Fire Safety Journal xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Fire Safety Journal

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

A review of competencies in tunnel fire response seen from the first responders' perspectives

Ove Njå[b,*], Mona Svela[a,b]

[a] Rogaland Fire and Rescue, Jærveien 107, 4318 Sandnes, Norway
[b] University of Stavanger, PO Box 8600 Forus, 4036 Stavanger, Norway

ARTICLE INFO

Keywords:
Major fire
First response
Competence
Complex road tunnel
Training

ABSTRACT

Norway has an increasing number of long and complicated road tunnel designs, which can be defined as complex sociotechnical systems. To avoid major accidents and fire situations, knowledge about the fire safety is required by both the fire and rescue services and the society. This article focuses on how representatives from fire and rescue services express uncertainties and expectations regarding the knowledge dimension of the road tunnel fire and rescue systems. The article is based on investigations of two tunnel fires in Norway, in addition to data from a workshop with tunnel fire response experts. The data has been analysed using systems engineering approach combined with an understanding of learning. This study has revealed tunnel fire safety concerns related to the Norwegian emergency response personnel's state of competence both in the pre- and post-accidental phases. The situation regarding tunnel fire safety is unclear and fragmented, with corresponding weaknesses in the existing knowledge. The future will bring even more complex road tunnels, also subsea-crossings, that challenge all parties: road owners, road users, vehicle producers, emergency responders and authorities. Norway needs facilities for tunnel safety training that can complement existing facilities and provide new knowledge.

1. Introduction

In the wake of the tunnel disasters in Tauern, Mont Blanc and St. Gotthard some 15 years ago, the fire events and safety management systems in the Oslofjord tunnel (23 June 2011 - [1]) and the Gudvanga-tunnel (5 August 2013 - [2]) have been critically considered by the Norwegian society. The Accident Investigation Board Norway (AIBN) has carried out its investigations with the aim to provide lessons learned. Of particular concerns are the interactions between the public roads authorities, the tunnel systems, the emergency response systems and the road-users. The society does not accept fire disasters in road tunnels, thus there is a demand for knowledge about the fire safety. The stakeholders within these systems have a common goal to avoid major accidents and fire situations. However, albeit the good intentions, the current status of knowledge is restricted to few events, some experience data from traffic accidents, experimental tests from low scale facilities, exercises and fire simulation tools. In Norway, the Runehamar tunnel is a full-scale test tunnel. This tunnel has been employed for various fire experiments and research projects [10,16,17,3,9].

Norway has an increasing number of long and complicated road tunnel designs. Today the road infrastructure consists of over 1000 tunnels. There are 33 subsea tunnels and 24 mountain tunnels with steep slopes (> 5%), and these tunnels comprises 5% of the length of the Norwegian road tunnels [19]. Subsea tunnels have no entrances beside the tube and they are long with often steep slopes. The Norwegian Government has decided to build the world's longest and deepest subsea road tunnels. When the Ryfast tunnel is complete in 2019, it will be 14.3 km long, 290 m below sea at the deepest, with a maximum gradient of 7.9%. Five years later the Rogfast tunnel is scheduled, with a planned length of 26.7 km, a depth of 390 m below sea and maximum gradient of 5%. Both tunnels will be dual tube.

According to numbers retrieved from the five Traffic Control Centres in Norway, 42% of the registered tunnel fires in Norway in the period from 2008 until 2015, occurred in these 57 tunnels described above. Heavy goods vehicles (HGV) were involved in most of these fires, mainly caused by technical malfunctions [19]. The fires in the Oslofjord and Gudvanga tunnels in 2011 and 2013 both started in HGVs. And, both tunnels are bi-directional single tubes, they have steep slopes and primary emergency exits through the tunnel portals. Another situational resemblance in the events was the location of the fire related to the ventilation direction, which caused smoke spreading

* Corresponding author.
E-mail address: ove.njaa@uis.no (O. Njå).

http://dx.doi.org/10.1016/j.firesaf.2017.05.005
Received 28 November 2016; Received in revised form 28 April 2017; Accepted 5 May 2017
0379-7112/

in large portions of the tunnels. There were no fatalities in the fires, but many people were trapped in the smoke; 34 in the Oslofjord tunnel [1] and 67 in the Gudvanga tunnel [2], many which sustained acute smoke injuries and psychological traumas. Neither the tunnel-owners nor the rescue services were in control of the smoke flows and the concentrations of toxic gases in those events.

The road-users' expected emergency response behaviours in tunnel fires is based on the *self-rescue principle*. This means that the road-users are supposed to evacuate from the tunnel themselves, either by car or by foot. Experiences from the tunnel fires mentioned are that not all road-users evacuate. Some of them stay in their vehicles (mostly HGVs) with recirculating air condition [1,2]. Professional rescuers are on call and the predominant approach is to extinguish the fire as soon as possible in order to provide access for the rescuers to reach people trapped in the tunnel. In single tube tunnels, the fire ventilation is a vital tool for the firefighters to provide access to the fire, and significantly dilute the smoke concentration downstream to improve the conditions for the evacuating people. The fire ventilation direction is usually predefined, based on the idea that the most capable fire department shall be in charge of the fire and rescue operation. However, the fire and smoke dispersion modelling and related validation as basis for the strategy chosen is scarce, and there has been a major discussion whether this strategy is better than suppressing ventilation in order to increase the time margins for all road-users with urgent need for evacuation. A predefined fire ventilation might also contribute to fire spread to other vehicles downstream.

