concept is still missing. The paper introduces the concept of risk analysis in the scope of risk management and employs methods well-known in aeronautics and aircraft industry, yet, still unused in tunnels. The proposed methodology enables building and refurbishing costs minimization subject to preservation of satisfactory safety level. The outcomes of the proposed method have clear technical and economic interpretation and create a strong support tool for the decision making process. The paper also includes a case study of the Strahov tunnel in Prague, Czech Republic.

1. Introduction

1.1. Risk analyses in tunnels

Risk analysis is a tool developed initially in industries with potentially dangerous applications (chemical plants, nuclear power plants). According to Stamatelatos et al. (2002a) and Rausand and Høyland (2004), the purpose of risk analysis is to establish a proactive safety strategy by investigating potential risks. In last 15 years, risk analysis methods were also adapted in tunnel safety. Risk analysis in tunnel enables comparison of safety measures in terms of risk reduction as well as risk-based cost/effectiveness analysis, which can evaluate the cost of risk reduction.

Even though quite a long time has passed since the first risk analysis methods have been introduced in tunnels and a number of serious tunnel accidents has occurred, there has been no common standard or method used in PIARC[1] member countries (PIARC, 2007; PIARC, 2008). In spite of basic framework of road safety introduced by EU Directive 2004/54/EC (2004) on minimum safety requirements for tunnels in the Trans-Europeans Road Network and several recommendations issued by PIARC, most of the countries use their own methods. Oftentimes, a quantitative approach is chosen to calculate probabilities of respective events/scenarios/..., fire included, which is, according to the majority of available publications (Beard and Cope, 2007; PIARC, 2007; PIARC, 2008) the most serious threat in tunnels. The lack of statistical data for fire occurrence is an ultimate problem most methods are encountering. This is in sharp contrast with the essential statistical requirement for data validity. This paper proposes a method based upon probabilistic risk assessment, yet independent of calculating of fire probability.

The methods introduced in this paper are not fully unknown to tunneling. According to several presentations given at the World Tunnel Congress 2009, the fault trees and event trees have recently been introduced by some companies and institutions, but only for the construction phase of the tunnel, especially for mining (Sander et al., 2009; Yan and Ye, 2009). Sturk et al. (1996) aim to assess risks during the construction phase of a tunnel and to support the decision making process. The case study uses FMEA (Failure Modes and Effects Analysis) and FTA (Fault Tree Analysis) as separate risk analysis tools. On the other hand, Hong et al. (2009) use ETA (Event Tree Analysis) for similar purposes. Eskesen et al. (2004) present general guidelines for performing risk management in tunnels; however, application of specific Risk Analysis methods is not in the scope of their paper. Petelin et al. (2010) provide comparison of the most frequent risk analysis methods used in tunnels – QRAM, TuRisMo and RWQRA; general concept of the risk management is provided, which is similar to our approach, but no detailed information about the background of the specific methods is given. The Austrian TuRisMo approach, described, e.g. by Kohl et al. (2007), uses ETA and consequence analysis for accident scenarios, but again as a stand-alone tool. Holicky (2006) presents an alternative probabilistic risk analysis based on Bayesian networks; however, this approach requires a lot of accurate data, which are usually not available for tunnels.

Even though some of said papers (Eskesen et al., 2004; Hong et al., 2009; Sander et al., 2009; Sturk et al., 1996; Yan and Ye,

* Corresponding author. Tel.: +420 777 855 363; fax: +420 224 916 648.
E-mail address: ferkll@control.felk.cvut.cz (L. Ferkl).

[1] PIARC is an acronym for Permanent International Association of Road Congresses.

0886-7798/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.tust.2010.06.010

2009) and documents (EU Directive 2004/54/EC,; PIARC, 2007; PIARC, 2008) use similar risk analysis methods as will be presented in this paper, they do not exploit all possible outcomes they can provide. We will therefore focus on these additional features of risk analysis, in order to present more support for the decision making process.

1.2. Relationship of the risk analysis and risk management

In the state of the art, Risk Analyses (RA) are not considered as stand-alone tools, but are rather incorporated into a more complex Risk Management system (RM), which forms a part of a decision making process (Risk Management ..., 2002; Stamatelatos et al., 2002a). RM provides means for quality management, risk mitigation, production and maintenance planning, safety and reliability analysis, etc.

