

Austrian Risk Analysis for Road Tunnels **Development of a new Method for the Risk Assessment of Road Tunnels**

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ABSTRACT

In Austria, in the past the assessment of road tunnel safety was based on experience and prescriptive RVS 9.261 guidelines. In the course of updating the Austrian design code for road tunnel ventilation, it was decided to develop a methodology for an integrated quantitative risk analysis. Initially, the main objective was to establish a risk-based decision tool for the specification of important safety requirements of road tunnels (e.g. ventilation system).

For the Austrian Risk Analysis for Road Tunnels TuRisMo 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. The respective shares of risk due to mechanical effects, fires and hazardous goods are shown.

Risk evaluation is done by relative comparison

- of risk reducing effects of different safety measures
- of the risk of the tunnel investigated to the risk of a reference tunnel

A tunnel of the same length, type and traffic characteristic, fully complying with the minimum safety requirements as per EU Directive is used as reference case.

Key words: tunnel safety, quantitative risk analysis, risk reducing effects, safety measures

1. BACKGROUND

In Austria, in the past the assessment of road tunnel safety was based on experience and prescriptive RVS 9.261 guidelines. In the course of updating the Austrian design code for road tunnel ventilation, it was decided to develop a methodology for an integrated quantitative risk analysis.

Based on the results of this risk analysis, a simplified method for standard tunnels (without specific characteristics) ought to be defined.

In April 2004, the EU Directive on road tunnel safety 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 requirements of the EU Directive were implemented in the design process.

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.

2. TuRisMo –TUNNEL RISK MODEL FOR ROAD TUNNELS

2.1. Database of risk analysis

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, data on accidents with property damage and breakdowns are available for some tunnels e.g. Tauern and Katschberg tunnels.

The following recorded tunnel properties and accident parameters are examined in more detail for the risk analysis:

- Traffic operation: bi-directional or uni-directional traffic
- Traffic volume and operating days
- Tunnel length
- Type of accident (recorded as stipulated in the Austrian code: single-vehicle accidents, accidents in uni-directional traffic, accidents in bi-directional traffic)
- Vehicle involvement
- Accident severity

As an example of the data implemented in the risk analysis, the distribution of accident types in uni-directional or bi-directional tunnels is shown in Table 1:

	Bi-directional tunnel	Uni-directional tunnel
Accident type 0 Single car crash	17 %	40 %
Accident type 1 Front-end collision	50 %	59 %
Accident type 2 Head-on collision	33 %	1%

Table 1: Relative share of accident types in uni-directional and bi-directional road tunnels in Austria (own evaluation board upon [1])

In addition to Austrian data, foreign data sources are used for comparison and completion. The development of the risk analysis is coordinated with an expert group in Austria, with all members having extensive experience with regard to the risks in road tunnels on account of their activities.

2.2. Methodical approach

2.2.1 General Consideration

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)

The relevant influencing factors are included in the risk model according to their mode of action.

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 sequence of the risk analysis is shown in Figure 1:

