Quantitative risk analysis model

Professor Hermann Knoflacher, Technical University Vienna, describes a quantitative risk analysis model for the transport of dangerous goods through tunnels.

Increasing transport volumes on roads is the result of the economic development in our societies and improvements in the road infrastructure. However, the public is becoming more sensitive towards traffic noise and air pollution. Therefore, more sections of new roads are being built in tunnels, although there is no need from a topographical point of view. Number, type and length of tunnel sections are increasing worldwide.

The chemical industry is an innovative branch of the industrial sector. The number and type of goods on roads are also increasing. Public awareness of the risk associated with the transport of dangerous goods is growing, too.

Different countries have different regulations for the transport of dangerous goods through tunnels, and in some countries different tunnel operators have their own regulations. So far there is no common mechanism to deal with the problem internationally. Consistent international regulations would make it easier for the transport sector to get information about how to use the road network and under what conditions.

To contribute to this goal, the PIARC tunnel committee and the Road Research Division of the OECD established a scientific expert group which organised and monitored the development of the Quantitative Risk Assessment Model (QRAM). An external consortium of consultants developed the software model.

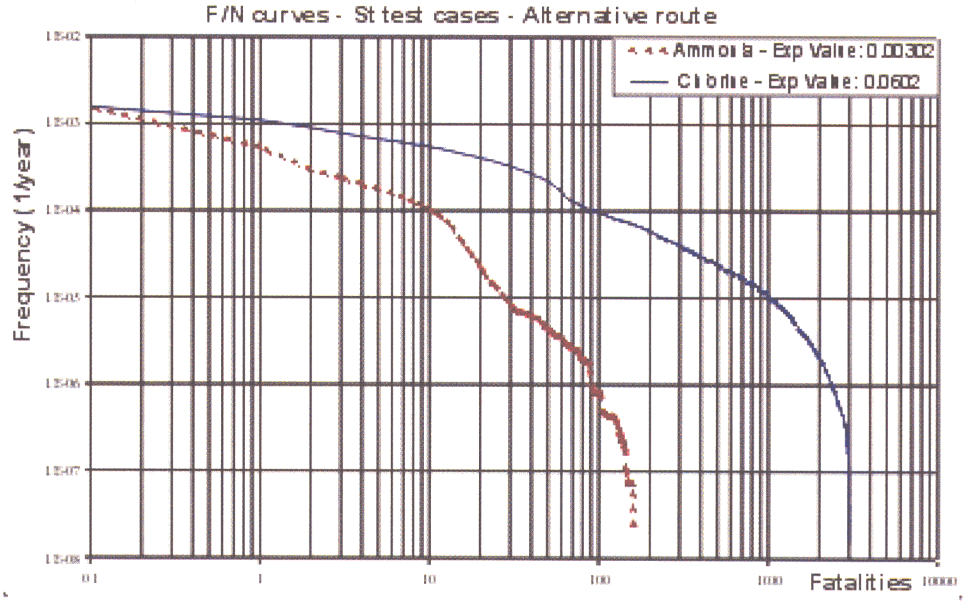

Figure 1: Example of F/N curves for two different scenarios for a given road section.

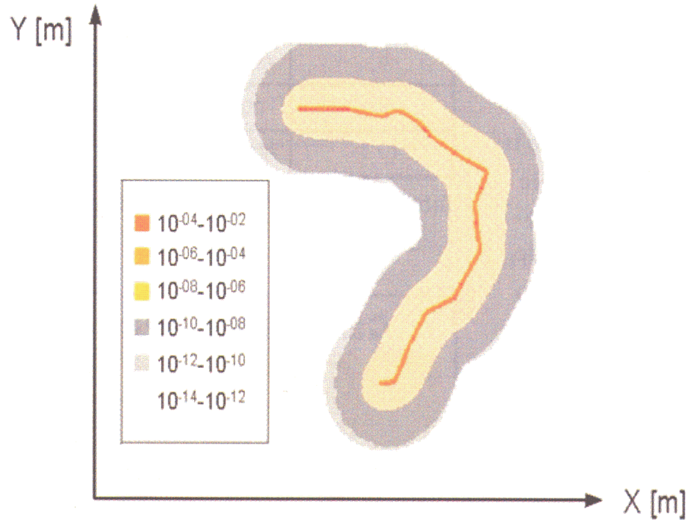

Figure 2: Example of an iso-risk contour.

