Quantitative Risk Analysis Model for Transport of Dangerous Goods through Tunnels

Joint Project of OECD and PIARC
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General Problem

- Increasing transport volume on roads is the result of the economic development in our societies and the improvements of the road infrastructure.
  If roads become congested new carriageways are provided, following traditional traffic planning principles, which try to keep car traffic flowing, more or less under all circumstances. Growth of car traffic therefore induce growth of road infrastructure and vice versa. With decreasing transport resistance which means better, faster and cheaper industry can use the advantages of the principles of "Economy of Scale". Bigger plants on fewer locations are the economic advantage on one side, longer distances in transport an more kilometres driven are the disadvantages on the other side. And the amount of car traffic ist still growing. Better road infrastucture has not only the effect of better transport, but also effects on all other fields of our life. It change all living, producing and distribution structures, it change nearly everything – also the transport if dangerous goods.
- On the other side public is becoming more sensitive toward traffic noise and air pollution. More and more section of new roads have to be built in tunnels, although sometimes there are no needs from the topographical point of view. Politicians and people think that car traffic in tunnels Number, type and length of tunnel sections are increasing worldwide.

Chemical industry is an innovative branch of the industrial sector, the number an kind of goods on roads are also increasing.
Public awareness of the risk is growing.

Different countries have different regulations for the transport of dangerous goods through tunnels and in some countries different tunnel operators have their own kind of regulations.
So far there is no common instrument to handle the problem in an international comparable way, which makes it easier for the transport sector to get information about the possibility how to use the road network and under what conditions.
To contribute to the solution 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, among other issues. The model itself was built by an external consortium of consultants.

Complexity of the Problem

Due to the complexity of the problem (many variables: 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 system behaviour in an accurate way.

The main indicator for the system is Risk, defined in general as:

Risk = Probability x Consequences

For the problem of tunnels it is defines as *Societal Risk* described in F/N curves and as *Individual Risk*, given in absolute numbers.