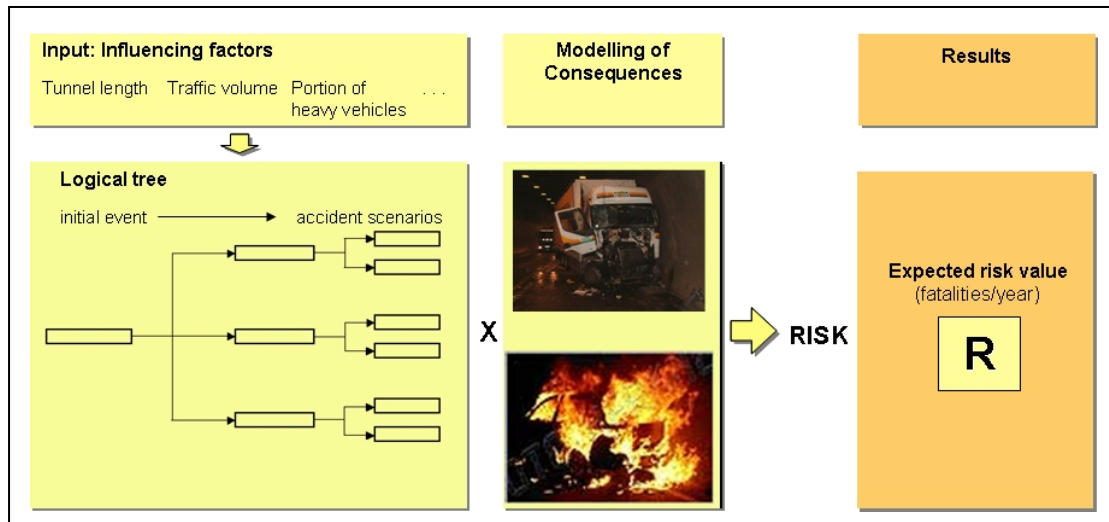


Figure 1: Sequence of risk analysis

2.2.2 Influencing factors

Prior to the development of the methodical approach an expert group identified and laid down the decisive influencing factors for road tunnel risks that should be implemented in the method.

The following main influencing factors and their interrelations were taken into account in the risk analysis:

- traffic volume
- uni-directional or bi-directional traffic
- additional points of conflicts such as ascending and descending ramps
- dangerous goods (amount and composition – general approach only)
- portion of heavy vehicles (> 3.5 tonnes)
- portion of busses
- tunnel length
- ventilation system
- length of escape route to emergency exits
- Operational components (fire detection, etc.)
- longitudinal gradient in tunnel
- longitudinal gradient in front of tunnel
- frequency of traffic jams
- cross section type

2.2.3 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.

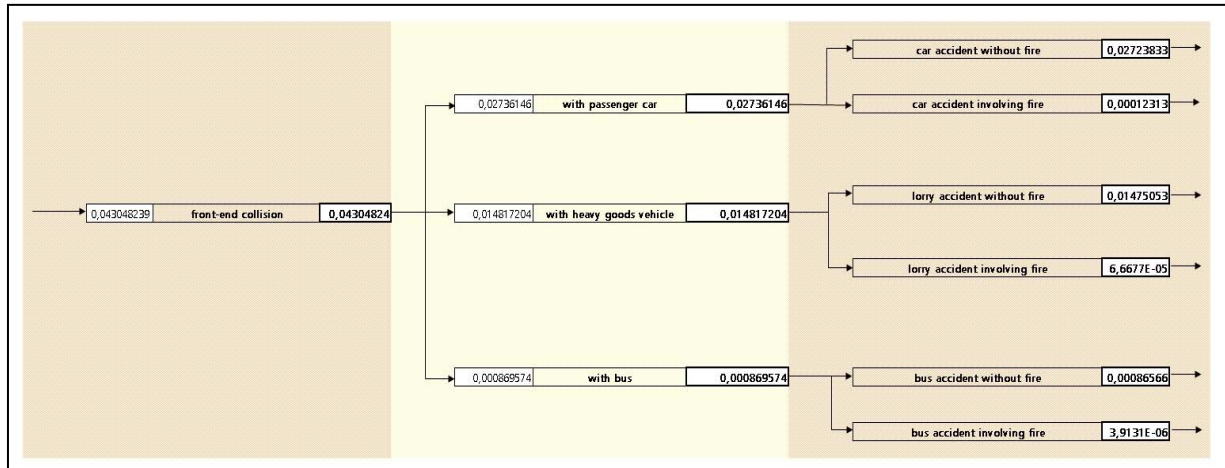


Figure 2: Part of event tree

The individual branches are quantified taking account of the experiences from accidents in Austrian road tunnels. Accident rates for relevant scenarios (vehicle breakdowns with fire, vehicle accidents with personal injury, vehicle accidents with fire) are calculated based on an evaluation of data from 81 Austrian motorway tunnels (60 with uni-directional, 21 with bi-directional traffic) covering the period 1999-2003. The accident rates are modified in dependence of tunnel length and traffic volume.