Complexity of the problem

Due to the complexity of the problem (a large number of variables, including: type of dangerous good, road and tunnel conditions, traffic composition, speed management, environment, wind, population, etc.), it is necessary to define indicators which represent the

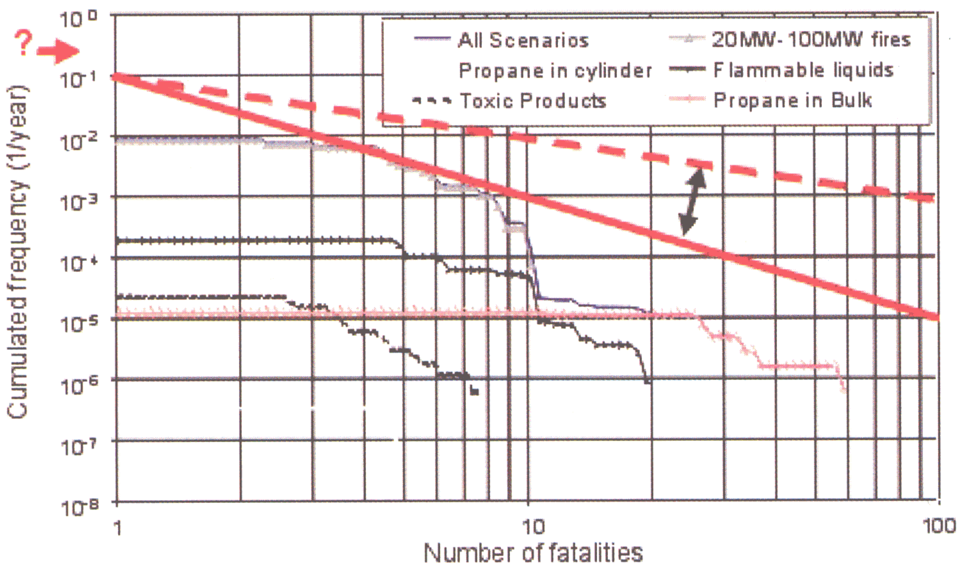

Figure 3: Specification of position and gradient of the line to define the intolerable risk.

system behaviour in an accurate way. The main indicator for the system is 'Risk', defined in general as:

Risk = Probability x Consequences

Risk can be divided into:

- *Societal Risk*, described in F/N curves (see Figure 1).
- *Individual Risk*, given in absolute numbers.

The individual risk can be calculated in two dimensions to visualise the effect for the population along the road (see Figure 2).

When these indicators are available it is necessary to specify what is tolerable from the point of the society and what risk level can be neglected. Society has a different approach to accidents depending on the number of victims. Ten accidents with one victim has a different magnitude for politicians than one accident with 10 victims. This estimation has to be done by the decision-makers or an expert group drafting some recommendations.

The position and the gradient of the line have to be specified. In the same way, the area for negligible risk has to be specified (see Figure 3). The area between these two lines is called the ALARP region (As Low As Rational Possible). If the calculation shows results in this area, measures have to be introduced to lower the risk level as much as possible

Necessary input data to run the model

There are two possibilities (levels) for using the model: the normal user and the expert user. In both cases detailed descriptions of the tunnel and open sections are needed. If one relevant variable changes, a new section has to be defined. The same has to be done

Scenario Nr.	Description	Capacity of tank	Size of breach (mm)	Mass flow rate (kg/s)
1	HGV fire 20 MW	-	-	
2	HGV fire 100 MW	-	-	
3	BLEVE of LPG in cylinder	50 kg	-	
4	Motor spirit pool fire	28 tonnes	100	20.6
5	VCE of motor spirit	28 tonnes	100	20.6
6	Chlorine release	20 tonnes	50	45
7	BLEVE of LPG in bulk	18 tonnes	-	
8	VCE of LPG in bulk	18 tonnes	50	36
9	Torch fire of LPG in bulk	18 tonnes	50	36
10	Ammonia release	20 tonnes	50	36

Table 1: Scenarios chosen for the calculations.

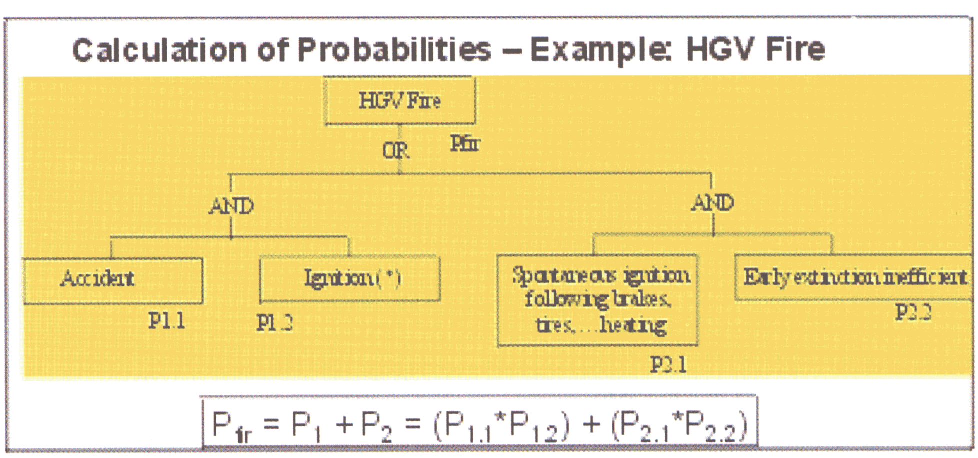

Figure 4: Example of an event tree.

for the detour route.

