GIS Interfaced OECD/PIARC QRA Model for Road Transportation of Hazardous Goods.

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1 Introduction

Within the framework of a research project carried out for both the OECD and the PIARC, INERIS developed a Quantitative Risk Assessment Model (QRA model) for the transport of Hazardous Goods on roads including tunnel sections. This work was also carried out with the collaboration of WS-Atkins (UK) and the University of Waterloo (Canada).

INERIS, which was the leading developer of this original model, launched a new research project in order to facilitate the generation of data necessary for a given risk study. A new version of the model is in development. These new developments have been funded by the French Ministry of Ecology and Sustainable Growth and the French Ministry of Equipment, Transport and Buildings, Tourism and the Sea.

These new developments have been processed in order to enhance the user-interface performance of the original models (QRAM 3.20 and 3.60) and to extend the QRAM capacities to the study of longer routes. These objectives has been reached by the introduction of a linked Geographical Information System (GIS).

In between the original model (QRA v3.20) has been used for the application of the French regulation (circular 2000-82, 30th november 2000). Up to now approximately twenty tunnel safety cases have been studied in order to choose the lowest risky route between the open air route and the tunnel one. Doing that the risk level for the road transportation of hazardous goods has been reduced.

In order to have in one hand a global view of the various developments of the QRAM and in an other hand to linked these models to the European regulation framework the present paper deals with the following topics :

- The present regulation for the transport of dangerous goods by road in Europe,
- The methodology governing the QRAM,
- The lessons from the French application of the QRAM,
- The new developments for a GIS interfaced QRAM,
- The application of the QRAM at European and International level.

2 Present regulation for road transport of dangerous goods in Europe

The road transport of dangerous goods is regulated by the Council Directive 94/55/EC of 21 November 1994 on the approximation of the laws of the Member States with regard to the transport of dangerous goods by road [i] and its annex the European Agreement concerning the International

Carriage of Dangerous Goods by Road (ADR) [ii]. This directive has been amended by the Directive 2000/61/EC of the European Parliament and of the Council of 10 October 2000 [Official Journal L 279, 01.11.2000] [iii] and the Commission Directive 2003/28/EC of 7 April 2003 [Official Journal L 90, 08.04.2003] [iv]. These regulations do not give specific indications related to the transit of dangerous goods through road tunnels.

On the 13th of May 2003, the working party on Land Transport of the Council of the European Union released the inter-institutional file 2002/0309 (COD) for the subject: Proposal for a Directive of the European Parliament and of the Council on minimum safety requirements for tunnels in the Trans-European Road Network [v]. Chapter 2.5 deals with the transport of dangerous goods and says:

Member states and their Administrative Authorities shall apply the following measures concerning access into tunnels of vehicles, transport and dangerous goods:

- *place signs before the last exit before the tunnel and at tunnel entrances indicating which groups of dangerous goods are permitted /prohibited;*
- *perform a risk analysis in accordance with Article **13**, before deciding on tunnel requirements with dangerous goods;*
- *consider operating measures designed to reduce the risk of transporting dangerous goods in tunnels, such as a declaration before entering or escort, on a case by case basis; this may require the formation of convoys and accompanying vehicles for the transport of some types of particular dangerous goods;*
- *improve traffic management for the transport of dangerous goods.*

The joint Organisation for Economic Co-operation and Development (OECD) and World Road Association (formerly known as the Permanent International Association of Road Congresses and still known by the abbreviation PIARC) Scientific Expert Group ERS2 developed objectives for all four points mentioned above within the OECD Road Transport Research Programme [vi,vii ,viii]. These main objectives are the skeleton around which the QRAM, developed by INERIS (overall model: open and tunnel section) and WS-Atkins (tunnel section), was constructed.

3 Methodology governing the OECD/PIARC QRAM

The QRAM reference manual [ix] provides extended explanations on the overall assessment hypotheses. Thus only overview information is given in this section.