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

Table 2: Basic values of accident rates (own evaluation board upon [1])

2.2.4 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 injuries (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.

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.

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;

- Basic principle of ventilation model

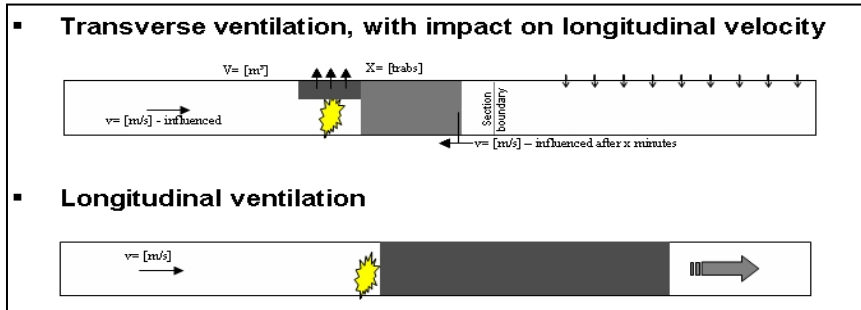


Figure 3: Ventilation systems

Evacuation simulation model:

For the evacuation simulation the software package “buildingExodus 4.0” 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, CO₂ and lack of O₂ 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, such as

- fire alarm / start of ventilation
- reaction of people
- walking velocity with/without smoke
- walking distances
- congestion effects, etc.

Figures 3 -5 demonstrate the principle of modelling the extent of damage in case of fire, using the example of a bi-directional tunnel with a distance between emergency exits of 1000 m (above) and 250 m (below).