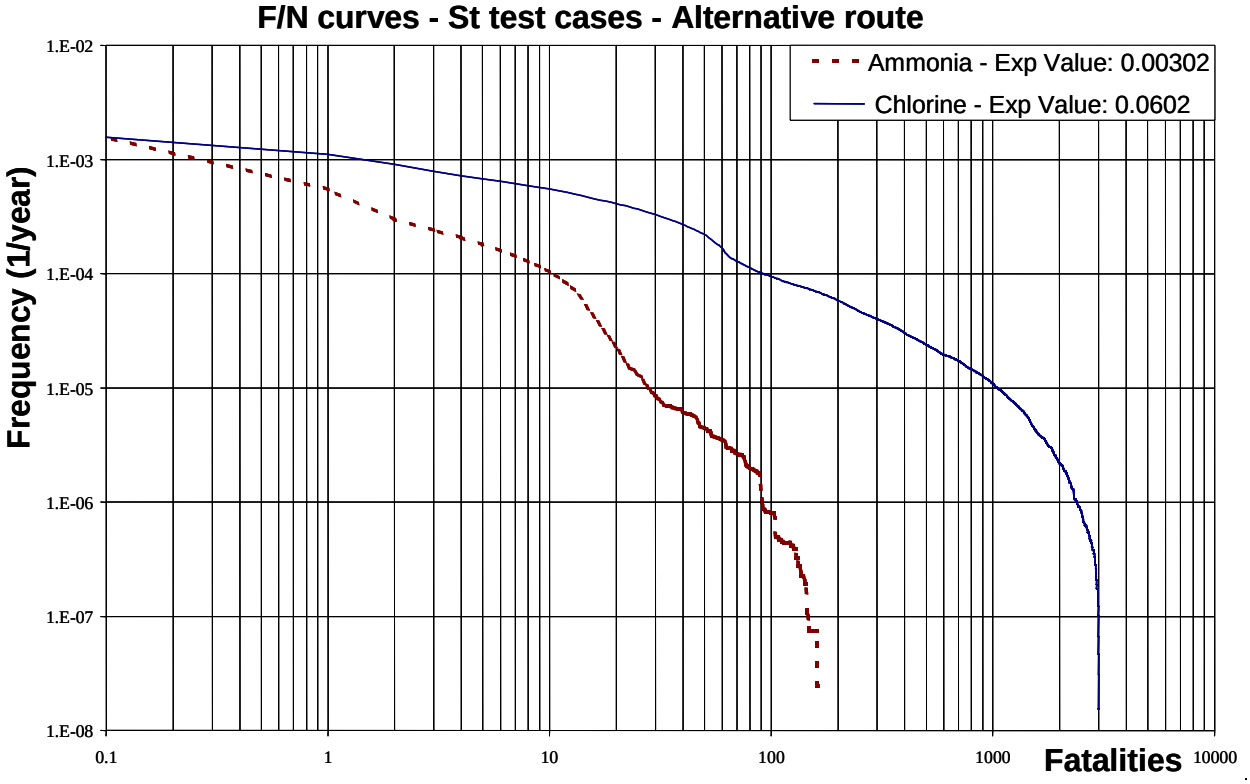


Fig.1 Example of F/N curves for two different scenarios for a given road section

The individual risk can be calculated in two dimensions to visualize the effect for the population along the road.

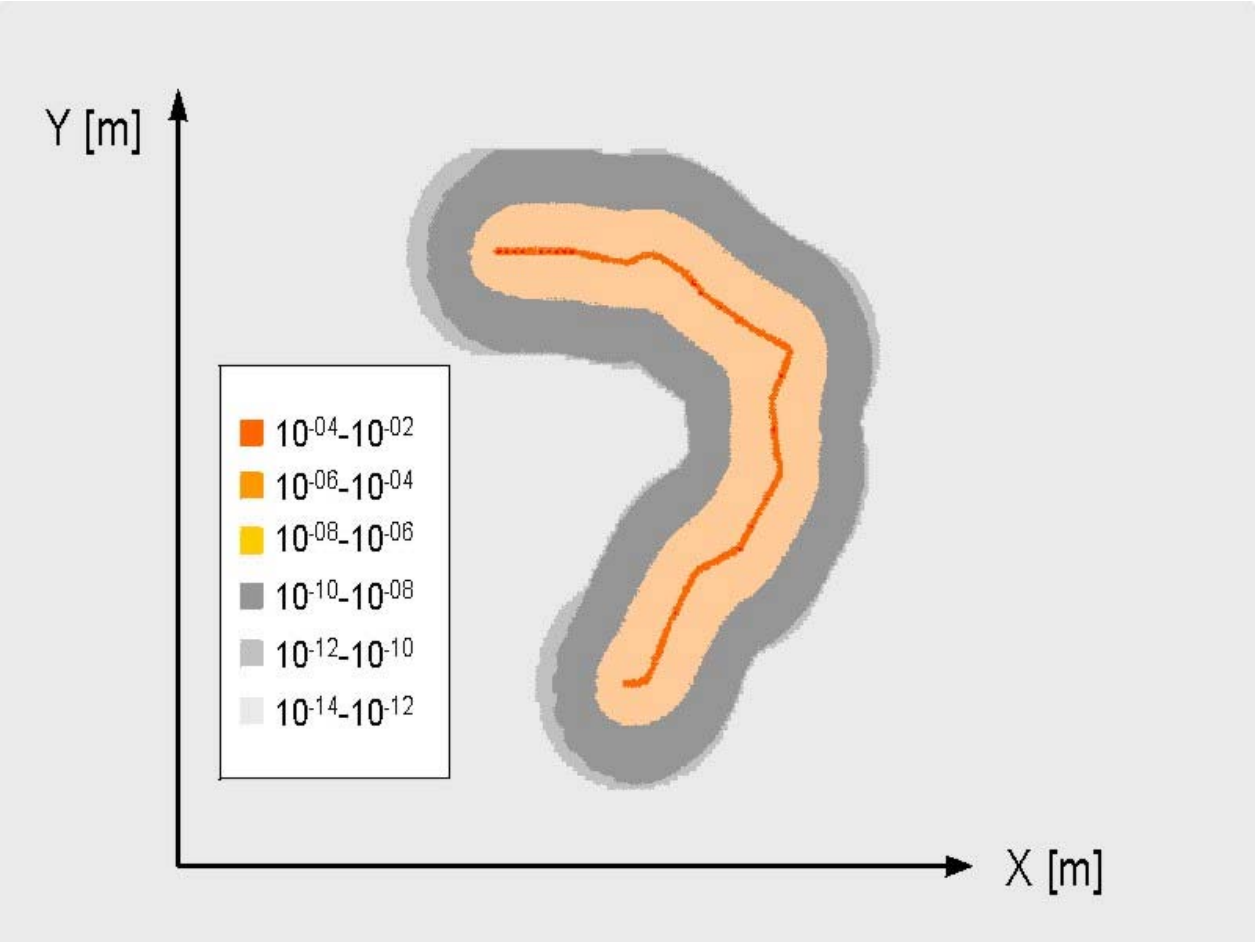


Fig 2 Iso risk contour Example

When this indicators are available it is necessary to specify what is tolerable from the point of the society and what risk level can be neglected. The society has a different approach to accidents depending on the number of victims. 10 accidents with one victim has an other magnitude for the politicians than 1 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.

