Risk Assessment of Transport for the Dangerous Goods in Austrian Road Tunnels

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ABSTRACT

In the Austrian guideline "RVS 09.03.11" the Austrian Tunnel Risk Analysis Model "TuRisMo" defines how to assess the risk for tunnel users. The same guideline stipulates that the specific risk involved in the transport of Dangerous Goods (DG) through road tunnels should be assessed in a separate process. Consequently, based upon EC-Directive 2004/54/EC and the Austrian Road Tunnel Safety Law, a uniform risk assessment procedure for the transport of dangerous goods through road tunnels has been developed. For a methodic risk analysis approach, the OECD/PIARC-Model DG-QRAM was chosen.

In a first part of the objective study, a simplified risk assessment approach was elaborated. In 2009 another research project was initiated on behalf of the Austrian Ministry of Traffic, Innovation and Technology with the objective of developing a complete risk evaluation procedure. The results shall be published in another Austrian "RVS" guideline.
This research project is supported by a working group including experts from the Austrian Ministry of Transport, Innovation and Technology, the Austrian Ministry of Internal Affairs, federal Authorities, fire brigade, transport industry and consultants.

The main objectives of this research project are the verification of existing DG transport data, the development of a risk assessment process in line with the new ADR tunnel regulations and the definition of acceptance criteria for each level of investigation (step-by-step process).

KEYWORDS: dangerous goods, road tunnel safety, risk analysis, risk assessment, expected value

EVALUATION OF RISK

Risk is characterized by the probability of an event and the consequences of an event. The consequences of accidents are expressed as expected numbers of fatalities. The two kinds of risk indicators generally considered are:

- Individual risk:
  From the individual's perspective, only the risk of one human being is of relevance; this human being can be a member of a certain group (e.g. a worker).

- Social risk:
  From the society's perspective, risk is perceived as a collective phenomenon. This collective risk is defined through the occurrence of certain incidents, leading to several fatalities. It is illustrated in a graph on a double logarithmic scale in which the number of victims (N) is plotted against the frequency (F) to generate the "F-N curve".

Risk acceptance
Identical risks may be perceived quite differently by society. Risk acceptance is for example influenced by the benefit and the controllability of the respective risk.
For example, a person's decision to climb a mountain is a voluntary act; the individual benefit is viewed to be very high and the personal risk is considered to be calculable. Since the interest of the media is low, there is no call of the public for the prevention of these individual risks.
The situation is completely different with an industrial chemical plant in a built-up area. The population living close to the plant receives no personal benefit from its operation and their risk exposure in case of an incident is neither voluntary nor can it be controlled by the residents. In the event of an incident, the interest of the media turns out to be very high and the call of the public to prevent such incidents is correspondingly passionate.

When preparing a risk model, such factors which have a direct influence on the perception of the risk, have to be taken into account applying a risk aversion approach (e.g. 1 accident causing 10 fatalities outweighs 10 accidents causing one fatality).

