Quantitative Risk Assessment for Road Tunnels

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Summary

The field of safety in road tunnels has always been an important issue for operators, owners and the responsible authorities. After the tunnel fires in 1999 the subject gained however in importance. In order to fulfil the requirements of the Directive 2004/54/EC of the European Parliament and of the Council on minimum safety requirements for tunnels in the trans-European road network Member States are to develop a methodology for a risk assessment in addition to the existing standards. The methodology will allow calculating the risks for a specific tunnel in a unified way, considering the main influence parameters and the effect of additional or alternative safety measures by using a comparative approach. The development and implementation of risk based approaches according to the requirements of the Directive 2004/54/EC in the national guidelines is intended to be finalised until April 2009.

1. Introduction

The severe tunnel fires in 1999 in the road tunnels of Mont Blanc (F/I) and Tauern (A) pointed out, to which specific risks – mainly related to confinement – road tunnel users can be exposed in comparison to open roads. After the tunnel fires, guidelines and standards in the context of road tunnel safety equipment have been defined or upgraded in several European countries.

In Germany, in 2003 the revised guideline "Richtlinien über die Ausstattung und den Betrieb von Strassentunneln (RABT)" [1] was published, in which the actual safety requirements for German road tunnels are defined. In April 2004 the Directive 2004/54/EC of the European Parliament and of the Council has been issued [2]. The Directive aims at ensuring a minimum level of safety for road users in tunnels in the trans-European network by the prevention of critical events that may endanger human life, the environment and tunnel installations, as well as by the provision of protection in case of accidents. It shall apply to all tunnels in the trans-European road network with lengths of over 500 metres, whether they are in operation, under construction or at the design state. The demands for safety measures posed by the RABT 2003 are in most aspects higher than the minimum requirements contained in the new EC tunnel directive.

On the other side the EC tunnel directive implies certain requirements, for example requirements for the risk assessment for road tunnels, which are until now not implemented on national level. In Germany the implementation of the requirements of the EC tunnel directive has been done by updating the RABT to a new version, called RABT 2006 [1].

2. Management of Road Tunnel Safety in Germany

As a consequence of the incidents during the last years and because of the increasing number and length of road tunnels in Germany (figure 1), tunnel safety has become an important issue. On the owner and operator side this has lead to enforcement of standards. On the other side efforts have been made to support the right behaviour of users in road tunnels.

In 2002, the Federal Ministry of Transport, Building and Urban Affairs initiated a comprehensive retrofitting programme for road tunnels in order to ensure that existing tunnels reach as soon as possible the same level of safety than new road tunnels. Altogether a total of about € 300 million has been made available to further improve the safety of road tunnels mostly by implementing state of the art safety facilities. The retrofitting programme is scheduled to be largely completed by 2010.