Problem: Tolerable Risk ??

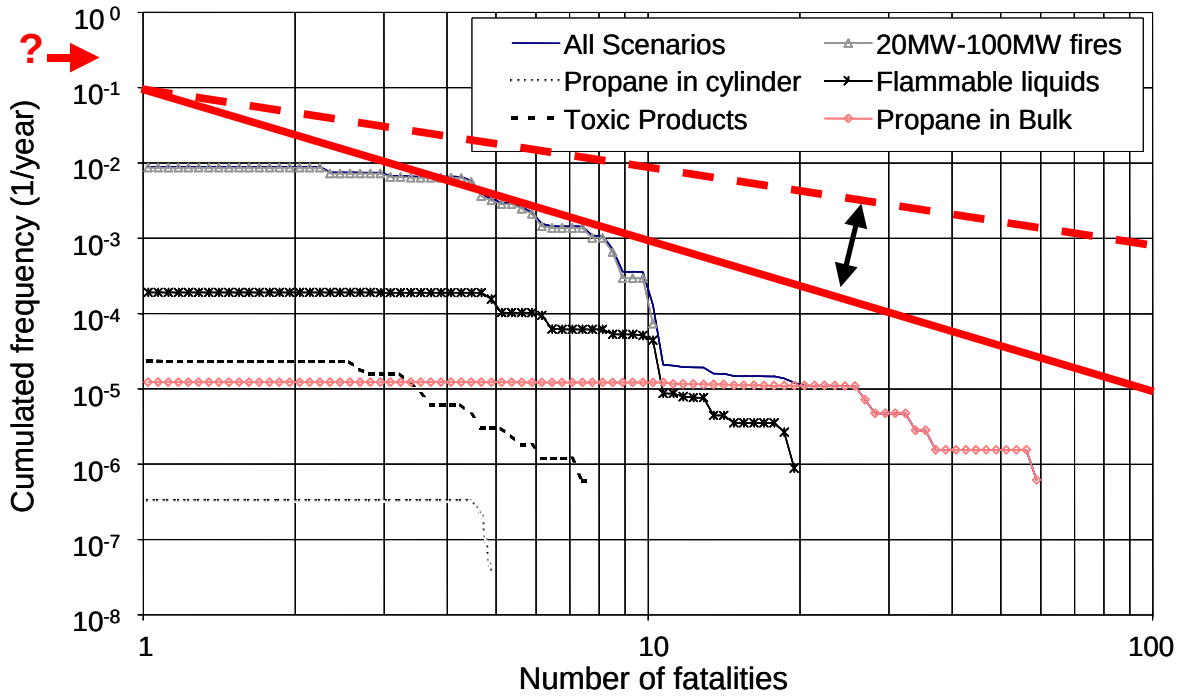


Fig.3 Specification of position and gradient of the line to define the intolerable risk.

In the same way the area for negligible risk has to be defined. The area between this two lines is called ALARP- Region. If the calculation show results in this area, measures have to be introduced to lower the risk level as much as possible. (As Low As Rational Possible)

What are the necessary input data to run the model?

There are two possibilities (levels) to use 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 change, a new section has to be defined. The same has to be done for the detour route.
Information about traffic include data on average daily traffic flows, peak hour volumes ets. Heavy good vehicles, vehicles with dangerous goods and kind of this goods. Accident data from local statistics have to be used, 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. Additional Scenarios can be added in the program.

