RVS 09.03.11 – UPGRADING OF THE AUSTRIAN TUNNEL RISK MODEL TuRisMo

Hörhan R.[1], Forster C.[2], Kohl B.[2]
[1]BMVIT Federal Ministry for Transport, Innovation and Technology, Vienna
[2]ILF Consulting Engineers, Linz

ABSTRACT

The Austrian Tunnel Risk Model TuRisMo was published in the Austrian guideline RVS 09.03.11 [1] in 2008. Since then, this method has been applied for a risk-based assessment of many road tunnels in Austria as well as in other European countries. However, definitions fixed during the development of the risk model set limits to its application in specific cases. Certain tunnels and some specific problems cannot be investigated with the existing model. Therefore it is intended to improve the model, in particular by implementing new simulation tools to achieve a more flexible applicability to all kinds of tunnels as well as to enhance the reliability and accuracy of the results by implementing more parameters in a more specific way. The results of the research project under way shall be published in an updated guideline RVS 09.03.11.

Keywords: Tunnel safety, risk analysis, risk model, smoke propagation simulation, evacuation simulation

1. THE AUSTRIAN TUNNEL RISK MODEL TuRisMo

In 2004 – as a consequence of the big tunnel fires in Montblanc, Tauern and Gotthard tunnel – the EC issued the Directive 2004/54/EC on minimum safety requirements for road tunnels [2] on the trans-European road network.

This Directive established the risk based approach as a complement to the traditional prescriptive approach to tunnel safety. Article 13 of the EC-Directive obligates the EU member states to use at national level, a detailed and well-defined risk analysis methodology, corresponding to the best available practices. More specifically, in annex 1 a set of parameters is defined, which have to be taken into account.

On the level of the Austrian Research Association Road-Rail-Traffic a working group had already started to develop a quantitative tunnel risk model. Expanding its focus on the requirements of the EC-Directive, the working group elaborated the Austrian tunnel risk model TuRisMo, which was published as RVS 09.03.11 [1] in 2008.

The Austrian Tunnel Risk Model – TuRisMo – is the standard method for a quantified, system-based risk analysis in Austria. It focuses on frequently occurring mechanical accidents and fire accidents with small and medium sized fires.

For the development of TuRisMo great emphasis was put on the implementation of a realistic data base. Hence an in-depth study of comprehensive tunnel accident data was carried out covering 447 tunnel accidents with personal injuries in order to define specific input data for various characteristic tunnel types. The Austrian Tunnel Risk Model combines a set of different methodical tools to analyse the whole system of safety relevant influencing factors. The method consists of two main elements: A quantitative frequency analysis and a quantitative consequence analysis.

The risk model covers the personal risk 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 seperately.

An event tree analysis including a representative set of characteristic accident scenarios is performed to calculate the frequencies of these scenarios

These scenarios differ significantly from each other as regards type of accident, vehicle involvement, involvement of dangerous goods and influence of fire.

For each scenario in the event tree the corresponding model value for the extent of damage is defined.

- Extent of damage of mechanical accidents:
  The consequences of each scenario are estimated based on the results of the evaluation of tunnel accident data.

- Extent of damage of fires:
  The extent of damage of fires 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 influence on longitudinal air velocity)

The Austrian tunnel risk model as defined in RVS 09.03.11 is a standardized method which on the consequence side provides characteristic damage values for tunnel accidents and tunnel fires for a set of model tunnels, which are representative for the Austrian tunnel collective. As explained above these values were elaborated on the basis of statistical evaluations (for mechanical accidents) and simulations (for fires) during the development of the method and have been compiled in tables in the guideline. For the application of the model the user has to establish an event tree for the investigated tunnel, quantifying it by implementing suitable standard probabilities and standard consequence values taken out of the guideline.

