Risk assessment for the transport of goods through road tunnels

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RISK ASSESSMENT FOR THE TRANSPORT OF GOODS THROUGH ROAD TUNNELS

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SUMMARY

1 FOREWORD

This paper is written for the specific purpose of the International Workshop on Promotion of Technical Harmonisation on Risk-based Decision Making organised by the European Commission - DG JRC to be held between 22 and 24 May, 2000 in Stresa (Italy).
Its main aim is to present personal views of the authors concerning QRA development and use.
The authors have been part of an international team in charge of the development of a software dedicated to assessment of risk due to transport of Dangerous Goods (DGs) by road.
They have also used the QRA software and assessed risk for real cases.
Tunnels represent singularities where risk per km may be high, so special care has been taken so as to explore their contribution when a risk assessment is performed for a whole route including tunnels.
Presentation will focus on QRA for transport of goods through road tunnels (by Heavy Good Vehicles : HGVs).
These personal views have been also expressed by filling out a questionnaire sent to all experts attending the workshop and addressing detailed points on QRA development and use.

2 FACTS ON ROAD TUNNELS

2.1 Tunnel statistics

Mainly for environmental reasons, the number of road tunnels is quickly increasing in many countries, but even so, corresponding lengths appear as relatively negligible compared to those of open air rail and road routes. However tunnels are confined spaces where accident may produce catastrophic outcomes and a specific assessment is needed.
It should be kept in mind that needlessly banning dangerous goods from tunnels may create unjustified economic costs and force them on more dangerous routes, through dense urban areas for instance, and thus increase the overall risk.
Table 1 indicates global lengths of tunnels in different countries.

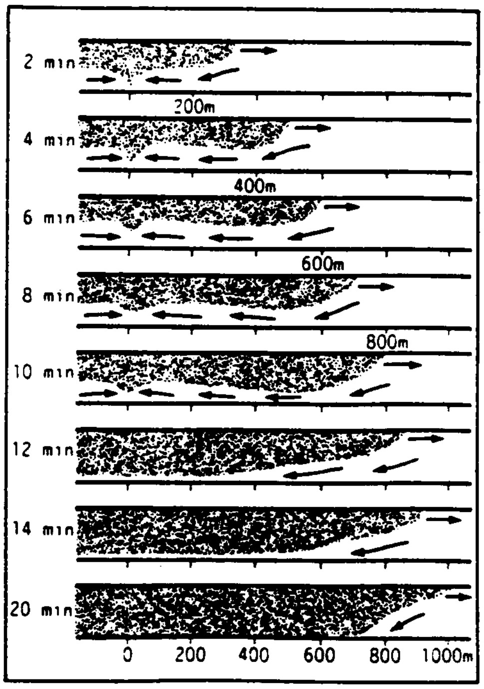
Country	Métro	Rail	Road	Total
Austria	15	105	210	330
Switzerland	-	360	140	500
Germany	550	380	70	1000
France	270	650	180	1100
UK	200	220	30	450
Italy	60	1150	600	1810
Norway	20	260	370	650
Spain	200	750	100	1050
Total	1315	3875	1700	6890

Table 1 : Cumulated lengths of tunnels (km) in 1990

2.2 Tunnel equipment

Roughly one can separate road tunnels in two kinds according to their number of bores.
For each location in a two bore tunnel, there is a direction upstream traffic and one downstream.

Ventilation is primarily used in normal operation so as to maintain tunnel atmosphere under pollution predefined levels.
In case of a fire, normal ventilation may be ineffective and an emergency ventilation is then activated.
In case of a fire in a two bore tunnel, it is possible to envisage to use the emergency ventilation to push smoke in the downstream traffic direction. If there is no traffic jam downstream of the accident, smoke will represent a danger neither for road users downstream (because they get out of the bore faster than smoke) nor for those upstream because it is pushed away from them.
This sort of pushing ventilation is called longitudinal.
If longitudinal ventilation is not strong enough, it will not fully succeed in pushing smokes downstream and a back layering of hot smokes will develop in the upper part of the section in the zone fire (Figure 1).



Effect of a petrol fire in a tunnel where the air flow is under 0.5m/s.

Figure 1: Smoke invading both directions of a tunnel because of back layering.

In case of a bi-directional traffic in a one bore tunnel, longitudinal ventilation may blow hot smoke on stopped and trapped road users. So other forms of emergency ventilation have to be used.

There are different sorts of ventilation:
- ❖ Natural
- ❖ Longitudinal
- ❖ Transverse
- ❖ Semi-transverse

It is not envisaged here to go into details, Figure 2 presents simply the basic schemes and terms.

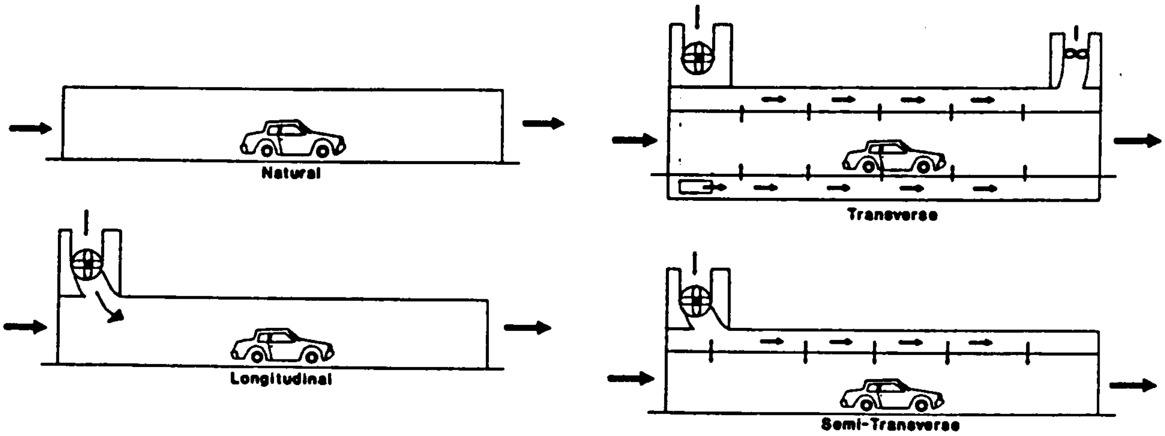


Figure 2: Different principles for the ventilation of tunnels.