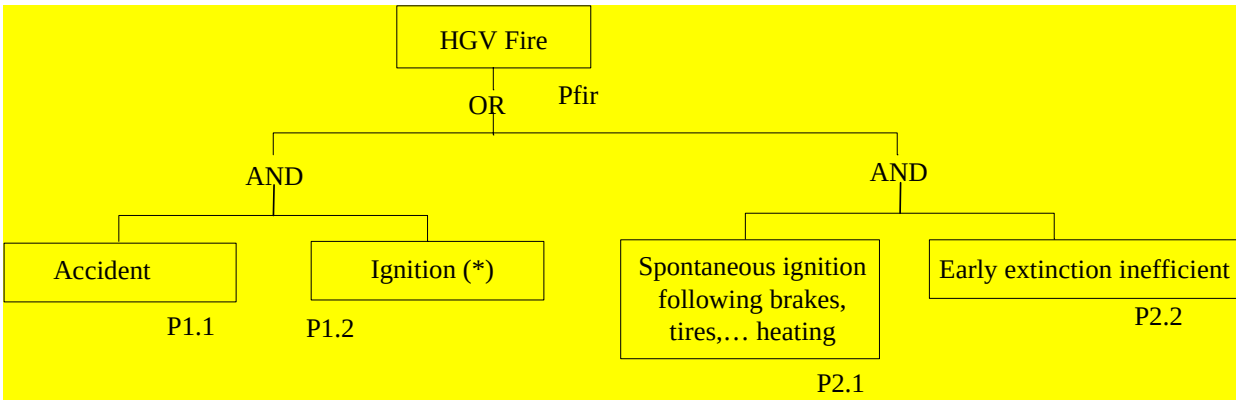
Scenario Nr:	Description	Capacity of tank	Size of breach (mm)	Mass flow rate (kg/s)
1	HGV fire 20 MW	-	-	
2	HGV fire 100 MW	-	-	
3	BLEVE of LPG in cylinder	50 kg	-	
4	Motor spirit pool fire	28 tonnes	100	20.6
5	VCE of motor spirit	28 tonnes	100	20.6
6	Chlorine release	20 tonnes	50	45
7	BLEVE of LPG in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

Tab. 1 Scenarios chosen for the calculations

For each of the scenarios an event tree was developed to calculate the probabilities for different circumstances and conditions. Fig 4 show an example for a simple case.
The left part of the event tree represent the Mont Blanc tunnel fire, the lower part of the event tree represent the Tauern Tunnel accident.

ERS2: Event trees for each scenario

Calculation of Probabilities – Example: HGV Fire



$$P_{fir} = P_1 + P_2 = (P_{1.1} * P_{1.2}) + (P_{2.1} * P_{2.2})$$

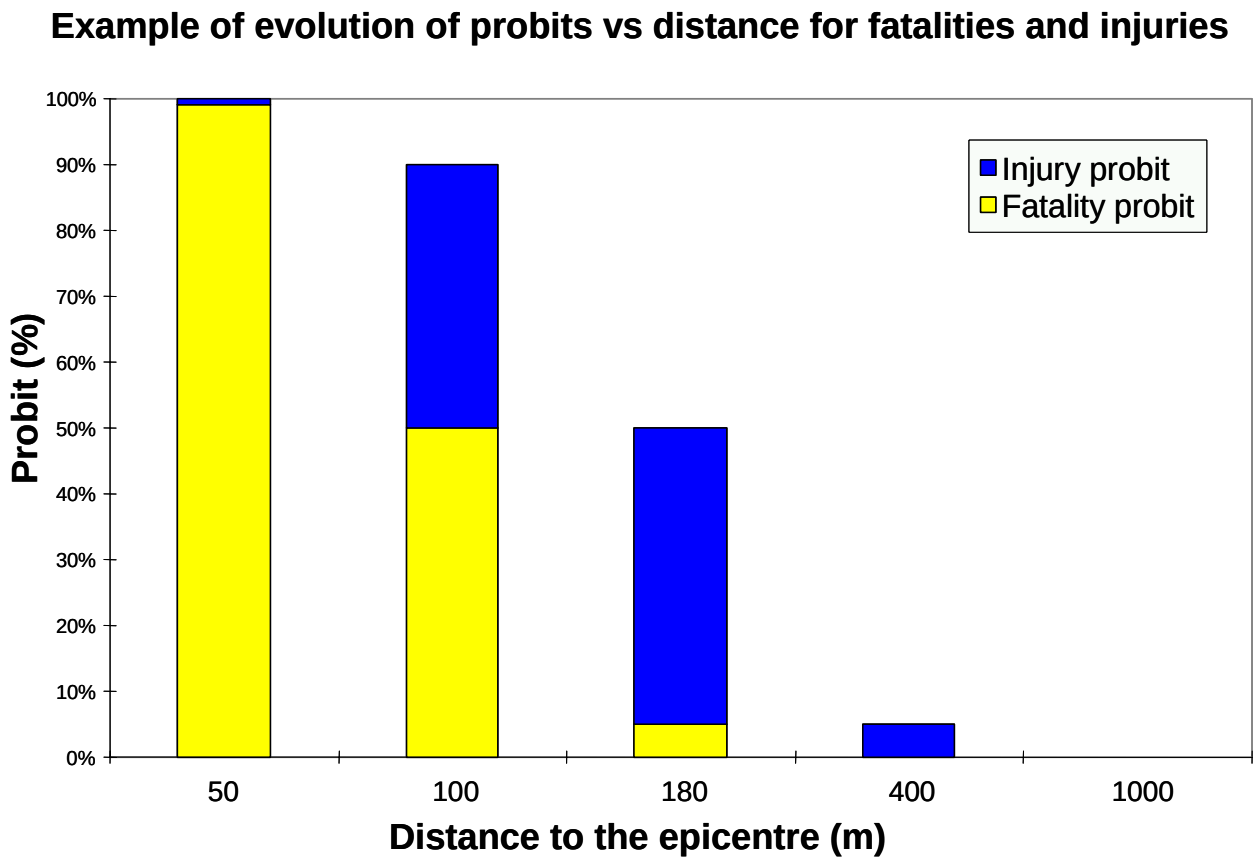
An important part of the work was the estimation and calculation of Dangerous Good – Heavy Good Vehicle scenario rates. This part was carried out by the University of Waterloo and is based on statistical data from France, Canada, US, Norway and Great Britain. Table 2 show some of the results, which can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

