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APPLICATION OF RISK ANALYSIS IN HIGHWAY TUNNELS

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Abstract

Safe operation of the tunnel is important for the function of the transport infrastructure. Tunnels are structures, which are used to carry persons and general cargo, in order to shorten transport routes and improve traffic safety. Risk analysis will be good aid for designers for design tunnel with possible correction.

Key words: *dangerous goods, emergency exits, expected risk value, risk analysis, risk model.*

1. INTRODUCTION

In April 2004 European Union adopted Directive 2004/54/EC on minimum safety requirements for tunnels in the trans-European road network with a length exceeding 500 m. Two years later, according to this directive, the Government Decree SR n. 344/2006 Z. z. (hereinafter referred to government regulation) was approved, in which the Slovak Republic has committed to establish a uniform methodology for determining the risk analysis of security tunnels. Risk model for the risk analysis of road tunnels in Slovakia has been developed on the base of Austrian model TuRisMo (Tunnel Risk Model) and established by Technical specifications 02/2011 „Risk Analysis for Slovak Road Tunnels“ (hereinafter TS) in October 2010. Besides the principle of the whole model of risk analysis, model characteristics based on simulation calculations were also included. There were considered extensive data of acquired from documentation, respectively data that more accurately capture the reality of the Slovak tunnels. The model in TS is designed in the way to allow changes in model parameters additionally. It should be mentioned that the use of the model is not easy according to given data base, which is made up of the output data of simulation models that are not described in detail in this regulation. Therefore, a typical user of these specifications without access to databases will not be able to make a correct calculation of the expected value of risk. TS determine only the boundary requirements of simulation conditions, without a detailed derivation of the output data needed to take account of specific danger. Nowadays, safety documentations of Slovak tunnels in operation are updated first time according to new legislative risk model. Risk analysis of prepared, built and operated road and highway tunnels should increase their safety. At the Department of Construction Management, Faculty of Civil Engineering, University of Žilina the calculations for bi- and unidirectional tunnels were performed. Models of influence formulation of individual tunnel elements are processed and within the solution of project “Centre of Transport Research”, founded by the ERDF, should be processed prediction models on estimation of operating phases.

2. TECHNICAL SPECIFICATIONS TP 02/2011

Technical specifications TP 02/2011 Risk analysis for Slovak road tunnels serve like a methodical base on quantitative determination of road tunnels risk parameters in Slovak highway and road

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network longer than 500 m. It is possible to improve safety operation of new prepared tunnels by utilization of risk analysis results.

2.1 Technical safety of road tunnels

Realization of quantitative risk analysis is only one step of evaluation of technical safety of road tunnel which consists of the following four steps:

1) **specific hazard analysis –** qualitative safety control with systematic evaluation of all relevant safety and technical parameters of the tunnel. It is used to identify specific risk aspects and special characteristics of tunnel and also as a background for determining the risk model input data.
2) **safety evaluation on the base of Slovak and international technical-safety guidelines –** minimal requirements of government regulation must be unbroken. Besides in this step can be associated also other regulations like a background for arbitration (e.g. Slovak regulation for fire safety of road tunnels or national specifications other countries of various domains).
3) **risk analysis and risk assessment –** quantitative application of risk model and prospective realization of other risk analysis steps for deeper exploration of special questions (e.g. transport of dangerous goods) incl. estimation of possible supplementary safety measures.
4) **safety documentation –** elaboration of safety documentation in terms of government regulation requirements.

