Centre d'Études des Tunnels

Guidance

Guide to Road Tunnel Safety Documentation

Booklet 3

Assessing risks related to the carriage of dangerous goods

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MINISTÈRE CHARGÉ DES TRANSPORTS

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Guide to Road Tunnel Safety Documentation

Safety documentation must be submitted to the prefect for all road tunnels over 300 metres long. The procedures for examining this documentation are defined by regulations.

All parties with responsibility for tunnel safety (owner, operator, emergency and rescue services, and the prefecture) must be involved in preparing the documentation. Once completed, it contains all the key information needed to operate the tunnel in all circumstances.

The **Guide to Road Tunnel Safety Documentation** is intended for all of these bodies as well as for project managers and consulting firms.

The **Guide** is divided into the following five booklets:

- Booklet 1: The role of safety documentation in safety procedures (to be published);
- Booklet 2: In-service tunnels: "from inventory to reference state" (June 2003);
- Booklet 3: **Assessing risks related to the carriage of dangerous goods (2005; updated 2018);**
- Booklet 4: Specific Hazard Investigations (SHIs) (September 2003);
- Booklet 5: The Emergency Response Plan (ERP) (October 2006).

Regulatory context

- *Texts applicable to tunnels over 300 metres long*
  – Book I, Chapter VIII of the French Roadway Code:
    - Legislative part: articles L.118-1 to L.118-4
    - Regulatory part: sections 1 to 3

- *Additional texts applicable to all tunnels over 500 metres long on the Trans-European Road Network*
  – Book I, Chapter VIII of the French Roadway Code:
    - Legislative part: article L.118-5
    - Regulatory part: section 4
  - Order of 08/11/2006, amended by the order of 09/11/2007
  - Order of 18/04/2007, article 3

- *Additional texts applicable to State-managed tunnels over 300 metres long*
  – Circular 2000-63 (IT 2000), Appendix 2
  – Circular no. 2006-20
  – Circular of 12 June 2009

- *CDG regulations*
  – ADR,[1] the European agreement regulating the international carriage of dangerous goods by road (updated every two years)
  – Order of 29 June 2009, amended (the so-called "CDG order")
  – Order of 25 June 2009 amending the order of 24 November 1967 on road and motorway signage

[1] ADR: European Agreement concerning the International Carriage of Dangerous Goods by Road.

Booklet 3
Assessing risks related to the carriage of dangerous goods

Introduction

Accidents involving toxic, flammable, explosive and other dangerous goods are extremely rare. However, the consequences of these accidents can be much more disastrous in tunnels than in the open air. For this reason, it is essential to carry out an objective risk assessment before deciding on regulations for dangerous goods transport (DGT).

The initial version of this booklet, published in December 2005, recommended assessing the risks to people (road users and local residents) primarily based on death from accidents related directly to the dangerous goods in question. The risk of death was assessed using a so-called Quantitative Risk Assessment (QRA) software program. Where the tunnel was found to present a high risk from a DGT perspective, the same assessment was carried our for each possible route (route through the tunnel plus alternative routes as applicable), based on the use of each route by all vehicles carrying dangerous goods. The results for each route were then compared with one another.

Changes in DGT-related legislation, which came into effect on 1st January 2010, meant that the method recommended in 2005 needed to be revised. The revised recommendations, which are explained in this document, also reflect experience gained in applying the method over the previous decade.

The updated guidelines feature two major changes. Firstly, whereas the previous method was largely binary in its approach (dangerous goods were either allowed to pass through the tunnel or prohibited), the revised recommendations allow for greater flexibility, allowing some types of dangerous goods to pass through the tunnel. Secondly, a multi-criteria analysis is now advised in all circumstances, whereas this was previously only recommended if the death risk assessment was inconclusive.

This booklet describes the approach from an operational perspective. It also outlines the various risk reduction measures that can be adopted for tunnels used by vehicles carrying dangerous goods. These are divided into preventive measures (i.e. that reduce the likelihood of an accident occurring) and protective measures (i.e. that limit the impact of an accident should it occur).

Additional information on the chosen approach and the reasoning behind it can be found in the appendices.

For the sake of convenience, the term “consulting firm” is used throughout this booklet to refer to any public or private body capable of carrying out all or part of the DGT-related risk analyis. Such a body should have personnel who are trained in applying the method as described and using the associated tools. These personnel should, individually or as a team, possess the requisite knowledge and experience to understand the theory behind the method, to correctly interpret the results, and to present an appropriate risk assessment to the owner.

This booklet has been discussed with and presented to the French National Commission for the Safety Assessment of Highway Engineering Structures (CNESOR).

1 Issues surrounding dangerous goods transport (DGT)

1.1. DGT and the general regulatory framework

In France, vehicles carrying dangerous goods represent around 5% of total heavy goods vehicle (HGV) traffic. The sheer variety of types of dangerous goods means that the associated risks are equally varied.

The table below shows how these goods are categorised under the international classification system and what labels should be applied to the goods in question (other labels are also used for certain classes of goods, according to the hazards they present).


1. Explosive substances and articles


2. Gases


3. Flammable liquids


4.1 Flammable solids, self-reactive substances and solid desensitised explosives


4.2 Substances liable to spontaneous combustion


4.3 Substances which, in contact with water, emit flammable gases


5.1. Oxidising substances
5.2 Organic peroxides


6.1 Toxic substances


6.2 Infectious substances


7 Radioactive material


8 Corrosive substances


9 Miscellaneous dangerous substances and articles

Dangerous goods classes and sample labels

Statistics show that vehicles carrying dangerous goods are involved in comparatively fewer accidents than other HGVs (presumably because drivers are better trained and vehicles are more carefully maintained). Accident severity is broadly similar on average (personal injury accidents as a share of all accidents, number of deaths relative to the number of personal injury accidents, etc.). Overall, the number of accidents involving vehicles carrying dangerous goods is therefore relatively low (around 200 per year across the entire French road network). Each year, these accidents cause somewhere between 10 and 20 deaths. In most cases, these are road-traffic accidents where the dangerous goods are neither a cause nor an aggravating factor.

However, although accidents involving vehicles carrying dangerous goods are a thankfully rare occurrence, some substances and materials have the potential to cause extremely serious accidents (such as explosions involving flammable gases or liquids, major fires and the release of toxic gases). In 1997, for instance, 13 lives were lost when a train collided with a fuel tanker truck at a level crossing in Port-Sainte-Foy, south-western France. In recent decades, western Europe's most devastating accident involving a vehicle carrying dangerous goods by road was the Los Alfaques disaster in Spain: some 216 people died after a tanker truck carrying liquefied propylene exploded near a campsite on 12th July 1978.

Given the dangers associated with the transport of these goods, they are subject to specific, international rules and requirements. These are set out on the ADR[1], which was drawn up in Geneva under the auspices of the United Nations Economic Commission for Europe (UNECE). The rules and requirements set out in this international agreement, which is revised every two years, are mandatory within the European Union, applying to both domestic and international transport. The ADR has therefore been transposed into French law[2], which also includes supplementary provisions and clarifications.

Under these regulations, all dangerous materials and substances are assigned a four-digit number (known as a "UN number"), and there is a classification system for dangerous goods based on the associated risks (see table above). The regulations also set out the technical requirements and rules on the use of containers (packaging, tanks and other types of container), as well as rules on the approval and annual servicing of vehicles, which are subject to specific requirements (electric circuits, brakes, fire extinguishers, etc.) that go beyond the provisions of the Highway Code. In addition, the ADR contains shipping-related requirements (covering issues such as package marking and labelling, hazard plates and orange signage for containers, mobile tanks and vehicles, and documentation). It also deals with the training of personnel, especially drivers, and with transport safety arrangements for companies (who must for instance, be advised by a qualified safety expert). On top of this, the regulations stipulate requirements for loading and unloading, and the safety rules that all parties in the transport chain (hauliers, shippers, etc.) must follow.

The regulations allow for certain routes to be closed to vehicles carrying dangerous goods, where appropriate, in order to take account of significant local vulnerabilities.

Since 1st January 2010, specific signage must be used for road tunnels. This is detailed in section 1.4.

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1 European Agreement concerning the International Carriage of Dangerous Goods by Road.

2 Order of 29/05/2009 on the carriage of dangerous goods by road (so-called "DGT order").

Figure 1: Example of signage for a vehicle carrying dangerous goods: green label (gas), yellow label (oxidising solid or liquid), orange plate (UN number for liquid oxygen)

1.2. DGT and specific tunnel-related issues

Accidents involving dangerous goods can have more severe consequences in tunnels than in the open air due to the confined nature of the space. Below is a list of the major hazards that can cause mass casualties in tunnels and, in some cases, severely damage the structure itself:

- **Explosions, which can be subdivided into two categories**:
  - "very large" explosions, such as when an LPG[3] tanker is heated by a fire (explosion caused by the uncontrolled expansion of vapours emitted from boiling liquefied gas, followed by a fireball),
  - "large" explosions, such as when a tanker carrying non-flammable liquefied gas is heated by a fire (explosion caused by the uncontrolled expansion of vapours emitted from boiling liquefied gas, but without a fireball).

- **Major leaks of toxic gas**: These leaks can be caused by a breach in a tank containing toxic gas or volatile toxic liquid. Such leaks can lead to the death of people located in the immediate vicinity, as well as further afield where the gas is driven by the air current (including outside the tunnel).

- **Major fires**: When a fuel tanker catches fire, for instance, it produces significant amounts of smoke, toxic gases and heat (see Appendix C of Booklet 4 on Specific Hazard Investigations). Depending on the tunnel type, it can prove extremely difficult to protect users inside the tunnel from the effects of such a fire, meaning that the accident may claim a high number of victims.

[3] Liquefied petroleum gas.

Since such incidents can have much more severe consequences inside a tunnel than in the open air, it is justifiably necessary to consider which dangerous goods may be permitted within the structure. But the existence of an alternative, open-air route cannot alone be sufficient grounds to prohibit the transport of all dangerous goods through a tunnel. The main reasons for this are the following:

- The alternative route may pass through densely populated areas where some DGT-related accidents could have disastrous consequences, whereas the route through the tunnel passes through sparsely populated zones.
- The alternative route may be more prone to accidents than the route through the tunnel, which may even have been created at least in part for the purpose of enhancing road safety.