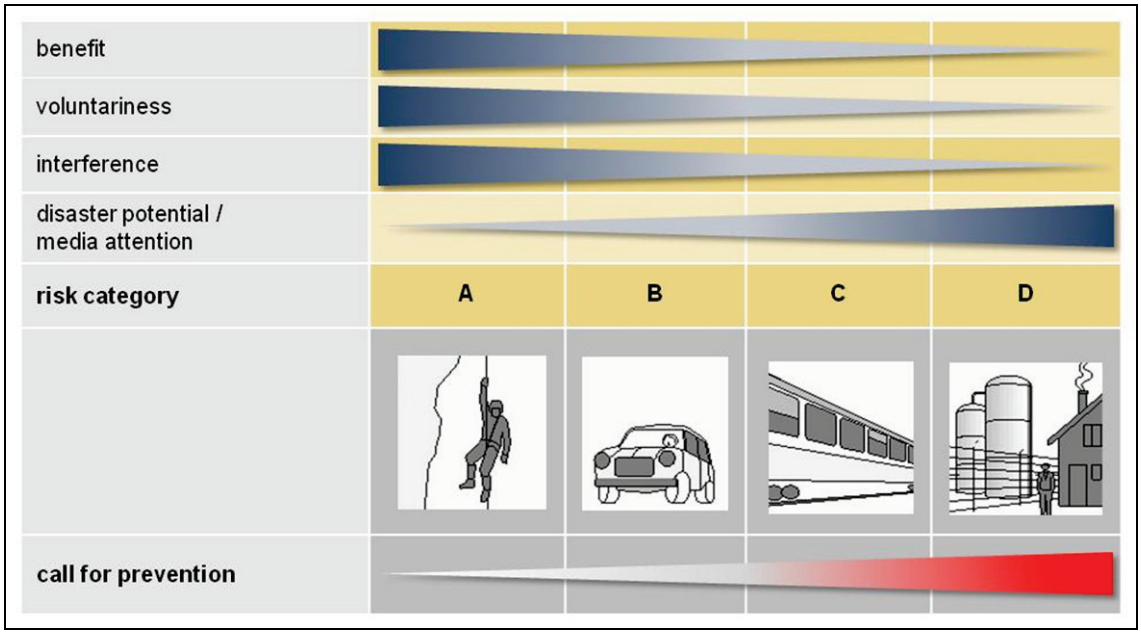

Figure 1 Categories of risk acceptance

LEGAL BASIS OF TUNNEL SAFETY

EU Directive 2004/54/EG
This EU Directive [1] defines minimum safety requirements on an international level to be met by road tunnels forming part of the Trans European Road Network (TERN). This is the first international guideline addressing the tunnel safety topic and it is applicable to all TERN tunnels >500 m, which are currently under design, in construction or in operation. The remarkable aspect about this Directive is the fact that it combines both a "directive-oriented" and a "risk-oriented" approach. According to Article 13 of this Directive, a risk analysis shall be performed for all tunnels featuring a special characteristic, taking into account all design factors and traffic conditions.

Under the terms of a "guideline-oriented" design, a tunnel is considered as safe, if it is designed in compliance with all applicable relevant guidelines. This type of design guarantees a specified technical standard. The technical standard in Austria, in comparison to Europe is quite high, and as a result the requirements stipulated in the EU Directive either met or even exceed these standards in every respect. If a tunnel is designed adopting a "risk-oriented" approach, a tunnel is only considered as save, if it complies with the defined risk criteria. The "risk-oriented" approach checks the functionality and

efficiency of risk-reducing measures, also evaluating risk potential of those tunnels which the guideline considers as save.

Austrian Road Tunnel Safety Law
The Road Tunnel Safety Law [2] translates the requirements contained in the EU Directive into Austrian law. It is applicable to all tunnels with a length exceeding 500 m of the primary road network (federal roads). The road tunnel safety law defines the following measures for the transport of dangerous goods:

- Prior to the definition or modification of regulations and requirements regarding the transport of dangerous goods through a tunnel, a risk analysis is to be performed.
- To enforce the regulation, appropriate signs indicating alternative routes are to be posted ahead of the last possible exit before the tunnel and at tunnel entrances, to allow drivers to choose alternative routes.
- In individual cases, specific operating measures designed to reduce the risks related to some or all of the vehicles transporting dangerous goods in tunnels are to be checked subsequent to the risk analysis, e.g. passage in convoys escorted by accompanying vehicles.

ADR 2007 / 2009
When the European Agreement concerning the International Carriage of Dangerous Goods by Road [3], commonly known as ADR was amended in 2007, so called tunnel restriction codes were introduced for all dangerous goods**.** These tunnel restriction codes serve as a basis for a uniform European regulation governing the transport of dangerous goods though road tunnels.