Tunnel	Holland	Billwerder-Moorfleet	Velsen	Nihonzaka	Caldecott	Gothard	Fréjus	Guadarrama
Constr. Date	1927	1963	1957	1969	1964	1980	1980	1972
Country	USA	RFA	Hollande	Japon	USA	Suisse	FR/IT	Espagne
Location	New York	Hambourg	Velsen	Shizuoka	Oakland	Goschenen Airolo	Modane Bardonecchia	Guadarrama
length	2 550 m	243 m	770 m	2 045 m	1028 m	16221 m	12868m	3 330m
Nb of bores	2	2	2	2	3	1	1	2
Fire date	13/05/1949	31/08/1968	1978	11/07/1979	07/04/1982	02/04/1984	03/02/1983	14/08/1975
distance between fire and entry portal	900 m	120 m	500 m	1625 m	530 m	6 000 m	4 300 m	220 m
vehicle origin of Fire	1 HGV	1 HGV trailer	2 HGVs 4 cars	4 HGVs 1 coach 1 car	1 HGV	1 HGV	1 HGV	1 HGV
Loading	11 t of carbone bisulfure	14 t of plastic granulate			33000 l motor spirit	rolls of plastic sheets	plastic goods	pine resin
Fire origin	fall of loading	blocked brakes	collision front-rear	collision front-rear	collision front-rear	HGV motor in fire		
delay of intervention (min)	20	60	10	40	90	11	8	70
Fire duration	4 h	1 h 30'	1 h20'	4 days	2 h 40'	24	1 h 50'	2 h 45'
Fataliies / Injuries	66 injuries		5 fatalities 5 injuries	7 fatalities 2 injuries	7 fatalities 2 injuries			
Vehicles involved	10 HGVs destroyed 13 cars severely damaged	1 destroyed trailer	2 HGVs and 4 destroyed cars	179 destroyed vehicles	3 HGVs 1 coach 4 destroyed cars	1 HGV destroyed	1 HGV destroyed	1 HGV
stuct. instal.	severe damage along 200 m	severe damage along 34 m	severe damage along 30 m	severe damage along 1100 m	severe damage along 580 m	severe damage along 30 m	severe damage along 200 m	severe damage along 210 m

Table 2: List of accidents in road tunnels involving DGs.

Let us just say that because of different number of bores, different ventilation principles, the tremendous importance of ventilation in the outcomes in case of fire, a software able to assess these outcomes must adapt to very different configurations and use models describing smoke dilution and drifting.

2.3 Tunnel catastrophes

Table 2 indicates tunnel major accidents involving DGs.
They are very rare which makes impossible the possibility to derive statistics from them.

2.4 Catastrophes with no DGs

The recent (24 March 1999) Mont Blanc catastrophe: 39 fatalities did not involve any DG.
It clearly shows that fires due to HGVs loaded with non DG combustible materials are likely to produce catastrophes. That is why in the title of this paper we did not put the word dangerous before goods.

3 JOINT OECD/PIARC PROJECT ERS2

A paper /1/ written by D. LACROIX, P. CASSINI, R. HALL and F. SACCOMANNO delivered for the ESReDA seminar held in Oslo in May 1999 presents the ERS2 project launched by OECD and PIARC aiming at an international harmonisation of practices and regulations and the QRA model which is only a part in this vast project.
QRA model development has been mainly financed by the OECD. It has been co-funded by the EU (DG VII).

The general purpose of project ERS2 is to improve the overall safety of the transportation of dangerous goods by road while facilitating its organisation and preventing unnecessary costs. The output should be recommendations on best methodologies to analyse risks, make decisions, apply them using standard formulations, and implement risk reduction measures.

A Scientific Expert Group, with members from 14 countries, OECD and PIARC, has prepared the detailed objectives, plans and budget, and is responsible for the general advancement and results of the project.

3.1.1 Task 2: Methodologies relating to risk assessment and decision process

The objectives of task 2 of the project are to recommend methodologies and propose examples for evaluating the risks induced by dangerous goods transport in tunnels, comparing them with alternative routes and possibly risk acceptance criteria, and proposing decisions using standard formulations.
An inventory and comparison of existing methods were presented at a seminar in Oslo /2/ in March 1996 and led the Scientific Expert Group to structure this task as appears in figure 2.

Technical data on tunnel/routes, Traffic and DG transport data → QRA model → Risk indicators → DSM → choice of alternative

Figure 2: Splitting of risk assessment and decision making; respective roles of the tools

So Decision Support Model (DSM), which incorporates political aspects, is clearly separated from the QRA, which is purely technical.
Also, in order to harmonise tunnel regulations, it was proposed to develop a grouping system (GS) for loadings of dangerous goods. Each tunnel would be characterised by the loadings grouping which is allowed through it. These groupings, in small number (3 to 5), would range from all dangerous goods to none. A first proposal on the principle of a GS has been submitted to the interested international bodies and is available at OECD.
Detailed specifications for a QRA model were drafted and submitted to a peer review. Further to an international call for tenders, the QRA development was entrusted to a consortium led by INERIS (France) and including W.S. Atkins (UK) and the Institute for Risk Research (Canada).
A Danish consultant reviewed available models and analysed the decision problem. It has then been entrusted for the development of the DSM.
Present actions are led in order to ensure the perfect consistency of the QRA model, GS and DSM.