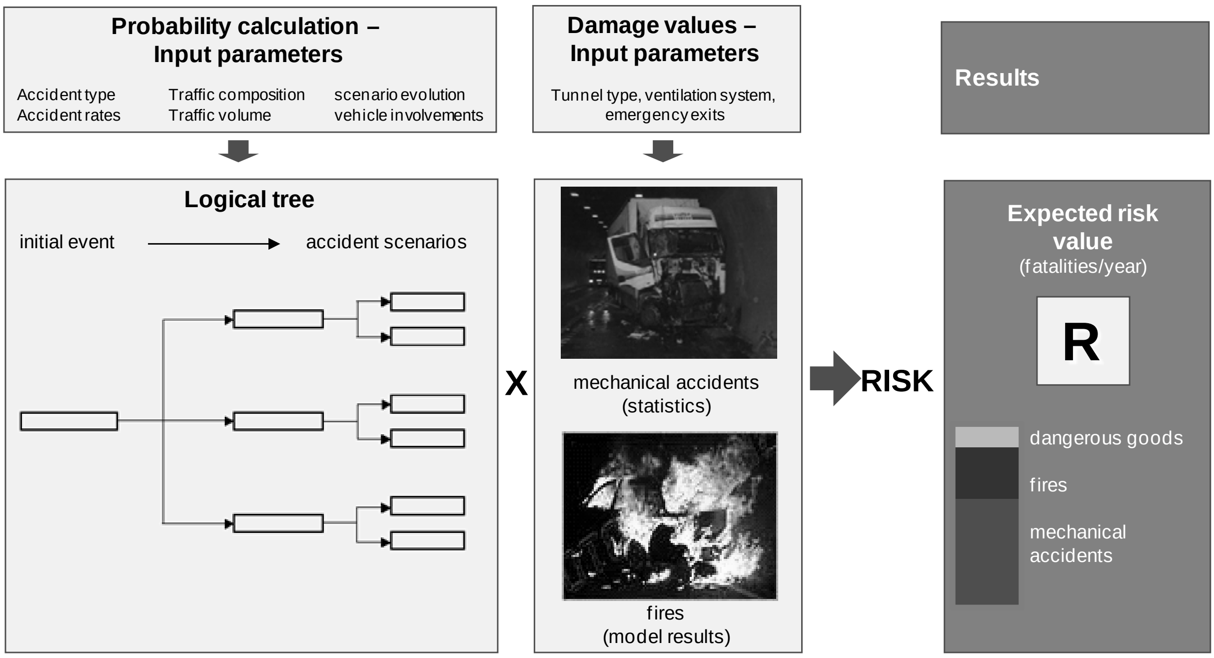

Figure 1: Structure of the Austrian Tunnel Risk Model

However, the application of the standardized values of the model presumes that the investigated tunnel fulfils specific conditions and requirements defined in the Austrian tunnel design guidelines, because these were taken as a basis for the calculation of the standardized risk parameters of the risk model.

This allows a rather simple and straight forward application of the risk model, however at the same time limits its use to standard tunnels, which fulfil crucial prescriptive requirements. For expert users it is nevertheless possible to investigate different types of specific characteristics too, by modifying specific parameters on the basis of individual considerations or sub models.

Consequently, the application of the risk model is limited, the most relevant limitations are listed in chapter 2 of RVS 09.03.11 (e.g. tunnel cross sections with 2 lanes only, not suited for combined ventilation systems, on complex tunnels).

2. EXPERIENCES IN THE PRACTICAL APPLICATION OF THE RISK MODEL

In Austria, many tunnels were investigated on the basis of TuRisMo assessing the influence of key safety parameters (e.g. like the distance of emergency exits) and classifying them in one of four danger classes according to their risk level. TuRisMo was also applied for risk analysis studies in other European countries, like in Slovakia, Slovenia, Greece, Croatia and Portugal. Furthermore the countries Slovakia and Slovenia decided to use TuRisMo as basic risk model for their tunnels as well, implementing some specific modifications to take national peculiarities into account.

However, with the expanding application the limits and shortcomings of the model came up as well, which in particular are relevant for the following applications:

- Investigation of road tunnels, which were designed on the basis of meanwhile outdated guidelines.
- Investigation of complex tunnels and tunnel systems.
- Investigation of specific safety relevant design parameters or specific boundary conditions (like for example, extraordinary meteorological conditions).

In particular the following aspects cannot be investigated in the risk model according to the existing RVS 09.03.21:

- Longitudinal gradient:
  The model calculations for the fire damage values of RVS 09.03.11 were performed with low gradients (app. 1 %); for tunnels with higher gradients it was assumed, that the specification of the ventilation system is such, that the target values of the Austrian ventilation design guidelines (RVS 09.01.32) are met and the smoke propagation can be controlled accordingly. Tunnels not fulfilling these requirements and other peculiarities like specific effects of steep gradients or tunnels with varying gradients cannot be investigated.
- Specific influence on air flow – conditions (e.g. traffic movement in bidirectional tunnels):
  The damage values for fires used in the model were calculated based on standardizes assumptions for air flow conditions in the first phase of an event; in practice – however – the air flow in the first minutes is dominated by the traffic movements still taking place in particular in a bidirectional tunnel. Hence the location of the fire, the traffic density and movements in both directions and the time requirement for stopping

the traffic have great influence on direction and velocity of air and smoke movements in the tunnel in the first phase of an event.