Table 1 Tunnel restriction code of dangerous loads

Tunnel restriction code of the whole load	Restriction
B	Passage forbidden through tunnels of category B, C, D and E
B1000C	Passage forbidden through tunnels of category B, C, D and E; Carriage where the total net explosive mass per transport unit exceeds 1000kg: Passage forbidden through tunnels of category B, C, D and E
B/D	Tank carriage: Passage forbidden through tunnels of category B and C Other carriage: Passage forbidden through tunnels of category D and E
B/E	Tank carriage: Passage forbidden through tunnels of category B, C and D; Other carriage: Passage forbidden through tunnels of category E
C	Passage forbidden through tunnels of category C, D and E
C5000D	Carriage where the total net explosive mass per transport unit: - Exceeds 5000kg: Passage forbidden through tunnels of category C, D and E - Does not exceed 5000kg: Passage forbidden through tunnels of category D and E
C/D	Tank carriage: Passage forbidden through tunnels of category C, D and E; Other carriage: Passage forbidden through tunnels of category D and E
C/E	Tank carriage: Passage forbidden through tunnels of category C and D and E; Other carriage: Passage forbidden through tunnels of category E
D	Passage forbidden through tunnels of category D and E
D/E	Bulk or Tank carriage: Passage forbidden through tunnels of category D and E; Other carriage: Passage forbidden through tunnels of category E
E	Passage forbidden through tunnels of category E – Passage allowed through all tunnels (for UN Nos. 2919 and 3331, see also 8.6.3.1)

If restrictions regarding the passage of vehicles transporting dangerous goods through a tunnel shall be

applied (passage forbidden), the relevant authority shall assign the road tunnel to a category defined in the ADR (new tunnel regulations valid as per 1st of January 2010).

Table 2 Tunnel categories and signature

Tunnel categories	Restrictions	Sign	Traffic Sign
A	No restrictions for the transport of dangerous goods	No sign	-
B	Restriction for dangerous goods which may lead to a **very large explosion**	Sign with additional panel bearing the letter B	
C	Restriction for dangerous goods which may lead to a **very large explosion, a large explosion or a large toxic release**	Sign with additional panel bearing the letter C	
D	Restriction for dangerous goods which may lead to a **very large explosion, to a large explosion, to a large toxic release or to a large fire**	Sign with additional panel bearing the letter D	
E	Restriction for all dangerous goods other than UN Nos. 2919, 3291, 3331, 3359 and 3373	Sign with additional panel bearing the letter E	

DEVELOPMENT OF RISK ANALYES IN AUSTRIA

In Austria there are currently two tunnel risk models, which are applied on a regular basis. One is the Austrian Tunnel Risk Model "TuRisMo" [7] and the other one is the international dangerous goods assessment model "DG-QRAM" [6] developed of OECD/PIARC.

Austrian Tunnel Risk Model (TuRisMo)

The Austrian Tunnel Risk Model – TuRisMo is a quantitative, system-related method focusing on mechanical accidents and realistic fire scenarios. This model was developed to permit a quick and efficient risk class allocation for standard tunnels. In 2008, this method was published as Austrian guideline (RVS 09.03.11) and has subsequently been used on numerous occasions. This method meets all the requirements stipulated in Article 13 of the EU Directive.

OECD/PIARC Model (DG-QRAM)

The international risk model DG-QRAM was developed on behalf of OECD/PIARC to assess the risk involved in transporting dangerous goods on defined transport routes (tunnels or open road sections). It is widely used on an international basis, but is obviously not the only method available for assessing the risk resulting from the transport of dangerous goods.
The results of the risk analysis are depicted as "Expected Values (EV)" or "F-N curves", illustrating the relation between accident frequency and accident consequences (graph in a diagram). Whereas the expected value (EV) represents the average expected number of fatalities as a result of all accidents involving dangerous goods the F-N curve gives more comprehensive information on the extent of damage in relation to the probability of individual accidents.

DEVELOPMENT OF A UNIFORM RISK ASSESSMENT PROCESS FOR DG TRANSPORTS

In the year 2009, the Austrian Federal Ministry for Transport, Innovation and Technology (BMVIT) launched a research project with the objective of establishing a uniform investigation and assessment

procedure concerning risk analyses for dangerous goods (using DG-QRAM). This research project is exclusively focused on assessing the risk of dangerous goods accidents (mechanical accidents and conventional fires are addressed by the risk model TuRisMo). The final results shall be presented in an Austrian guideline update which is scheduled to be published in the year 2010. This research project serves the purpose of defining a clearly structured risk assessment process in line with the new ADR tunnel regulations, based upon reliable dangerous goods data. In the course of this project, risk reference criteria for every step of the assessment process have to be laid down. This research project is supported by a work group comprising technical and legal experts of the BMVIT and the Austrian Ministry of Internal Affairs, the Austrian federal provinces, the Austrian Chamber of Commerce, the ASFINAG, the fire brigade, the transport industry as well as ILF Consulting Engineers.