3.1.2 Task 3: Risk reduction measures (including transport and tunnel operation)

The objective of this task, co-ordinated by Mr Haastrup (European Commission), is to recommend measures well adapted to each specific case, with detailed specifications and an evaluation of the costs and benefits vis-à-vis the associated risks. A first phase produced a list of 28 “mitigation” measures on the basis of interviews with tunnel operators. The report has been written under the auspices of PIARC.
Then QRA model and DSM have been completed so as to quantitatively take into account the cost and benefits towards risk of measures when deciding on a tunnel equipment and operation.

3.1.3 Task 4: Conclusions and recommendations

The last task, co-ordinated by Mr A. S. Caserta (USA), will use the results of previous tasks to draw lessons and recommendations. Its objectives are:

* to propose a standard international formulation for tunnel regulations concerning dangerous goods,
* to recommend a general methodology to prepare decisions on authorising or refusing dangerous goods (using the aforementioned loadings groupings if they prove to be effective)
* to recommend appropriate measures to reduce risks.

4 THE QUANTITATIVE RISK ASSESSMENT (QRA) MODEL

4.1 Scope

The purpose of the QRA model is to produce quantitative information about risk levels due to the transport of dangerous goods on given routes, some of them including tunnels. This information, referred to as 'risk indicators', will be used in the DSM to propose decisions which may be based on the comparison of:

* different possible routes to find the safer one,
* the risk level of a route with an absolute acceptability criterion.

Risk is characterised by two aspects: yearly frequency of occurrence and severity. Severity may be expressed as fatalities, injured people, destruction of buildings and structures, damage to the environment. The number of fatalities has been retained as the most pertinent severity criterion. To characterise the societal risk, the model plots F/N curves which give the yearly frequency F to have an accident with N fatalities or more. It also calculates the individual risk for permanent populations (yearly frequency to die from the considered traffic). Injuries and damage to property and the environment are estimated in a qualitative way.
For open sections tools are available. Because of the specific nature of underground accidents, adapted modules had to be developed for the assessment of risk in tunnel sections. It is thus possible to quantify risks for routes including tunnel and open sections.

In the detailed presentation below, we will present the parts of QRA addressing tunnels, but also open air sections.
We will do so for two reasons:

❖ it will more easily show the analogies with QRA for fixed installations,
❖ since some scenarios originated inside of a tunnel may produce victims (fatalities and/or injuries) outside, a risk assessment always uses the open air part even in case the only route section considered is a tunnel.

4.2 General Approach

A complete assessment of risks due to DGs would require the examination of all possible meteorological conditions, all possible accidents, sizes of breaches, vehicles fully or partially loaded, etc. Such an assessment is totally impracticable and simplifications are needed. The developed QRA model relies on a methodology based on the following steps:

* Choose a small number of representative DGs
* Imagine a small number of representative scenarios involving these DGs
* Determine the physical effects of these scenarios (for open and tunnel sections)
* Determine the physiological effects of these scenarios on road users and local populations (fatalities)
* Take account of possibilities of escape/sheltering
* Determine the associated probabilities of occurrence.

Computations for scenarios leading to no fatality would be a waste of time. So a set of rather severe scenarios was chosen. They correspond to common types of DGs able to produce fatalities because of various effects: overpressure, thermal effect, toxicity.
Two scenarios are relative to fires of medium and important intensity that could concern heavy goods vehicles (HGVs) without DGs and nevertheless represent a serious risk in a tunnel. The choice of representative DGs and scenarios was operated keeping in mind the future possible ranking of DG loadings in groupings to be used in tunnel regulations. The list of the 10 scenarios initially selected appears in table 3.
Additional DGs and scenarios might be added. table 2 indicates DGs and scenarios which are likely to be added in future.
Two different software tools have been developed for computations in the open:

* the Fortran program Rk-DG deals with a 2D grid where population densities and a wind rose are set.

* the spreadsheet-based tool Sk-DG uses a simpler representation: population densities are supposed to be homogeneous within each section, so that wind directions are not needed.

Inside tunnels, only the spreadsheet-based tool Sk-DG is used.

Scenario No.	Description	Capacity of tank	Diameter of breach (mm)	Mass flow rate (kg/s)
1	HGV fire 20 MW (no DG)	N.A.	N.A.	N.A.
2	HGV fire 100 MW (no DG)	N.A.	N.A.	N.A.
3	BLEVE of LPG in cylinder	50 kg	N.A.	N.A.
4	Pool fire of motor spirit	28 tonnes	100	20.6
5	VCE of motor spirit	28 tonnes	100	20.6
6	Release of chlorine	20 tonnes	50	45
7	BLEVE of LPG in bulk	18 tonnes	N.A.	N.A.
8	VCE of LPG in bulk	18 tonnes	50	36
9	Torch fire of LPG in bulk	18 tonnes	50	36
10	Release of ammonia	20 tonnes	50	36

Table 3: Main characteristics of the 10 scenarios initially selected

4.3 Modelling of Risk Consequences and Frequencies

4.3.1 In the open

In the open, models exist to calculate the consequences of the scenarios. Then probit equations allow the derivation of fatality percentage from physical exposure. These models and probit equations have been used to create contingency tables where calculation results are stored in such a way that the software tools Rk-DG and Sk-DG can use them directly.

