AUSTRIAN RISK ANALYSIS FOR ROAD TUNNELS – DEVELOPMENT OF A NEW METHOD FOR THE RISK ASSESSMENT OF ROAD TUNNELS

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1 ABSTRACT

For the Austrian Tunnel Risk Model a set of different methodical tools are used to analyse the whole system of safety relevant influencing factors; the method consists of two main elements:

- Quantitative frequency analysis: event tree approach for calculating the frequencies of defined accident scenarios
- Quantitative consequence analysis:
  - mechanical accidents: estimation of consequences based on tunnel accident data
  - fire accidents: modelling of consequences by combining a ventilation model with an evacuation simulation model

The risk model covers the personal risks of tunnel users. The result of the risk analysis is the expected value of the societal risk of the tunnel investigated.

Risk evaluation is done by relative comparison of the tunnel investigated to the risk of a reference tunnel (tunnel of the same length, type and traffic characteristic, fully complying with the minimum safety requirements as per EC Directive).

A case study of the evaluation of an existing tunnel is added to instance the effects to the risk of safety measures.

2 BACKGROUND

In April 2004, the EC Directive on road tunnel safety (Directive 2004/54/EC) was issued. Article 13 of this Directive obliges every member state to develop a method for a risk analysis on a national level. Therefore, the Austrian ministry started a design process to develop a methodology which meets the specific requirements of Austrian Road Tunnels. The work process was coordinated with an expert group of tunnel safety and ventilation experts.

The Austrian Risk Model focuses on frequently occurring mechanical accidents and fire accidents with small and medium sized fires. For a more thorough investigation of accidents involving hazardous goods, the DG-QRA model developed by OECD/PIARC shall be used in Austria.

3 TURISMO – TUNNEL RISK MODEL FOR ROAD TUNNELS

3.1 METHODICAL APPROACH

3.1.1 General Consideration

The risk analysis aims to investigate the risk to tunnel users (personal injuries and fatalities); as relevant reference value the societal risk (fatalities per year) of the tunnel is calculated.

The methodical approach consists of two basic elements:

- a quantitative frequency analysis (event tree approach) and
- a quantitative consequence analysis (evaluation of statistical accident data for mechanical accidents and modelling of fire accidents).

Due to the great number of tunnels in Austria and the extensive collection of data on accidents, the risk analysis is done based on Austrian data and experiences.

Data were collected from accidents with personal injury in tunnels on motorways and expressways for the years 1999 – 2003. In addition to Austrian data, foreign data sources are used for comparison and completition.

The sequence of the risk analysis is shown in Figure 1.