Moreover, for some types of dangerous goods (such as corrosive substances), being in a confined space has no bearing on accident severity.

Decisions as to which dangerous goods are allowed to be transported through a tunnel should therefore be based on a comparison of risks. Making such comparisons is a difficult exercise because:

- the disasters in question have an extremely low probability of occurrence,
- the number of victims that these disasters claim is both extremely low when taken as an annual average (far less than the number of road traffic accident victims) but likely to be high in the event of an exceptionally serious accident,
- the breakdown of road users and local residents as a proportion of total victims differs between open-air and in-tunnel routes.

The method outlined in this booklet should therefore be followed in order to avoid the DGT regime being decided on arbitrarily.

1.3. Principles for the passage of dangerous goods through tunnels

1.3.a. Basis

The principles for the passage of dangerous goods through tunnels are based on the assumption that, in tunnels, there are three main dangers capable of leading to numerous victims or seriously damaging the structure (see 1.2):

a) serious explosions, which include “very large” and “large” explosions,
b) major leaks of a toxic gas or volatile toxic liquid,
c) major fires.

The order in which these dangers are shown above corresponds to the decreasing magnitude of consequences in terms of severity and the increasing efficacy of possible protective measures. The five tunnel categories defined by the ADR were drawn up on the basis of this ranking.

1.3.b. Tunnel categories

The passage of dangerous goods through a tunnel may only be restricted by assigning one of the five categories described in Table 1.1 below to the tunnel in question.

Category A	No restriction on vehicles carrying dangerous goods
Category B	Passage forbidden for vehicles carrying dangerous goods capable of causing a very large explosion
Category C	Passage forbidden for vehicles carrying dangerous goods capable of causing a very large explosion, a large explosion, or a major toxic leak (gas or volatile liquid)
Category D	Passage forbidden for vehicles carrying dangerous goods capable of causing a very large explosion, a large explosion, a major toxic leak, or a major fire
Category E	Passage forbidden to all vehicles carrying dangerous goods (apart from vehicles carrying UN numbers 2919, 3077, 3082, 3291, 3331, 3359 and 3373)[4]

* UN 2919, 3077, 3082, 3291, 3331, 3359 and 3373 are also authorised.

Table 1.1: ADR tunnel categories

The choice of category precisely determines which dangerous goods are authorised in the tunnel and which are not. There is no provision for an exception or modification to the list of dangerous goods authorised/forbidden in a tunnel of a given category.

On the other hand, specific operating risk reduction measures may be applied to some or all vehicles carrying dangerous goods using a tunnel. These provisions are specified in section 5.

[4] 2919 Radioactive material, transported under special arrangement, non fissile or fissile excepted
3077 Environmentally hazardous substance, solid
3082 Environmentally hazardous substance, liquid
3291 Clinical waste, unspecified
3331 Radioactive material, transported under special arrangement, fissile
3359 Fumigated unit
3373 Biological substance, Category B

1.3.c. Restriction codes for the transport of dangerous goods in tunnels

The regulations specify that each dangerous good is given one of the 4 tunnel restriction codes described in Table 1.2 below.

Code B	Goods presenting the risk of a “very large” explosion
Code C	Goods not presenting the risk corresponding to code B but presenting the risk of a “large” explosion or major toxic leak
Code D	Goods not presenting the risks corresponding to code B or C hazard but presenting a risk of major fire
Code E	Goods not presenting the risks corresponding to code B or C or D
No code	In terms of consequences of an accident involving their release, five dangerous materials present no specific features in tunnels in comparison with in the open air. They concern vehicles carrying UN numbers 2919, 3291, 3331, 3359 and 3373.

Table 1.2: restriction codes for the transport of dangerous goods in tunnels

The restriction code for the transport of dangerous goods is determined by the haulier in accordance with the ADR, based on the associated goods code(s). This code appears in the logbook. It is not affixed to the outside of the vehicle. It may also depend on the quantity of goods being carried or on their packaging.

To determine the restriction code for its load, the haulier relies on the restriction code for each substance shown in table A of chapter 3.2 of the ADR (in brackets in column 15). In this table, the code for a given substance may contain:

- **a single letter**, which applies irrespective of the quantity and packaging,
- **two letters separated by a number**: in this case, the first letter applies when the total net mass transported (in kg) exceeds this number, while the second letter applies in the opposite case (e.g. code B1000C means a tunnel restriction code of B if the vehicle is carrying more than 1,000 kg of the substance in question, and C otherwise),
- **two letters separated by a forward slash (/)**: in this case, the first letter applies when the substance is transported in a tank or in bulk form, while the second letter applies in other cases (e.g. code D/E means a tunnel restriction code of D if the substance is transported in a tank, and E otherwise). Where the same vehicle is carrying more than one substance, the most restrictive code applies.

It should be noted that tunnel restrictions, like those for the open air, only apply to the vehicles required by the ADR to display external signs (orange plates). Also excluded are materials transported in small quantities or possibly in small packages. In addition, the ADR regulations do not apply to substances used for powering the vehicle.

1.3.d. Principles of passage

A vehicle carrying dangerous goods may only pass through tunnels of a category situated before its restriction code in alphabetical order. For example, a vehicle transporting goods with a code C may only pass through tunnels of categories A and B. Transport of the five low-risk substances which do not have a tunnel restriction code (see 1.3.c) is thus authorised in all tunnels. This principle is explained in Table 1.3.

Tunnel category	Restriction codes for authorised vehicles carrying dangerous goods
A	B, C, D, E*
B	C, D, E*
C	D, E*
D	E*
E	Dangerous goods without a tunnel restriction code (UN 2919, 3077, 3082, 3291, 3331, 3359 and 3373).

* UN 2919, 3077, 3082, 3291, 3331, 3359 and 3373 are also authorised.

Table 1.3: Correlation between tunnel category and dangerous goods restriction code

The carrier is required to ensure that the proposed route only contains tunnels through which the goods the vehicle is carrying are permitted to pass.

1.3.e. Reference texts

Since 1st January 2007, the ADR has included specific provisions for tunnels. These were amended on 1st January 2009. The key tunnel-related provisions can be found in the following sections:

- Annex A, Part 1, Chapter 1.6, para. 1.6.1.12,
- Annex A, Part 1, Chapter 1.9, para. 1.9.5 – Tunnel restrictions (which contains the provisions on tunnel categories),
- Annex A, Part 3, Chapter 3.2, para. 3.2.1, and in particular Table A (which includes the tunnel restriction code for each substance),
- Annex B, Part 8, Chapter 8.6 – Road tunnel restrictions for the passage of vehicles carrying dangerous goods (which includes provisions on tunnel restriction codes).

The provisions of the ADR on tunnels have been mandatory since 1st January 2010 for all underground road constructions open to public traffic, irrespective of their length or owner.

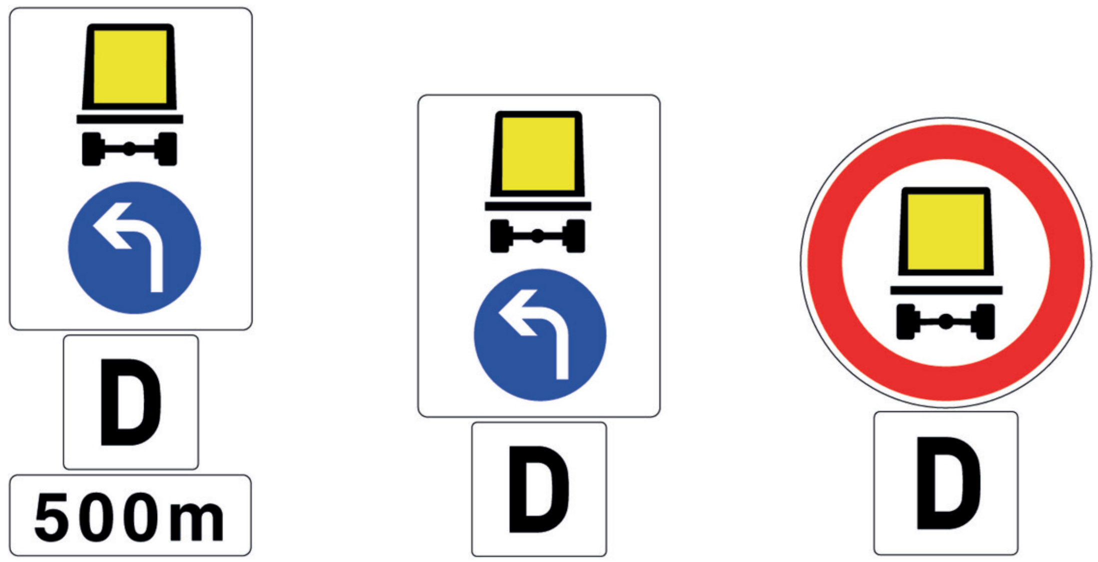
1.4. Signage

The regulations on the transport of dangerous goods require appropriate signage of tunnel categories. This requirement was introduced by the order of 25th June 2009, which amended both the order of 24 November 1967 on road and motorway signage, and the interministerial directive on road signage (IISR) of 13th August 1977.

Category A tunnels require no special signage because there are no restrictions on the transport of dangerous goods in these structures. All other tunnels must have both advance warning signs and in-situ signs:

- **Advance warning signs** must use the new **C117 sign** alongside the M11c1 sign bearing the tunnel category letter. The C117 sign must be situated before the final decision point on the approach to the tunnel, at a distance equivalent to around 6 seconds of driving time. It may be preceded by an identical sign positioned further from the tunnel, which must be accompanied by both the M11c1 sign bearing the tunnel category letter and another sign (M1) indicating the distance remaining until the final decision point.

- **The in-situ sign is positioned at the final decision point on the approach to the tunnel.** It consists of the **B18c sign** alongside an M4z sign stating the tunnel category. This combination of signs may also be repeated on the tunnel access route if a U-turn is possible. In this case, it is situated at the turnaround point. These signs are shown in Figure 2.



Optional advance warning signs (C117 + M11c1 + M1)

Advance warning signs before the final decision point (C117 + M11c1)

In-situ sign located at the final decision point (B18c + M11c1)

Figure 2: Advance warning and in-situ signs for a category D tunnel

As previously, the signage requirements for diversion routes are set out in article 49-1 (“Category-specific diversion routes”) of the IISR, which remains unchanged. On the diversion route, the directional signs include the existing SC12 symbol, with no accompanying M11c1 sign (see Figure 3).