	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

Tab.2 DG-HGV Scenario rates

Consequences for the different scenarios are calculated for fatalities and injury probits, based on the physical effects for the specified scenarios.
Fig 5 show an example of evolution of probits versus distance from the spot of accident for fatalities and injuries.
A rough assessment physical damage is made in four categories:

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



Based on empirical data the model produce also information about the financial consequences, (reinstatement cost) as 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.

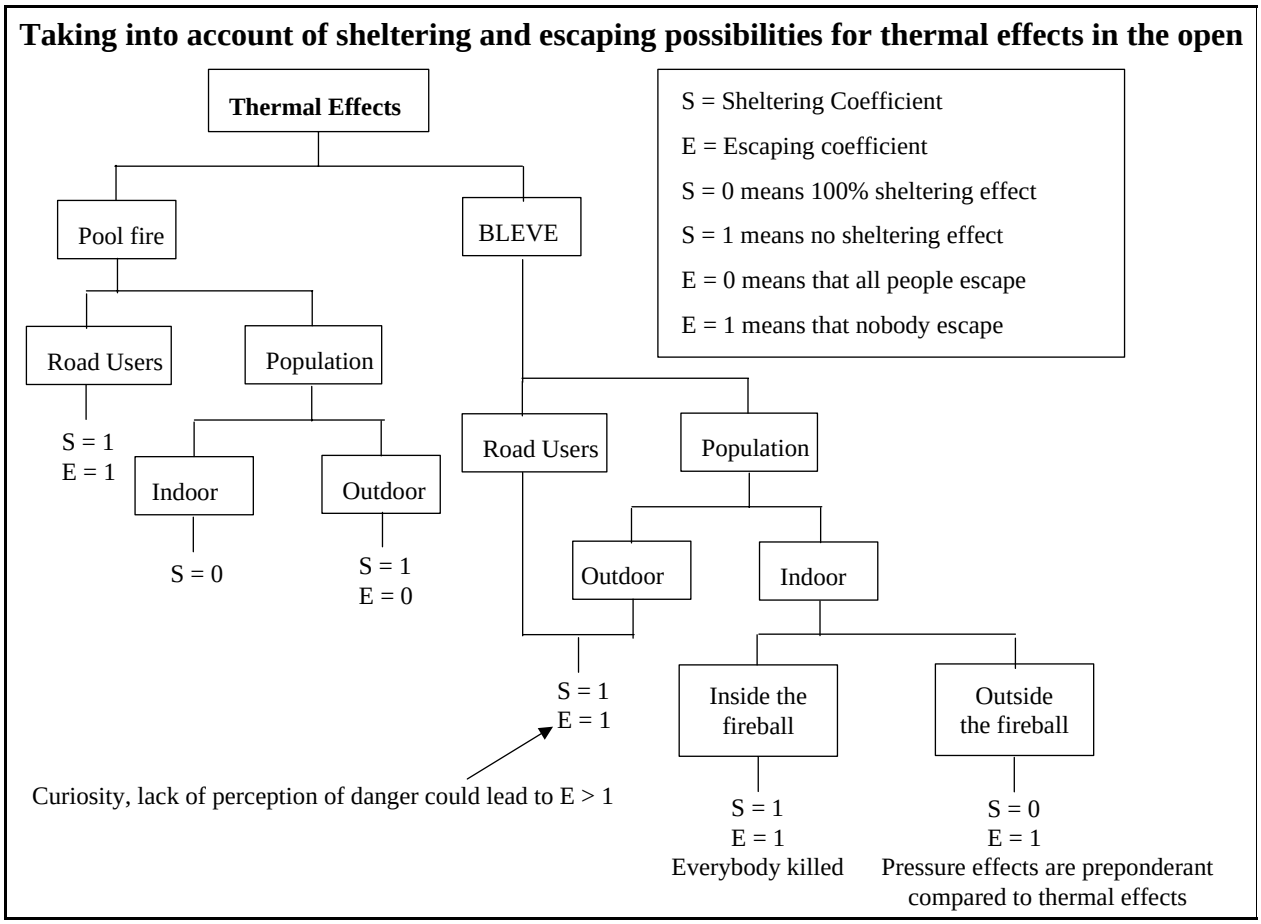


Fig. 6 Event tree for the calculation of the effects of escape, shelter or mitigating measures

What measures can be covered by the model?

In principle all measures which can be represented by the set of parameters of the model. This 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 and
- Other measures, depending on the expert knowledge.

Output Data

- F/N curves for the Societal risk
  for the tunnel route
  for the detour route ... for fatalities and injuries

- Individual risk in a 2D presentation
- Consequences for structures
- Consequences for the environment
