1. RISK ASSESSMENT FOR ROAD TUNNELS

1.1. A SHORT INTRODUCTION TO RISK ASSESSMENT

The operation of technical systems always induces associated risks. Technical failures, malfunction, failures in operation or misuse may cause different kinds of incidents (breakdowns, accidents, etc.) with adverse effects for safety of people, property, or environment. The development of a technical system is always combined with efforts to avoid or reduce these risks. In principle this can be achieved by two different approaches:

- by practical experience,
- by systematically investigating potential hazards and resulting threats in advance, trying to eliminate their causes and / or reduce their consequences.

In the past in many countries the safety design of road tunnels to a great extent was based upon regulations and guidelines: if the applicable prescriptions of relevant guidelines were fulfilled the tunnel was regarded as safe. These guidelines had been developed over decades and were mainly based on the experience of everyday operation, including incidents and accidents.

However, this prescriptive approach has some shortcomings which are particularly evident in accidents exceeding the range of existing operational experience:

- even if a tunnel fulfils all regulative requirements it has a residual risk which is not obvious and not specifically addressed;
- a prescriptive approach defines a certain standard of tunnel equipment etc. but is not suited to take the specific conditions of an individual tunnel into account. Furthermore, in a major accident the situation is completely different to normal operation and a great range of different situations exceeding existing operational experience may occur.

Hence, in addition to the prescriptive approach, especially for complex systems a supplement is needed which specifically addresses emergency situations: a risk-based approach. Risk-based approaches allow a structured, harmonised and transparent assessment of risks for an individual tunnel, including the consideration of local conditions in terms of relevant influence factors, their interrelations and possible consequences of incidents. Moreover, risk-based approaches make it possible to propose relevant additional safety measures for the purpose of risk mitigation and can be the basis for decision-making considering cost-effectiveness in order to assure the optimum use of limited financial resources.

However, a risk-based approach cannot replace technical design specifications. For example, the results of a risk analysis can help to define functional requirements for a ventilation system of a tunnel, but to guarantee an adequate performance of the ventilation a set of technical parameters has to be defined which for example can be done in a technical design guideline; hence the prescriptive approach and the performance based approach are indispensable supplementary elements of a state of the art for safety planning of a road tunnel. Consequently, new international (such as the EC Directive 2004/54/EC, [2]) and national tunnel regulations are addressing risk assessment to an increasing extent.

In a risk-based approach, emergencies are systematically analysed, typically by applying scenario techniques; both the probabilities of scenarios as well as their consequences are addressed. A quantification of risks can be achieved by combining probability and consequences of each scenario. By summarising the partial risks of all scenarios the overall risk of a tunnel can be calculated. This approach also includes scenarios which may not yet have happened (and consequently are not covered by experience) but which may happen and may have major consequences. However, not all effects can be quantified and a risk analysis may also focus on specific questions or specific scenarios without investigating the complete range of possible accidents. Therefore different methods have been developed and are practically applied (see *chapter 1.3. page 14* and *appendices, page 64*) and the selection of the most suitable method to investigate given issues has to match the specific problem, the required depth of assessment and the available resources.

In a risk analysis different types of risk can be investigated:

- harm to a specific group of people (fatalities and/or injuries): the most common risk indicator is fatalities referring to the group of tunnel users; in specific situations it may also be necessary to address other groups of people possibly affected by the consequences of accidents, e.g. people living next to tunnel portals (in case of accidents with dangerous goods) or above the tunnel (in case of damage to the tunnel structure);
- loss of property/economical loss: typical examples are damage to the tunnel structure (resulting in repair costs) and longer periods of tunnel closure due to damage caused by an accident (resulting in loss of toll income /and/or higher transport costs as well as consequences for local, regional or national economy);
- damage to the environment: although tunnels normally limit the damage to environment the spill of dangerous fluids through the tunnel drainage system may cause environmental pollution if adequate protection measures are not in place;
- damage to immaterial values: e.g. damage to the reputation of a company, region or a country as a consequence of the reaction of media to an accident with major consequences; these indirect long-term effects tend to be underestimated; they are of considerable importance for risk evaluation (see *chapter 2, page 16*).

Furthermore, results of a risk analysis can be used as a basis for further investigations, such as evaluation of socio-economic consequences.

Risks can be addressed in a quantitative or in a qualitative way. Qualitative methods typically focus on the functional analysis of the sequence of events and the interaction of people, systems and procedures. With quantitative methods, characteristic risk values for the whole tunnel can be calculated (discussed in more detail in *chapter 1.3. page 14*).

If risks are quantified, this can be done for individuals or for specific groups of people. The individual risk is the risk to an individual person who uses a tunnel, or lives near the tunnel. It is not only determined by the hazards (which provoke the risk) but also by the exposure of the individual person to these hazards. The risk to a defined group of people is called societal risk. The societal risk to tunnel users/neighbours is the most common quantitative risk indicator for the risk assessment of road tunnels.

1.2. THE RISK ASSESSMENT PROCESS

Risk analysis is embedded in the risk assessment process which includes the following three elements:

- **risk analysis:** Risk analysis 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 (see the previous PIARC report *"Risk Analysis for Road Tunnels"* [1]);
- **risk evaluation:** Risk evaluation is directed towards the question of acceptability of the identified risks to answer the question *"Is the estimated risk acceptable?"* For a systematic and operable risk evaluation, risk criteria have to be defined and it has to be determined whether a given risk level is acceptable or not.
- **risk reduction:** If the estimated risk is considered as not acceptable, additional safety measures have to be proposed to reduce risk.

The procedure for a risk analysis can be divided into the following 4 steps:

- definition of the system;
- hazard identification: Systematic process to identify and structure all relevant hazards, and to analyse their correlating effects;
- probability analysis: Determination of the probabilities of relevant events/scenarios;
- consequence analysis: Investigation of consequences of relevant scenarios.

The simplified flowchart in *figure 1, following page,* illustrates the main steps of the risk assessment process.