The main purpose of the QRA model is to assess the risks relative to the transport of Dangerous Goods in a quantitative way. The model evaluates simultaneously the consequences and the frequencies of occurrence of possible scenarios. This makes it possible to assess quantitatively the societal risk (if the distribution of the people liable to be exposed is at hand) and the individual risk.
A complete assessment of the risks due to Dangerous Goods would require to evaluate all kinds of accidents with all types of vehicle partially or fully loaded, for all the possible materials etc. Such an evaluation is completely impossible and some simplifications have to be introduced. Thus the QRA model is based on the following steps:

- Choice of a restricted number of Dangerous Goods,
- Choice of some representative accidental scenarios implying those Dangerous Goods with their usual packaging (please see table 1),
- Identification of physical effects of those scenarios for an open air or a tunnel section,
- Evaluation of their physiological effects on road or rail users and local population,
- Taking into account of the possibilities of escape/sheltering,
- Determination of the yearly frequency of occurrence for each scenario.

Table 3: Main characteristics of the 13 selected scenarios (QRAM v3.60)

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
11	Acrolein in bulk release	25 tonnes	100	24.8
12	Acrolein in cylinder release	100 litres	4	0.02
13	BLEVE of liquefied CO_2	20 tonnes	-	-

Notes: BLEVE = Boiling liquid expanding vapour explosion
HGV = Heavy goods vehicle
LPG = Liquid petroleum gas
VCE = Vapour cloud explosion

Source: QRAM reference manual **[Chyba! Záložka nenf definována.]**, table **4.9-1**

The risk assessment of each accident scenario is based on a different event tree leading to the major possible hazards that are pressure wave effect, thermal effect or toxic effect.

F/N curves and their expected values are the major outputs of the **QRA** model. They are **defined** as follows:

- **Frequencies** / **Gravity** curves **(F/N** curves): stand for the annual frequency of occurrence F to have a scenario likely to cause an effect (generally, the number of fatalities) equal to or higher than N.
- Expected value **(EV):** number of fatalities per year, obtained by integration of a **F/N** curve

The risk is characterised by two main aspects: frequency of occurrence and consequences. Consequences can be expressed by a number of fatalities, of injuries, structure and building destruction, damages to the environment. The number of fatalities can be considered as the main criteria to quantify risks. Injuries are also calculated. In order to determinate the societal risk, **F/N** curves are built (figure 1). Structure damages are evaluated through a semi-quantitative way and environmental damages through a fully qualitative way.

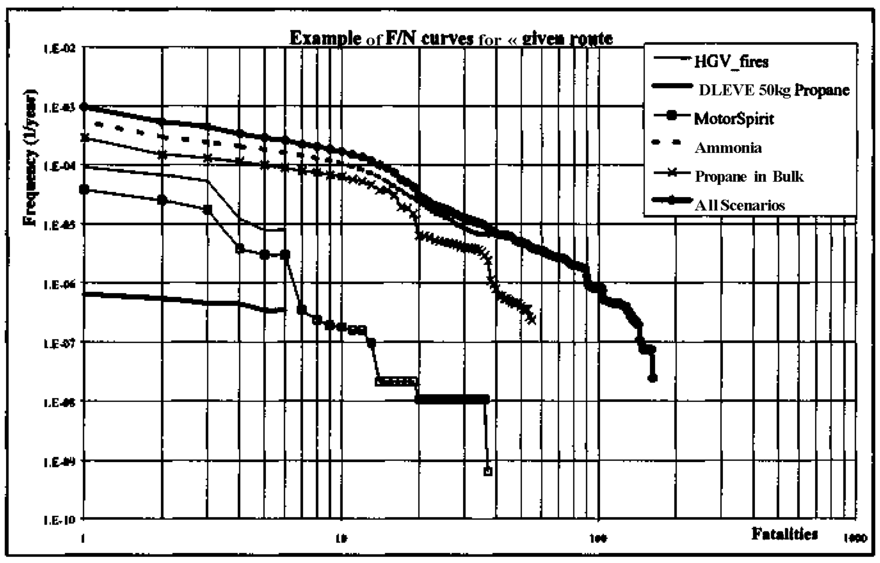


Figure 1: Example of F/N curves. Frequency means "yearly frequency of N or more fatalities"

Individual risks can also be obtained. The individual risk indicator refers to the risk of fatalities or injuries to the local population due to an incident. Individual risk is expressed as a frequency per year. It could also be expressed in terms of return time, i.e., average number of years between two accidents with the considered consequence (fatality, injury).