In Rk-DG the calculations are performed by interwoven do-loops in order to take into account:

- period of day (with associated traffic and population),
- direction of traffic,
- section of route (nature and related frequency of accidents),
- accident location on this section (discretisation),
- wind direction,
- wind velocity.

Each calculation provides a number of victims and the corresponding yearly frequency. In Sk-DG, a smaller number of do-loops is necessary. They are operated by spreadsheet macro-command modules.

The frequency for a scenario related to a given DG to occur in one year on a 1 km section is assessed according to the following methodology:

* find the yearly frequency for a HGV to be involved in an event (traffic accident, spontaneous fire, loss of containment, etc.) on the route section (function of country, road type, global traffic, HGV traffic),
* find the conditional probability that this HGV transports the given DG (function of traffic composition),
* use the conditional probability to develop the scenario once a HGV with the given DG is involved in an event.

4.3.2 In tunnels

In tunnels, the techniques used for consequence modelling of scenarios in the open do not apply and a specific treatment is needed to derive:

* the zones of the tunnel that will be affected,
* the effects that will go out of the tunnel and create a risk in the surroundings.

A specific spreadsheet tool called hereafter 'pre-conditioner' has been developed. It determines the zones in the tunnel that will be affected by each scenario and the corresponding effect levels. For instance in case of a fire in a tunnel, the spreading of smoke is very dependent of the ventilation regimes. After a delay, the emergency ventilation is generally activated. The ventilation regimes may be very different from a tunnel to another. Even for the same tunnel, the emergency ventilation may vary drastically according to the fire location. The extent, duration and heat release of a motor spirit fire are also very dependent of the drainage provisions.
Because of the complexity of the assessment of the zones affected and the numerous possible cases (one or two bores, longitudinal, semi-transverse or transverse ventilation), the pre-conditioner uses simplified models.
Appropriate measures in a tunnel may reduce the frequency of accidents, their severity, the delays for detection and allow greater possibilities of escape/sheltering. Some of these measures are taken into consideration in the pre-conditioner and the QRA. It is thus possible to explore the influence of mitigation measures on the F/N curves. Table 3 shows a list of the mitigation measures and indicate those that can be dealt with by the QRA.

4.4 Input / Output of the Software

4.4.1 Spreadsheet-based tool Sk-DG

The tool Sk-DG produces the following quantitative outputs for fatalities:

* F/N curves (global and also for each DG involved at least in one scenario),
* expected values (number of fatalities per year).

It also provides qualitative indications on risks of injuries, structural damage in the tunnel sections, environmental pollution.
For the open, the software computations are based on :

* contingency tables in which the shape and extent of the zones of physical effects for the scenarios in the open have been stored,
* contingency tables in which the translation of physical effects into physiological ones has been stored,
* contingency tables in which the elements needed for the yearly frequency assessment have been stored. They are derived from accident statistics issued from France and Canada.

For the tunnel sections, the software computations are based on :

* the aforementioned pre-conditioner which performs a simplified assessment of the physical and physiological effects in a tunnel,
* contingency tables in which the elements needed for the yearly frequency assessment have been stored. They are derived from accident statistics relative to tunnels issued by Canada, France and Norway.

All these contingency tables store input data that have been calculated and validated by the developers and should not be changed. Nevertheless if changes were to be performed, for example use a new probit equation for chlorine, this could be performed inside the contingency tables by an expert user. More generally, expert users may change values in contingency tables so as to:

* modify the physiological effects of the phenomena (change probit equations, etc.),
* modify the way the escape/sheltering possibilities are taken into account,
* modify a scenario (this requires specialists),
* modify default values (traffic composition, ratio of fires not induced by an accident, etc.).

Expert users may also change values in some parts of the pre-conditioner.

The final users will not have such possibilities. The inputs they will have to provide for the spreadsheet-based tool Sk-DG, are: traffic description, route description, distribution of wind velocities if available, indications on weather conditions that may affect the frequency of accidents: fog, rain, etc. Some elements are typically relevant to the site: global traffic, layout of the route, length and nature of each section and must be entered. Other inputs may be omitted and a default value accepted.

4.4.2 **Fortran program Rk-DG**

Data to be supplied to this software are very similar to those needed by Sk-DG, except that a 2D description of the population density is needed and a wind rose indicating time ratio of wind velocity for 18 (adjustable number) direction sectors is needed.

4.4.3 **Tunnel pre-conditioner**

Input data are:

* geometry of tunnel (number of bores, layout of lanes, length, cross-section, gradient, camber, drainage possibilities, etc.),
* normal and emergency ventilation regimes (longitudinal, extraction if any),
* delays for activation of the emergency ventilation.

4.5 Test cases

A panel of 4 test cases was used during the development to validate the contingency tables and sub-models, clearly feel the difficulty for a final user, help in writing user guides.
For each case, a comparison of risk between a route including a tunnel and an alternative open route was conducted. The 4 tunnels were intentionally chosen to be very different. Figure 4 shows an example of the outputs obtained with Sk-DG for one of the test cases: F/N curves per type of transport (cumulating the risks for all scenarios relative to that transport) and their global contribution.