Figure 3: Example of a sign with an SC12 symbol on a diversion route

Notes

Notes

2 Principles of a DGT-related risk analysis

The risk analysis should answer the following question:

Which category should be chosen for the tunnel in order to minimise the overall risk related to the transport of dangerous goods for the entire route comprising the tunnel being studied and other possible routes?

The method described in this booklet will be limited to giving elements of risk assessment that can clarify this choice.
It consists in comparing the five tunnel categories (A to E) in terms of DGT-related risks. When the tunnel is category A, the transport of all dangerous goods is permitted in the tunnel. If it is category E, no dangerous goods can be transported through the structure[5] and vehicles carrying such goods must take alternative routes. The other three categories (B to D) lead to a distribution of dangerous goods between the route comprising the tunnel and any alternative route or routes. The method described in this booklet is underpinned by a different approach than the one set out in the 2005 version, which only involved comparing routes (the route containing the tunnel against the alternative route(s)).

2.1. Determining whether a risk analysis is necessary

An analysis of DGT-related risks is not required in the following cases:
- new tunnels over 300 metres long on a route that is already forbidden for vehicles carrying dangerous goods,
- existing tunnels over 300 metres long that are prohibited to vehicles carrying dangerous goods and where there are no plans to allow such traffic in the future.

In any event, DGT-related risk analysis should be carried out:
- when compiling the preliminary safety documentation for a new tunnel;
- when compiling the initial safety documentation for an in-service tunnel over 300 metres long;
- when updating the safety documentation for the renewal of the operating authorisation in one of the following cases:
  - when there has been a significant change in traffic and/or planning conditions,
  - when feedback or specific circumstances call into question the existing DGT regime,
  - when the DGT-related risk analysis pre-dates the first version of Booklet 3 (December 2005) and is no long appropriate, e.g. because it is based on an outdated iteration of the QRA model and/or because it has too many shortcomings relative to the method recommended in the first version of the booklet,
  - when the category (A, B, C, D or E) of an in-service tunnel partially authorised for vehicles carrying dangerous goods was chosen prior to 1st January 2010 via so-called "expert opinion".

In all of these cases, the principle of dangerous goods categories should be built into the new risk analysis, even if this was not the case with the previous one.

[5] With the exception of certain goods that pose no additional, specific risk in tunnels (see 1.3.c).

2.2. Role of a risk analysis

When planning a new tunnel, it is advisable to consider the DGT regime at the stage of the preliminary engineering structure studies, so as to build the basis for an informed decision early on in the process. This decision should then be confirmed at the planning stage (or, as relevant, at the preliminary planning stage), where a DGT-related risk analysis must be carried out. In fact, the choice of DGT regime will determine whether certain features are required (e.g. a continuous slot drainage channel to collect dangerous liquids, or the design of the ventilation system).

Important:

The DGT-related risk analysis should be based on the tunnel option selected at the end of the first phase of the preliminary planning stage. Although it may be tempting to use this method to compare different tunnel design options, such an approach is not recommended. In fact, the method is not intended to be used to optimise risk reduction measures or to carry out a comparative assessment of ventilation/ smoke extraction systems. These limitations aside, such an approach would have major shortcomings since the assessment would not take into account other risk factors such as non-DGT-related fires.

The DGT-related risk analysis should be carried out prior to the Specific Hazard Investigation (SHI), so that the SHI is based on the DGT passage regime that has already been approved. Moreover, where the risk analysis reveals that dangerous goods other than liquid hydrocarbons make a significant contribution to the DGT-related risks, consideration should be given to including trigger events involving these goods in the SHI (see Booklet 4: Specific Hazard Investigation (SHI)).

In any event, the DGT-related risk analysis should begin with the owner carrying out a detailed analysis of actual or predicted dangerous goods-carrying traffic passing through the tunnel (see ad hoc subsection of the situational analysis, as explained in Annexe A).

2.3. Risk analysis criteria

2.3.a. Risk of death from type "M" accidents[6]

The death of road users or those in close proximity is a basic element for assessing the risks related to the transport of dangerous goods. There are two scenarios in which an accident involving a dangerous goods vehicle could result in the death of a user.

The first occurs if the accident causes a release of the dangerous goods being transported, in which case the user and/or local residents may be victims of the consequences of this release (see 1.3.a). These are type "M" accidents.
In the second scenario, a road traffic accident may cause serious injury or death without the release of dangerous goods. These are type C accidents[7].

Type "M" accidents have a very low probability of occurrence, but the consequences may be very serious and have a significant effect on society. Type "C" accidents have a much higher probability of occurrence but with less serious consequences. Although type "C" accidents are less serious, this does not offset the fact that they occur more frequently. The risk of death from type "C" accidents is therefore significantly higher than from type "M" accidents.
Consequently, if the risk of death was assessed without distinguishing between type "M" and type "C" accidents, type "M" accidents would be non-discriminatory and the specific impact they might have on society would not then be taken into account. The risks of death related to type "M" accidents and type "C" accidents are therefore analysed separately. This separate treatment implicitly gives greater weight to accidents liable to cause a large number of deaths and thus manifests an aversion to risk in relation to this type of accident.
As a result of the above, the first risk assessment criterion is the risk of death from type "M" accidents, i.e. accidents causing the release of the dangerous goods.

2.3.b. Risk of death from type "C" accidents

For the same reasons as those developed in 2.3.a, the second risk assessment criterion is the risk of death from type "C" accidents, i.e. accidents not causing the release of the dangerous goods.

[6] Consideration should be given to the risk of major accidents, even if their probability of occurrence is extremely low. Across the 13 serious-accident scenarios used in the QRA model, the average conditional probability of an aggravated material accident involving a vehicle carrying dangerous goods is 2-in-1,000 in the open air and 5-in-1,000 in a tunnel. Accident statistics for the period 1987-1997 show that type "M" personal injury accidents accounted for around 40% of all personal injury accidents involving vehicles carrying dangerous goods, yet their severity (number of injuries and deaths) was almost identical to the severity of type "C" accidents. This can be attributed to the fact that, in the period in question, most accidents involving the release of dangerous goods were limited in scale.

[7] The letter "C" may be used throughout this booklet to refer to this type of accident, the tunnel category and the dangerous goods code under the ADR.

2.3.c. Vulnerability of routes with regard to accidents involving dangerous goods

In order to take vulnerability into account, the study of each potential route must include issues (mainly environmental, economic and urbanistic) such as:

- The presence of natural sites (mainly watercourses) that might be damaged (for example by a fire) or affected by accidental pollution in the event of spillage of a dangerous material
- The presence of structures (bridges, tunnels), buildings (historical monuments), industrial sites, etc., that might be damaged during an accident involving a vehicle carrying dangerous goods
- The presence of population concentrations that might be affected by pollution related to the accident or its management (apart from the risk of death covered by the two criteria explained in 2.3.a and 2.3.b) such as, for example, noise or olfactory pollution, and measures restricting residents' access to their homes
- Constraints that might arise in the case of prolonged closure of tunnels situated on the various routes studied (length and duration of the imposed diversion route, consequences for the local economy if, for example, industries are penalised by a longer supply time for dangerous goods, etc.)
- Constraints relating to the passibility of the different routes, particularly in winter (snow, ice), and due to natural risks (flooding, avalanches, rock falls, landslides, forest fires, etc.) that might affect them, these constraints being likely to complicate management of an accident involving vehicles carrying dangerous goods
- Distance from rescue services.

This list is not exhaustive. It should be noted that the deaths of local residents or road users should not be taken into account as this is covered by the previous two criteria (see 2.3.a & 2.3.b).

2.3.d. Economic implications of the decision

Independently of the risks related to accidents, which are covered by the previous criteria, the DGT regime chosen has economic implications for the owner and for hauliers and shippers. These impacts should be taken into account, particularly:

- Additional costs of tunnel investment and operation resulting from permitting the passage of vehicles carrying dangerous goods
- Cost related to additional measures to be taken to protect the environment (such as pollution and noise) in view of the additional traffic occasioned by the vehicles carrying dangerous goods
- The additional costs imposed on shippers and hauliers by these restrictions, for example if they require one or more longer and possibly more restrictive alternative routes (with a high density of traffic, congestion at rush hours, etc.).

2.4. A quantitative risk assessment model for type "M" accidents

The risk of death from type "M" accidents is assessed using the quantitative risk assessment (QRA) model[8]. This model is subject to change, so it is advised to use the version approved by CETU at the time when the assessment is carried out[9]. Since the QRA model cannot distinguish between categories D and E, these are grouped together into a single category (D/E) for the purpose of this assessment.
The model can be obtained from PIARC which, along with CETU, can provide the details of bodies offering technical support and user training. Because of its complexity, users of the model must possess adequate risk-assessment expertise, have read the accompanying documentation attentively, and have been trained on how to use it by an expert. Future users therefore need to develop a clear understanding of the model and its limitations.
The QRA model quantifies two aspects of the risk: the probability of occurrence of events and the seriousness of their consequences. Seriousness may be expressed in terms of deaths, injuries, the destruction of buildings or structures, or damage to the environment. Although the model provides insights into all these aspects, only the results relating to deaths are used for the purpose of the assessment described here.
A complete assessment of risks of type "M" accidents would require the study of all accident scenarios that might occur. It would therefore examine all possible weather conditions, all possible kinds of accident with all types of vehicle, fully or partially loaded, possible road traffic offences, etc. Since such an assessment is completely unrealistic, simplifications have been introduced.

The model is based on the following procedure:
- Selection of a restricted number of representative dangerous goods
- Selection of some representative scenarios of serious accidents involving these goods, which could occur at any point along the route
- Determination of probabilities that these events might occur
- Assessment of the effects of these scenarios on users of the route and on residents.

The simplest way to use the results produced by the model is, for each chosen accident scenario, to multiply the number of deaths it causes by its annual probability of occurrence, and then to add together the amounts for all the scenarios: this weighted average is known as the "mathematical expectation", or "ME" for short. The ME therefore represents the average numbers of deaths per year caused by accidents involving dangerous goods[10].