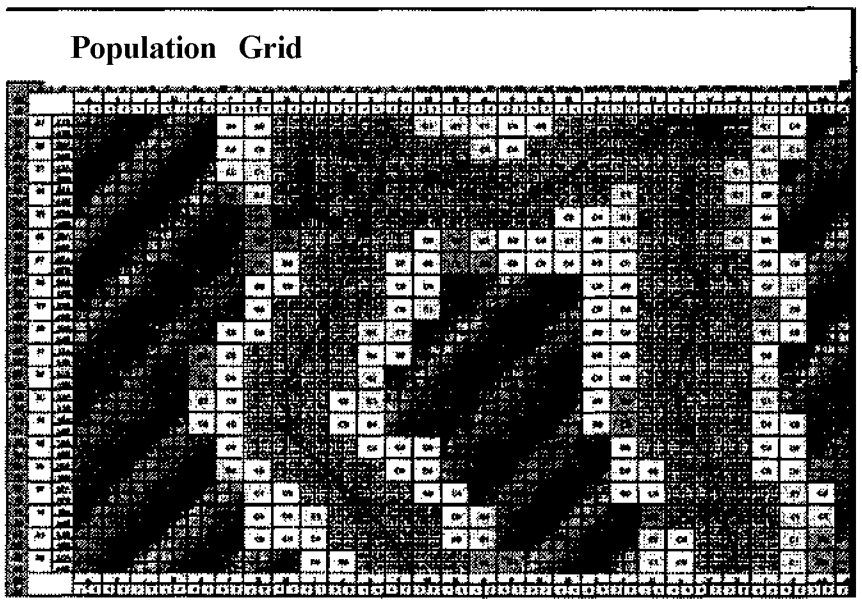


Figure 2: Example of the 2D-population location around a given route (QRAM 3.2)

The QRAM calculates the spatial allocation of risk knowing the average location of the population (figure 2). Thus two-dimensional maps containing the individual risk for the surroundings could be extracted.

4 Lessons from the French application of the QRAM.

Following the Mont Blanc fire accident the French regulations covering road tunnel safety issues were changed and currently rely on two new circulars. One of them, the Circular 2000-82 of November 2000 [x] sets up a new procedure concerning the definition of the restrictions for the transit of dangerous goods through road tunnels. The main requirement is for an evaluation of the risk levels obtained for a given set of alternative routes existing around a tunnel. The evaluation implies the choice of the least risky route on the basis of a quantified risk assessment. In the case of the existence of an obviously low risk tunnel, the risk level assessment process can be based on a qualitative engineering judgement. In a case where a full QRA procedure is needed, the recommendation was made to use the QRAM 3.2 or other comparable model which has been through a similar amount of testing. Quantitative risk assessment is to be considered for all road tunnels with a length of more than 300 metres.

After three years this new legal procedure has led to the evaluation of the quantified risk level of approximately twenty tunnels' routes and their alternative routes in France. This procedure has been shown to give a good level of applicability in the overall decision process of the risk management associated with dangerous goods transport on roads.

These studies have been performed by different consultants who had attended a preliminary one-day basic training course [xi]. The experience acquired during this training period and during the performance of the risk studies allows the consultants to know reasonably well the capabilities and the limits of the model and also provides an indication of how the given results have to be interpreted or presented.

The French experience was also used to suggest a slightly simplified legal procedure by the end of 2003 and suggestions have been accepted by the Comité d'Evaluation de la Sécurité des Tunnels Routiers (CESTR, Committee for Road Tunnel Safety Assessment). The main modification is a simplified evaluation process for tunnel risk level and the implementation of a rough comparison with pre-defined risk level criteria. This first-step comparison routine allows one to decide whether or not it is necessary to perform a complete comparative and quantitative risk study.

