Road Tunnel Ventilation

Compendium and practical guideline

Petr Pospisil

MSc, Mech. Eng.

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Have courage to use your own understanding

Immanuel Kant, 1724-1804

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1 Preface

Investors, operators and designers of road tunnels are responsible for decisions related to significant investments. The tunnel ventilation is an important element for the safety of a tunnel, as well as for investment and operational costs. Therefore, comprehension of basic aspects of tunnel ventilation should be advanced to provide useful criteria for decisions.

Over a decade after some catastrophic road tunnel fires in alpine tunnels with a lot of media attention and extensive experience with the new safety standards that have been implemented as a consequence of those fires, the findings from that experience shall be consolidated to define the actual state of the art of road tunnel ventilation. With the explanations in this compendium, open questions shall be answered, and errors, ambiguities and misunderstandings shall be cleared. Only the reader can judge whether these goals are achieved or not.

Simple, clearly understandable und practically oriented specifications for concept, design, realisation and operation of road tunnel ventilation systems shall be described. With its help, decision makers, stakeholders and interested parties shall be enabled to assess tunnel ventilation concepts in the context of general safety of road tunnels. Design fundamentals, which are considered as common knowledge and available in corresponding technical literature, are not repeated, but only commented or adapted if necessary.

This compendium is based on the knowledge from the author's practical experience over years in the realisation, design and conception of technical systems, particularly tunnel ventilation systems since 1998. Unlike scientific papers, most of the findings have never been published, besides in the project documentation. Important is also the value of insights from failed experiments, problems during realisation and operation, and real incidents, which of course are never made public. That’s why only a few particular examples, which are publicly available, will be mentioned.

Special thanks goes to colleagues, partners and other professionals who worked and discussed with the author, and from whom the author has learnt a lot about theory and practice of the treated areas of expertise.

2 Analysis of the present situation

Pollutant emissions have significantly decreased in countries with strict emission standards since the 1980s. Nevertheless, in many road tunnels, tunnel users complain about poor visibility and air quality.

Until the end of the 1990s, transversal tunnel ventilation systems with equally distributed extraction were designed. These systems were unable to control the smoke propagation in case of fire, and often even worsened the situation[1]. Since then, thanks to the media presence, public opinion focused on safety and ventilation of tunnels.

Since the millennium, many norms and guidelines focussing on the design of tunnel ventilation systems have been worked out (see Chap. 15.1). A lot of investigations about fires in tunnels can be found among the technical literature. However, in practice, many incidents show that the safety and ventilation equipment fails to fulfil satisfactorily its purpose.

Extraordinary high costs, which are justified by safety requirements, lead to financial shortages and therefore many tunnel projects cannot be realized or essential refurbishments are delayed. In an overall view over a long time period, this leads to a decrease in safety.

Particularly in existing tunnels with obsolete, unsuitable ventilation systems (from today's point of view), a significant increase of tunnel safety would be possible with simple modifications[2].

The ventilation must not be seen as individual equipment, but as an important element of a general operational and safety concept. For ventilation aspects, its control, instrumentation and power supply, and also the traffic management, constructional provisions, and other tunnel equipment (e.g. signals, lighting, etc.) have to be considered.

An improvement of the present situation is necessary and possible with the help of following measures:

- Basics, principles and goals of the tunnel ventilation as part of the general operational and safety concept of a tunnel must be clearly defined (Chap. 4, 5, 6, 7, 8, 10)
- Conceptual decisions must be worked out on basis of a systematic analysis taking into account benefits and costs, with appropriate emphasis on particular criteria (Chap. 3, 11)
- It must be ensured that the requirements are reliably achieved during the whole lifetime of the tunnel (Chap. 9, 12, 13). For this, the inspection and test concept is essential (Chap. 14).

[1] Particularly, the fire incidents in the Mont-Blanc and Tauern tunnels (1999) and in the Gotthard road tunnel (2001) with a total of 62 deaths.

[2] In many cases, an enhancement of the ventilation software would be sufficient.

3 Rational decision-making

Discussions about useful concepts and appropriate systems often become a matter of conviction: What is the ultimate truth? Rational decision-making goes against human nature. Humans (including engineers and technicians) tend to make decisions based on small random samples of easily available ideas or based on their gut feeling (Lit. [61], [62]).

However, time and funds are not unlimited. Irrational decisions tie up substantial funds and time which then lack for more efficient measures. Consequently, poor decisions on safety measures increase casualties and costs in a global context (Lit. [63]).

In a socio-political context, the decision about the right allocation of funds is a difficult and delicate matter. However, in practical technical questions, the right approach is easier. When the issue is about the safety of persons and long-term investments of several millions, decisions should be made based on a serious and objective analysis of benefit and costs of useful variants (Chap. 11).

For such a rational decision-making, first of all clear goals must be defined. Useful goals of a tunnel ventilation system may be:

- to ensure a clear visibility in the tunnel and at the portal zones
- to limit the concentrations of noxious substances in the tunnel and its environment
- to limit smoke propagation in the tunnel in case of a fire incident so that the danger to the tunnel users is minimized and safe evacuation is enabled

Naturally, there are many possibilities to strive towards these goals. These possibilities lead to different variants of concepts and technical solutions. Each variant has its advantages and drawbacks, limits of adaptability, an optimal range of application, uncertainties and costs.

For variants, which have their advantages in a certain, preferred context, humans tend to ignore the disadvantages, and vice versa (Lit. [62]). That’s why good solutions can be evaluated only by a systematic approach. At the end, what counts is whether a concept or a system achieves the defined goals reliably and at what price, taking the whole lifetime into account.

Finally, the optimal solution is always a compromise, taking into account different points of view and thus varying weightings of arguments in a given context:

- The public wants a tunnel to be a safe and comfortable line of communication.
- The tunnel user, i.e. the car or truck driver, wants to drive fast and safely through the tunnel.
- In case of an incident, the tunnel user shall be affected as less as possible, at least staying alive and unhurt.
- Emergency services need to fulfil their duty in case of an incident, that is, saving the tunnel users and mitigating the damages.
- The investor intends to minimize investment costs.
- The operator has an interest in low operational costs.
- Construction companies, equipment suppliers, the financial industry, and mostly also the designers, are interested in complex, expensive solutions.
- Lawyers, experts and consultants are intrigued by hazy, contradictory or faulty requirements and specifications, which lead to endless discussions.

Huge funds are invested for constructions and equipment with doubtful usefulness, which often do not even work in practice. This is in principle nothing bad, rather a question of point of view.

In this guideline, the focus is on defining useful goals and how to achieve those goals safely and reliably by simple, economic concepts, to efficiently allocate limited funds for an adequate level of safety.