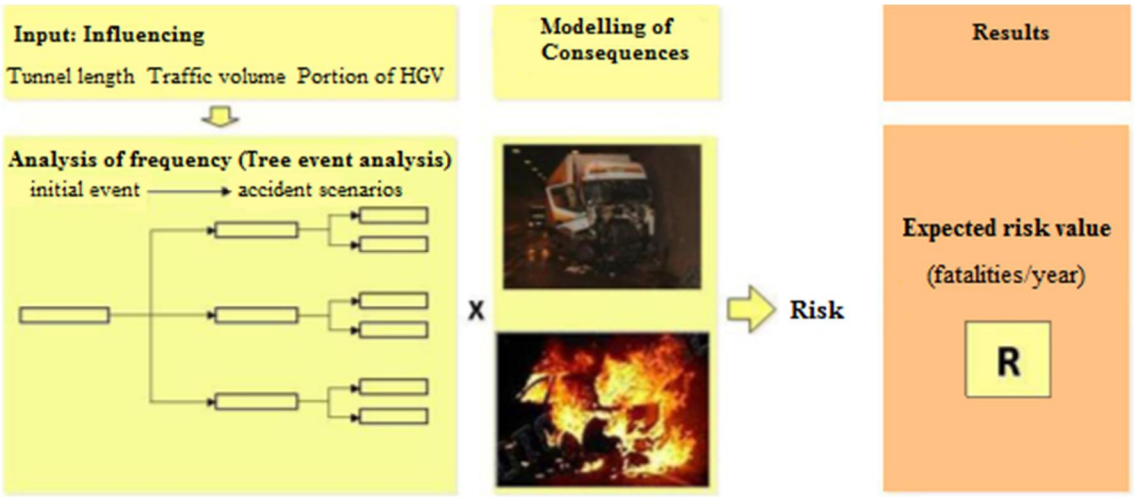


Fig. 1 Basic structure of tunnel risk analysis

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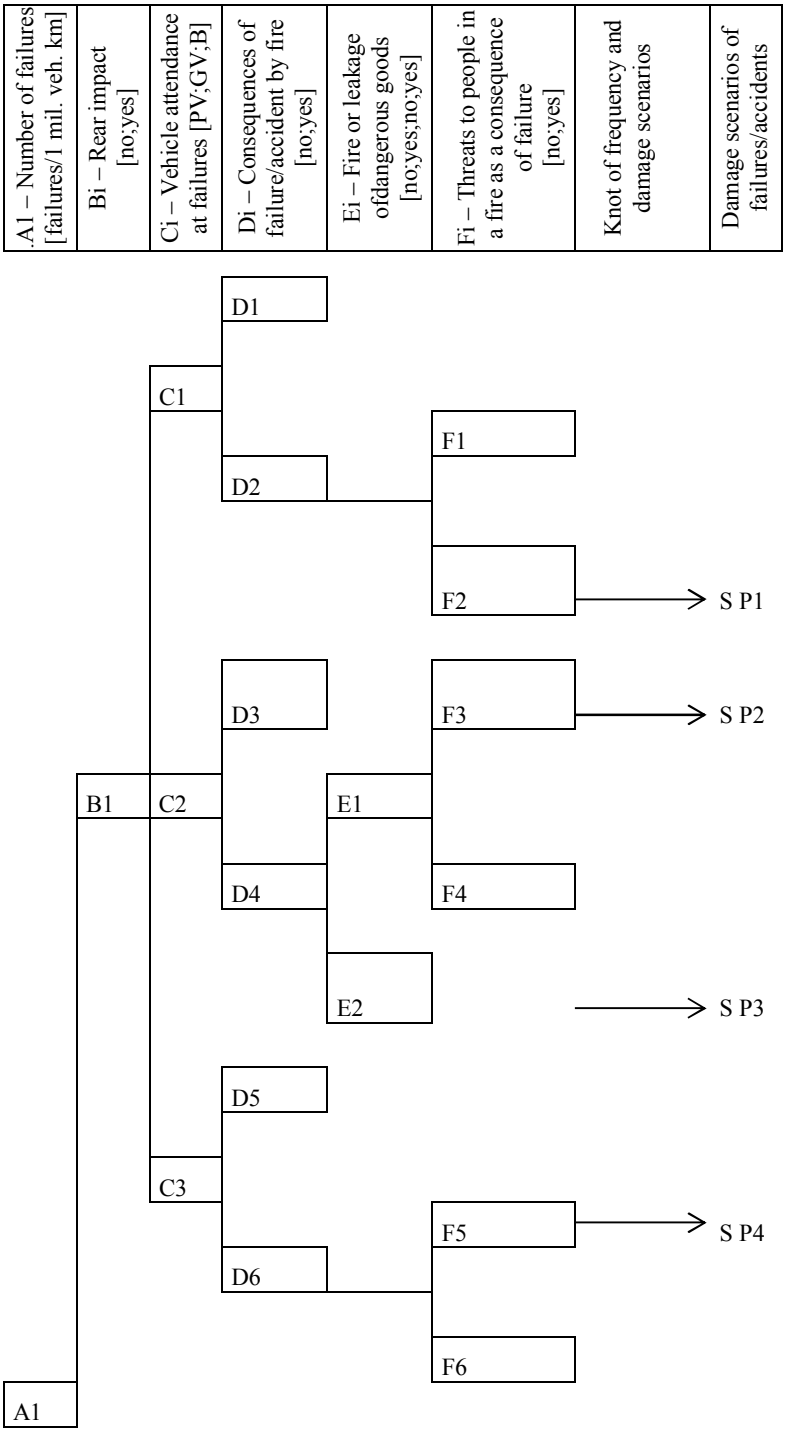