Existing literature on tunnel fire safety addresses aspects like smoke, ventilation, fire dynamics, design fires, construction, risk assessment etc., but the rescue and firefighting operations performed by the fire brigades have generally received less attention [12]. The first response services need to understand and comprehend the complex systems and related design fire scenarios in order to be able to optimise their performance [4]. There is a need to convert and communicate such knowledge to the first response personnel in a way that makes it relevant for their working situations and experiences. Tunnel fires are rare events, and actual experiences from such scenarios are scarce.

The limitations of fire and rescue operations in tunnel fires has been the focus of previous research projects [21]. Kim et al. [12] have developed general operational procedures and proposed a classification model for firefighting in road tunnels. The study establishes some key elements for fire and rescue operations in road tunnels: choice of strategy; obtaining necessary information; access route and approach distance; control of air flow; rescue operations; cooperation between fire brigades at different portals and jurisdictions; and operations under fixed fire suppression systems. They suggest a classification model to help diagnosing *"the risk status of each road tunnel from the fire brigade's point of view and to determine the proper solution to decrease the risk level"* (p. 60). Four parameters are suggested for classifying the tunnels: passage of HGV and vehicles carrying dangerous goods (1), type of tunnel (2), risk of congestion (3) and response time (4).

Research from Sweden has revealed how tactics and methods for firefighting in underground facilities can be adapted to the risks, and how these risks can be defined [11,21]. Results from the full-scale firefighting tests in the Tistbrottet Mine in 2013 emphasize that the available amount of breathing air is an important limiting factor in fire and rescue operations under ground. The tests also showed that time spent on organizing the team and arranging equipment were substantial compared to the time spent on walking. Time is a crucial aspect in every firefighting operation, and the test results indicates that there should be a focus on improving the equipment handling and team management. The use of IR image cameras proved necessary, but the tests also showed a need for adapting the usage of such tools to underground facilities, as well as training the users. The project points at the possibility of using reconnaissance teams as an alternative method for information gathering. This would not be in accordance with existing Swedish or Norwegian legislation, but are suggested for closer studies [18,20,21].

The study presented in this article challenges the knowledge dimension of the road tunnel fire and rescue systems in Norway, including the individuals involved. In this study knowledge is related to phenomena, tasks, communication and interaction abilities, and how the actors approach tunnel fire safety in general. By the term "actor", we mean any agency or person involved in the emergency management of road tunnels. We were interested in how representatives from responsible road tunnel fire and rescue services expressed their uncertainties and expectations. We analysed the data material in a systems engineering approach combined with an understanding of learning addressing change, confirmation and comprehension of the crisis response systems.

2. Systems engineering theory to safety management

2.1. The Norwegian tunnel fire and rescue services

The municipalities govern the fire and rescue services in Norway. The 428 Norwegian municipalities range from only 200 inhabitants to 600,000 in the largest. Some municipalities have engaged in partnerships regarding operation of the fire and rescue service. In 2013, the total number of fire and rescue services was about 295; 26 were organised as inter-municipal companies, 205 were independent, and the remaining were involved in some kind of cooperation with neighbouring municipalities. The smallest fire and rescue services cover less than 3000 inhabitants while the biggest cover more than 250,000 [30].

The Norwegian preparedness structure is founded on four principles: *responsibility*, *proximity*, *similarity* and *cooperation*. These principles states that those who are responsible for and involved in day to day crisis management, at all levels, are tasked with the same responsibilities and works during major tunnel fire events as in the daily work. The cooperation principle is especially interesting, and it implies that authorities, voluntary, private and official actors are individually responsible for establishing appropriate interactions with relevant parties regarding the fire and rescue situations. Good cooperation between the different actors in the tunnel system is vital for the planning and performance of the fire response. The public roads authorities, the fire and rescue service, the police and the ambulance service must agree on and understand each other's roles and responsibilities. Establishing effective emergency response cooperation requires coordinated response plans, procedures and routines as well as regular exercises and training involving all relevant parties. Thus, the knowledge and competencies within, across and along organisational units is of vital importance.

2.2. Complex sociotechnical systems

The term sociotechnical includes the interaction between social and technical factors when describing conditions underlying system performance [32]. Trist [31] refers to the Tavistock studies of the British coal mining industry when he draw the evolution of the socio-technical system (STS) approach. STS was analysed at three levels; the primary work system, the whole organisation and the macrosocial phenomena. Modelling sociotechnical systems has often taken the form of structural decomposition, where the system is decomposed into individual elements, and its function is described by the causal interaction between these elements [23,24]. Such models seek to control the system's activities and safety through a top-down command-and-control approach. Traditional top-down control mechanisms consist of laws, regulations, standards, procedures, routines etc. which strives "*to control behaviour by fighting deviations from a particular pre-planned path"* ([23], p. 191). These mechanisms are subjected to contextual interpretation and implementation by the different actors at