As illustrated in Fig. 1, the RM process has two major parts, which correspond to the engineering and managing departments of a company. The engineering departments perform the technical analysis which must provide a clear interface for the decision makers in the company management in order to carry out sound decisions.

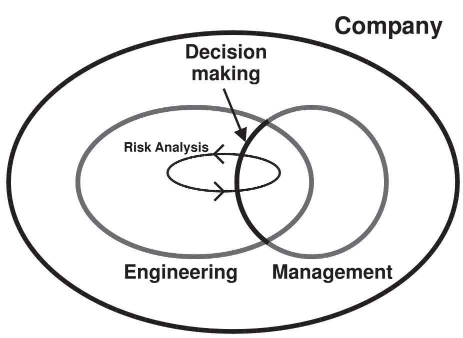

Fig. 1. Risk analysis as a part of a risk management process providing means for sound decision making.

In order to be efficient and to provide meaningful results, the RM process has to be scheduled for the entire lifetime of a system, as illustrated in Fig. 2. It is clear that each phase of the system life stage requires different approaches with respect to corresponding needs of decision making. Another factor is the input data available for the respective RA methods. If properly scheduled, the RM of a system is a continuous process that naturally follows the life cycle of the system (Risk Management ..., 2002). This continuity not only ensures appropriate results of the respective RA methods, but also saves significant amount of effort and resources needed for risk evaluation.

1.3. Risk optimization

One of the primary objectives of any RM process is to balance the cost of safety with the cost of accidents. It is very difficult to achieve as there is only a small evidence about the cost of accidents, while the cost of safety is usually known quite well. The problem is illustrated in Fig. 3.

The principle problem is to evaluate the total system risk. In any RA method, there are two factors that act against each other:

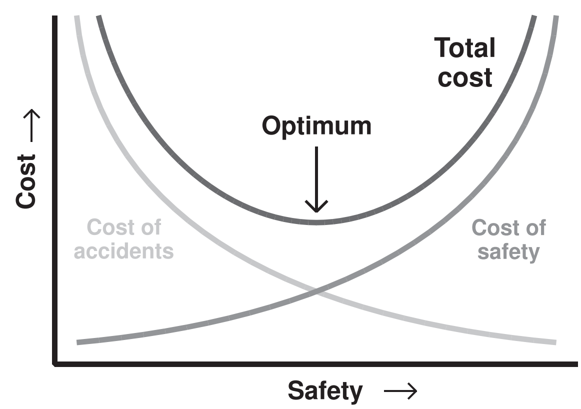

Fig. 3. Risk management – balance of cost of safety and cost of accidents.

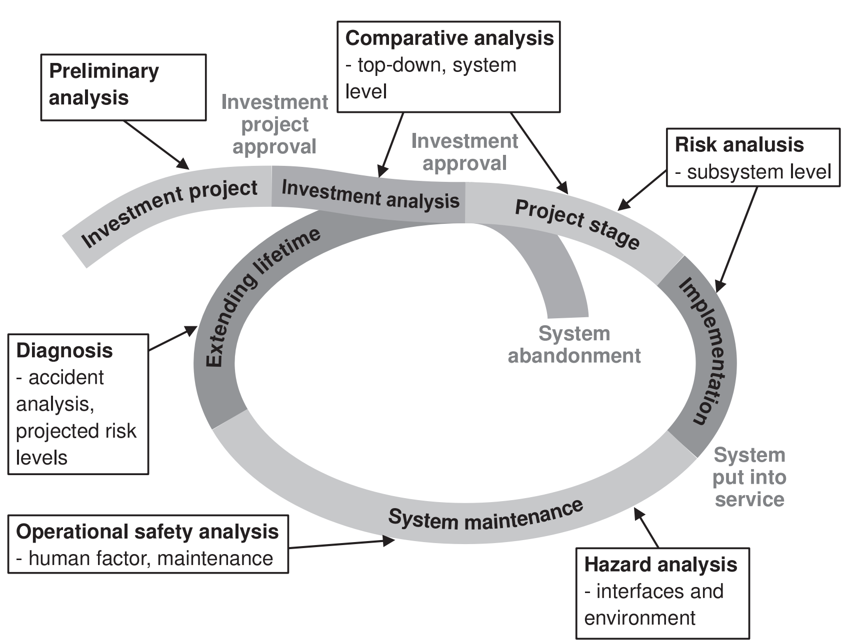

Fig. 2. The role of risk analyses in the system life cycle (Stamatelatos et al., 2002a).