Fig. 2 Fragment of tree event for risk analysis of road tunnel with unidirectional traffic
A1-basic volume for number of failures in tunnel; B1-secondary accident after failure without rear impact; B2- secondary accident after failure with rear impact; C1-failure of passenger vehicle; C2-failure of goods vehicle; C3-failure of bus; D1-neither fire after failure of passenger vehicle; D2- fire after failure of passenger vehicle; D3- neither fire after failure of goods vehicle; D4- fire after failure of goods vehicle; D5- neither fire after failure of bus; D6-fire after failure of bus

2.2 Structure of risk model

Risk analysis model examines the personal risk of tunnel users, which means that all parameters are used only to accidents with personal injury. It is detected the statistical value of risk for risk of tunnel users, namely **the value of statistically expected number of fatal casualties per year**. Effects of dangerous goods are considered only a simplified model. For deeper disquisition of risks from the transport of dangerous goods through the tunnel is needed to use special risk model DG-QRA which was developed in the framework of the joint OECD/PIARC. The risk analysis model consists of two main elements (Fig. 1):

- quantitative frequency analysis
- quantitative analysis of the accident consequences

By frequency analysis – using event tree (Fig. 2) – to calculate the potential numbers of events for a set of defined scenarios of damages. Based on the initiating event (failure or accident), whose frequency is known, is generated by several degrees different possible sequences of events that lead to different damage scenarios. Damage scenarios are different types of events, vehicles involved, damages and the like

The E1, E2 (up to E18) express participation costs for the transport of dangerous events, such as fire involving a truck, leakage of dangerous goods in a fire involving a truck. Threats to people in a fire as a result of failure express values of F1 to F6. The values of E and F are combined damage scenarios (SP).

By analyzing of accident consequences for each damage scenario are estimated effects of the accident:

- *by accident only with mechanical damages* based on an assessment of accidents in tunnel with injured people from the data file of about 450 accidents in the Austrian road tunnels and adaptation to conditions in accordance with Slovak statistical data from the period 200 to 2009
- *by accidents with fire* – based on a model estimation of the damage proportion
- *by one-dimensional model of the spread of smoke* is calculated temperature distribution and concentrations of pollutants as a result of fire in the tunnel, taking into account tunnel ventilation; using the model of evacuation simulation are simulated escape movements of stricken road users and are combined with the results of the model spread of smoke

2.3 Application boundaries of risk model

The scope of applications is limited by types of tunnels examined in the analysis of the extent of damage, which satisfy the conditions:

- cross-section of the tunnel with two riding lanes without lay bay lane (square or vaulted section)
- surface area of the tunnel (no beams)
- natural, longitudinal or transverse ventilation of exhaust fumes (no combined ventilation systems)
- maximum time fire detection ≤ 150 s
- longitudinal slope < 3 % - ventilation system mast be designed to meet the targets in every situation

- exhaust smoke fire is put into operation immediately after detection

In addition to the main assumption of risk calculation model must meet many other frameworks for longitudinal and transverse ventilation system, an evacuation model and the impact of various factors. Before using the parameters entering the calculation is necessary firstly to verify that the calculation basis in accordance with the actual tunnel under investigation. If one of the preconditions for the calculation is not suitable, then it should be possible to estimate the effects of the damage first quality check. If the relevant effects can be expected, the data should be supplemented either estimated based on existing data or to the corresponding additional simulation.