- Influence of tunnel cross section:
  The simulations underlying the fire damage values of RVS 09.03.11 were performed with a standard 2 lane vaulted tunnel cross section (for systems with smoke extractions: with an intermediate ceiling); studies of the influence of different tunnel cross sections on fire risk show, that there is a relevant influence of the height, width and shape of the tunnel cross section on risk. Hence there is a need for a more detailed investigation of the rectangular cross sections and tunnel cross sections with more than 2 lanes. Results from research projects in Germany [3] indicate for instance, that there is a negative influence of a lower ceiling (like in case of a rectangular cross section) on fire risk.

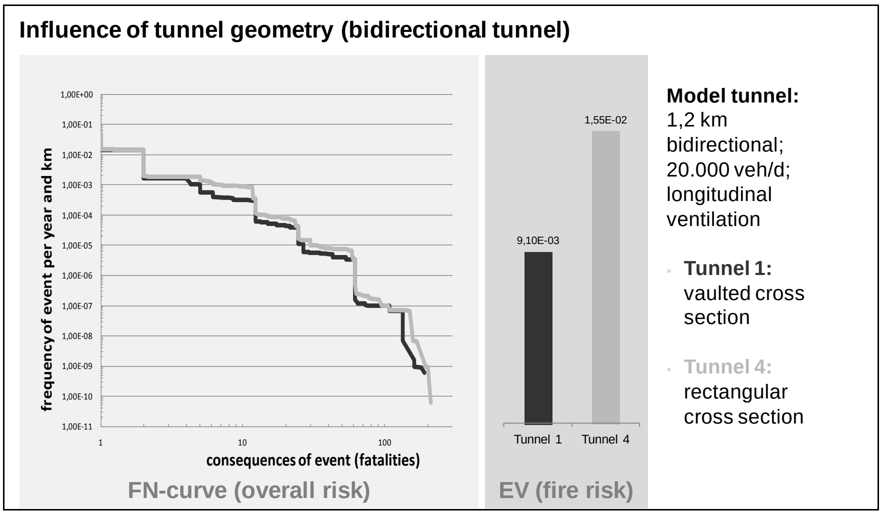

Figure 2 Influence of tunnel cross section on risk in a bidirectional tunnel with longitudinal ventilation [3]

- Fire scenarios bigger than 30 MW:
  For several reasons only 5 MW and 30 MW fires were included in the existing risk model. Most risk analysis methods on international level also include bigger fire scenarios (with – however – low probabilities). Furthermore – e.g. for the evaluation of specific improvements of the ventilation system – it is suitable to include in the risk analysis a fire scenario bigger than the design fire of the ventilation system. Therefore a 100 MW fire scenario will be implemented in the method.

- Complex tunnels / tunnel systems:
  Tunnels with changing cross sections, with ramps or with combined ventilation systems cannot be investigated with the existing risk model. The investigation of such a complex tunnel requires specific simulations for the calculation of damage values for fires and therefore cannot be handled with a method based on model tunnels. However, such tunnels often require a risk-based approach.

- Specific safety measures like improved incident detection/tunnel closure:
  With currently applied assumptions for incident detection and tunnel closure (i.e. fixed time frame for fire detection and no detection of congestions) the scenario development after an initial incident cannot be reproduced in a realistic way in tunnels where features like automatic incident detection or detection of congestions (in combination with efficient means for tunnel closure) are available.

Furthermore other tunnel risk models were developed which include the application of complex simulations on object level, allowing a more specific and detailed investigation of safety parameters but at the same time involving more effort for the investigations.

3. NEW RESEARCH PROJECT STARTED

Since its publication in 2008, the risk model has become a valuable, widely used tool for road tunnel risk assessment, however with some shortcomings in its practical application. Therefore, the “Austrian Research Association Road-Rail-Traffic” decided to start a new research project on road tunnel safety.