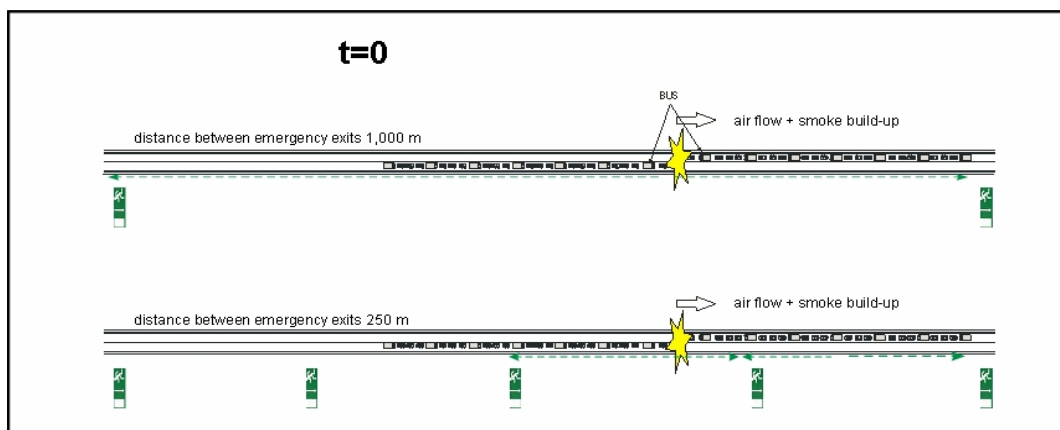


Figure 4: Scenario accident with fire incident – point in time t=0

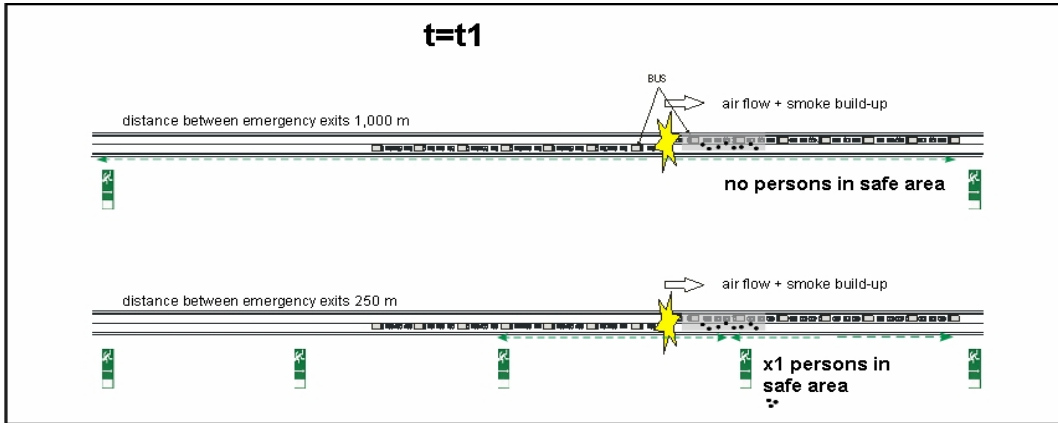


Figure 5: Scenario accident with fire incident – point in time $t=t_1$

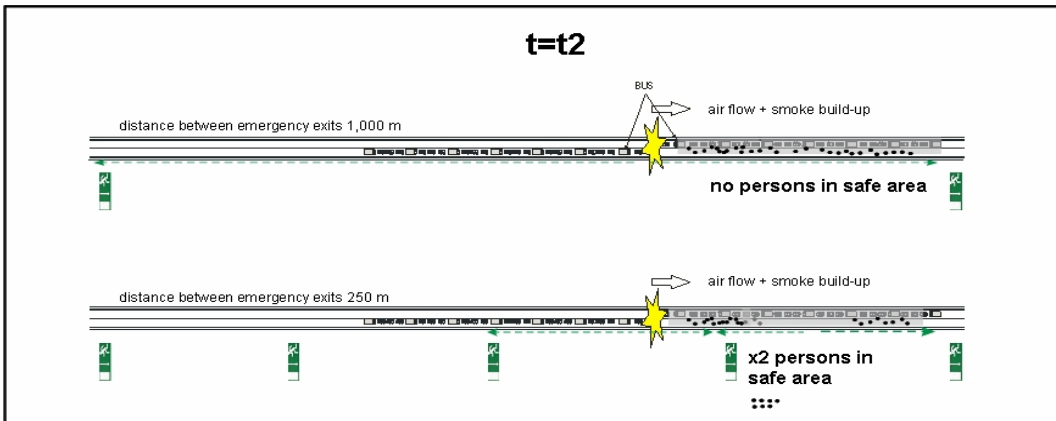


Figure 6: Scenario accident with fire incident – point in time $t=t_2$

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) – see figure 7:

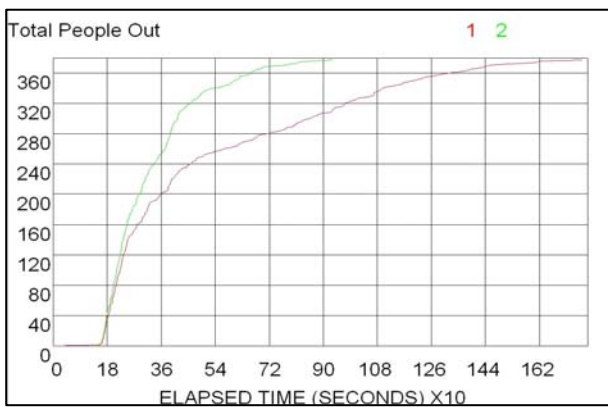


Figure 7: Diagram of the results of an evacuation simulation

Based on these results, various accident locations in the tunnel are investigated, 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 investigation.

2.2.5 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.