2.4 Evaluation of tunnel risk analysis results

Process of risk evaluation consists of several steps which are shown in the follow block diagram (Fig. 3)

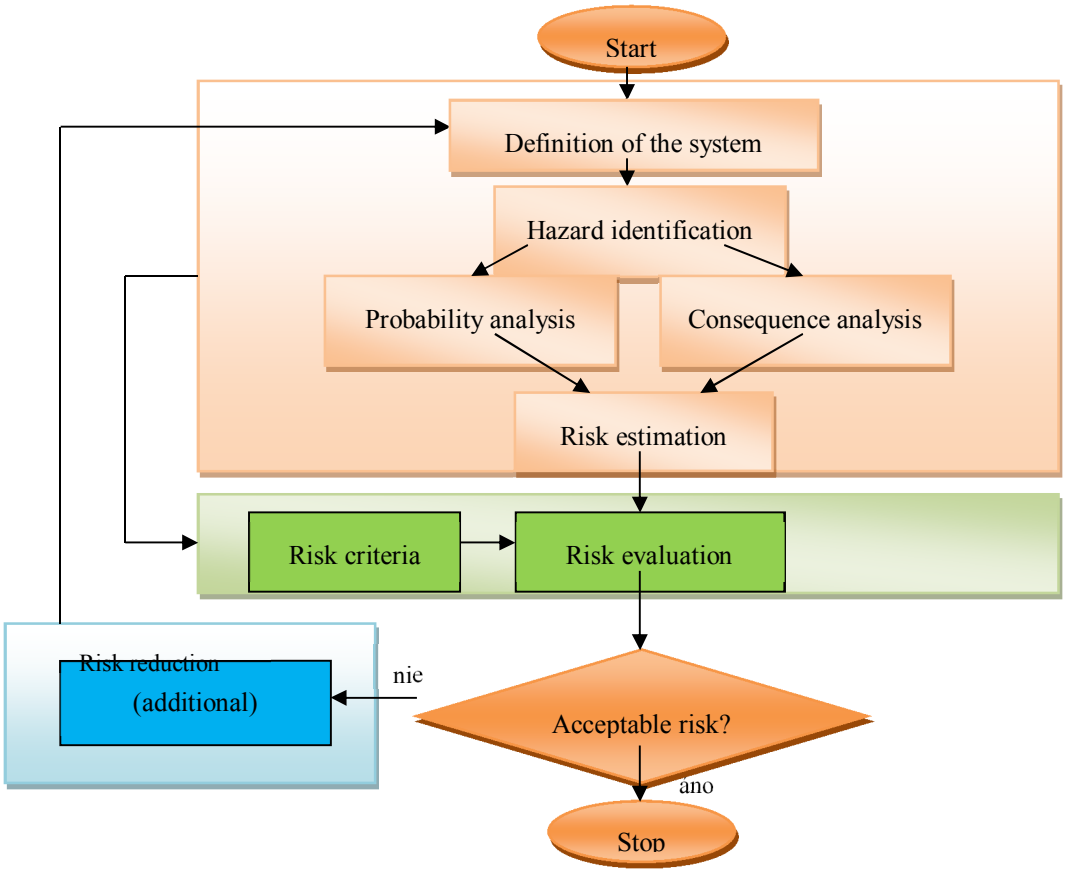


Fig. 3 Block diagram of risk evaluation process

2.4.1 Specific hazard analysis

This is a quality security monitoring with a thorough evaluation of all serious safety and technical parameters of the tunnel. If it is possible to identify the specific characteristics then is needed to quantitative analyse their effect on safety. The regulation is a proposal for the structure of a specific analysis of hazards as a checklist in terms of recommendations for the structure of PIARC road tunnel safety documentation shall contain the following elements:

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- details of transport (transport documents)
- horizontal and vertical alignment
- solution of the tunnel construction
- technological equipment of the tunnel

2.4.2 Relative risk evaluation

Relative risk evaluation consists in axiom that the tunnel with its all specific safety-technical relevant characteristic cannot allocate higher risk as a similar reference tunnel which satisfies in all points and authoritative parameters to minimal requirements of government regulation. This approach enables achieve that through the medium of prescriptive measures is possible to keep minimal safety level also by respecting of specific curiosities of individual tunnel. The principle of relative evaluation can be shown with follow diagram (Fig. 4).