Thus the three years experience acquired in France relative to the practical application of the OECD/PIARC QRAM leads to a confirmation of its efficiency as a tool to suggest the restrictions regarding dangerous goods transit through road tunnels.

5 New developments for a GIS interfaced QRAM

In parallel with the application of the QRAM within the French regulation framework, INERIS, which was the leading developer of the original model, launched a new research project in order to facilitate the generation of data necessary for a given risk study. These new developments have been funded by the French Ministry of Ecology and Sustainable Growth and the French Ministry of Equipment, Transport and Buildings, Tourism and Sea [xii].

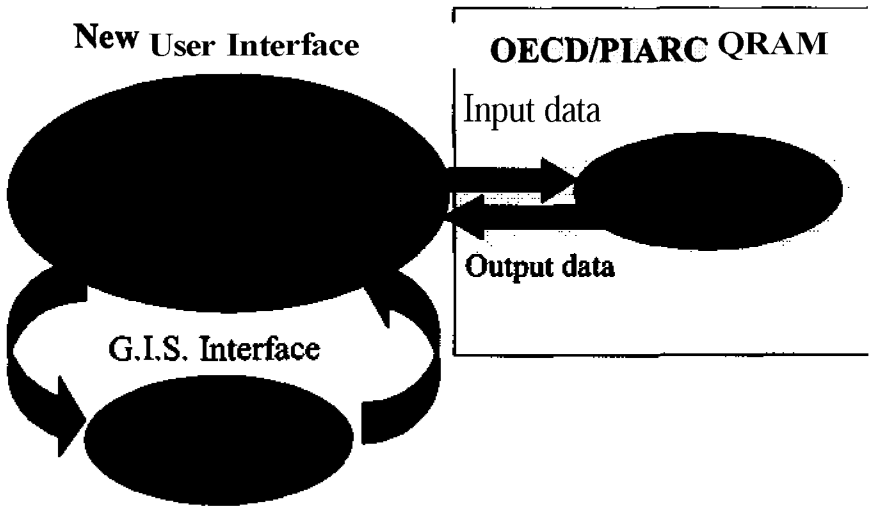
On the basis of the original OECD/PIARC model INERIS has followed up the development process in order to enhance the user-interface performance of the original models (QRAM 3.20 and 3.60) and to extend its capacities to the study of longer routes. In order to reach these goals, a two step development process was decided as follows:

- to enhance the user-interface performance of the original models,
- to extend capacities to the study of long routes by collecting all the needed road characteristics and population data with the help of a Geographical Information System (GIS).

In order to do that a two step development of the pre-existing model has been achieved: the development of new dialogue boxes and data management and the development of a Geographical Information System (GIS) interface for the data input of the routes and road characteristics. This work was essential for the reduction of the time spent to the data collection during the risk study and by this way to keep more time to spent to the HGs trafic study, risk analysis and the evaluation of options required by the decision-making process about the restriction possibilities