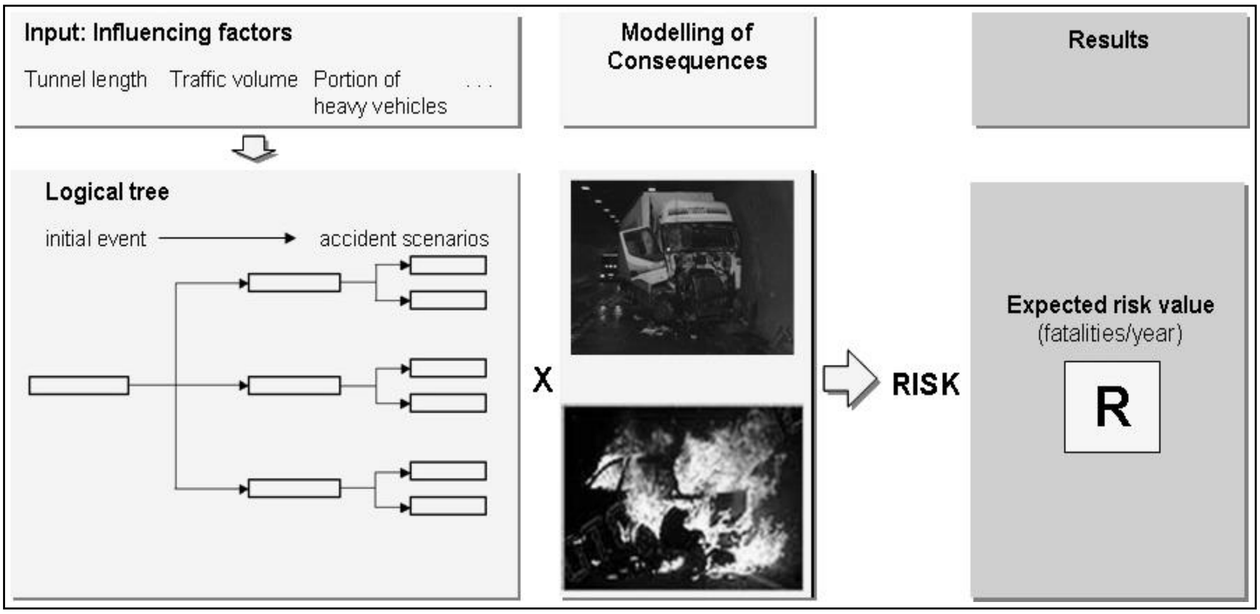

Figure 1: Sequence of the risk analysis

3.1.2 Event tree analysis

An event tree analysis is performed to calculate the frequency of defined accident scenarios. The event trees distinguish between accidents (with personal injury) and breakdowns. Starting from an initial event leading to a set of damage scenarios, possibly ensuing damage events are developed through the individual branches of the event tree. These damage scenarios differ significantly from each other as regards type of accident, vehicle involvement, involvement of dangerous goods and influence of fire. Taking into account the framework conditions of the tunnel infrastructure (e.g. distance between emergency exits), the extent of damage is estimated for the respective damage scenario.

The level of detail for an event tree is defined in such a way that the available data material can be used appropriately.

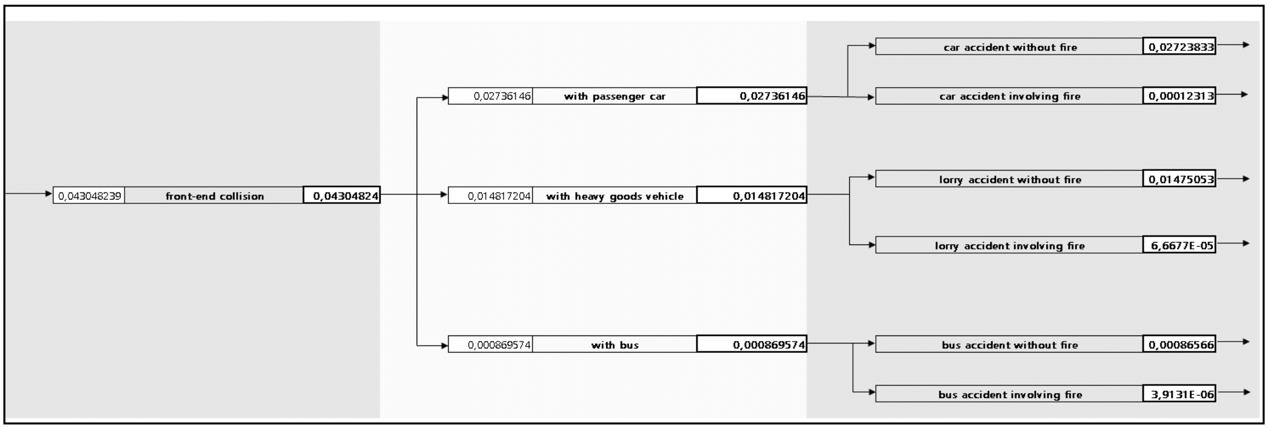

Figure 2: Part of event tree of the risk analysis

The input data of the event tree – accident rates and relative frequencies – are calculated based on an evaluation of data from 81 Austrian motorway tunnels (60 with uni-directional, 21 with bi-directional traffic). The accident rates (basic volumes shown in table 1) are modified in dependence of tunnel length and traffic volume.

	Bi-directional tunnel [fat./1mio.vehicle-km]	Uni-directional tunnel [fat./1mio.vehicle-km]
Accident rate in Austrian road tunnels (on motorways)	0,077	0,112

Figure 3: Basic values of accident rates (own evaluation board upon Robatsch et al. 2003)

3.1.3 Consequence analysis

For each damage scenario in the event tree the corresponding extent of damage is estimated.

- Estimation of extent of damage of mechanical accidents:

  The damage scenarios differ in terms of type of accident and vehicle involvement. The consequences of each damage scenario are estimated based on an evaluation of accident consequence data of 447 tunnel accidents with personal inju-ries (same database as for frequency calculation).