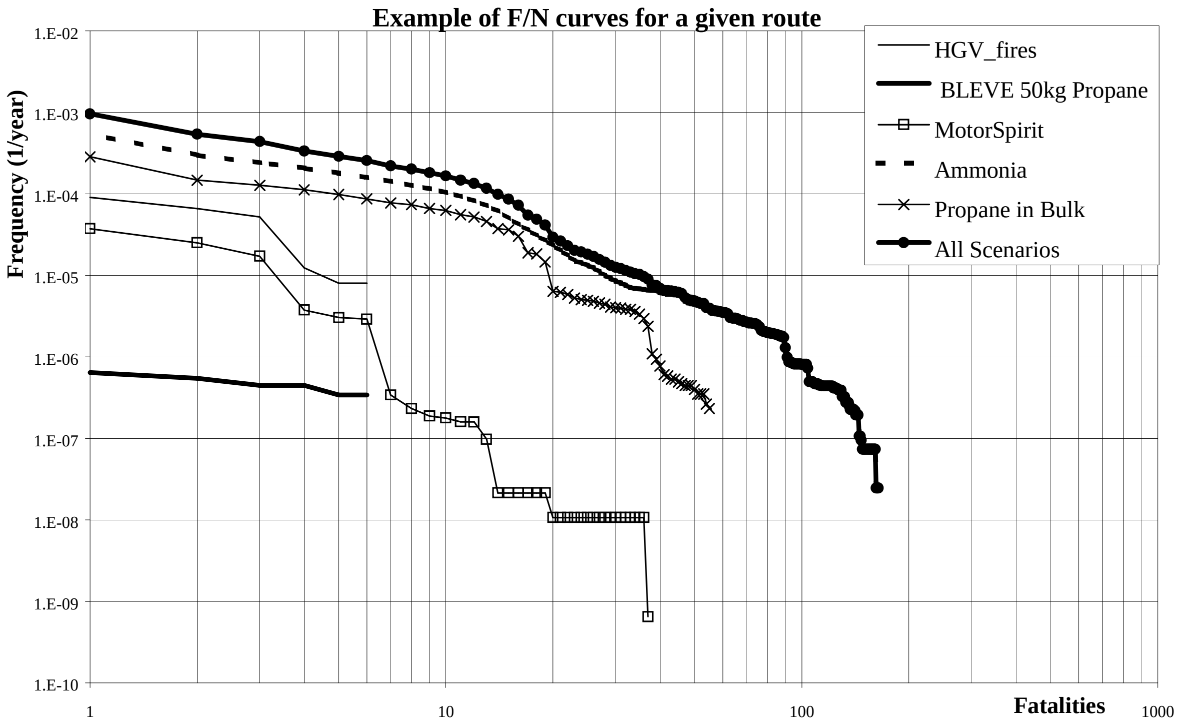


Figure 4: Example of F/N curves produced by the QRA model

4.6 Validation procedure

A QRA model may calculate systematically biased levels of risk, especially if it is based on a very limited number of DGs and scenarios. This may have limited incidence when comparing two alternative routes, if both have been miscalculated in the same manner. It may lead to wrong conclusions if risk levels have to be compared with 'absolute' acceptance criteria.

Sources of possible error when assessing risk are everywhere. They are present in:

* input parameters,
* physical models used for the consequence assessment,
* statistics available for the probability/frequency aspects and derived contingency tables,
* physiological aspects,
* people behaviour and ability to escape,
* emergency procedures.

So it appeared important to check that a correct order of magnitude was reached in the assessment. This has been performed by a comparison between:

* fatalities produced by real accidents available in a database indicating the number of fatalities due to DGs during a few years in France,
* calculations performed with the model for 3 open air sections representing:
  * motorways in rural areas,
  * national roads in rural areas,
  * urban routes,

  each with corresponding surrounding population densities, traffic rates and with lengths proportional to their ratio in the French road system.

Dividing the calculated number of fatalities by the numbers of kilometres and DG vehicles used to run the model leads to a result of:

$1.4 \cdot 10^{-9}$ fatalities due to DGs / (year . DG vehicle . kilometre).

Knowledge of the French DG traffic expressed in vehicle . kilometre per year allowed to derive from the database a mean figure of:
$1.9 . 10^{-9}$ fatalities due to DGs / (year . DG vehicle . kilometre).
So, it appears that the model seems to correctly evaluate the order of magnitude of risk on open sections.
A sensitivity analysis has been performed in order to indicate how the model reacts to different input parameters relative to open and/or tunnel sections. This is useful for the final users: if a parameter does not affect the results too much, it may be determined with less accuracy.

5 CONSIDERATIONS RELATIVE TO QRA DEVELOPMENT

In this part, the authors stress some difficulties or problems they encountered while developing the QRA. These considerations are personal views expressed for the specific need of the Workshop.

5.1 Duration to be considered and possibilities of extension

In the Mont Blanc, the fire went from an HGV to the following. So doing, it has been able:
- To last a very long time (several days),
- To submit considerable distances to very high temperatures.

A progression from a load to the next one had also been observed in case of the fire that occurred in the Channel railway tunnel /5/ and other cases before.
This progression takes time. It is very difficult to predict its speed and extent.
When developing a QRA a question that arises is: what duration should be investigated by the QRA so its assessment is correct.
Answer to this question is very different according to the outcomes considered:
- for fatalities, one could say the first hour is often decisive,
- for structural damage, one should take into account the whole development of the furnace.

But even for fatalities additional points have to be examined:
- In case shelters communicate with a safe escape issue, the first hour is certainly decisive,
- In case they do not, one can imagine people trapped in a shelter and whose fate depends of the progression of the furnace. Their fate is in that case linked with the conception and safety of the shelter ,its supply in fresh cool air, ...