- Input data for the Decision Support Model (which was also developed in this Sientific Expert Group)

What can this model be used for?

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

International Cooperation is inevitable for the solution of this problem

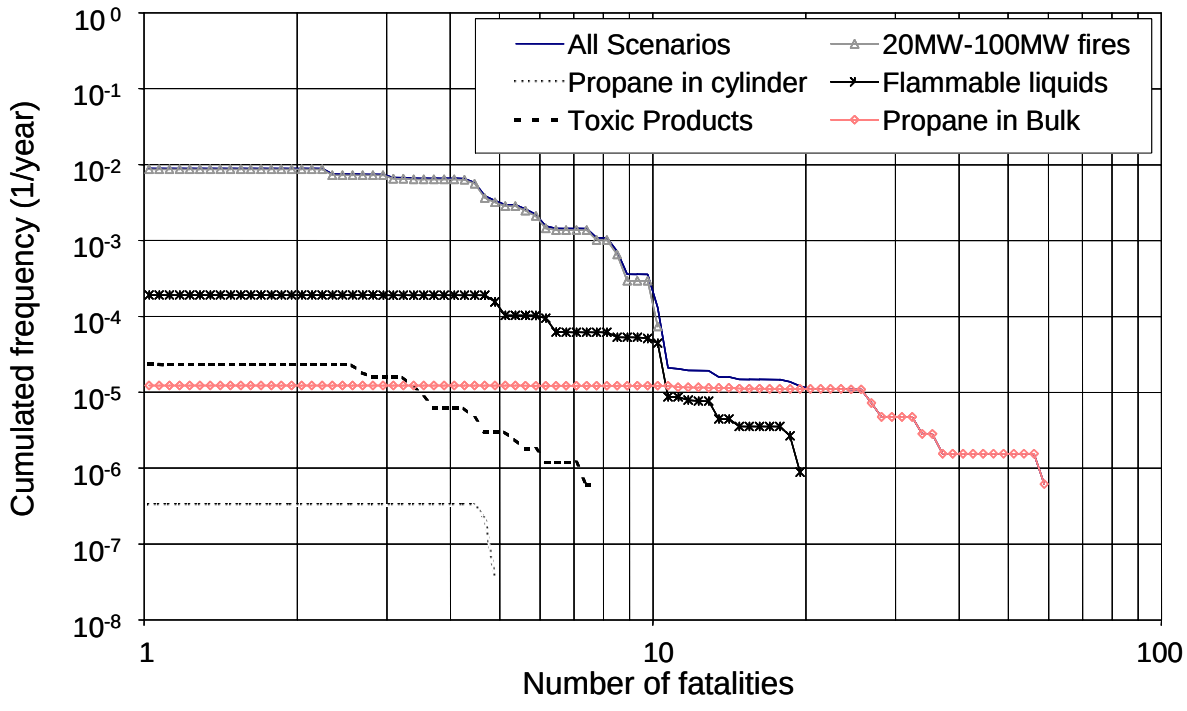
As the result of increasing speed and decreasing costs, economy is concentrating more and more. Transport has therefore to go more and more over long distances and is crossing national borders more and more. If there is no common tool to calculate the risk of the transport of dangerous goods through tunnels, each country has to decide on different expert knowledge, which might be difficult to compare. The PIARC Tunnel committee has therefore taken the initiative to carry out the development of a research project, together with the Road Research Division of the OECD for an international accepted instrument for the calculation of the Risk of transport of dangerous goods through tunnels. This was done from 1995 – 2000, including the the extensive validation work, which was done in several OECD member countries. This toop is now available on the market and can be used by national administrations, tunnel operators, consultants. Nevertheless the experiences with this instrument have to be collected in the future to improve it further.