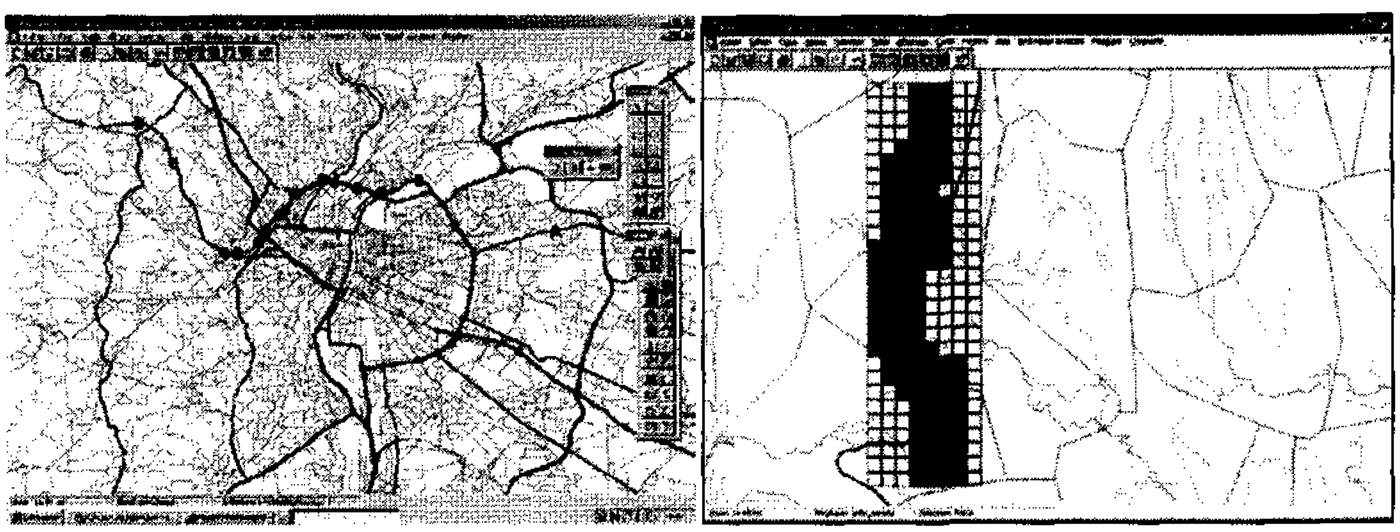
Concerning the basic user interface development, the main objective was to separate the data collection from the calculation phase. By doing this it is now possible to reset the data collection process, modify the data set and launch the calculation when all the elements of the data set have been collected. Figure 3 shows the new structure of the user interface. This new interface allows the user to manage the various options tested for a given route more easily. For example modifying 'section characteristics' or 'traffic vehicle hypotheses' etc, is now easier. Besides, the data collection optimised procedure allows the developers to work on data collection without changing the calculation process itself that had been tested and validated during the OECD/PIARC project. This development was also necessary for the GIS user-interface implementation and development.

Figure 3: Structure of the QRAM model with an enhanced user interface



Concerning the GIS user interface, the main objective was to reduce the time spent by the users for the data collection process, especially in the case of long routes. This was thought to be an important goal because during a risk study it is essential to spend as much time as possible on the other phases, namely traffic study, the risk analysis phase and the evaluation of options required by the decision-making process about potential DGs transit restrictions. Thus the time saved on data collection can lead to better risk analysis and better assessments of the possible restrictions. Figure 4 shows an example of a test case located to the North of the French Alps.

Figure 4: An example of the GIS interfaced QRAM - The selection of a long route around Grenoble (France) - 1D selection and 2D selection. [Chyba! **Záložka není definována.]**