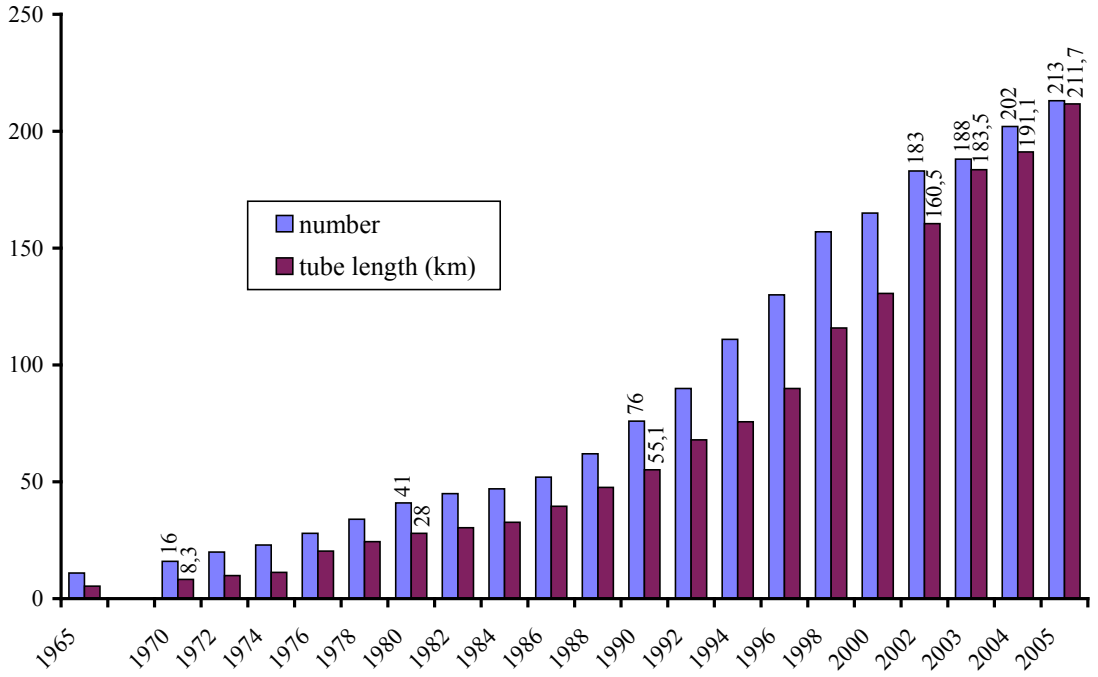

Fig 1 *Number and tube length of main road tunnels in Germany*

In Germany the implementation of safety measures has been done on the basis of more or less prescriptive guidelines like RABT 2003 and other standards, though the guidelines allow a risk based approach for certain cases. Beside this the application of risk-based approaches in the process of tunnel safety management gained in importance. For instance, the German RABT 2003 required carrying out a risk analysis for specific aspects in the context of dimensioning the ventilation and/or the questions of the transport of dangerous goods.

The European Directive on the other hand contains certain risk based approaches which can be applied in special cases and which are now also included in the RABT 2006. These cases are:

- structural requirements, which can only be satisfied through technical solutions which either cannot be achieved only at disproportionate cost, the administrative authority may accept the implementation of risk reduction measures as an alternative to application of those requirements, provided that the alternative measures will result in equivalent or improved protection,
- a road tunnel with special characteristics as regards the parameters which are listed in the annex of the directive,
- the dimensioning of the ventilation system in bidirectional tunnels with a length from 600 m to 1200 m and
- the determination of the fire performance in case of a high percentage of heavy goods traffic.

According to the directive a well defined methodology shall ensure that, at national level, a detailed and well-defined methodology, corresponding to the best available practices, is used for risk analyses. Member States shall inform the Commission of the methodology applied. According to Article 13 of the Directive risk analyses taking into account all design factors and traffic conditions that affect safety are to be carried out in certain cases. In the past risk analyses have been carried out on object level for new road tunnels in Germany however these analyses were not carried out on the basis of a unified approach which means that not in every case the full set of parameters mentioned in the EC-directive has been considered.

To fulfil the requirements of the directive regarding a unified approach towards risk analysis various research activities on this topic have been initiated. The following chapters describe the current state of these activities and highlight the methodology which will be used in Germany in the future for risk analyses in the field of road tunnels.

3. Methodology of Risk Assessment

For the process of safety management of road tunnels a broad range of qualitative and quantitative methodical modules are available. The general principle of a risk-based procedure is shown in the following figure 2.

Three steps characterise the risk-based procedure:

1. Risk analysis
2. Risk evaluation
3. Planning of safety measures (Safety management)

3.1 Risk Analysis

Risk analysis is concerned with the fundamental question: "What might happen and what are the consequences ?". Therefore a set of "typical" scenarios, which can occur in road tunnels, has to be defined and analysed. Risk analysis can be carried out in a qualitative or in a quantitative way or in as a combination of both. In case of a quantitative analysis probabilities of accidents and their consequences for different damage indicators (e.g. in terms of fatalities, injuries, property damage, interruption of services) and the resulting risk are estimated.