- Estimation of extent of damage of accidents involving fire:

  The extent of damage of fire is estimated with the support of an evacuation simulation model in combination with a one-dimensional ventilation model.

Ventilation model:

In the ventilation model two different scenarios (5 MW, 30 MW) und two different ventilation regimes can be selected:

– longitudinal ventilation

– transversal ventilation, with impact on longitudinal air velocity

They are valid for standard situations. However, the model also makes it possible to investigate non-standard ventilation systems and non-standard situations, but this requires more work to compute this data.

The smoke release rates of fires are defined and smoke concentrations in dependence on time and location in the tunnel are calculated. The design of the model allows a detailed investigation of the performance of the ventilation system in combination with the corresponding evacuation procedures.

Evacuation simulation model:

For the evacuation simulation the software package “buildingExodus 4.0” (Galea 2000) is used, which takes into account the effects of smoke gases according to the FED model (FED – Fractional Effective Dose) of Purser [2]. The influence of temperature, HCN, CO, CO_2 and lack of O_2 is included. The calculation is done for individual persons with individual characteristics.

In the evacuation simulation model, the location of the accident in the tunnel, the location of the emergency exits, the constellation of the vehicles on both sides of the accident, the propagation of smoke, the reaction of the people and their evacuation in the tunnel towards an emergency exit (a tunnel portal) are taken into account. This approach makes it possible to investigate all influences, which may effect the lapse of time concerning the interaction of propagation of smoke and self rescue.

The results of the evacuation simulation show, depending on the time elapsed, how many persons reach the “safe area” and how many persons are unable to get to safety due to the given framework conditions (length of escape route, start of evacuation, atmospheric conditions).

Based on these results, various accident locations in the tunnel are investigated in the model, and an expected value of the extent of damage for every damage scenario is calculated; this expected value is implemented in the event tree.

This element of the risk model can be used for the consequence assessment of defined fire scenarios (calculating a risk value) as well as for a detailed scenario analysis.

3.1.4 Risk calculation

As reference value the expected value of societal risk (fatalities / tunnel and year) is calculated by combining incident frequencies and consequence values for defined scenarios in the event tree; a distinction is made between risks from car accidents with mechanical effects only, from fires and from accidents involving hazardous goods.

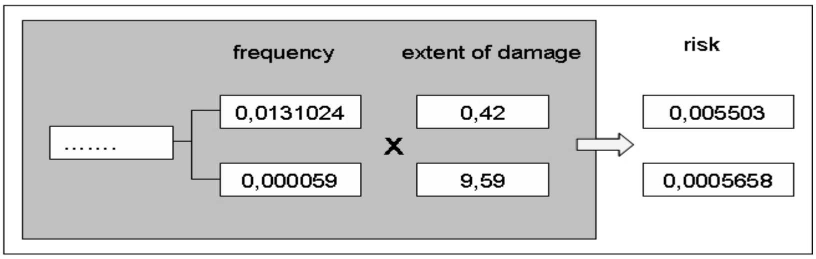

Figure 4: Combination of frequency and extent of damage

3.2 RESULTS OF RISK ANALYSIS AND STRATEGY OF RISK EVALUATION

In Austria no quantitative risk criteria are defined. The EC-Directive defines the minimum safety standard of a tunnel by laying down requirements for tunnel design and tunnel equipment in a prescriptive way. For this reason risk evaluation is done by relative comparison of the risk of the tunnel investigated with the risk of a reference tunnel. As reference tunnel a tunnel of the same length, type and traffic characteristic, fully complying with the minimum safety requirements as per EC Directive, is used. The identified divergences can be assessed in terms of risk. Additional safety measures to offset the divergences can be evaluated; the risk reducing effects of the different safety measures can be investigated in a similar way. The safety assessment of safety measures can be completed by a cost-effectiveness analysis.