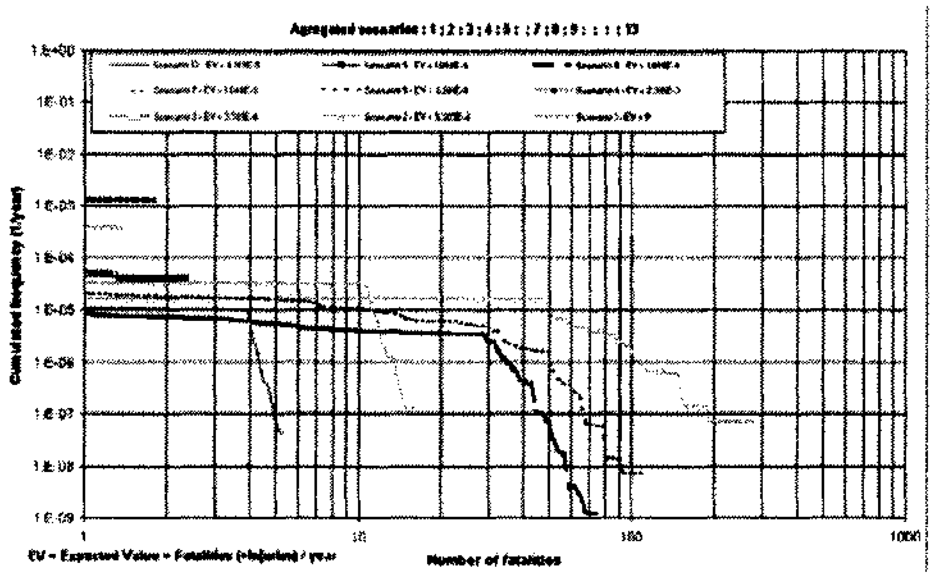


The two tested routes (only for GIS development testing purposes) were from **Bourgoin-Jallieu** to **Chambery (1)** via the Dullin and the Epine tunnels and (2) via Grenoble. The test has been focused on the long route via Grenoble (122 km) showing a good efficiency and quality of this new GIS interface. The quality of the data collection with GIS has been tested and compared to the manual process (the original **OECD/PIARC** model) leading to the conclusion that the GIS interface provides :

- a tremendous gain of time (typically a 1/100 ratio) for the road and local population data collection of long routes,
- the capability to evaluate the risk level for a long route and to detect the more risky locations (black points),

The new possibilities offered by the GIS interface might also help users to compare long road routes and rail routes, rail alternatives implying generally longer routes.
An example of **F/N** curves produced by the original **OECD/PIARC** model coupled to the GIS user-interface is given in Figure 5.

Figure 5: An example of the GIS interfaced QRAM - F/N curves



Cumulated frequency means "frequency of N or more fatalities "

In theory it could be possible to draw profit from this French experience for future practices in all European countries but the *sine qua non* condition is the existence of properly harmonised GIS databases. Such databases do not exist at the present time but this may change as the result of some projects currently being carried out about harmonisation of GIS data bases.

To conclude, it is now shown that the **OECD/PIARC** QRAM could operatewith a **GIS** interface (limited today to French databases) and adequate risk assessment pertaining to transport problems in the case of long road routes are now achievable. In particular, risk studies, such as quantified risk assessment, related to dangerous goods at regional scale, including tunnels or not, are now feasible.

6 Application of the QRAM at European and International level

Having harmonised regulations does not mean that the same regulation should apply to all tunnels, not even that two similar tunnels in two different places should have the same regulation. The only indispensable point is that the regulations should be expressed in the same way everywhere, which means that they should refer to the same lists of dangerous goods carriage which are authorised or banned.

The Working Party on the Transport of Dangerous Goods of the Economic Commission for **Europe's** Inland Transport Committee has accepted to introduce a table [xiii] into Chapter 1.9 of ADR (European Agreement concerning the International Carriage of Dangerous Goods by Road) containing, in grouped form, the various categories of dangerous goods which runnel managers could permit in accordance with parameters linked to tunnel construction, traffic **constraints,...,** in order to achieve a harmonised approach to restrictions on traffic in tunnels. This table defines the substances and types of load (packages, bulk, tank) to be included in each group of tunnel. These common **'lists'** are here called **'groupings** of dangerous goods **carriage'** (or more simply **'groupings').** In a number of the works cited here, the word **'loadings'** is used instead of **'carriage'**. **'Carriage'** (or **'loading')** refers not only to the nature of the transported goods, but also whether they are transported in bulk or packaged form and the possible presence of different dangerous goods in the same vehicle ("transport unit" in regulatory terms).

The basis of the proposed system is that the definition of the groupings of dangerous goods carriage should be the same for all tunnels in all countries (based on ADR). The decision making process would be unaffected by these regulations and it would remain the responsibility of the authority in charge of the tunnel to decide what is the authorised or banned **'grouping'** for a given tunnel. However the definition of the dangerous goods groupings is decided internationally and is based on the general definition given in table 2.