Data Basis

In this research project great emphasis was put on the data basis. In 2006 and 2007, investigations of DGs transports were carried out at 12 different cross-sections on Austria's main traffic routes. In March 2009, the results of these earlier investigations were evaluated and expanded by a detailed review of DG transports in cooperation with the Austrian Ministry of the Interior. The second investigation delivered precise information about the UN number, the amount, type and destination of the dangerous goods transports which allows a much better allocation of the composition of DG transports to the accident scenarios of the risk model.
In addition, the results revealed that in Austria the composition of the dangerous goods transported varies only slightly on different traffic routes and that these variations have only little influence on the risk faced by tunnel users. A standardized composition of DGs transports on Austria's main roads could hence be defined as a basis for the risk analysis.

Definition of Assessment Process for Austrian Road Tunnels

In principle, the risk involved in the transport of dangerous goods is determined in a multi-stage assessment process.

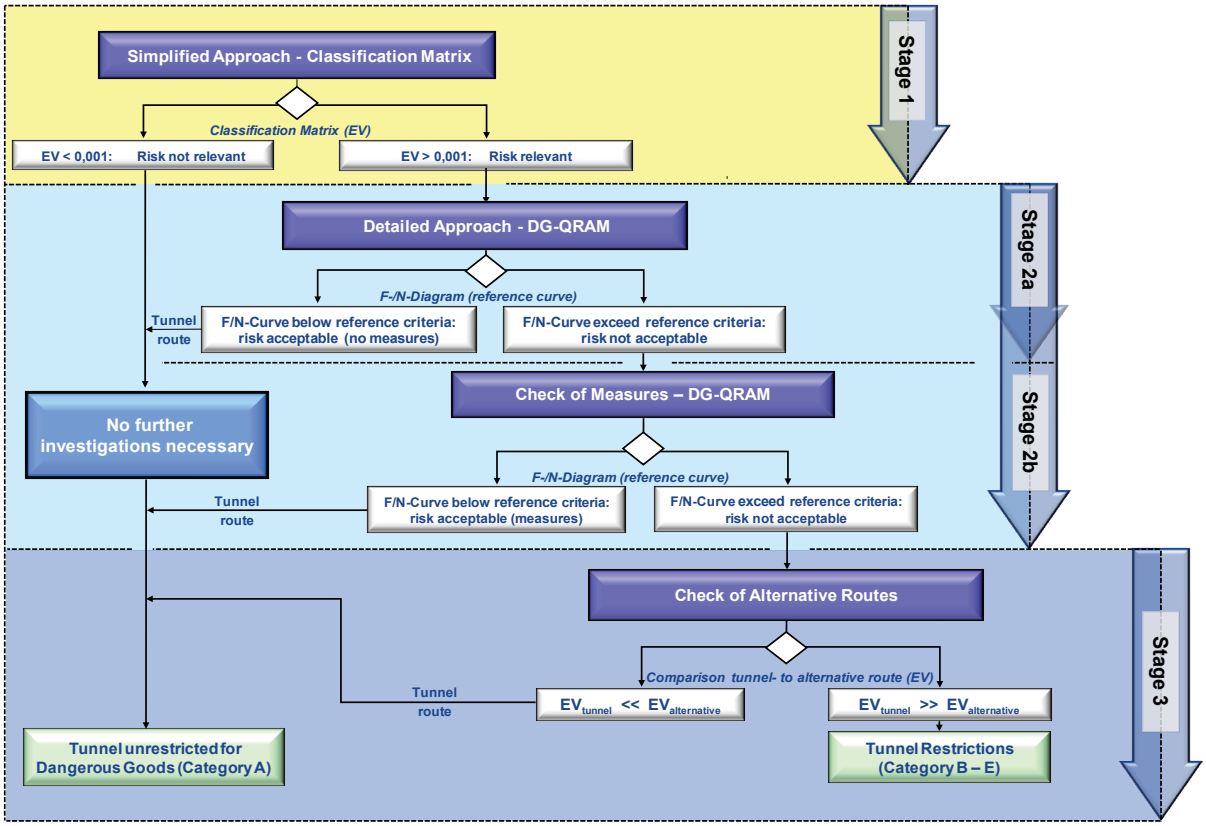

Figure 2 Process for assessment of DG transport risk in road tunnels

Stage 1 – Classification Matrix (Simplified Approach)

The process starts out with a simplified assessment (stage 1). Stage 1 shall permit a simple identification of tunnels with a low dangerous goods transport risk, considering the type of tunnel (bidirectional or unidirectional traffic), the ventilation system, the traffic volume and the percentage of heavy goods vehicles. The respective parameters of the matrix were defined in a former study performed