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8 The model was developed and fine-tuned by INERIS (France), WS-Atkins (United Kingdom) and IRR (Canada) as part of a joint research project by the Organisation for Economic Co-operation and Development (OECD) and the World Road Association (PIARC). The European Union contributed financially to the project.

9 Version 4.04 as of the date on which this booklet was published.

10 The ME is an aggregate of various possible events, some of which cause few deaths and others of which have a high death toll but have must lower probabilities of occurrence. There are two important observations to make here:
- Where one event has a death toll 10 times higher than a second, but where the second is 10 times more likely to occur, both have the same weighting in the ME.
- If an event has an annual probability of occurrence of 1-in-1,000, its probability remains unchanged from year to year, regardless of whether or not such an event occurred in the previous year. If such an event did happen in the previous year, that does not of course imply that it will not happen again for another 1,000 years. All the probability of occurrence means is that, over an extremely long time period, the number of accidents of this type divided by the time period will be around 1/1,000 (it will be exactly 1/1,000 over an infinite time span).

The model also produces results that support a more detailed analysis. This is because it generates F-N curves, which indicate the annual frequency (F) at which an accident causing a given number (N) of deaths or more will occur. These curves can be generated on aggregate for a given route or for each type of dangerous good carried. Using the curves, it is possible to:

- assess the share of accidents causing a high number of victims on each route, and/or for each category of dangerous goods
- compare curves between categories, although this comparison is only meaningful if the difference between the ME values for each category is significant
- work out the contribution of each type of dangerous good or accident to the overall ME value.

Further details on the QRA model and how to use it can be found in Annexe B.

2.5. A two-stage risk assessment process

The method comprises two stages, described in detail in sections 4 and 5. The first takes the form of a simplified analysis, the results of which determine the value of doing a more in-depth risk assessment in the second stage.

The QRA model is required in both stages, albeit using a larger data set in the second.

2.5.a. Stage 1: Assessing intrinsic risk related to the tunnel and determining the existence of one or more alternative routes

This first stage only requires the collection of a limited data set (tunnel characteristics, tunnel traffic including vehicles carrying dangerous goods, and basic weather information). The owner approves the data, then uses the QRA model to calculate the mathematical expectation of death from type "M" accidents for category A tunnels (no restriction on vehicles carrying dangerous goods). This mathematical expectation is known as the intrinsic risk.

If the intrinsic risk is low, the tunnel is not considered to be of particular concern in terms of DGT-related risks and is not taken into account when deciding on the DGT regime for the route. At this point, there is no need to take the DGT-related risk analyis any further.

If the intrinsic risk associated with the tunnel is not low, the next step is to determine whether one or more alternative routes exist for vehicles carrying dangerous goods. In exceptional circumstances, there is no alternative route and these vehicles will therefore have no option but to pass through the tunnel. In such a case, the assessment focuses on risk reduction measures (see section 5). If an alternative route exists, the exercise moves to stage 2.

2.5.b. Stage 2: Comparing different categories

The second stage is only carried out if the findings of the first stage show it is necessary. This part of the exercise involves the extensive collection of additional data about the route including the tunnel, and about each of the alternative routes. A specialist consulting firm will need to be brought in at this stage. First of all, it aids understanding and characterises the DGT-related risks for each possible tunnel category. These categories are then compared in order to reveal the one presenting the lowest level of risk. The level of risk of each possible category depends on the distribution of vehicles carrying dangerous goods between the various routes (the one that includes the tunnel and the alternative routes) but also the characteristics of these routes.

This second stage is divided into two steps.

The first takes the form of a situational analysis, which begins with the selection of the various alternative routes that vehicles carrying dangerous goods might take. Each of these routes is then analysed, along with the route including the tunnel. This analysis should give the consulting firm and stakeholders a clearer picture of these routes and issues surrounding them, as well as providing the input data required for the second step.

The second step begins with an analysis, evaluation and comparison of the possible tunnel categories according to the four risk criteria identified in 2.3. The possible tunnel categories are A, B, C and D/E (D and E are grouped together because they cannot be differentiated in the death-risk assessment for type “M” accidents) (see 2.4). This second step is concluded by a multi-criteria analysis intended to reveal the most appropriate category, or possibly categories, with regard to all the criteria. This analysis helps the owner to make the final decision as to the tunnel category. If the tunnel is assigned a category other than A, the results of the analysis exercise are used to determine which route hauliers should take when transporting dangerous goods that are not permitted in the tunnel.

The flowchart in Figure 4 shows what tasks need to be performed and by whom, along with the decisions that the owner needs to take.

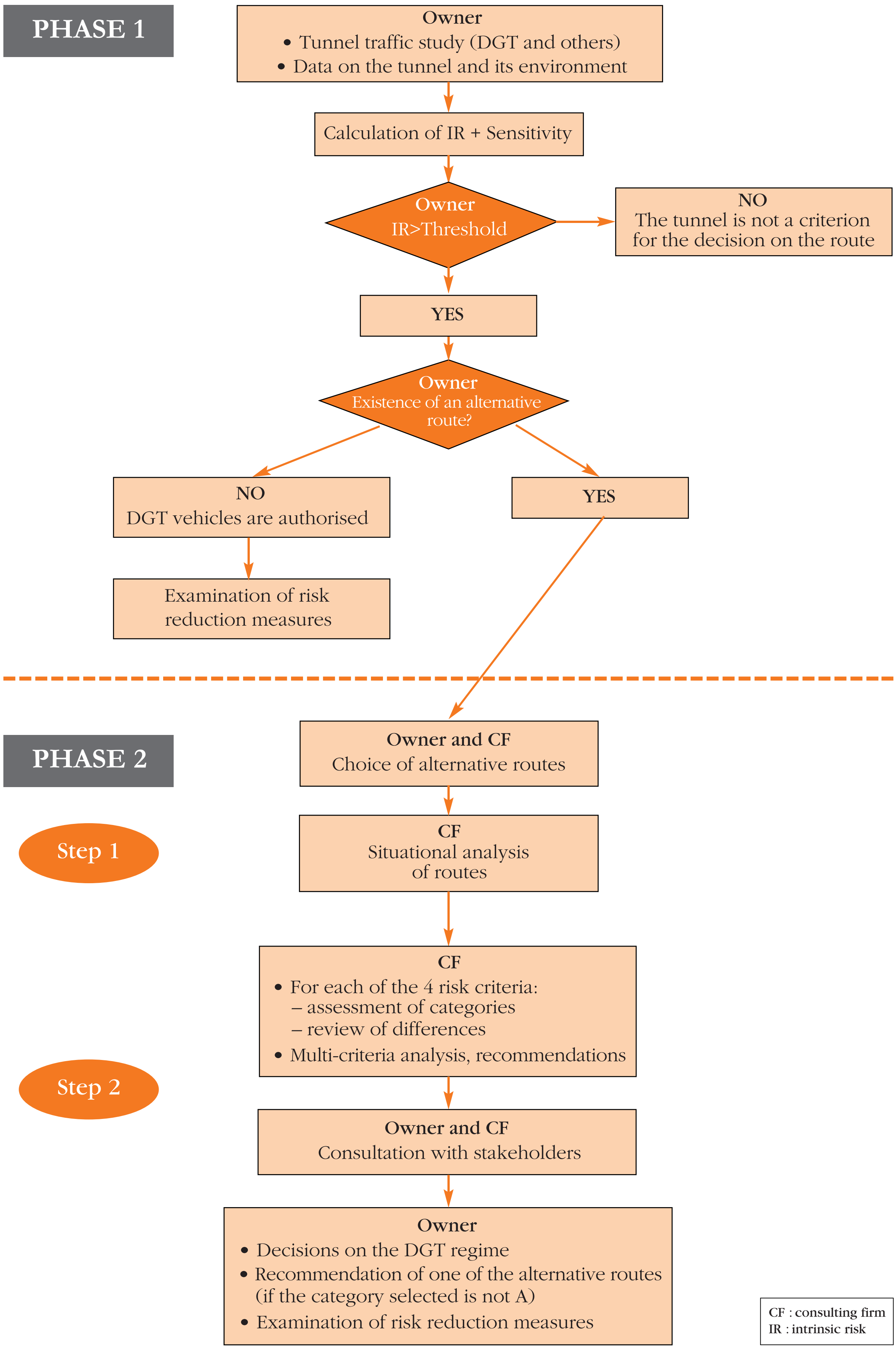

Figure 4: Flowchart of the method

3

Stage 1 in practice (intrinsic risk assessment, determining if an alternative route exists)

Before carrying out a comparative risk assessment of the different possible tunnel categories, it is first necessary to decide whether such an assessment is necessary.

The intrinsic risk (IR) is therefore assessed. This is the mathematical expectation (ME) of death from type "M" accidents occurring in a category A tunnel. It is calculated using the QRA software.

The IR is calculated by a competent body, using data collected and approved by the owner. This body then reports the result to the owner, along with a sensitivity analysis that varies the values of the most important parameters, namely the dangerous goods traffic (doubly) and all vehicle traffic (30%, possibly more if justified by the local or national situation). Guidance on how to perform the calculation can be found in the documentation supplied with the QRA software.

The IR is then compared to an indicative threshold set at 1/1,000[11 & 12].

If the IR is below this threshold, the passage of vehicles carrying dangerous goods through the tunnel is considered to involve limited absolute risks and the existence of the tunnel should not affect the DGT regulations to be implemented on the route. We do not therefore proceed to the second phase.

Before concluding that the IR is below the threshold, the owner should examine the results of the sensitivity analysis. If the IR value is close to the threshold and if the threshold is significantly exceeded when certain data is varied within plausible limits, the owner is advised to consider the IR as not being below the threshold. This will prevent the threshold being subsequently exceeded following changes to the tunnel project or traffic increases. It would then be necessary to launch the second stage and possibly to question choices already made.

[11] It is not an absolute threshold, but it results from an examination of some 20 tunnels that have been the subject of a comparative risk analysis. Its value is linked to the modelling accepted in the QRA model.

[12] Successive tunnels on a journey may come under the same DGT regime if there is no possibility of leaving the route between them. In such circumstances, it may be the case that although each tunnel's intrinsic risk value is below the threshold, the sum of their intrinsic risk values exceeds the threshold. It is this sum that should be taken into account.