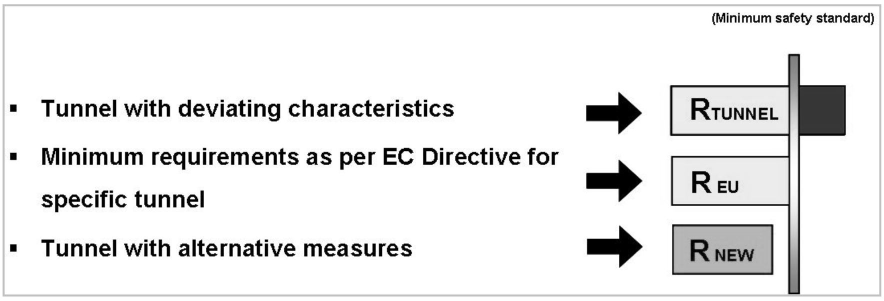

Figure 5: Risk evaluation in accordance with EC Directive (assessment through relative comparison)

4 EXPERIENCE IN PRACTICAL APPLICATION

4.1 CASE STUDY

Design and equipment of an existing tunnel are not fully in line with the requirements of the EC-Directive. The additional risk shall be compensated. Therefore several possibilities of upgrading of the existing tunnel by additional safety measures shall be investigated by calculating their effects on risk.

Definition of the system:

- Existing single tube tunnel, length 14 km
- Bi-directional traffic, 6.500 vehicles per day, 16 % heavy goods vehicles
- Emergency exits: every 1.700 m
- Ventilation: transversal ventilation
- Automatic fire detection system

Additional safety measures to be investigated:

- cross passages every 500 m to an near already existing tunnel tube
- sectional control of speed (“Section Control”)
- reduction of velocity of all vehicles from 80 km/h to 60 km/h
- construction of a second tunnel tube

As reference value the expected value of the societal risk is calculated (fatalities/year); a distinction is made between risk due to car accidents with mechanical effects only, due to fires and due to accidents involving hazardous goods.

For the tunnel investigated the following results are obtained (Figure 6):

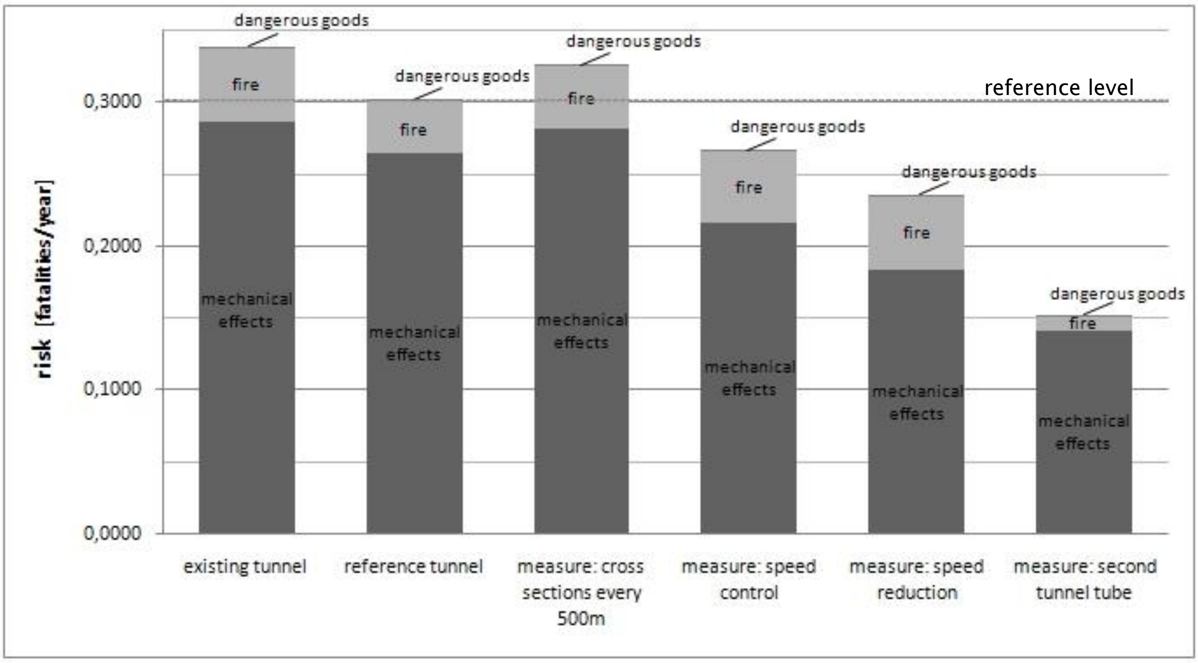

Figure 6: Graphical survey of results of case study

Risk evaluation is done by relative comparison, mainly by comparing the tunnel as it is to the situation as it should be (reference case). The additional safety measures envisaged contribute to risk reduction as follows