in 2008 by systematic risk calculation for selected reference tunnels using DG-QRAM. As relevance criteria an expected risk value of 1 x 10^{-3} fatalities/year was applied for the elaboration of the classification matrix. The first evaluation revealed, that as a result of this simplified assessment, approximately half of the road tunnels in Austria require no further detailed risk analysis. These tunnels could, in line with the ADR, directly be allocated to tunnel category A.

Type of Traffic	Ventilation System	Tunnel length	Traffic Volume [veh/day]																	
			≤ 5000	≤ 10000				≤ 15000					≤ 20000					≤ 30000		≤40000
	HGV [%]		≤ 25	≤ 10	≤ 15	≤ 20	≤ 25	≤ 5	≤ 10	≤ 15	≤ 20	≤ 25	≤ 5	≤ 10	≤ 15	≤ 20	≤ 25	≤ 5	≥ 10	≥ 5
uni-directional	longitudinal	≤ 700																		
	longitudinal	≤ 1000																		
	longitudinal	≤ 1500																		
	longitudinal	≤ 2000																		
	longitudinal	≤ 2500																		
	longitudinal	≤ 3000																		
	transverse	≤ 4000																		
	transverse	≤ 7000																		
bi-directional	natural	≤ 700																		
	natural	≤ 1000																		
	longitudinal	≤ 1500																		
	longitudinal	≤ 2000																		
	longitudinal	≤ 2500																		
	transverse	≤ 3000																		
	transverse	≤ 4000																		
	transverse	≤ 7000																		

Figure 3 Classification matrix

Stage 2 – Detailed Approach (DG-QRAM)

All those tunnels which indicate a relevant dangerous goods risk during the simplified approach are subsequently reviewed in a detailed, tunnel-specific risk analysis using the DG-QRAM model (Stage 2a). In Stage 2, a comparison with a defined reference criterion is made in the F-N diagram for the tunnel system under evaluation.