The main objectives of this project are twofold: on the one hand, the methodical approach shall be enhanced, and the model itself shall be expanded in order to cover more relevant parameters in a more specific way. Additionally, the complete model and the conditions for its application shall be defined in a way that it can be applied directly for the investigation of complex tunnels. On the other hand, the improved model shall be used to improve the standardized “old” model as well, in order to enlarge its range of application. The improvements envisaged are in particular relevant for tunnel fires.

Further objectives of the study are:

- Actualisation of the data base of the risk model (for mechanical accidents).
- Systematic parameter study for relevant influence factors in order to gain more knowledge and – if possible – quantitative data about their influence on risk.
- Improvement of evaluation capabilities for risk mitigation measures.
- Check of the option to implement the effects of assistant rescue.

On the basis of the results of the research project the RVS 09.03.11 shall be modified and expanded.

4. IMPROVED METHODICAL APPROACH FOR THE CALCULATION OF FIRE RISK

4.1. Combined smoke propagation model

The 1-dimensional smoke propagation model used during the development of TuRisMo shall be replaced by a new combined 1D / 3D smoke propagation model. The idea is to first perform a 1-dimensional simulation in order to calculate the longitudinal airflow in the tunnel resulting of global influencing factors which have no direct influence on local effects such as smoke stratification at the fire location. The subsequent 3-dimensional simulation of smoke propagation then takes into account the 'local influencing factors' such as cross section, inclination, presence of vehicles (turbulences) etc. based on the longitudinal velocities calculated before. The influencing factors included in the 1-dimensional and the application on the 3-dimensional model are illustrated in Figure 3.

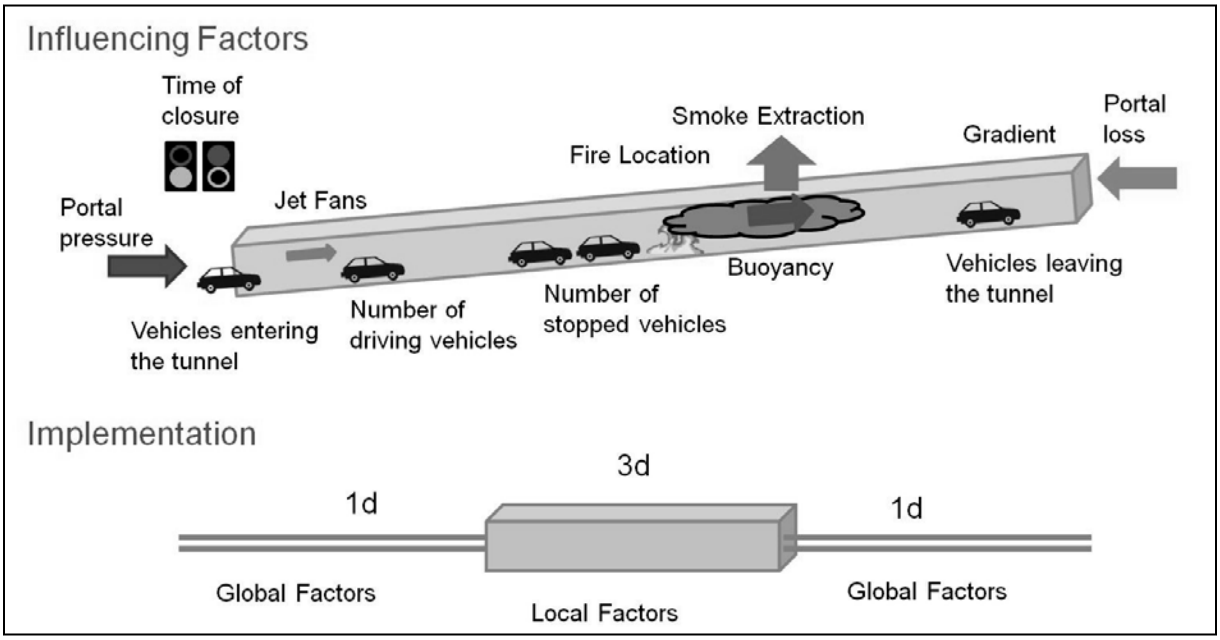

Figure 3: Influencing factors taken into account in the new 1D / 3D smoke propagation model

<u>Parameters included in 1D model</u>

- Drag at the tunnel walls and equipment
- Portal effects (loss of momentum at portals, wind pressure)
- Influence of moving vehicles (piston effect) and standing vehicles (drag)
- Influence of ventilation system (spin up time for jet fans and exhaust machine, position, etc.)
- Thermal forces of hot gases in the tunnel
- Heat exchange with tunnel walls (conduction effects)

Naturally the geometric properties such as overall tunnel length, cross section, circumference, inclination, ambient temperature etc. were included in the 1d model for a proper description of the resulting transport equations.