If the IR is above the threshold, two cases should be considered:

- In exceptional cases, the owner states that **there is no alternative route**, and this is confirmed by the authority in charge of policing traffic in the tunnel. The second stage is therefore not conducted. Nevertheless, measures that **might reduce risks in the tunnel should be investigated** (see section 5), since vehicles carrying dangerous goods have to use the tunnels (category A tunnel).
- **If one or more alternative routes exist**, stage 2 of the assessment should be conducted.

Notes

4

Stage 2 in practice (comparison of different categories)

4.1. Step 1: Situational analysis

4.1.a. Selecting possible alternative routes

Firstly, the owner should work with the consulting firm to identify the alternative routes to be considered. As a general rule, there is no benefit in selecting and analysing more than two alternative routes. Where appropriate, it is advised to select just one. In addition, the nearest routes should be given priority.
It may be necessary to select alternative routes due to the origin/destination pairs of vehicles carrying dangerous goods, which presupposes that they had been previously identified in the DGT traffic survey.

Annexe C provides more detailed guidance on how to select alternative routes and how to justify these decisions, along with a practical example.

4.1.b. Analysis of each route

Each selected route (comprising the tunnel and identified alternative routes) is examined in detail. This examination gives a better understanding of the route and the issues relating to the movement of vehicles carrying dangerous goods along it. It enables a certain amount of data to be collected, namely that required for use of the QRA software. This information is essential for analysis of the four risk criteria for each of the possible categories.

For each route, the situational analysis presents:
- The technical characteristics of the route (geometry, equipment, etc.).
- The traffic regulations and their enforcement (speed limit, actual speeds, etc.).
- General traffic excluding vehicles carrying dangerous goods: light vehicles, heavy goods vehicles, buses, two-wheeled vehicles.
- Dangerous goods traffic with quantified distribution between the different routes (that comprising the tunnel and the alternatives) for each possible category. The dangerous goods taken into account on alternative routes are only those which would have been able to go through the tunnel, but which are prohibited from doing so due to the category considered. Vehicles carrying dangerous goods travelling on alternative routes, whether authorised to use the tunnel or not, should not be taken into account.
- Road accident statistics.
- Route monitoring and operation.
- The way the surrounding area is organised according to the different uses and its sensitive points.
- The societal context, particularly population density and possible sensitive zones.
- The environmental context, particularly the existence of possible nature reserves and natural risks.
- The economic context.

For each, any DGT-related specifics will need to be included.

Further guidance on examining these routes can be found in Annexe A.

4.2. Step 2: Comparing categories by criterion – multi-criteria analysis

This section outlines the method for comparing the possible categories (A, B, C and D/E) according to each of the four risk criteria, then carrying out the multi-criteria analysis. A practical example is given in Appendix E.

4.2.a. Criterion 1: Risk of death from type "M" accidents

The data required for the calculation are collected as part of the situational analysis (see 4.1.b and Annexe A). The consulting firm then uses the QRA model to calculate the ME values for all the possible categories[13]. Guidance on using the data and the model can be found in Annexe B.

Modelling techniques and hypotheses for phenomena brought into play by the software on the one hand, and uncertainties about input data on the other, mean cautious consideration should be given to the results. Their robustness will thus be tested by a sensitivity analysis on the model's input parameters, namely the local population (20% or possibly more if justified by urban development dynamics), all vehicle traffic (30% or possibly more according to the local or national context) and the accident rate (for example the model's default rate versus the observed rate).

The mathematical expectations of death for each category (A, B, C and D/E) are then compared two at a time. The difference is assessed as indicated below:
- If the ME ratio[14] is greater than 10: we systematically consider there to be a **significant difference** between the ME values of the 2 categories.
- If the ME ratio is less than 3: we systematically consider there to be a **non-significant difference** between the 2 categories.
- If the ME ratio is between 3 and 10: we consider:
  - there to be a **significant difference** between the ME values of the 2 categories only if the sensitivity analysis shows situations considered plausible where the ME difference is above 10 and does not show any situations where it is below three,
  - the difference is otherwise **indeterminate**.

[13] To recap, the dangerous goods taken into account on alternative routes are only those which would have been able to go through the tunnel, but which are prohibited from doing so due to the category considered. Vehicles carrying dangerous goods travelling on alternative routes, whether authorised to use the tunnel or not, should not be taken into account.

[14] For the purpose of the comparison, the ratio will always be such that the numerator will be greater than the denominator.

The results can be shown clearly in a table. It lists the comparison of pairs of categories in which the difference between the mathematical expectations of death is significant or indeterminate (see example in subsection E.1.1). The indeterminate differences should be interpreted with caution particularly for the multi-criteria analysis. If, for example, category A presents an ME value greater than category C, and the difference is indeterminate, this is an argument in favour of a preference for category C over category A. This argument is not of course as strong as if the difference had been significant, and should be assessed against the other comparisons and criteria. Non-significant comparisons between two categories are of little interest (the order of the comparison can be reversed according to variations within the margin of uncertainty).

4.2.b. Criterion 2: Risk of death from type "C" accidents

For each of the possible categories (A, B, C and D/E), the mathematical expectation of death from type "C" accidents involving vehicles carrying dangerous goods is assessed over the entire network formed by the tunnel route and the selected alternative route(s)[15].

Calculation of the mathematical expectation is based on the rates of occurrence and deaths from accidents involving heavy goods vehicles (HGV). The consequences of a type "C" accident are actually the same whether the HGV is carrying dangerous goods or not since, by definition, there is no release of the dangerous goods. The frequency of occurrence differs between the two types of transport as the number of vehicles carrying dangerous goods on the road is much less. They therefore have different mathematical expectations of death. The value for vehicles carrying dangerous goods is calculated in accordance with the recommendations given in Annexe D.

The mathematical expectations of death for the categories are then compared two at a time determining whether their difference is significant or not. This analysis is extremely dependent upon the nature and representativeness of the data used. The rules for establishing whether a difference is significant or not must be defined on a case-by-case basis in keeping with the data used (local or default), their uncertainties and the value of mathematical expectations of death. For example, a very low mathematical expectation is very sensitive to a slight increase in the number of deaths. Particular vigilance must be given to the critical analysis of the data used.

The results can be shown clearly in a table. It lists the comparison of pairs of categories in which the difference between the mathematical expectations of death is significant (see example in subsection E.1.2).

[15] To recap, the dangerous goods taken into account on alternative routes are only those which would have been able to go through the tunnel, but which are forbidden from doing so due to the category considered. Vehicles carrying dangerous goods travelling on alternative routes, whether authorised to use the tunnel or not, should not be taken into account.

4.2.c. Criterion 3: Vulnerability of routes in relation to accidents involving vehicles carrying dangerous goods

The categories are compared two at a time in terms of the "vulnerability of routes in relation to accidents involving vehicles carrying dangerous goods". This comparison is based on the situational analysis (see 4.1.b). Its aim is to determine whether, for each possible pair of categories, one of the two presents a significant advantage over the other. The advantage is considered significant if the category significantly minimises the negative impact of dangerous goods on all the routes concerned taking into account the issues identified in section 2.3.c.

In view of the wide range of possible impacts which depend on the situation, the categories are assessed from a mainly qualitative perspective (according to expert opinion).

Whichever method is chosen, the findings must be substantiated rigorously. A table would be useful for summarising the results clearly and listing pairs of categories for which one of the two presents a significant advantage over the other (see example in subsection E.1.3).

4.2.d. Criterion 4: Economic implications of the decision

The categories are compared two at a time in terms of the "economic implications of the decision". This comparison is based on the situational analysis (see 4.1.b). Its aim is to determine whether, for each possible pair of categories, one of the two presents a significant advantage over the other. The advantage is considered significant if the category minimises the cost of carrying dangerous goods for the owner and for hauliers/shippers, taking account of the impacts identified in section 2.3.d.

As with the previous criterion, and for the same reasons, it is not within the scope of this document to propose a method for conducting the comparison. The conclusions must, however, be substantiated rigorously.

A table would be useful for summarising the results clearly and listing pairs of categories for which the difference is considered significant (see example in subsection E.1.4).

4.2.e. Multi-criteria analysis

The significant differences noted between pairs of categories (see 4.2.a to 4.2.d) are first summarised by criteria. A table is drawn up for this purpose (see example in subsection E.2). It gives a particularly useful overview for later presentation to the stakeholders.

The multi-criteria analysis is then carried out by the consulting firm on the basis of these significant differences. This analysis should take account of the great importance given to the risk of death, aversion to the risks created by type "M" accidents and the regulations that apply to the tunnel. Particularly convincing arguments are necessary so that significant differences in terms of risk of death are challenged by other criteria.

A numerical weighting of criteria is not recommended, particularly in view of the difficulty of putting a numerical value on the criteria of "vulnerability of routes in relation to accidents involving vehicles carrying dangerous goods" and "economic implications of the decision".

The multi-criteria analysis must highlight the category that minimises the overall risk related to the transport of dangerous goods. It is important that this analysis is discussed and shared with the tunnel owner and other stakeholders before the owner decides on both the category and on the route(s) for passage of dangerous goods.

If passage of all or some dangerous goods is permitted in the tunnel, the consulting firm and the owner must give consideration to risk reduction measures.

If the owner chooses a category other than A, a number of dangerous goods will be prohibited from passing through the tunnel. Regulations require that an alternative route be indicated for these. The study can propose elements for selection of alternative routes to be indicated for dangerous goods prohibited in the tunnel.

Notes

Notes

5

Measures for reducing DGT-related risks in tunnels

The Technical Instruction (IT)[16] on safety in tunnels on the State-managed road network contains specific provisions for new tunnels where the passage of vehicles carrying dangerous goods is permitted.

In any event, for all tunnels where the passage of vehicles carrying dangerous goods is permitted, the owner must consider applying the risk reduction measures set out in the Technical Instruction (IT 2000). These measures may concern both the structure itself (civil engineering aspects, equipment) and the tunnel's operation. They may consist of passage in convoys or time restrictions. These measures are examined in the following paragraphs[17].

Importantly, if the transport of certain dangerous goods is prohibited in the tunnel (categories B to E), controls must be put in place to ensure compliance with this ban. Otherwise, there is a potential risk of having a highly dangerous situation with the passage of unauthorised dangerous goods, even though the tunnel's technical and/or operational provisions are not suitable for dealing with an accident involving them.