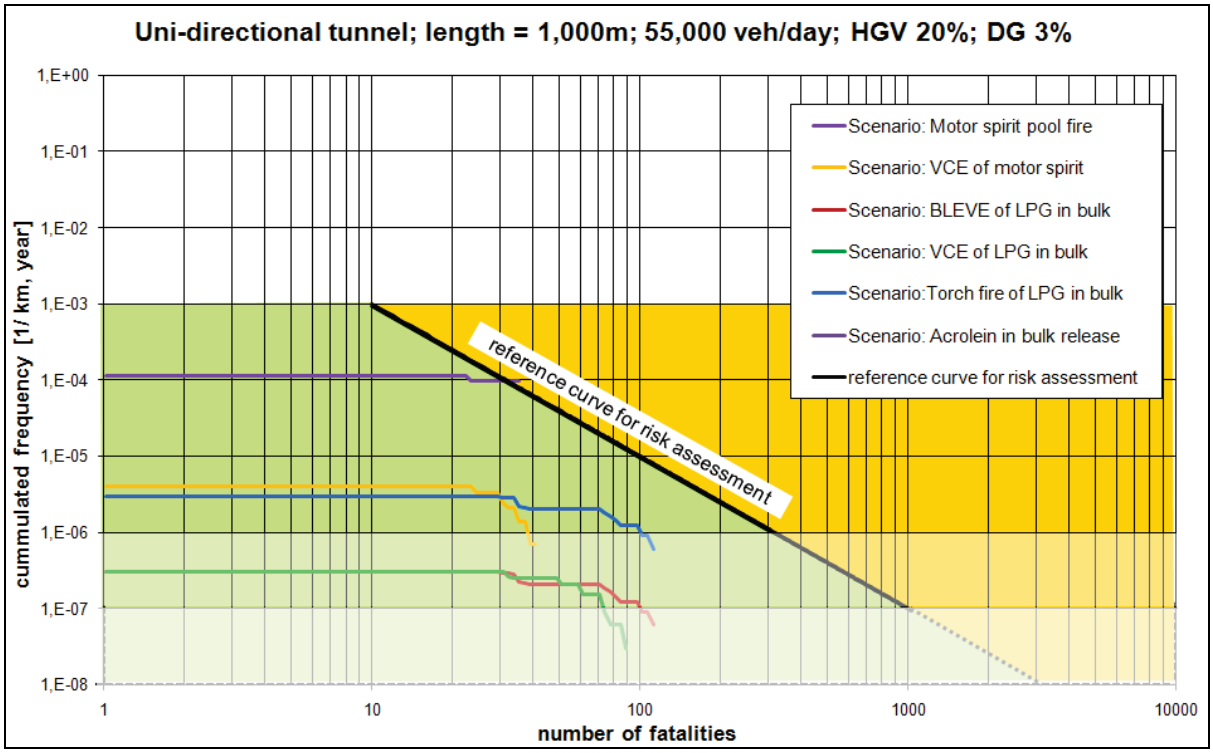

Figure 4 Reference curve as assessment criteria in the F-N diagram (example)

If the reference criterion in the F-N diagram is exceeded, the dangerous goods risk is rated as unacceptable and special additional risk reduction measures are to be investigated (Stage 2b). Considerations made to improve traffic safety predominantly focus on organisational and operational measures. In this context it is to be pointed out that not every measure is equally suited or efficient. The envisioned measures will thus have to be checked individually for the respective tunnel system in an in-depth risk analysis. The current Road Traffic Regulations [4] issued by the BMVIT, Federal Law Gazette 395/2001 [5], use two different categories for motorways:

- Tunnels with a length between 1,000 m and < 5,000 m:
  Flashing warning light

- Tunnels with a length of > 5,000 m:
  Flashing warning light,
  Escort vehicle following the transport unit and
  Distribution of transport documents to the personnel of the escort vehicle

Additional operational measures aimed at reducing the transport risk of dangerous goods, which have to be checked individually for each tunnel, may for example include:

- Introduction of an overtaking ban
- Introduction of a speed limit
- Installation of an information system
- Installation of a speed control system (”Section Control“)
- Installation of a headway control system

Stage 3 – Alternative Route

As a last possible measure, tunnel restrictions for certain substances, possibly with a transportation time limit may be declared (Stage 3 – Checking of Alternative Routes). In this case it is to be checked, whether an adequate alternative route actually exists. A road only qualifies as alternative route if the entire road segment is suited and approved for heavy goods traffic. This requires such aspects as number of lanes, longitudinal gradient, curve radii, road width, etc. to be reviewed on a case-to-case basis.
Additionally, proof has to be furnished that the transport of dangerous goods on the bypass road entails a significantly lower risk for the resident population than the unrestricted transport through the tunnel for the tunnel users and the population living near the tunnel portal.