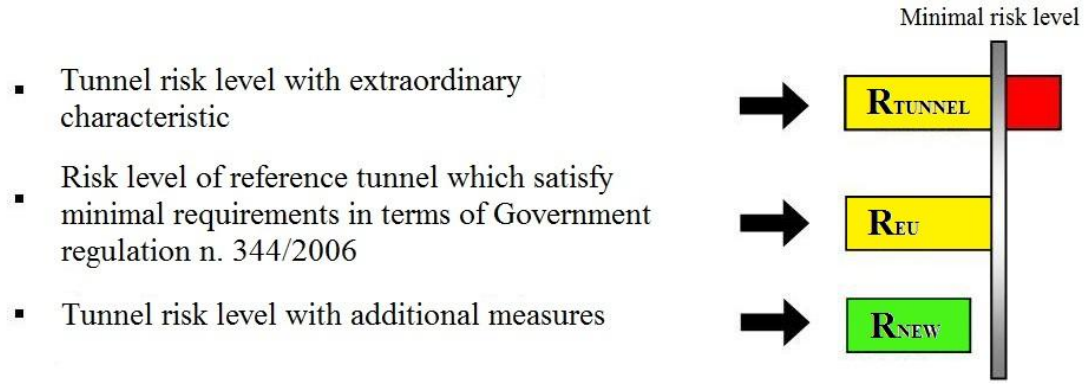


Fig. 4 Relative tunnel risk evaluation of results

2.4.3 Absolutely risk evaluation

Absolutely risk evaluation complements the relative evaluation and its goal is to provide information about absolute risk margin. Based on the expected value of risk (specified risk analysis) the studied tunnel is assigned to risk (hazard) class according to Tab. 1:

Expected Risk Value		**Hazard Classifications**
Lower thresholds	**Upper threshold**	
-	0,02	I
> 0,02	0,10	II
> 0,10	0,50	III
> 0,50	-	IV

Tab. 1 Distribution of hazard classes

This classification provides an overview of the absolute risk level of tunnel (regardless of whether it was under government regulation assessed as safe or not) and can serve as an additional criterion for safety relevant technical decision.

3. PARAMETRIC ANALYSIS

3.1 Parameters of evaluated tunnels

The following values of parameters are selected:

- tunnel length: 700, 1500, 3000, 5000, 7000 m
- distance of emergency exits: 300 m
- length of connecting bar section: 0 m
- AADT (annual average of daily traffic) – traffic volume: 17 500 veh/24h
- density of vehicles in traffic: 80 % (personal vehicles - PV)
  18 % (heavy good vehicles - HGV)
  2 % (buses - B)
- number of traffic jams: 100 h/year
- density of transport of dangerous goods: 3 % (from total number of HGV)

3.2 Principle of evaluation

Values of input parameters are sorted from TP (AADT, density of vehicles in traffic, number of traffic jams a density of transport of dangerous goods) like averages in Slovak conditions. Lengths of tunnels were stated on the basis of analysis model accident consequences principles. Length 700 m responds to maximal tunnel length with natural ventilation with unidirectional or bidirectional traffic. Lengths 700 m, 1500 m a 3000 m are minimal tunnel lengths from intervals, by which the change of extend damages values for fire events and events with dangerous goods is considered. Simultaneously presenting values by which the longitudinal ventilation system is used in unidirectional traffic anymore. Principle of parametric study of influence mentioned parameters is based on two phases of tunnel lifecycle and possible changes those parameters during them:

1) **design phase of tunnel** (tunnel length, distance of emergency exits, length of connecting bar section)
2) **tunnel operation** (AADT, density of vehicles in traffic, number of traffic jams, density of transport of dangerous goods)

By calculation program TUN_RISK of Department of Construction management, University of Žilina were obtained partial data according to evaluated parameters, while two parameters were changeable (during the modelling) and others were invariable.