<u>Parameters included in 3D model</u>

- Exact local tunnel geometry (cross section at fire location)
- Gradient around the fire location
- Stopped vehicles in the vicinity of the fire location (causing turbulences)

The velocity development obtained in the 1-dimensional simulation is applied as boundary condition in a distance large enough to not interfere with the smoke stratification.

4.2. Integrated evacuation simulation model

For the calculation of the fire damage values in TuRisMo the evacuation simulation software buildingExodus [4] was applied. For that purpose the results of the smoke propagation simulations (time dependant smoke concentrations at a height of 1,6 m) had to be transformed into the evacuation model. On the other hand many applications of buildingExodus for road tunnel environments showed, that for this specific purpose many features of this simulation software are not required. Therefore it was decided to directly implement a simplified evacuation tool in the smoke propagation model. The following features were included in this simplified evacuation tool:

- Reduction of evacuation grid to 1 dimension. This allows to reduce model complexity and computational demands while the loss of precision is minimal. The low influence of this dimensional reduction results from the fact that the distance to the nearest emergency exit is normally much larger than the tunnel inner diameter. Furthermore bottleneck effects at doors where queuing would require a 2-dimensional grid normally do not occur in road tunnels as the density of agents is not large enough (in contrast to railway tunnels!).
- Accumulation model by D. A. Purser [5] to calculate the accumulated dose of toxic gases and their effect on human physiology. This model was selected because the application of accumulation based vs. limit based models has shown that limit based models (i.e. 'if visibility is lower than 5m than self-rescue fails') may give inconsistent results, especially in tunnels with smoke extraction.
- Obscuration triggeres start of self rescue. This means that agents start moving as soon as the visibility at walking level (head level of 1.6m) drops under a certain level which is a more realistic approach than the definition of a fixed alert time when all agents start to evacuate. The time is limited by a (realistic) alert time when all people are requested to leave the tunnel.
- Direct data transfer for higher precision and optimisation of work flow. As the data transfer from the output files of the simulation of smoke propagation to the evacuation environment was limited to a specifically parameterized method the whole transfer was extremely time consuming and lacking accuracy because of the required (non linear) transformation. The new tool on the other hand can directly access the result sheets and import the local concentrations without any preconditioning resulting in higher accuracy.
- Definition of representative populations with different types of agents. As the algorithm calculates zones with/without self rescue for each type of agents the simulation has to be run one time only in contrast to evacuation environments where a statistical set of agents is simulated at each run.
- Shift of the fire location vs. the configuration of emergency exits. This has shown to have big influence on the calculated number of victims and is therefore included in the evacuation model. Therefore the fire location is moved along the tunnel accessing the smoke data of the nearest simulation.

Overall the newly developed evacuation tool can achieve better precision with a reduced amount of work for each individual scenario. This allows to increase the total number of scenarios (fire locations in the tunnel, traffic scenarios) which can be covered within the risk analysis and therefore obtain better and more representative results.

4.3. Enhanced use of statistical traffic data

So far the fire risk damage values were calculated on the basis of the AADT, hence for an average situation. In future it is envisaged to take at least 3 different traffic scenarios into account: one each for low, average and high traffic situations. These values shall be defined on the basis of statistical traffic data of one complete year of the investigated tunnel or of representative adjacent road sections. This approach allows to take effects into account which directly depend on the traffic situation at the time of the fire such as the resulting longitudinal velocity or the length of queuing vehicles behind the fire location. Especially in bidirectional tunnels these locations may have a large impact on the calculated number of victims.

5. OUTLOOK

The development of the new risk model is almost completed; the combined smoke propagation model and integrated evacuation simulation have been successfully tested in test calculations as well as for specific tunnels. The new model works and delivers comparable results to the existing model.

As a next step, systematic parameters studies will be performed to investigate the influence factors addressed in chapter 2 more in detail and to gain experience in the application of the expanded model.

The final step will be the modification and completition of the standard damage values of the RVS and the documentation of the new model in the updated guideline. The model shall be finished by end of 2012.

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