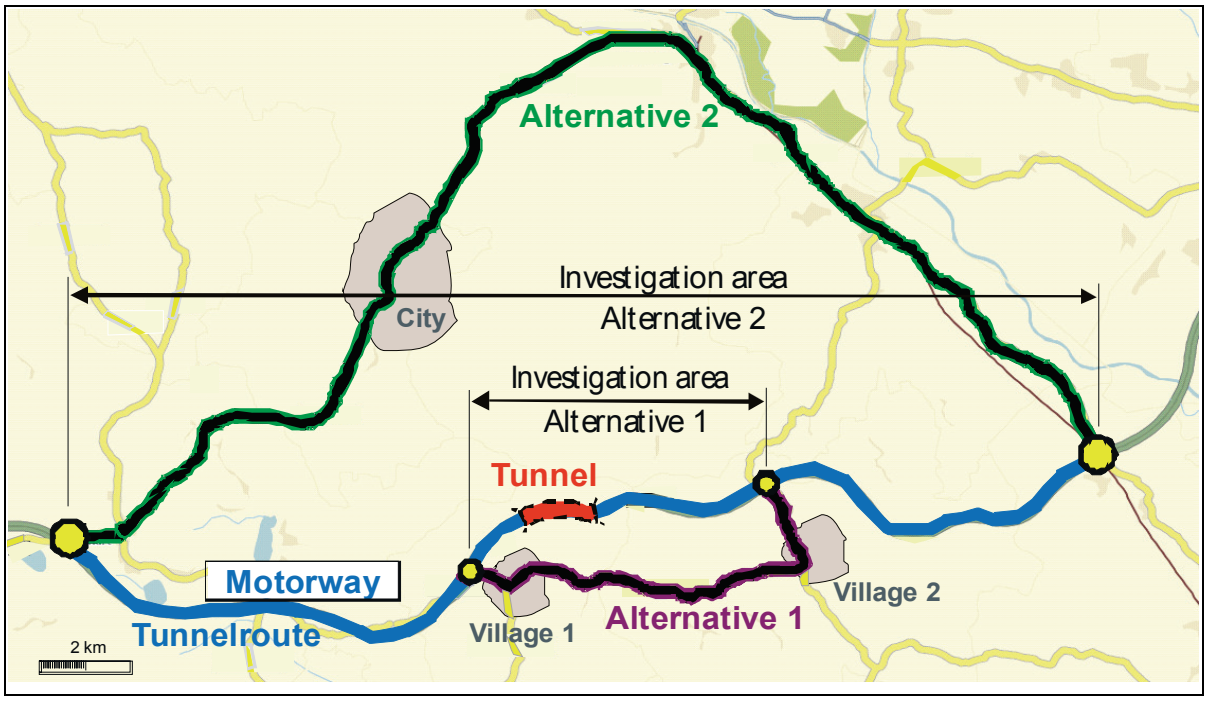

Figure 5 Alternative route

DEFINITION OF RISK CRITERIA

As mentioned before the societal risk is usually expressed in a graph (F-N diagram). An assessment of the societal risk can be made, based upon a risk relevance curve which is often determined specifically for the project in question to determine whether the safety level is acceptable or not.
Officially established risk limit curves are for example used in Switzerland, where reference is made to the Swiss Accidents Ordinance [8] or in the Netherlands [9].

Reference curve for risk assessment

For the detailed assessment (stage 2), a reference curve based on empirical values in the F-N diagram is used as assessment criterion (see Figure 4).

For N ≥ 10 fatalities:

$$F = \frac{10^{-1}}{N^2} \qquad (1)$$

The gradient of the curve reflects the risk aversion level: If the number of fatalities increases by a factor of 10, the acceptable occurrence frequency decreases by a factor of 100. By adopting this approach, more stringent criteria are applied when rating accidents causing a substantial damage.

Adjustment of the reference curve against the tunnel length

A risk assessment based upon the defined reference curve requires a standardised tunnel length of 1 km, as the reference criterion $F = 10^{-1} / N^2$ is always based on 1 km. For the assessment criterion to be used in the F-N diagram, an adjustment to the length of the tunnel has to be made. As, with accidents involving dangerous goods, the length of the tunnel is an especially critical factor, this adjustment shall not be linear but depending on the length of the tunnel. This adjustment is taken into account by the implementation of a root function on the tunnels length in equitation (2).