Practical experience

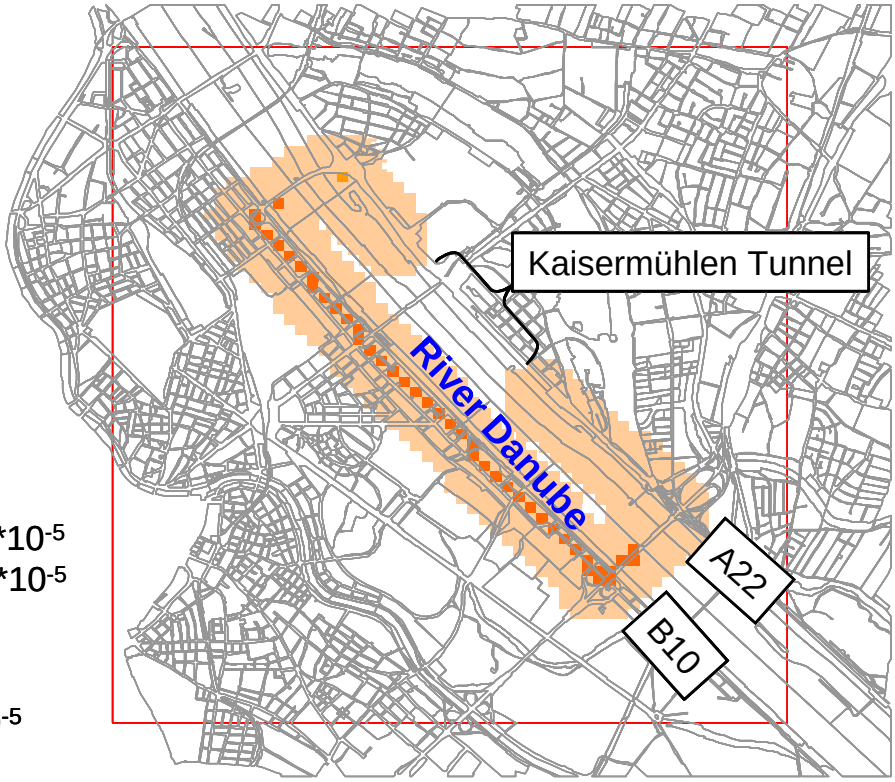
The model was tested by a group of expert users from five countries in Europe for a wide variety of tunnels. The experience of this validation group was the feedback to the model developers to improve the model for practical use, since a lot of problems arose only in practical applications. This input 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.
The following figures show some results from the Vienna test case, a two bore, cut and cover tunnel, with heavy traffic and also some amount of HG-DG vehicles)

Fig. 6 Picture of the Vienna test case

F/N Curve: example Vienna tunnel



Test case: 2D calculation individual risk



Maximum IR
- B10 Detour: $2.44*10^{-5}$
- A22 Tunnel: $1.02*10^{-5}$

Individual Risk
- 0 to $1*10^{-5}$
- $1*10^{-5}$ to $2.5*10^{-5}$

References:

Transport of Dangerous Goods through road tunnels Quantiative Risk Assessment ModelReference Manual OECD/PIARC/EU, written by P Cassini (INERIS), R. Hall (WS Atkins). P:Pons(INERIS), March 2001