Information about traffic includes: data on average daily traffic flows, peak hour volumes, etc.; number of heavy good vehicles; number of vehicles with dangerous goods; and the kind of goods. Accident data from local statistics have to be used. Also, wind conditions, tunnel ventilation, drainage systems, escape and sheltering installations, etc., have to be provided. Scenarios to represent different kinds of dangerous goods were chosen by the OECD-PIARC Expert Group (see Table 1). Additional scenarios can be added to the program.

For each of the scenarios an event tree was developed to calculate the probabilities for different circumstances and conditions. Figure 4 shows an example for a simple case. The right part of the event tree represents, e.g., the type of incident which caused the Mont Blanc tunnel fire, the left part of the event tree represents the type of incident which caused the Tauern Tunnel accident.

An important part of the work was the estimation and calculation of Dangerous Good – Heavy Good Vehicle scenario rates. This part was carried out by the University of Waterloo and is based on statistical data from France, Canada, United States, Norway and Great Britain. Table 2 show some of the results which can be used in the program.

Consequences for the different scenarios are calculated for fatalities and injury probits, based on the physical effects for the specified scenarios. Figure 5 show an example of evolution of probits versus distance from the spot of accident for fatalities and injuries.

A rough assessment of physical damage to the construction is made in four categories:

- Tunnel structure (collapse or structural integrity problem).
- Internal civil structures including road-way (general integrity is not an issue).
- Damage to protected equipment.
- Damage to unprotected equipment, e.g., lighting.

Based on empirical data the model also produces information about the financial consequences, (reinstatement cost) as a percentage of construction costs, related to the damage category.

Environmental effects on air, water and ground are estimated in a simple procedure.

Important for practitioners is the opportunity to calculate the effects of shelter and/or escape measures and other mitigating measures, which can be done by using this program (see Figure 6).

	Scenario	DG Type	Load	Urban Open	Rural Open	Urban Tunnel	Rural Tunnel
Scenario	Scenario Characteristics			Scenario Rates			
BLEVE of Propane in Cylinder	3	2	Small	4.3E-04	8.0E-04	1.7E-03	5.1E-03
Pool Fire of Motor Spirit	4	3	Large	2.7E-03	4.5E-03	2.8E-03	2.0E-02
VCE of Motor Spirit	5	3	Large	2.7E-04	4.5E-04	2.8E-04	2.0E-03
Chlorine Release	6	1	Large	3.1E-02	5.4E-02	3.1E-02	5.4E-02
BLEVE of Propane in Bulk	7	2	Large	2.3E-04	4.2E-04	2.8E-04	2.0E-03
VCE of Propane in Bulk	8	2	Large	2.3E-04	4.2E-04	2.8E-04	2.0E-03
Torch Fire of Propane in Bulk	9	2	Large	2.3E-03	4.2E-03	2.8E-03	2.0E-02
Ammonia Release	10	1	Large	3.1E-02	5.4E-02	3.1E-02	5.4E-02

Table 2: Dangerous Good – Heavy Good Vehicle scenario rates.