Table 4: Groupings of dangerous goods

Grouping A	All goods, including all dangerous goods carriages authorised on open roads.	*Least restrictive*
Grouping B	All carriages in grouping A except those which may lead to a very large explosion (**'hot** BLEVE' or equivalent).	
Grouping C	All carriages in grouping B except those which may lead to a large explosion (**'cold BLEVE'** or equivalent) or a large toxic release (toxic gas or volatile toxic liquid).	
Grouping D	All carriages in grouping C except those which may lead to a large **fire.**	
Grouping E	No dangerous goods (except those which require no special marking on the vehicle).	*Most restrictive*

In fact, a system with six groupings could be chosen to differentiate between the risks of a large explosion and a large toxic release. However cold **BLEVEs** can happen with any non-flammable compressed or liquefied gas transported in bulk, including those that are toxic. For this reason, and in order to limit the number of groupings, it was deemed appropriate to deal with large toxic releases and large (cold BLEVE) explosions in the same grouping, which led to the proposed system.

The QRAM incorporate accident scenarios representative of each of the groupings then it is possible to assess the risks resulting from a given grouping (table 3). Within that regulation framework the QRAM can be used for defining the practicable grouping class to apply to a given tunnel taking into account its environment and the possible alternative routes. Thus the decision to allow or not a tunnel to a given grouping can be helped by the analysis of the QRAM results.

Table 5: Carriages representative of each grouping in the QRAM

Groupings of carriages	Representative carriages for QRAM and corresponding scenarios	Restrictions
Grouping A	Liquefied Petroleum Gas (LPG) in bulk and in cylinders (Scenarios 3, 7, 8 and 9 of the QRAM), Carbon dioxide in bulk (Sc. **13),** **Ammonia/chlorine*** in bulk (Sc. 6 and 10), Acrolein in bulk and cylinders (Sc. **1 1** and **12),** Motor spirit in bulk (Sc. 4 and 5), Heavy Goods Vehicle **(HGV)** without dangerous goods (Sc. 1 and 2).	Least restrictive
Grouping B	Carbon dioxide in bulk (Sc. **13),** **Ammonia/chlorine*** in bulk (Sc. 6 and 10), Acrolein in bulk and cylinders (Sc. **1 1** and 12), Motor spirit in bulk (Sc. 4 and 5), LPG in cylinders (Sc. 3), HGV **without** dangerous goods (Sc. 1 and 2).	
Grouping C	Motor spirit in bulk (Sc. 4 and 5), LPG in cylinders (Sc. 3), Acrolein in cylinders (Sc. 12), HGV without dangerous goods (Sc. 1 and 2).	
Grouping D	LPG in cylinders (Sc. 3), Acrolein in cylinders (Sc. 12), HGV without dangerous goods (Sc. 1 and 2).	
Grouping E	HGV without dangerous goods (Sc. 1 and 2).	Most restrictive

* *Chlorine is considered in countries **where** its transport is allowed in appreciable quantities on roads.*

With this system, for example, a tunnel authorised to accept **'Grouping A'** carriages would be allowed to admit vehicles carrying the most dangerous carriages, whereas tunnels authorised to accept only **'Grouping E'** carriages would generally not be allowed to admit vehicles carrying any dangerous goods. When a transport unit carries dangerous goods of more than one class, the most restrictive grouping shall apply to the whole load.

7 Conclusion

The transport of hazardous goods through tunnels is growing rapidly. There is a lack of knowledge about how to organise this transport in a responsible way and how to find the right balance between economic demands and safety needs. The scientific and research work done so far is the first step on the way to a more rational and responsible treatment of this problem.

At present it is intended that the QRAM v3.60 software be distributed by PIARC at the International level and entraining to users be organised by PIARC with the help of the model developers and skilled bodies.

Tunnels are part of the transport system which can contribute to offer an adequate option for transit of people and goods. However, particular problems occur with the transport of dangerous good through tunnels. There is no simple or uniform solution, and a risk assessment process will be necessary for each individual tunnel, based on a rational scientific methodology, which is now available from the OECD / PIARC research work for the road mode. The efficiency of this tool has been proved for three years in France but there is still the need to extend this experience among others states in the coming years.

There are still many assumptions, which may or may not be justifiable, and not enough sound engineering data. In future years administrations, tunnel operators and experts from fire brigades and research institutes could help to further use and improve the road model.

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