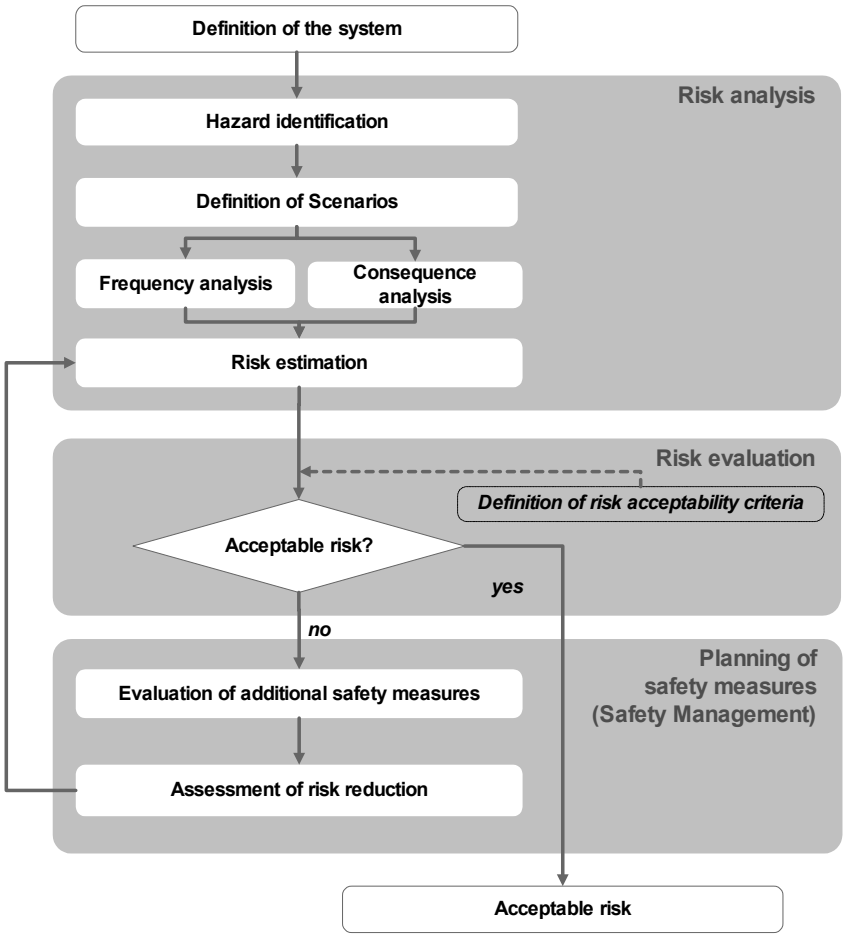

Fig 2 *Elements of the risk assessment procedure*

3.2 Risk Evaluation

Risk evaluation is directed towards the question of acceptability and the explicit discussion of safety criteria. For a systematic and operable risk evaluation one has to define safety criteria and to determine whether a given risk level is acceptable or not. In other words risk evaluation has to give an answer to the question "Is the estimated risk acceptable?"

As experience shows, the question of risk evaluation and the definition of what level of risk is acceptable, is a significant and debatable part of the risk management. In this context, a valuation of the different aspects of risk has to be included.

3.3 Planning of Safety Measures (Safety Management)

If the estimated risk is considered as not acceptable, additional safety measures have to be proposed. Therefore the effectiveness and also cost-effectiveness of different safety measures can be determined by using the initial frequency and consequence analysis of the scenarios which will be positively or negatively affected under the assumption that the investigated safety measure has been implemented. Planning of safety has to answer the question "Which measures are necessary to get a safe (and cost-efficient) system?"

3.4 Methodical aspects

A broad spectrum of applicable qualitative or quantitative methodology modules exists for each step of the procedure of risk management as described. The available methodical modules can be arranged roughly into two groups:

- *Qualitative modules* normally have a lower complexity than quantitative and are based on the application of arbitrarily definable evaluation standards. Qualitative methods are often simple and easily and flexibly applicable and can be used for almost every problem (even in situations, where no quantitative data is available). On the other hand there is the risk that too much weight is put on subjective impressions and that correlations of different individual measures/modules of the analysed system are not (or not in a sufficient way) taken into account.
- *Quantitative modules* try to structure possible events of a system in a logical and integrative way: Different scenarios and possible subsequent events are analysed and the relevant influences are identified. For each path of subsequent events the scenario-specific frequency and consequences are estimated. The measured variables, which affect the development of a specific event, are identified and the appropriate risk is determined. A substantial advantage of using quantitative methods is the transparent representation of the risk estimated, whereby a better understanding of complex correlations can be achieved. On the other hand there are problems which cannot be modelled in an adequate way (with reasonable resources of time and money) and it also may happen that not sufficient quantitative data is available to enable a proper quantification of the most important parameters. Quantitative approaches are often characterised by a high degree of complexity, which reduces their comprehensibility as well as their controllability.

The experience in handling risk assessments shows, that for some applications (such as comparison of different design features, comparison of different safety measures, cost-effectiveness-analysis of safety measures) the use of quantitative methods is practically preferable for system-spreading safety evaluations. By using quantitative methods, comparable evaluations can be ensured. The integrated approach, quantitative comparability and in some cases also comprehensibility are the most important advantages of quantitative approaches. Simple qualitative methods, as for instance "expert judgements", often do not keep the two steps risk analysis and risk evaluation sufficiently apart.