3.3 Results of evaluation

Influence of distance between emergency exits on final value of risk in bidirectional tunnels with longitudinal ventilation is shown in Fig. 5 and in unidirectional tunnels with natural ventilation in Fig. 3.

Impact of distance between emergency exits practically doesn't evocate any change of risk. The value of risk changes just very slightly from 2.10^{-5} to 38.10^{-5} depending up the length of tunnel. This

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heightening for every 50 m of distance between emergency exits is very small inasmuch as the length impact of emergency routes on risk of tunnels users is objectively important. Risk margin is absolutely independent from the distance of emergency exits in short unidirectional tunnels with natural system of ventilation (Fig. 6).

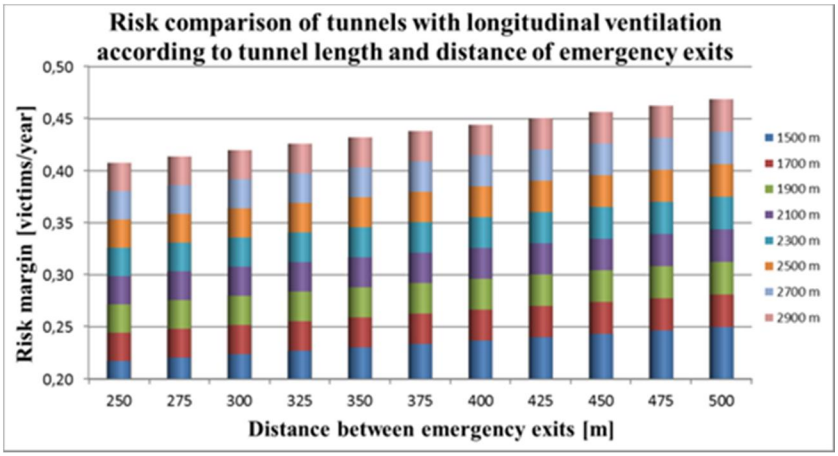


Fig. 5 Influence of emergency exits distance on risk margin in bidirectional tunnels

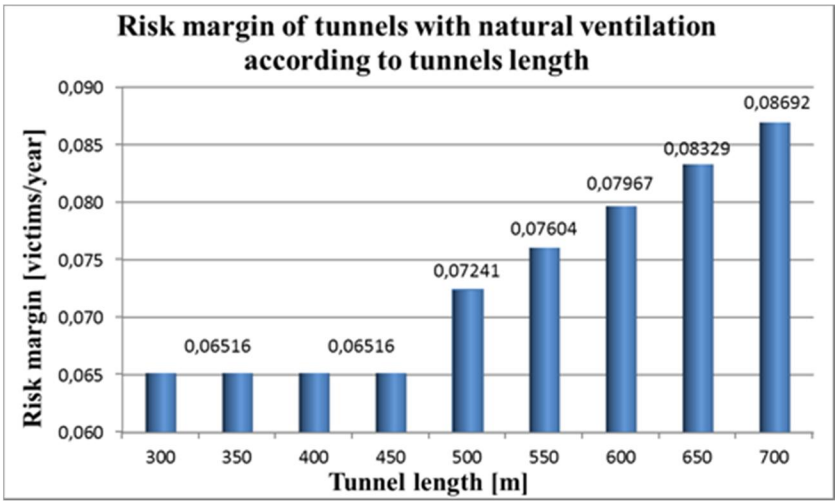


Fig. 6 Risk margin in unidirectional tunnels with natural system of ventilation

Impact of risk increase within change of length of connecting bar section (every 25 m) in unidirectional tunnels uniform length is small. The value depends on type of ventilation system and tunnel length. Graphic trend is presented in Fig. 7.