5.2 Simplified statistical traffic representation

Traffic is described by the user accordingly with possibilities offered in the QRA.
In the models developed, traffic is supposed to be uniformly distributed, which means one will consider that the distance (m) in fluid traffic between 2 vehicles is obtained by dividing speed (m/h) by traffic (veh/h).
When a traffic jam appears, calculations are different and are based on global lengths of vehicles (including gaps) and number of lanes.
Anyway, if buses and coaches represent only 0.5 % of global traffic, they will be distributed accordingly by the model.
In France, we had recently on the A10 motorway in an open air section a traffic accident due to fog which involved 17 coaches (buses). There was a protest in Paris organised against some

new law project. Opponents rent the services of a tour operator and a sort of informal convoy (protesting against future laws) went its way … into the fog !.
Now if such an accident occurs in a tunnel, how many people will be able to enter a shelter on time. If the shelters are cul de sac (not communicating with a safe escape), there might be some “Titanic” effect because shelters capacities will not suffice just as Titanic rescue boats did not.
How is it possible to take account of this in a QRA ? Should it be taken into consideration ?
Statistically, yearly frequency to get 17 coaches involved in the same accident is so close to zero !

5.3 Road users attitude

Once an accident has been detected, a key factor is the attitude of road users. This attitude will depend on the information they are given but also on many other factors that may lead to a bad response (human error).
In the developed QRA software, the models deal with physical problems and check how fast visibility will disappear at eye level (for a standing man) and the evolutions of temperatures and concentrations of chemical species in the tunnel.
If visibility remains correct, if a sidewalk exists, it is assumed road users evacuate their vehicles at a certain walking speed and go in the shelter direction. Question is then; will “bad” atmosphere go faster than fleeing persons ?
It is supposed that road users (because of clear visibility) will find the shelter/escape door and be able to open it (because emergency lighting, sidewalks, shelters, escape issues, doors, have been build accordingly to regulations or recommendations based on state of the art and because signs are present, easily understandable even for foreigners …).
In fact, foreigners might not understand radio information, cars might be stopped on sidewalks, people might panic and follow the more panicked ones …
Once again, how is it possible to take account of this in a QRA ? Should it be taken into consideration ?

5.4 Trespassers

Trespassers are another difficulty when assessing risk.
Some violations are easy to take into account in the model: for instance when speed is limited to 80 km/h but speed controls clearly show that cars and even HGVs pass a great deal faster than that. The developed QRA software deals with speed limit as a mitigation measure. The speed limit to be used for assessment should not be the permitted one but the observed one (not exceeded by 95 % of users for instance).

Now, let’s imagine a DG is forbidden in a tunnel but the HGV driver violates this interdiction (intentionally or not).
How to deal with that ?
The QRA user should know about the real traffic and if trespassers are “not exceptionally rare” take them into account in the assessment.
For instance, if LPG tankers are forbidden, corresponding scenarios could still be activated and used with a small well chosen trespassing traffic.

5.5 Shelters

Against certain types of aggressions like thermal fluxes and drifting toxic clouds, people may be initially sheltered or have the possibility to find a shelter.
A car driver will be affected differently if his car is:

- closed and ventilation not recycling,
- or with windows open.

Same thing for people in their dwellings.
If the exposure time is long (toxic), differences will tend to disappear. The dose is in relation with air flows rates between shelter and exterior.
We devised a way to deal with that in the QRA model and proposed it to the Experts follow up committee which accepted it.

5.6 Uncertainties

The QRA developed is so complex that there are no ways to compose basic uncertainties to obtain an estimate for the global result.
In fact, preceding every other one, there is a basic initial difficulty. We want to assess risk due to thousands of DGs each one to be found in multiple different conditionings loaded on HGVs which may be full or partially unloaded, … and for this we use only 10 scenarios !. We could call this the "original sin" of the QRA methodology.
A confidence interval is normally aimed at taking into account random errors, but not really systematic errors and certainly not the "original sin" just mentioned.
So, in order to address this major difficulty, we checked one assessment against an observed corresponding value as mentioned in § 4.6.

6 CONSIDERATIONS RELATIVE TO PRACTICAL USE OF QRA MODEL

6.1 Background

In UK, in Switzerland and in The Netherlands, QRA techniques are used so as to produce societal risk and/or individual risk assessment for DG transport that can be compared to acceptance criteria.
In France, such QRA techniques are used to compare the risks due to the transport of dangerous goods on 2 (or more) possible routes to join a starting point A to a point B.
Aims of the QRA use are:

- to find lower level of risk,
- detect DGs that give the greatest contributions to risk,
- explore strategies and level of equipment, …

All these elements are at hand for the decision maker, who so far has no DSM to help him in the decision making.
This approach is consistent with regulatory text /3/ that states that the general rule should be to forbid the transport of dangerous goods through tunnels but that exception are possible if the route without tunnel presents important risks (routes that go through densely populated areas for instance)

6.2 Typical study in France

6.2.1 Objectives

So, in France QRA is used typically to compare the risks on 2 routes (between point A, where the routes separate and point B where the routes converge), the first one going through a tunnel and the second one being entirely in the open (see **figure 5** below).
In some occasions, several alternative (open) routes can be studied simultaneously. It is also possible to study different strategies as the fact to allow to go through the tunnel under specific conditions:

- during limited periods of time (low traffic period),
- with escorting vehicles,
- with some material authorised and some others forbidden.

The aim is the same in every case: compare the different situations so as to define the one that presents the lower risks.