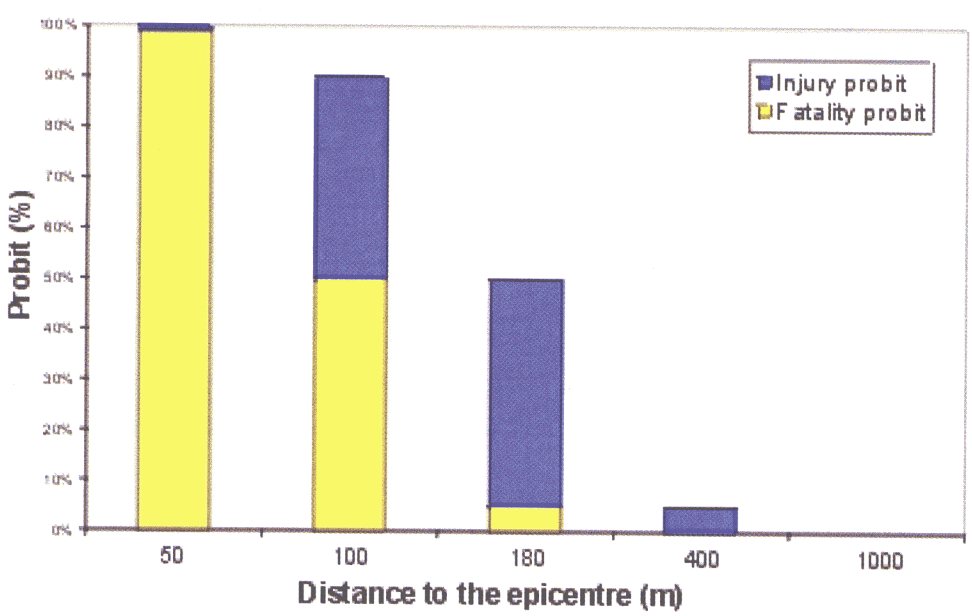

Figure 5: Fatalities and injuries.

Which measures are covered by the model?

In principle, all measures which can be represented by the set of parameters of the model can be determined. These measures can be:

- regulations concerning the kind of vehicles which are not allowed in the tunnel.

- regulations concerning the traffic flow (speed, convoy, distance between vehicles, etc.).
- tunnel equipment and information system.
- other measures, depending on the expert knowledge.

Output Data

- F/N curves for the Societal Risk for fatalities and injuries for:
  - the tunnel route.
  - the detour route.
- individual risk in a 2-D presentation.
- consequences for structures.
- consequences for the environment.
- input data for the Decision Support Model (which was also developed by this scientific expert group).

What can this model be used for?

The QRAM model can be used:

- to support expert knowledge with the quantitative risk assessment.
- to analyse system behaviour under different circumstances (forecast, different construction parameters, e.g., single/twin-bore tunnels, etc.).
- to save money on field tests, if data from existing tests are available (better and more specific planning of tests, or to replace a test by using the model, etc.).
- better and/or more cost effective design of tunnels.
- supporting rational decisions.
- development of international standards for the transport of dangerous goods through tunnels on an international and comparable scientific basis.

Practical experience

The model was tested by a group of expert users from five European countries on a wide variety of tunnels. The feedback from this validation

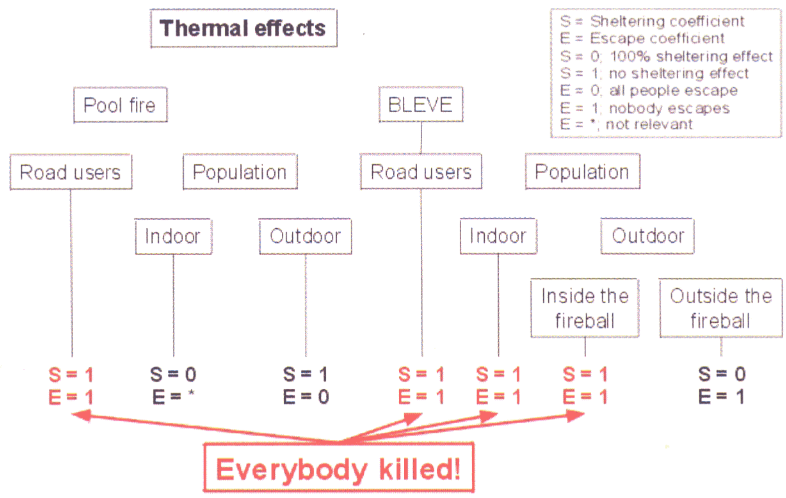

Figure 6: Event tree for the calculation of the effects of escape, shelter or mitigating measures.

Figure 7: The Vienna test tunnel.

