SYSTEM-BASED RISK MODELS FOR ROAD TUNNELS

Zulauf Christoph
Ernst Basler + Partner AG, Switzerland

ABSTRACT

Besides the implementation of prescribed safety measures according to guidelines and standards, the application of risk-based approaches in the process of tunnel safety management has gained greater importance in the last years. System-based risk models for road tunnels allow a structured, harmonised and transparent assessment of risks for a specific tunnel including the consideration of the relevant influence factors and their interactions. Based on the basic principles of risk-based approaches, the specific aspects of system-based risk models are discussed.

Keywords: risk assessment, risk analysis, risk evaluation, scenario, cost-effectiveness

1. INTRODUCTION

Risk analysis is a tool which was initially developed to investigate safety of potentially dangerous industrial processes (e.g. in the chemical industry) or potentially dangerous industrial plants (such as nuclear power plants). The application of risk analysis should help to establish a proactive safety strategy by systematically investigating potential risks. This proactive safety strategy was intended to replace experience-based concepts mainly relying on findings from incidents or accidents that had already happened.

During the past 20 years, some system-based risk assessment methods have been adapted to the investigation of tunnel safety in general and road tunnel safety in particular. For road tunnels risk analysis is explicitly required by the European Directive 2004/54/EC, on minimum safety requirements for road tunnels on the Trans-European Road Network, which was passed in April 2004.

2. BASIC PRINCIPLES OF SYSTEM-BASED RISK MODELS

In general, risk assessment models deal with potential negative consequences of a system such as road tunnels. The meaning of a system-based risk assessment and its characteristics can be summarised as follows:

- System-based risk assessment is a systematic approach to analyse sequences and interrelations in potential incidents or accidents, hereby identifying weak points in the system and recognising possible improvement measures.
- The terms “Risk assessment” and “Risk analysis” covers a large family of different approaches, methods and complex models combining various methods for specific tasks.
- System-based risk assessments usually include a quantification of risks which can be used as the basis of a performance-based approach to safety.
- A general basic principle of all kinds of system-based risk assessment models for road tunnels is a holistic approach including infrastructure, vehicles, operation and - last but not least – tunnel users.
For system-based risk assessments for road tunnels a broad range of qualitative and quantitative methodical modules are available. The general principle of a system-based risk assessment is shown in the following Figure 1.

![Figure 1: Procedure for a system-based risk assessment](image)

Three steps characterise the system-based risk assessment procedure:

- Risk analysis
- Risk evaluation
- Planning of safety measures (Safety management)

2.1. 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. For system-based risk assessments quantitative methods are common practice. Thus probabilities of accidents and their consequences for different damage indicators (e.g. in terms of fatalities, injuries, property damage, interruption of services) – considering relevant factors of the system and their interaction – and the resulting risk are estimated quantitatively.
2.2. 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.

2.3. 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. METHODICAL ASPECTS

3.1. Spectrum of methodical components

A broad spectrum of applicable qualitative or quantitative methodology modules exists for each step of the procedure of risk management as described (see Figure 2). 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.

3.2. Methodical aspects of system-based risk models

3.2.1. Scenarios

In the past years several system-based risk assessment models have been carried out for road tunnels. All of them take several different scenarios into account. They can be grouped into four types of scenarios:

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

Normally the scenarios of fires, collisions and release of dangerous goods are in the focus of the assessments which are mostly based on a quantitative event-tree-analysis.
3.2.2. Analysis of frequencies and consequences

The two following aspects of risk are analysed separately:

- **Quantitative frequency analysis**: Analytical approach for analysing the sequence of events from an initial event (e.g. accident, release of dangerous goods) to a set of consequence scenarios. Therefore an assessment of the scenario frequencies depending on risk relevant factors such as type of tunnel (unidirectional/bidirectional traffic), length, volume of traffic etc. has to be done. In most cases the assessment is based on a statistical analysis of accidents or analytical methods such as fault-tree-analysis.

- **Quantitative consequence analysis**: The consequences of mechanical effects of collisions can be assessed on the basis of a statistical analysis. The consequences of tunnel fires are mostly assessed by using specific models in order to simulate smoke spread and the effect of the tunnel ventilation. In addition specific models to assess evacuation are used (considering 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 separate methods according the DG-QRA model from OECD/PIARC or comparable models are in use.

3.2.3. Risk estimation

The resulting calculated risk – based on the analysis of frequencies and consequences – for tunnels are mostly graphed as FN curves or expressed as expected value of the societal risk (see Figure 3).

3.2.4. Risk evaluation and planning of safety measures

At the time being, risk evaluation is done mostly by relative comparison, mainly by comparing the tunnel as it is to the situation as it should be, taking the requirements of the relevant guidelines into account. Some countries (e.g. Switzerland, Netherlands) have introduced a maximum tolerable level of risk in terms of an acceptability line in an FN diagram in order to evaluate risk.

For the planning of safety measures the aspects of cost-effectiveness often are to take into account. This approach allows comparing the effect of additional safety measures in terms of risk reduction with the required costs for implementation and operation.
4. CONCLUSIONS

System-based risk models for road tunnels allow a structured, harmonised and transparent assessment of risks for a specific tunnel including the consideration of the relevant influence factors and their interactions. But it should always be kept in mind that every kind of risk analysis – whatever method is used - is a more or less simplified model relying on preconditions and assumptions and is not a copy of reality. Nevertheless system-based risk assessment models provide a much better understanding of risk-related processes than merely experience-based concepts may ever achieve. Moreover, they allow coming up with the best additional safety measures in terms of risk mitigation and enables a comparison of different alternatives. Hence, the system-based risk assessment 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.

5. REFERENCES


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