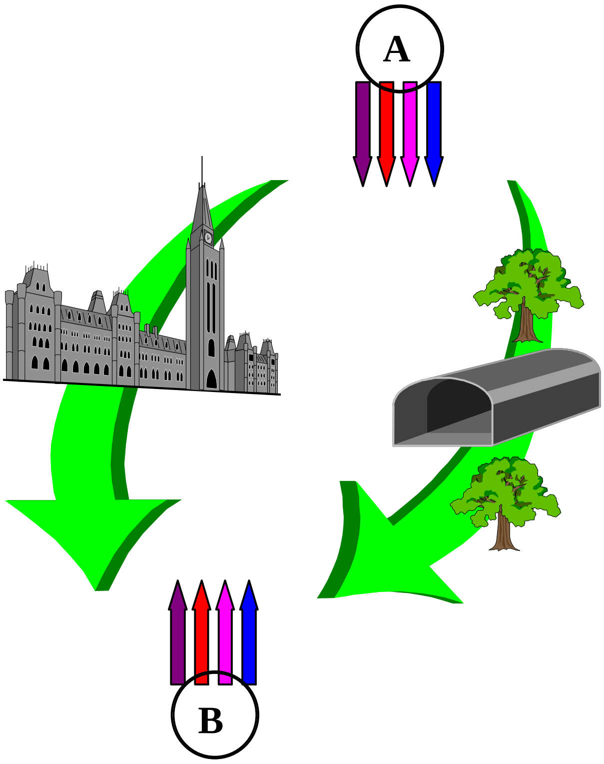


Figure 5: *QRA is used typically to compare the risks on 2 routes (between point A, where the routes separate and point B where the routes converge), the first one going through a tunnel and the second one being entirely in the open*

6.2.2 Data needed for the study

So as the QRA model can be used, a number of data have to be collected:

- data related to the geometry/characteristics (number of lanes…) of the studied routes.
- data related to the geometry/characteristics (ventilation, drainage…) of the studied tunnel(s).
- data related to the dangerous goods traffic (and its composition) that is expected through the tunnel route if authorised, and its evolution over time (peak hour…). It is often necessary to assess such a traffic at a date not to proximate in the future so as the decision can be considered as durable.

- data related to the general traffic (light vehicles, HGV, bus/coaches) on the studied routes and its evolution over time (peak hour…).
- data related to accident rates on the studied routes (those accident rates can be different from a section to another).
- data related to the population (and its evolution over time) living in the vicinity of the studied routes.
- data related to the meteorological conditions (wind rose).

Some of those data may be more or less easy to collect (for instance when the studied route/tunnel is manned or not). But it is time consuming in every situations (at least a few months).

6.2.3 Calculations

When no fully integrated QRA was available, it was necessary to address manually the questions related to the choice of scenarios, to the assessment of the consequences/frequencies in tunnels/in the open.
This was experienced to be long, time consuming and with possibility to make calculations errors. As a consequence, it was not possible to perform a lot of calculations corresponding to different strategies for the dangerous goods to go through the tunnel (escort…).
Now that a fully integrated QRA is available, this part of job has been considerably reduced: the QRA addresses automatically the consequences/frequencies calculations given the data entered by the user, and produces F/N curves in the end (and also other types of results).

6.2.4 Comparison of results

The F/N curves produced by the QRA are presented:

- separately for each selected scenarios,
- separately for each selected type of material,
- aggregately for all scenarios.

This allows to define strategies that could lead to forbid some dangerous goods and authorise some others through the tunnel route (accordingly to Grouping System concept).
When compared, the F/N curves related to the studied routes can:

- intersect (or be intermeshed),
- be clearly separated.

In the second situation, the conclusion is easy: one route (or strategy) presents clearly a lower risk than the other one (see **figure 7**), whatever the case.
In the first situation, the conclusion is less obvious: for example one route (or strategy) has a lower frequency to produce a small number of victims and the other one has a lower frequency to produce a large number of victims (see **figure 6**). Some consideration concerning aversion can then be used. It is also possible to compare the integral of the curves (the expected values): even if the curves are intersecting, the level of risk (the expected value) can be noticeably lower for one route (or strategy).
If the curves are intermeshed and the expected value of the same order of magnitude, then no conclusion is possible through the use of the QRA: the decision concerning the authorisation for the dangerous goods to go through the tunnel or not must be taken by considering other criteria.