5.1. Measures concerning the tunnel and its operation

Measures concerning the tunnel, its equipment and its operation are detailed in chapter 7 of the Technical Instruction:

- tunnel geometry, preventing accidents in general and the puncturing of tanks in particular,
- improvement of drainage with sufficient transverse gradient and continuous slot drainage channels to limit the extent and duration of a pool of inflammable or toxic liquids,
- more numerous emergency exits, to allow speedy evacuation of users and facilitate access for the emergency services,
- study of ventilation performance[18] for fires greater than 30 MW,
- stepping up equipment for fire detection, communicating with users, ensuring tunnel closures, firefighting and signage, etc.
- operational actions.

[16] Formerly appendix 2 of circular no. 2000-63 of 25th August 2000, kept in force by circular no. 2006-20.

[17] The effectiveness of these measures is, at least in part, taken into account in the QRA model.

[18] A cost/benefit analysis will be required for transverse ventilation.

The Technical Instruction is only mandatory for new tunnels on the State-managed road network and allows these a degree of discretion for a number of the above-stated measures, depending on the more or less sensitive nature of the tunnel. The same concept of tunnel sensitivity can be used for analysing an existing tunnel.

In addition to the criteria shown in the Technical Instruction (para. 7.1), the sensitive nature of the tunnel may be assessed by using the results of the DGT risk assessment, particularly those of stage 1 which characterises the intrinsic risk of the tunnel. These results enable the share of risk of each scenario and its order of magnitude to be assessed.

5.2. Passage in escorted convoys

In large tunnels, especially two-way tunnels, with toll gates or vehicle control facilities at each end, provision may be made for all or some vehicles carrying dangerous goods to be escorted through the tunnel. These vehicles are then grouped into convoys.

Despite the possibility of a domino effect inside the tunnel, the effectiveness of escorted passage is undeniable for increased safety, even more so if the tunnel is closed to other traffic while the convoy is passing through it.

Quantification of this improvement requires still more numerous hypotheses that are poorly understood (reduction of accident and incident rates, reduction of probabilities of disasters caused), and would in principle require the very structure of the QRA software, designed for continuous traffic, to be adapted (see Annexe F for a more detailed explanation).

Implementation of escorted passages requires the existence of a vehicle parking area and the availability of escort staff, conditions that very rarely occur.

An essential point is to make this waiting area safe for vehicles carrying dangerous goods intended to form part of a convoy.

5.3. Time restrictions

It is possible to allocate variable categories to a tunnel according to time of day, day of the week, etc.

The QRA model distinguishes different time periods, and thus makes it possible, for certain periods, to see if a comparison between the risks of each possible category of the tunnel leads to a modification of the ranking. This may make it possible to plan and optimise time restrictions[19].

Such an optimisation only produces significant effects if the risk differences between possible categories vary considerably, depending on whether or not it is in a period of heavy traffic. This may for example occur if a peak time of tunnel traffic corresponds to the presence of low numbers of residents along alternative routes and vice versa.

In general, we see no advantage in applying a time restriction to the whole day, rather than only at peak times (see Annexe F for a detailed explanation). As with escorted passages, a parking area has to be provided and made safe.

Restrictions applying to vehicles carrying dangerous goods during peak times may be beneficial when the traffic of such vehicles is mainly local. Peak hours are actually often periods of high traffic volumes with possible passage of regular lines of school buses. The owner will find it useful to approach the local businesses concerned with regard to information delivery to ensure compliance with these restrictions, and consultation so that the businesses make appropriate arrangements.

It may be necessary to review any time restrictions using the QRA model. This decision is the responsibility of the owner, acting on the advice of the consulting firm, if any.

[19] In order to assess the effect of these measures, it is necessary to predict what vehicles carrying dangerous goods will do in response to such restrictions: use alternative routes or change the time at which they pass through the tunnel. Making such predictions is often a difficult exercise.

Annexes

Situational analysis: data collection

This appendix provides detailed guidance on the situational analysis presented in section 4.1.b.

The aim of this analysis is to gain a more detailed understanding of each route. It should be limited to a reasonable and appropriate portion of the area in question. In some cases, contextual elements at a greater distance can have an impact on the route and on the problems associated with the passage of vehicles carrying dangerous goods.

The analysis addresses urban, societal and other aspects from the perspective of DGT-related risk. In particular, the analysis should provide an opportunity to collect the data needed to assess the criteria in stage 2 of the risk analysis exercise. Some of the collected data will also prove useful for the QRA model (criterion relating to type "M" accidents), although this aspect will not be covered exhaustively in this booklet. More detailed guidance (on DGT-related traffic in particular) can be found in the software's accompanying documentation.

Some of the data can be obtained directly from the owner or operator, while other data will need to be collected. Doing so may prove more or less complex depending on the local environment. Some data-collection operations can, of course, be outsourced.

It may, however, be difficult to obtain some essential data to a sufficient degree of precision due to a lack of available information (e.g. accident statistics measured over too short a period, or no statistics yet available for a planned tunnel). In such cases, more general default values may be used instead (such as departmental, regional or national averages for accident statistics, or the default values of the QRA model).

It is also important to note that the degree of detail of available data can vary markedly from one route to another (e.g. accident data for a motorway route versus a route on low-traffic secondary roads). In such cases, efforts should focus on achieving a level of description that is as uniform as possible across the routes.

The themes outlined in sections A.1 to A.8 will be analysed for each route.

A.1. Urban and societal context

The analysis describes how the area in question is structured. It locates features such as residential zones (individual and collective housing) and sensitive points such as schools and hospitals. It describes the population density within a strip measuring approximately 1,000 metres in width centred on each route under consideration (the resident population and, where relevant, workers, visitors to premises that are open to the public, etc.). It pinpoints the location of facilities from which rescue services are dispatched.

It also indicates the locations of engineering structures and notable buildings (such as historic monuments) that could be impacted by an accident involving a vehicle carrying dangerous goods.

A.2. Environmental situation

The analysis provides general information about the natural risks that could affect the various routes. The relevant natural risks include flooding, avalanches, rock falls, landslides and forest fires.

It also indicates the presence of sites of interest such as nature reserves and national parks that might be adversely affected by accidental pollution in the event of spillage of a dangerous substance.

The analysis also describes the weather conditions and provides the wind rose.

A.3. Economic context

As well as the urban context, the analysis also indicates the location of sites or areas where economic activity (manufacturing, agriculture, etc.) is intense and/or is likely to generate dangerous goods traffic. The analysis takes a qualitative approach (identifying sites, the economic activity at those sites, and whether or not they are likely to generate such traffic). There is no requirement to examine origin/destination pairs, although they can be used if this examination is carried out for another purpose.

A.4. Technical characteristics

The analysis specifies:

- the geometric characteristics for each direction of travel, based on the horizontal alignment and the vertical alignment;
- for the tunnel specifically: its length, gradient, crossfall, cross-section and hydraulic diameter, the location of emergency exits, the characteristics of the liquid effluent collection system, the performance characteristics of the ventilation and smoke extraction systems, etc.

A.5. Traffic regulations

The analysis specifies the prohibition or restriction regimes on the route in question, along with the speed limits and actual driving speeds. These speeds are broken down by vehicle type. The analysis also indicates whether the route can be used to relieve traffic on another, busier route.

A.6. Route monitoring and operation

The analysis describes the monitoring and traffic management systems along the entire route. It indicates the closure time scales and, specifically for the tunnel, the level of monitoring.

A.7. Traffic

This aspect of the analysis is divided into two parts: general traffic and specific dangerous goods traffic.

A.7.1. General traffic

The analysis indicates estimated light vehicle, HGV and coach traffic 10 years after commissioning, including seasonal, daily and other variations. It also notes any congestion risks.

These indications are based on the traffic study included in the safety documentation, plus the findings of any additional investigations as required (data research, counts).

A.7.2. Dangerous goods traffic

Dangerous goods traffic figures are produced from counts. For the sake of representativeness, these should be carried out over a period of at least three working days, ideally outside school holidays.

For each possible category, the situational analysis indicates the probable distribution onto the alternative routes of dangerous goods traffic that would otherwise have passed through the tunnel had it not been prohibited from doing so by the category in question. The analysis should state the nature and volume of this traffic, any seasons or daily variations, the origin/destination pairs, etc. All of these elements should be extrapolated to a time 10 years after the commissioning of the tunnel.

In practice, it is unlikely to be possible to determine a separate distribution per tunnel restriction code using the available data. The distribution will therefore be the same for all codes. There are various ways to assess this distribution, either by using existing methods or developing new ones. One approach would be to focus on the concept of the attractiveness of the route (including time and cost factors). The owner should select the appropriate method on the advice of the consulting firm. Since this theme has more to do with "traffic" than with the assessment of DGT-related risks in tunnels, it is not developed further in this booklet.

If there is only one alternative route, dangerous goods vehicles that are forbidden from passing through the tunnel are considered to take this route instead for each of the categories B, C and D/E.

When on the road, vehicles carrying dangerous goods are identified by way of an orange plate affixed for the front and rear of the vehicle. This plate normally includes two numbers. If present, these two numbers are as follows (see Figure 5):

- the hazard identification number (a 2- or 3-figure number),
- the UN number (a 4-figure number).

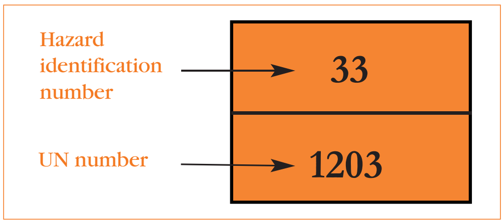

Figure 5: hazard identification number and UN number

For all investigation purposes, the hazard identification number and UN number should be recorded, together with the hazard labels and, if possible, the type of packaging (tank, cylinder, bulk, etc.).

The plate on the front or rear of the vehicle may be blank, especially in the following cases:

- The vehicle is a truck with several tanks (or several compartments within one tank), in which case several plates, each with a hazard identification number and a UN number, are affixed to the side of the truck. This situation usually only applies to a minority of vehicles carrying dangerous goods. In this case, it should be noted whether all the dangerous goods have the same hazard identification number (e.g. 33) or whether they have different numbers (e.g. 30 and 33).
- The vehicle is a curtain-sided truck. In this case, it is often difficult to identify the transported goods from the outside, and these are usually contained in small packages (paints, flammable liquids in packages, etc.). These types of vehicle generally make up only a small percentage of traffic and, other than in special cases, they can be omitted when determining the scenarios at the initial approximation stage.
- The vehicle is carrying cylinders. In this case, the hazard identification numbers must be read in order to link the transported goods in question to scenario 3 (flammable liquefied gas cylinder) and scenario 12 (toxic product in cylinder).