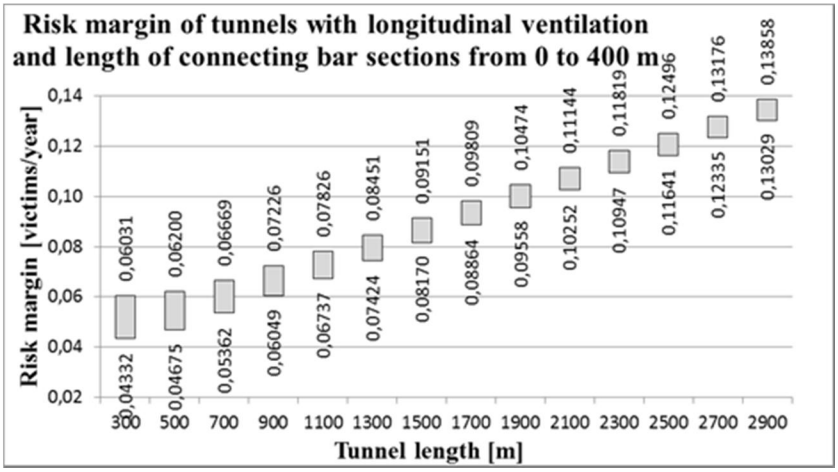


Fig. 7 Risk margin of unidirectional tunnels with longitudinal system of ventilation

The risk value improved, depending up the AADT in bidirectional tunnel 3000 m of length with longitudinal ventilation, supported by point exhausting, is presented in Fig. 8. The risk values in equal length tunnels with transverse ventilation are from 10 to 15 % lower than in tunnels with point exhausting. Approximately from the intensity 23 000 veh/24h till 27 000 veh/24h, those tunnels already falls with-in the highest class of hazard IV (according to Tab. 1).

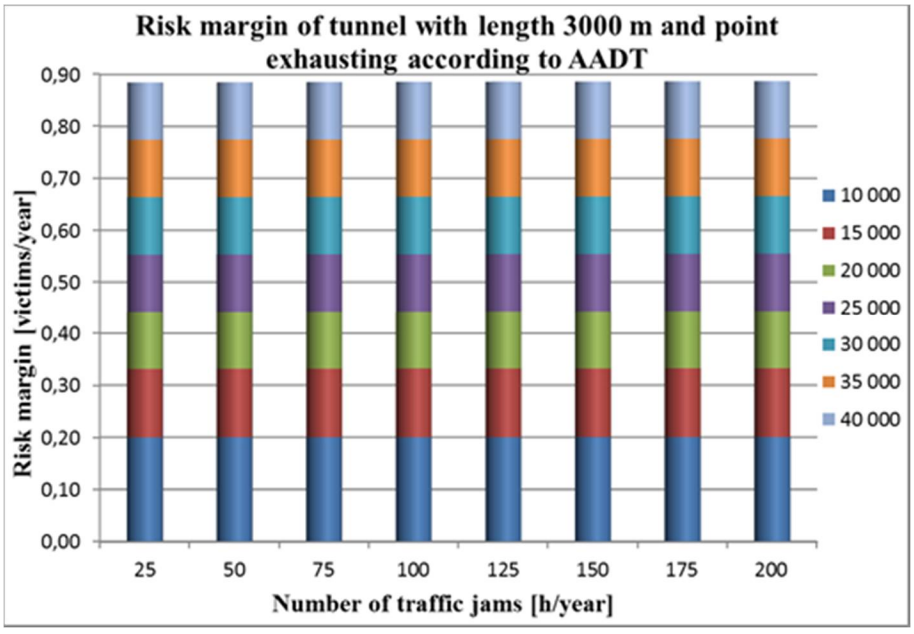


Fig. 8 Risk margin of tunnels with point exhausting system of ventilation

Risk margin doesn't depend to proportion of DG or it can be said that this dependence is very low. But the accidents from tunnels (Mt. Blanc, Gotthard, Fréjus, etc.) demonstrated that just small accident can

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lead to a catastrophe. Colored marking represent different percentage proportions of personal vehicles, HGV and buses (Fig. 9).