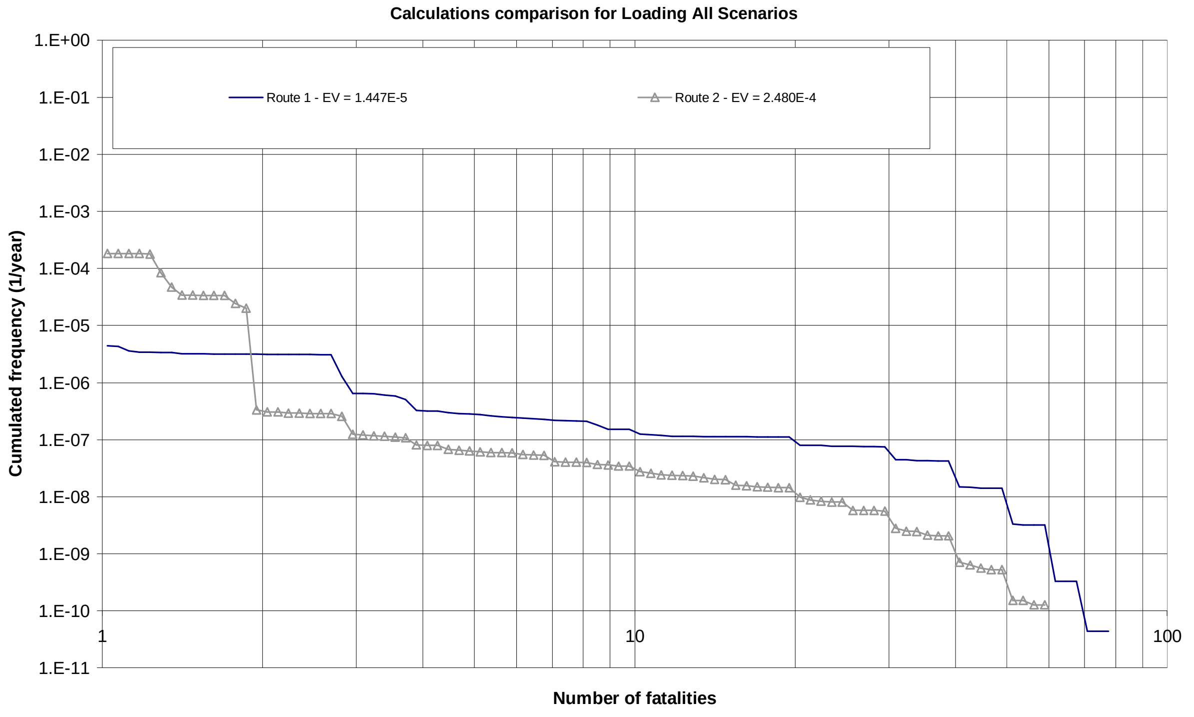


Figure 6: *Routes for which the F/N curves are intersecting but the Expected values are different*

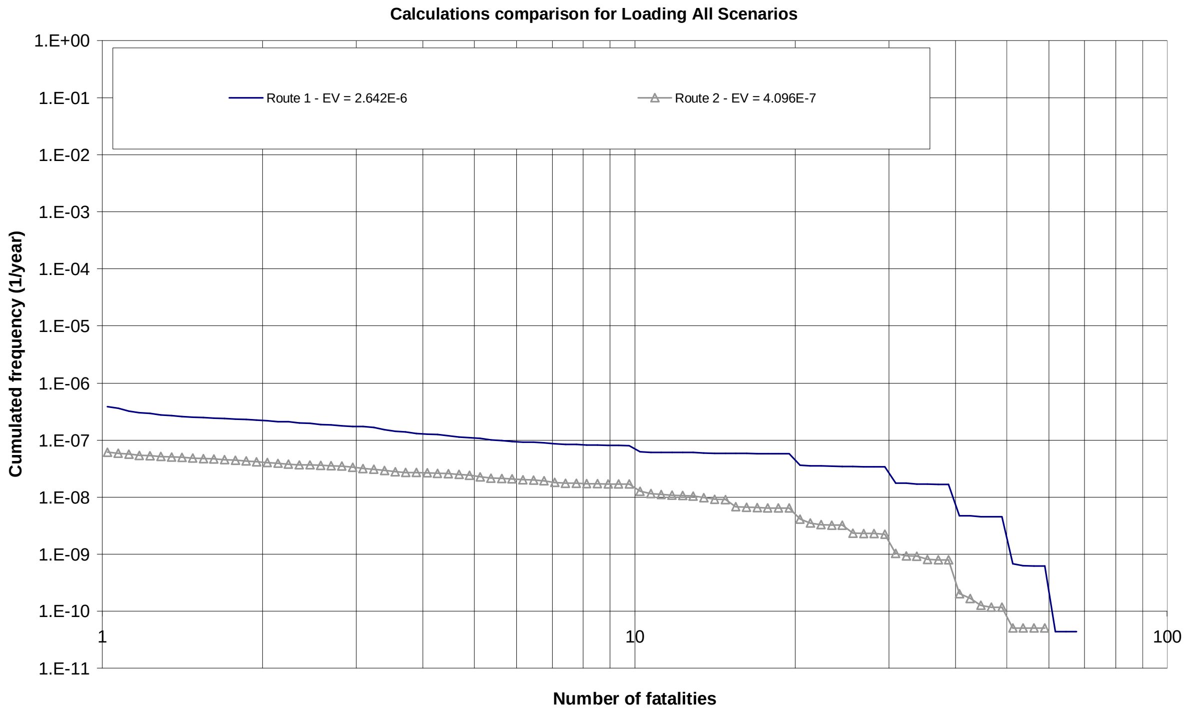


Figure 7: *Routes for which the F/N curves are not intersecting and the Expected values are different*

7 CONCLUSIONS

The joint OECD/PIARC research project ERS2 investigates the most important fields related to the transport of dangerous goods through road tunnels: current and future regulations, risk assessment, decision making, risk reduction measures.

A Quantitative Risk Assessment (QRA) model was developed by international consultants in order to provide risk indicators which can be used in a decision support model to compare a route including one or several tunnels with alternative open routes, and possibly with risk acceptance criteria. The QRA model consists of spreadsheet-based tools and a Fortran program for some finer results. It is aimed at being simple to use, but experts may make changes to take account of specific situations or data. The main outputs are F/N curves and individual risk contours for fatalities. Risks of injuries, damage to the tunnel and the environment are dealt with in a more qualitative way.

The development has included four test cases to try the various sub-models and the user-friendliness. A complementary check has been performed in several countries: final users have tested the model on their own cases before it is accepted. A detailed examination of the consistency of the QRA with the Decision Support Model (DSM) and the grouping system (GS) planned for future harmonised tunnel regulations has begun.

A major difficulty when developing the QRA was to combine three objectives:

- ❖ Produce a fully integrated, automated software that could be used by occasional users,
- ❖ Make it detailed enough so as to be able to explore the impact of mitigation measures and alternative strategies,
- ❖ Take account of tunnel ventilation which may be so different from a tunnel to another and is likely to play a major role on outcomes.

In the future, development of a QRA model that would allow the assessment of risk for railways is planned. This could lead to a further step that would be intermodal comparisons (rail Vs road). It could prove particularly useful since future very long railway tunnels are in project in the Alps.

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