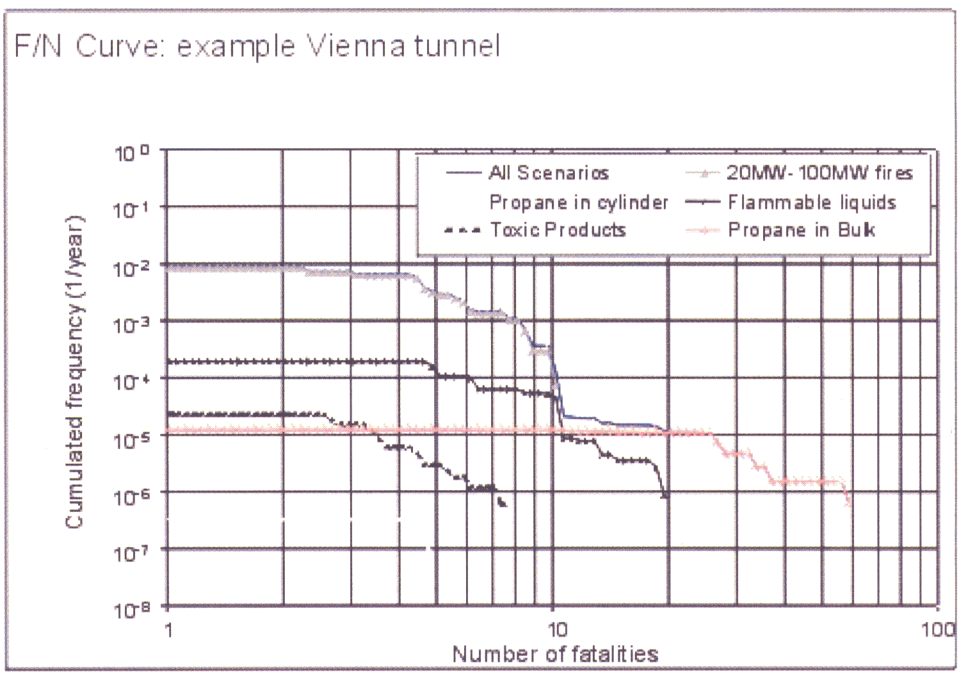

Figure 8: F/N curves for the Vienna test tunnel.

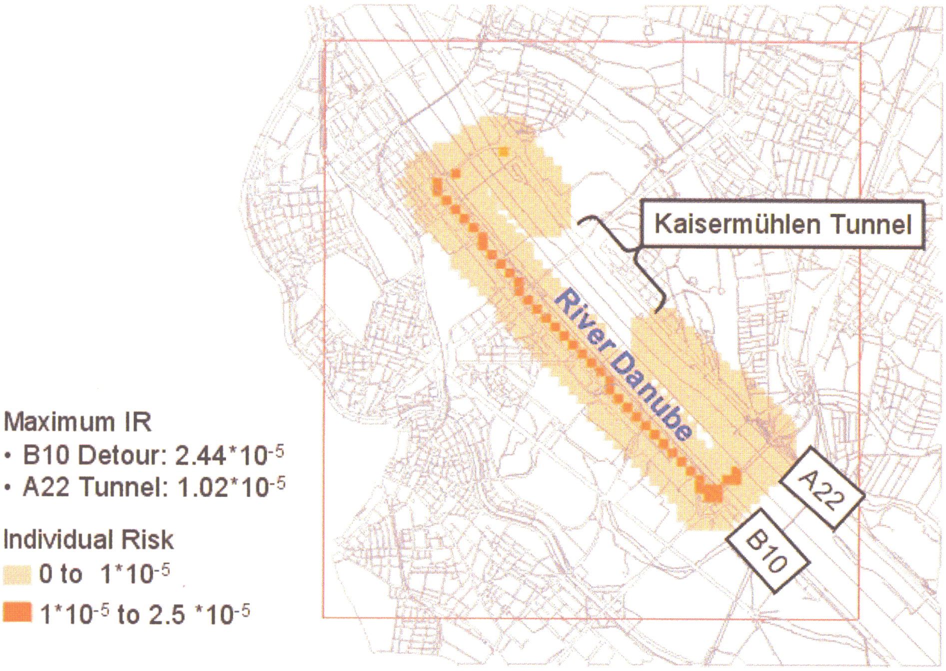

Figure 9: Iso-risk contour for the Vienna test tunnel.

group enabled the model developers to improve the model for practical use. This input finally lead to a so-called 'final version' of the model ('State of the art 2000' would be the better term) which is now available.

Figures 7-9 show some results from the Vienna test case, a twin-bore, cut-and-cover tunnel with heavy traffic and also a number of heavy good-dangerous good vehicles)

Reference

P. Cassini, R. Hall and P. Pons (2001), Transport of Dangerous Goods through Road Tunnels – Quantitative Risk Assessment Model Reference Manual, OECD/PIARC/EU, March.

About the author

Professor Hermann Knoflacher is the Head of the Institute for Transport Planning and Traffic Engineering, University of Technology Vienna. Between 1970-1983, he was the Head of the Institute for Transport, Austrian Road Safety Board.
His main areas of research are in the design of transport elements; transport system user behaviour; traffic-infrastucture and mobility; sustainable development of cities and mobility; traffic safety; energy-consumption; environment; and basic interdisciplinary research
Professor Knoflacher has written five books, more than 400 scientific publications, and given 500 expert opinions and more than 1000 lectures in the field of transport planning and traffic engineering.