For $N \geq 10$ fatalities:

$$F = \frac{10^{-1}}{N^2} \times L^x \quad \textit{(draft)} \tag{2}$$

To evaluate the reference criterion DG transport risks of typical road tunnels in Austria were calculated and assessed in the F-N diagram (empirically procedure). The final appointment of the reference curve and specially the exponent's value is still under discussion in the work group, thus the equitation for the reference curve has to be considered only as a proposal at the current stage.

INTERNATIONAL DEVELOPMENT TRENDS

In Austria, the development of a uniform process for the assessment of dangerous goods risks has reached a rather advanced level; a corresponding RVS draft is currently being prepared and will be published in 2010. In view of the special boundary conditions encountered in Austria (where often no alternative route is available), an effort is made to largely keep the dangerous goods traffic on the motorway network.
At the moment the BGBl. II No. 395/2001 already stipulates operational requirements for the passage of dangerous goods vehicles (→ orange warning light for tunnels >1,000 m; escort vehicle for tunnels > 5,000 m). Since from the legal perspective of the BMVIT, this Ordinance only regulates (not restricts) DG vehicles passing through the tunnel, Austria holds the view that the already existing exemption clause of the ADR, will also be effective beyond January 1st 2010, at least as long as no ADR passage restriction for dangerous goods will be issued. There would still not be any need to indicate the tunnel restriction code in the transport documents of the DG transport.
Starting in 2010, a road tunnel assessment initiative could be launched. Only then will it be possible to decide, whether Austria will be able to do without the introduction of tunnel passage restrictions for dangerous goods.

In France, all tunnels with a length exceeding 300 m are already subjected to a dangerous goods transport risk assessment using the DG-QRAM software. In those cases, in which the defined reference threshold value is surpassed, an alternative route investigation (i.e. checking of tunnel restrictions for dangerous goods) is initiated immediately. Greece decided to adopt a similar approach as France. In both countries, numerous ADR tunnel restrictions are expected to be imposed.

In Germany, a comprehensive tunnel investigation campaign is currently performed using DG-QRAM; if the defined threshold value is exceeded, an in-depth analysis or even an alternative route selection process is performed. It is currently to be assumed that for some tunnels, restrictions in line with the ADR will be imposed. This will mainly be applicable to those tunnels for which restrictions have already been put in place (e.g. Elbtunnel, Rennsteigtunnel, etc.)

Switzerland is about to introduce a network-wide risk analysis process to implement the ADR regulations. In order to be able to maintain existing tunnel restrictions until the assessment process is available to be applied, tunnels with existing restrictions are allocated to category E (= complete ban for dangerous goods transports). In total, this affects 15 tunnels in the Alps, including three with a limited time restriction. In 2010, Switzerland will start a network-wide investigation of all road tunnels, using a risk-based assessment process, which may ultimately lead to a re-assignment of the 15 road tunnels, which are currently classified as category E.

In the remaining European countries, a restriction for the transport of dangerous goods through road tunnels in line with the ADR requirements is partially to be expected. In general, an international tendency can be observed, that the lower the number of road tunnels in a nation, the more stringent the restrictions issued for dangerous goods transports. Countries like Sweden, Denmark or England allocate road tunnels to ADR's risk categories in most instances without conducting a risk-based approach (risk analysis). This approach frequently leads to a general ban for the transport of dangerous goods through road tunnels (tunnel category E) or quite often to transportation time restrictions (e.g. the Netherlands, partially Germany etc).

INTERNATIONAL OUTLOOK

It can generally be assumed that these new tunnel regulations will be implemented all over Europe. Yet this implementation process will not be completed in all countries by the 1st of January 2010, as especially in countries with a great number of road tunnels, the network-wide risk assessment process and the assignment to risk categories will take some time to be finalized.

Thus current development trends of the transport industry ought to be observed and taken into account even on a short-term basis. The transport industry is likely to face certain additional costs for the transport of dangerous goods, as alternative routes tend to result in longer transport times and longer transport distances.

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