- cross passages every 500m can reduce risk by about 7%; this measure considerably reduces fire risk but does not influence the risk portion due to accidents with mechanical effects
- installing a sectional speed control ("Section Control") causes a risk improvement of mostly mechanical effects (about 18%)
- reduction of velocity from 80km/h to 60km/h can reduce risk by about 30%, thus reducing it far below the risk value of the reference case. This measure considerably influences the risk due mechanical effects of accidents but influences fire risk only to a small extent
- a second tunnel tube considerably reduces the risk level of the tunnel to about 55% of the initial value, strongly influenced both, the fire risk as well as the risk due to mechanical effects

The measures sectional speed control and reduction of velocity can be realized within short term and causes only low costs, whereas additional cross passages are much more expensive and much more time consuming in terms of realization. Although very effective in terms of risk reduction, for cost-benefit reasons a second tunnel tube can only be justified, when the traffic volume is expected to increase considerably (up to 20.000 during the next 15 year – with reference to the EC-Directive, Annex I, article 2.1.2).

Therefore – if the effects on traffic flow are acceptable – a sectional speed control and/or a reduction of speed limit is recommended for cost benefit reasons as short term measure. If the traffic flow increases considerably, as long term measure a second tunnel tube should be envisaged.

4.2 RANGE AND LIMITATIONS OF APPLICATION:

In general the model is applicable to all tunnels with mechanical ventilation and also to (short) tunnels with natural ventilation; for specific situations (e.g. unconventional ventilation systems) the model can be used, but must be adapted. The advantages of the model are

- the high flexibility of the individual methodical elements, so that it is applicable to almost every tunnel, ventilation or traffic configuration
- the possibility of changing the most relevant input data very easily; thus new information can be implemented quickly in many cases; however, for a quantitative investigation in general quantitative input data is necessary, which may be difficult to get
- its capability to include the effects of almost every important safety relevant influencing factor in a quantitative way; one of its key elements is the modelling of the complex interaction of smoke propagation in the tunnel and the procedure of self rescue in the situation of a fire, which allows the investigation of all influences on the lapse of time within this process
- its simply, clearly understandable and easy comparable results.

The model can be used for a wide field of different applications, such as safety assessment of new or existing tunnels, support of the decision-making process for selecting additional safety measures (new tunnels) or upgrading measures (existing tunnels), definition of priorities for upgrading measures, cost-benefit analysis for safety measures etc.

The following tunnel characteristics or influencing factors can be examined in terms of their influence on risk:

<u>Traffic volume and traffic characteristics:</u> unidirectional or bidirectional traffic, portion of heavy vehicles >3,5 to, portion of DG transports, portion of busses, peak hours, frequency of traffic jams, points of conflict (e.g. ascending or descending ramps)

<u>Tunnel system and tunnel design:</u> single bore or twin bore tunnel, tunnel cross section, number of traffic lanes, width of traffic lanes, tunnel length, distance of emergency exits, lay-byes

<u>Line characteristics:</u> longitudinal gradient, speed

<u>Tunnel equipment, type and layout of ventilation:</u> cross ventilation, longitudinal ventilation, fire detection system, reaction and performance of ventilation; incident detection and alert of car drivers and passengers, fire suppression systems, measures to influence behavior of people during rescue phase

<u>Traffic control equipment:</u> speed limits, speed control, distance control

However, the results of the model (expected value) do not include information about the distribution of different accident consequence classes (such as F-N-curves); therefore the model is not suited to specifically investigate accidents with very low probabilities and very high consequences. Hence, the model is not suitable for a more thorough investigation of the effects of accidents involving hazardous goods.

4.3 ADVICES FOR THE APPLICATION OF TURISMO IN OTHER COUNTRIES

The Austrian Tunnel Risk Model TuRisMo was developed on the basis of Austrian experience with tunnel accidents hence the model goes back to Austrian conditions, Austrian design guidelines and the Austrian traffic situation. Therefore, before the model can be applied to a tunnel in another country it has to be assessed, whether the relevant parameters in this tunnel are comparable. In case of significant deviations the model has to be modified. This mainly concerns the accident situation (e.g. accident rates).

REFERENCES

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