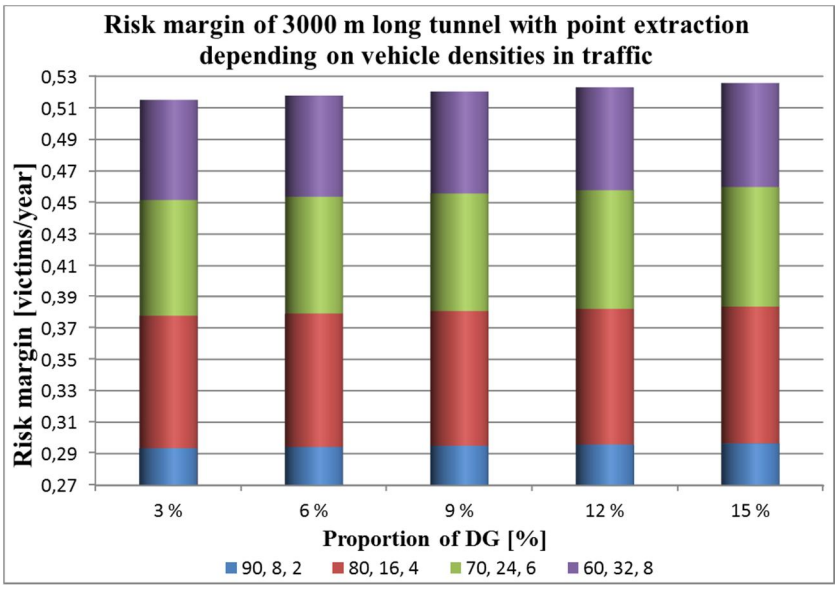


Fig. 9 Risk comparing of 3000 m long bidirectional tunnel with point extraction

Other dependence represents comparison with small changes in vehicle densities. But the results are very different and it is admirable that the risk, at the second figure with same densities of HGV and buses, has downtrend. The risk doesn't change with the increasing portion of DG in HGV traffic. Risk model in solves a problem of dangerous goods transport, but insufficiently. TP advises to use DG-QRA model, but without an interconnection of results with Slovak risk model for road tunnels.

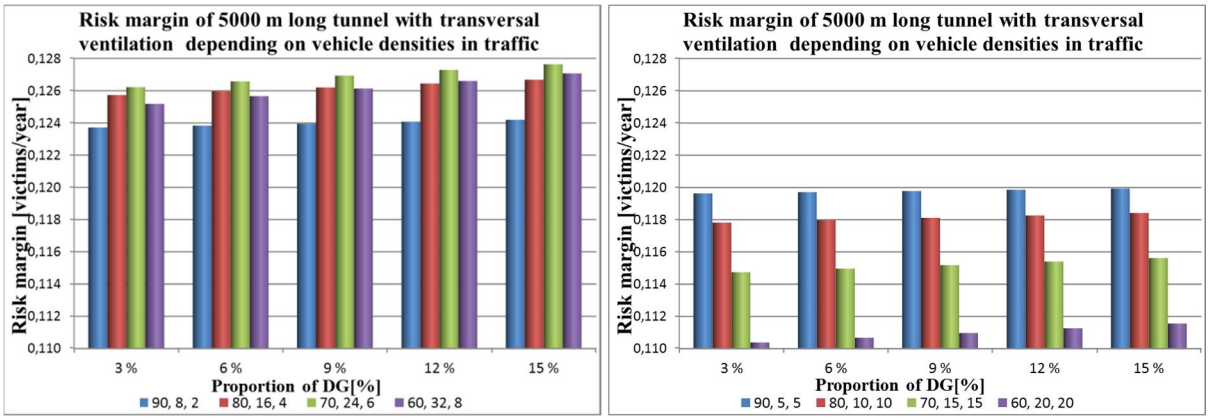


Fig. 10, 11 Risk comparing of 5000 m long unidirectional tunnels with transversal system of ventilation according to proportion of DG and vehicle densities in traffic

4. CONCLUSIONS

Results from performed calculations indicate:

- according to model of risk was demonstrated influence of tunnel length, traffic volume and density of vehicles in traffic providing that additional conflict point of connecting bar section including also with its territory gravity, what is with the speed of 80 km/h 222 m (at 100 km/h 278 m), is a measure of the impact of this parameter may be sufficient
- a very small proportion of the traffic impact of vehicles with dangerous goods. It would be convenient to resolve the influence also with consideration to shutout of transportation from tunnels (in Slovak republic and abroad also)
- number of traffic jams affects the extent of damages in case of fire, an increasing number of people in the tunnel, only with very small measure
- impact of distance between emergency exits is in specification considered by very small value. Due to the people self-rescuing, the distance between emergency exits is required to be higher.

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