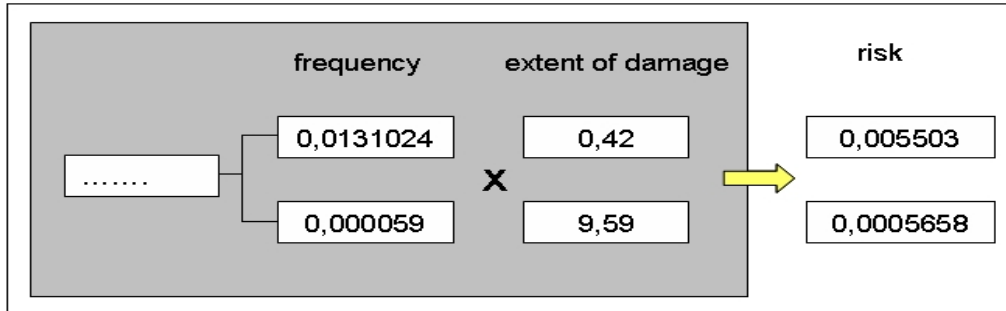


Figure 8: Combination of frequency and extent of damage

2.3. Results of risk analysis and strategy of risk evaluation

In Austria no quantitative risk criteria are defined. The EU Directive defines the minimum safety standard of a tunnel by laying down requirements for tunnel design and tunnel equipment in a prescriptive way. But the EU Directive allows limited derogations for these requirements, on the condition that the same safety level can be achieved by alternative risk reduction measures. For this reason risk evaluation is done by relative comparison of the risk of the tunnel investigated with the risk of a reference tunnel. A tunnel of the same length, type and traffic characteristic, fully complying with the minimum safety requirements as per EU Directive, is used as reference case. The divergences identified can be assessed in terms of risk. Alternative 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.

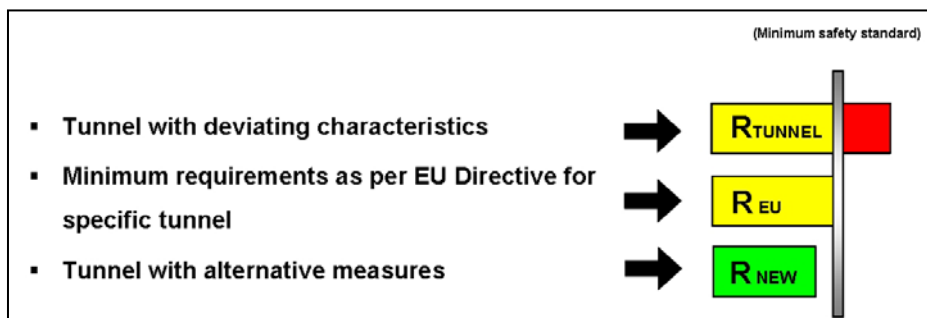


Figure 9: Risk evaluation in accordance with EU Directive (assessment through relative comparison)

3. EXPERIENCE IN PRACTICAL APPLICATION

3.1. Range and limitations of application:

In general the model is applicable to all tunnels with mechanical 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
- 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 a selecting safety measures (new tunnels) or upgrading measures (existing tunnels), definition of priorities for upgrading measures, etc.

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.

The method has now been completed and has been successfully adapted to several tunnels of the Austrian highway network.

3.2. View on the simplified method for Austrian codes

In the past, the safety design of road tunnels in Austria was mainly based on experience and prescriptive guidelines such as RVS 9.26 (ventilation), 9.27 (lightning) and 9.28 (operational and safety equipment). The Austrian standards in general fulfil or exceed the minimal safety requirements of the EU Directive 2004/54/EC.

One of these design codes, the RVS 9.261 for tunnel ventilation systems, already contains a very simple risk-related safety evaluation of road tunnels: a “hazard potential” is calculated based on a number of important influence parameters, thus dividing the tunnel into 4 different “hazard classes”. The hazard class defines the required safety standard of a tunnel in terms of tunnel design and tunnel equipment.

In the current process of updating RVS 9.261, this method has been reviewed and restructured based on the results of the investigation of a set of characteristic standard tunnels.

References:

- [1] K. Robatsch, C. Nussbaumer, (2003), Sicherheitsvergleich von Tunnels im Gegenverkehr und Tunnels im Richtungsverkehr auf Autobahnen und Schnellstraßen in Österreich mit anderen Straßenarten
- [2] E.R. Galea, S. Gwynne, (2000), Principles and practice of evacuation modeling