(gas cylinder) (flammable substance) (toxic substance)

Figure 6: markings for gas cylinders, flammable substances and toxic substances

As a reminder, the tunnel restriction code is not marked on the vehicle. It only appears in the logbook.

A.8. Road accident statistics

In addition to accident data for all vehicles, it is useful to look for statistics specific to HGVs, especially for assessing the risk of death from type "C" accidents. HGV traffic data can be used to study accident statistics for vehicles carrying dangerous goods. The rates of occurrence are the same since the consequences of a type "C" accident are the same regardless of whether or not the HGV is carrying dangerous goods, as no dangerous goods are released (this is the very definition of type "C" accident). The annual frequency of occurrence differs, however, because dangerous goods traffic is much lower.

Notes

Annexe B

Overview of the QRA model

This annex provides an overview of the QRA model and gives some specific guidance on calculating expectations of death for type “M” accidents. Detailed guidance on using the software can be found in the accompanying documentation. It is important to stress once again that the model should only be used by individuals with the appropriate skills and training (see 2.4).

B.1. The joint OCDE and PIARC research project

B.1.1. Background

One of the aims of the joint OECD/PIARC research project was to develop a quantitative risk assessment (QRA) model which, as its name implies, quantifies risk related to the transport of dangerous goods on a tunnel and non-tunnel route by factoring in two aspects:

- the probability of events occurring,
- the seriousness of their consequences,
  - in terms of loss of human life, potentially distinguishing between the local population and road users,
  - in terms of injuries, potentially distinguishing between the local population and road users,
  - in terms of damage (destruction of buildings or structures, and environmental damage).

Regulations governing the passage of vehicles carrying dangerous goods may take into account one or more risk assessment or comparison criteria. Different approaches exist in different countries. The main approaches are as follows:

- Assessing the risk in relation to one or more risk threshold(s) as set in advance in the regulations: these include all sorts of criteria, such as the mathematical expectation of the risk, one or more threshold F-N curves, the maximum number of deaths, etc.
- Comparing several possible tunnel categories in order to select the most favourable one in terms of risk, according to predefined criteria.
- A combination of the two groups of criteria given above.

The QRA model assesses various components of the risk and then applies either one or the other of these groups of criteria. The QRA model offers numerous possibilities. In order to properly interpret the results provided by the model, the corresponding methodological framework (and therefore the criteria) must therefore be identified in detail.

B.1.2. A model based on representative accident scenarios

Several thousands of goods are listed in the ADR. A number of events representative of the main risks associated with the transported goods were therefore selected in order not to make the process too cumbersome, and given the degree of precision that can be achieved with this type of model.

As a result, the QRA model covers a limited number of dangerous-good-and-packaging pairs, which are combined with certain accident types in which these pairs may be involved. Consequently, the latest version of the model (4.04) uses 13 base scenarios which are considered representative of mass casualty events.

Scenario No.	Description	Capacity	Size of breach (mm)	Mass flow rate (kg/s)
1	HGV fire – 20 MW (no dangerous material)	-	-	-
2	HGV fire – 100 MW (no dangerous material)	-	-	-
3	BLEVE[20] in a 50 kg LPG cylinder	50 kg	-	-
4	Premium petrol pool fire	28 tonnes	100	20,6
5	Premium petrol VCE[21]	28 tonnes	100	20,6
6	Chlorine spill	20 tonnes	50	45
7	BLEVE in an LPG tanker	18 tonnes	-	-
8	VCE of LPG	18 tonnes	50	36
9	Jet fire in an LPG tanker	18 tonnes	50	36
10	Ammonia spill	20 tonnes	50	36
11	Acrolein tanker spill	25 tonnes	100	24,8
12	Acrolein cylinder spill	100 litres	4	0,02
13	BLEVE of non-flammable gas (CO_2)	20 tonnes	-	-

Table 5.1: List of scenarios included in version 4.04 of the QRA model

Of these 13 scenarios, the first two concern fires without dangerous materials and are given for illustrative purposes[22].

[20] BLEVE: Boiling Liquid Expanding Vapour Explosion.

[21] VCE: Vapour Cloud Explosion.

[22] These first two scenarios of the QRA model, which concern HGV fires without dangerous goods, should of course not be considered in risk assessments relating to the transport of dangerous goods. It may prove insightful to compare their results against those of the SHI, but the standard scenarios in the SHI use different fire heat release rates.

Table 5.2 shows the relationship between these scenarios and the tunnel categories (see 1.3.b).

	Scenarios corresponding to the QRA software	
Categories	Tunnel route	Alternative route(s)
Category A	3 to 13	-
Category B	3 to 6 and 10 to 13	7 to 9
Category C	3 to 5 and 12	6 to 11 and 13
Category D/E	-	3 to 13

Table 5.2: relationship between QRA model scenarios and tunnel categories

The relationship between categories and scenarios of the QRA software is based on the ADR classification of goods used in the scenario. It depends on the tunnel restriction code for the goods (code determined from the UN code, the quantity and means of transport).

Version 4.04 also includes three optional scenarios for radioactive substances. These should only be used in exceptional circumstances (e.g. in the vicinity of an installation involving the transport of large quantities of radioactive substances).

Scenario No.	Description	Capacity	Size of breach (mm)	Mass flow rate (kg/s)
14	Release of natural UF	9,471 kg	50	360
15	Release of enriched UF	1,743 kg	50	360
16	Radioactive source (gamma radiation)	-	-	-

Table 5.3: optional scenarios (generally not relevant)

In each case, the scenarios specify the dangerous material leakage rate they cause. But they are then broken down by examination of a number of special circumstances (e.g. weather), hence the vast number of situations ultimately considered.

While the possibility of grouping goods presenting similar characteristics (e.g.: UN no. 1299 (turpentine oil) and UN no. 1300 (turpentine oil substitute)) into a limited number of representative scenarios is not a problem, it might become so when dangerous goods presenting significantly different characteristics are linked to the same representative scenario in the QRA model. For example, the transport of diesel in a tanker is frequently linked with the transport of petrol in a tanker, which was accepted in the QRA model, this connection being however upper bound for the results.

The choice of representative scenarios should therefore be based on a comparison between the possible effects of a release of the substance on the route and those of the good(s) selected in the representative scenarios of the QRA model. In the end, the most suitable scenario(s) should be selected. By comparing the possible tunnel categories, it is possible (to a certain extent) to work in relative terms and therefore to compensate for the “approximations” inherent in the exact risk assessment.

However, while the aim is to reflect the real risk as far as possible, modelling inevitably has its shortfalls, for two main reasons. Firstly, the dangerous goods vehicle traffic used in the model is not necessarily the real traffic, since only the usual traffic that may shift to other routes is considered. Secondly, the dangerous goods actually carried on the route are not always the same as those associated with the representative scenarios in the QRA model. Nevertheless, the assessed risk is usually overestimated, as in the case of the diesel tanker mentioned above.

To summarise:

- A QRA is a simplified assessment that uses representative “dangerous goods/accident scenario” pairs, and all dangerous goods identified on the routes are associated with one (or more) of these representative pairs.
- Linking the normally identified goods to representative pair(s) is a process that requires in-depth knowledge of both the characteristics of the goods and of the model.
- The risk as assessed by the QRA model depends to a large extent on the method used. It is unlikely to equate to the real risk, which it normally overestimates, but at the very least it supports useful comparisons between the possible tunnel categories.

B.2. Applying the model under the approach adopted in France

The approach used in France only uses the death-related results generated by the model. It is divided into two phases, each using the QRA model: the results of stage 1 determine the usefulness of further risk assessment in stage 2 (i.e. the comparison of categories). Stage 1 provides a simplified assessment of the risks, whereas stage 2 involves a more comprehensive assessment that allows the categories to be compared.

B.2.1. Using the model to calculate intrinsic risk (IR) (see section Stage 1 in practice)

This stage involves a simplified analysis, with the QRA model used solely to assess the risks directly induced by the presence of the tunnel.

At this stage, the assessment only looks at one route, i.e. the tunnel itself (the tunnel portals are treated as the origin and destination points of the route). For the purpose of the calculation, the structure is considered to be a category A tunnel.

The collection of input data is simplified because:
- the study area is limited to the surroundings of the tunnel (only the local population in proximity to the tunnel portals is taken into account),
- traffic data (and, in principle, accident statistics) do not generally vary along the route.

The IR calculation therefore uses only a small part of the model's capabilities and only requires data relating specifically to the tunnel. A detailed overview of this data is given in the documentation supplied with the software and in the methodological guide for calculating intrinsic risk (available from CETU). In terms of traffic, the data is identical to that required for the situational analysis (see A.7) but is restricted to the scope described above. The data should be extrapolated to a time 10 years after the commissioning of the tunnel.

More details on the method can be found in the guide mentioned in the previous paragraph.

B.2.2. Using the model to compare tunnel categories (see section 4 Stage 2 in practice)

At this stage, modelling with the QRA model is more complicated because the assessment includes several routes with one or more tunnels.

The larger and more complex the study area, the more input data needs to be collected. Additional data is needed on top of the data already defined for the IR calculation. This will be obtained from the situational analysis.

B.3. The modelling process for a category-based comparison

B.3.1. Method

B.3.1.1. Principle

The aim is to calculate the mathematical expectation of death for each of the possible tunnel categories (A, B, C and D/E).

For a given category, the first step is to calculate the mathematical expectation of death for the tunnel route and for each alternative route. The dangerous goods to be taken into account on alternative routes are only those which would have been able to go through the tunnel, but which are prohibited from doing so due to the category considered. Their distribution between the alternative routes comes from the situational analysis (see 4.1.b and Annexe A).

These mathematical expectations calculated per route are then added together to give the overall mathematical expectation of death for the category in question.

An example is given below.

B.3.1.2. Example

In this example, we consider that the tunnel route has two alternative routes.