4. Risk Assessment for Road Tunnels in Germany – current state

In the past years a few risk analyses have already been carried out for new road tunnels in Germany, but these analyses were not carried out on the basis of a unified approach. In order to fulfil the requirements of the Directive 2004/54/EC, a standardised methodology for a probabilistic risk assessment is currently worked out. The methodology comprehends four types of scenarios:

- Break-downs
- Collisions
- Fires
- Accidents involving dangerous goods

Especially the scenarios of fires and collisions are in the focus of the methodology which is based on an event-tree-analysis. For every tube of a road tunnel, the two following aspects of risk are analysed separately:

- *Quantitative frequency analysis:*
    - Analytical approach for analysing the sequence of events from an initial event (accident (including breakdowns), fires) to a set of consequence scenarios.
    - Statistical approach to quantify the initial events (rates of accident in tunnels) and the distribution (relative frequencies) to the branches of the event tree. Among other studies a comprehensive analysis of accidents in German road tunnels was carried out for the assessment of the scenario frequencies depending on risk relevant factors such as type of tunnel (unidirectional/bidirectional traffic), length, volume of traffic etc.
- *Quantitative consequence analysis:*
    - Statistical approach to quantify the consequences of mechanical effects of collisions
    - The consequences of tunnel fires (5 MW / 30 MW / 50 MW / 100 MW) are assessed by using specific models in order to simulate smoke spread and the effect of the tunnel ventilation. In addition a pragmatic method to assess evacuation is proposed (including the location of the accident, the location of the emergency exits, the spread of smoke and the resulting visibility, the constellation of the vehicles on both sides of the accident etc.).

For investigations of issues of transport of dangerous goods the methods according the DG-QRA model from OECD/PIARC [3] is intended to use.

The resulting calculated risk for all tubes of a tunnel can be graphed as FN curves or expressed as expected value of the societal risk. In addition the results can also be expressed in terms of the perceived societal risk: It is a fact that rare events with very high consequences are perceived much more in the public than frequent events with low consequences. Therefore governmental administrators or safety officers responsible for the safety of a third party have an additional concern to avoid catastrophic events. Such accidents may lead to additional safety precautions. The public perception of rare events with high consequences is disproportionate to the loss expectancy. In order to transform the societal risk into the perceived societal risk a consequence-dependent risk aversion is introduced.

At the time being, risk evaluation is done by relative comparison, mainly by comparing the tunnel as it is to the situation as it should be, taking the requirements of the RABT 2006 into account. The introduction of a maximum tolerable level of risk in terms of an acceptability line in an FN diagram is discussed.

For the planning of safety measures a methodical approach to take into account the aspects of cost-effectiveness is part of the proposed German method for risk analysis for road tunnels. This approach allows comparing the effect of additional safety measures in terms of risk reduction with the required costs for implementation and operation.

5. Conclusions

The process of a risk-based road tunnel safety management allows a structured, harmonised and transparent assessment of risks for a specific tunnel including the consideration of the relevant influence factors. Moreover, it allows coming up with the best additional safety measures in terms of risk mitigation and enables a comparison of different alternatives. Hence, the risk-based approach in the context of tunnel safety management can be an appropriate supplement to the implementation of measures to respect the requirements of standards and guidelines.

Among other risk relevant factors of influence the German methodology allows the assessment of risks for a specific tunnel considering the influence of different safety measures as required in the directives RABT 2006 and 2004/54/EC. Hence, the influence of alternative measures can be assessed too. Thus, the methodology can be used for decision support in the context of providing safety measures when upgrading or planning a tunnel.

6. References

[1] FGSV: Richtlinien für die Ausstattung und den Betrieb von Straßentunneln. Ausgaben 2003 und 2006, Hrsg.: Forschungsgesellschaft für Straßen- und Verkehrswesen, Köln

[2] EUROPEAN PARLIAMENT AND COUNCIL: Directive 2004/54/EC of the European Parliament and council of 29 April 2004 on the minimum safety requirements for tunnels of the trans-European road network, April 2004

[3] OECD/PIARC: Transport of Dangerous Goods through road tunnels – Quantitative Risk Assessment Model