Dangerous goods vehicles prohibited from passing through the tunnel take the two alternative routes according to the following arrangements:

- Restriction code "B": 30% on route 1, 70% on route 2.
- Restriction code "C": 40% on route 1, 60% on route 2.
- Restriction codes "D and E": 45% on route 1, 55% on route 2.

The calculation then proceeds as follows:

Tunnel category	ME on each route Index 0 is attributed to the tunnel route; indices 1 and 2 to the two alternative routes	ME per category
A	1. Tunnel - all dangerous goods vehicles ME(A_0)	ME(A)=∑ME(A_i) {i=0,1,2}
	2. Alternatives - without dangerous goods vehicles ME(A_1)+ME(A_2)=0	
B	1. Tunnel - dangerous goods codes C, D, E: ME(B_0)	ME(B)=∑ME(B_i) {i=0,1,2}
	2. Alternative 1 - code B: 30%: ME(B_1)	
	3. Alternative 2 - code B: 70%: ME(B_2)	
C	1. Tunnel - codes D, E: ME(C_0)	ME(C)=∑ME(C_i) {i=0,1,2}
	2. Alternative 1 - B 30%, C 40%: ME(C_1)	
	3. Alternative 2 - B 70%, C 60%: ME(C_2)	
D/E	1. Tunnel without dangerous goods vehicles[23]: ME(D/E_0)	ME(D/E)=∑ME(D/E_i) {i=0,1,2}
	2. Alternative 1: B 30%, C 40%, D/E 45%: ME(D/E_1)	
	3. Alternative 2 - B 70%, C 60%, D/E 55%: ME(D/E_2)	

[23] Except numbers: UN 2919, 3291, 3331, 3359 and 3373.

B.3.2. Step 1: Acquiring the input data

The input data required by the software will already have been collected for the situational analysis and will be extracted for the calculation.

As indicated in Annexe A, some of the data may not present a sufficient degree of precision. In such cases, default values can be used (these are built into the QRA model) in order to continue the process. The sensitivity analysis for the QRA model parameters then provides a picture of the sensitivity and representativeness of the result.

However, performing the calculation depends on having descriptive data for the route (including the tunnel) as well as traffic data.

An effort should be made to ensure that the data used in the analysis are uniform in terms of precision. Doing so helps to limit bias introduced into the calculations by any inconsistencies. If inconsistent data are used for a parameter that has a first-order impact on the results, the sensitivity analysis will need to focus on this particular point in more detail.

B.3.3. Step 2: Configuring the model

B.3.3.1. Selecting the scenarios

Generally speaking, this step involves linking the dangerous goods carried on the routes to the most representative scenarios in the QRA model for each possible category.

In some cases, the hazard identification code provides enough information to select the representative scenario(s). Otherwise, the corresponding UN numbers will also need to be taken into account. This is especially true of dangerous goods for which toxicity poses the primary or secondary hazard.

The documentation supplied with the QRA software contains a correlation table indicating which hazard identification codes map to which scenarios in the QRA model. Of course, this table is no substitute for expertise on the individual properties of the identified goods (i.e. the substances and their packaging). It is intended more as a guide to support a consistent approach to the question of the representativeness of the scenarios included in the model.

In order to link the tunnel restriction code, readers may refer to Table 5.2 in section B.1.2.

Analysing the properties of the goods in this way helps to determine the composition of dangerous goods vehicle traffic to be used in the model, and to define the associated representative scenarios.

Hazard Identification Number	% of dangerous goods vehicle traffic	Dangerous goods observed (counts) or estimated (survey)
22	6%	Refrigerated liquefied nitrogen or CO_2
23	4%	Natural gas, compressed gaseous hydrocarbons, LPG
30	19%	Diesel, liquid tars
33	40%	Petrol, ethanol, isopropyl acetate
50	7%	Ammonium perchlorate and persulphate
60	3%	Toxic organic liquid, solid pesticides
80	20%	Phosphoric acid
90	1%	Miscellaneous substances

Table 5.4: Sample description of dangerous goods vehicle traffic by hazard identification number

B.3.3.2. Selecting the time periods

A maximum of three time periods (hourly or seasonal) can be defined, based on traffic and population data. These periods should be defined in a way that takes account of variations in traffic, accident statistics, local population numbers and, in some cases, the geometry of the route (e.g. when a route is unused in winter).

B.3.3.3. Dividing the route into uniform sections

At this stage, the aim is to divide the route(s) into uniform sections in terms of traffic, accident statistics and geometry for each of the previously defined time periods.

This task is typically performed by the consulting firm carrying out the calculation.

B.3.3.4. Choosing between the Sk-DG and Rk-DG models

The Sk-DG model (a one-dimensional representation of the location and quantification of populations in the open air) should only be used in specific cases wher populations are uniformly distributed along the route in question. The Rk-DG model (two-dimensional) is more appropriate in most circumstances.

B.3.4. Step 3: Performing the calculation

The calculation is performed by the consulting firm. This task must be carried out by an appropriately trained professional who can identify the sensitive or difficult points of the matter. It should then be checked by an experienced professional.

B.3.5. Step 4: Carrying out the sensitivity study

Given the uncertainties associated with the input data, the influence of the key parameters on the calculation result needs to be verified. This sensitivity analysis provides an opportunity to assess the representativeness and robustness of the results.

The sensitivity of a result is assessed by looking at how the mathematical expectation of death changes when a single input is changed, all other things being equal. The extent of variation in the modified input data depends on the range of uncertainty inherent in the estimate. Each route analysed and, ultimately, each possible tunnel category must therefore be subject to a number of sensitivity calculations.

The robustness of the analysis refers more generally to the fact that the essential conclusions drawn from the model are not called into question when the input parameters vary within a range of uncertainty.

B.4. Understanding and interpreting the results

How the results are interpreted depends on the type of analysis performed (IR calculation or, where applicable, comparative analysis of categories). This is a key step in the process, since it is as this point that the work carried out is summarised and the main lessons are drawn.

It is important to treat the calculation results with some caution and to be mindful of the approximations and uncertainties inherent in the method, so as to focus on the main issues.

The model generates very comprehensive results. The most concise of these is the mathematical expectation (or “ME”), which corresponds to the statistically predictable number of deaths per year.

The ME can be calculated for each accident scenario, for a set of scenarios chosen by the operator (e.g. for a given category), for all scenarios for the same dangerous good, and for all scenarios for all dangerous goods included in the modelling.

In addition to the mathematical expectation, the QRA model also produces results that support a more detailed assessment. It plots frequency/severity (F-N) curves on a log scale[24], indicating the frequency (F) at which a scenario causing a given number (N) of deaths or more will occur, for different values of N. These curves make it possible to assess the share of mass casualty accidents on each route or on all routes for a given category (if necessary for each type of dangerous goods). Of course, depending on the category, this F-N curve may not prove relevant for one or more routes. For category A tunnels, for instance, examining the F-N curve is only relevant for the tunnel route.

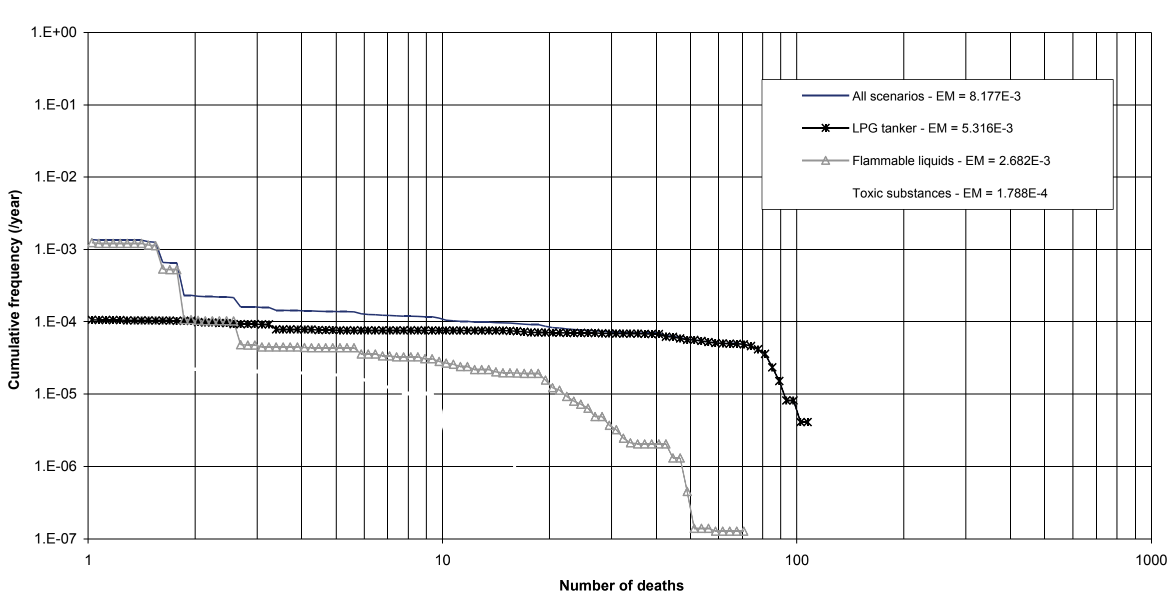

Figure 7: Example for a single route:
three F-N curves, each relating to a type of dangerous goods vehicle,
and one F-N curve relating to all the scenarios taken into account
because of the category in question

Curves such as this show how each type of dangerous good (and, where applicable, different types of packaging) contributes to the overall risk on the route or across all routes for a given category. Looking again at the example shown in Figure 7:

- Most of the risk on the tunnel route is attributable to LPG, whereas flammable liquids account for the majority of the dangerous goods transported.
- For single-casualty accidents, flammable liquids are the dominant risk.
- For accidents with more than 20 fatalities, LPG is by far the leading risk.
- Accidents involving LPG claim twice as many casualties as those involving flammable liquids.

[24] The F-N curves are plotted on log scales for practical reasons (very wide ranges of values). If plotted on a linear scale, the area under the curve would equal the ME value.

The comparison of the possible categories is based primarily on the F-N curves for each one. The F-N curve for a category is obtained by adding together the F-N curves for each route (following a principle similar to that explained in B.3.1). Each route's F-N curve is the sum of the F-N curves for the scenarios corresponding to the types of dangerous goods carried on the route as per the category in question[25].

The curves for the different categories can be superimposed on the same chart.

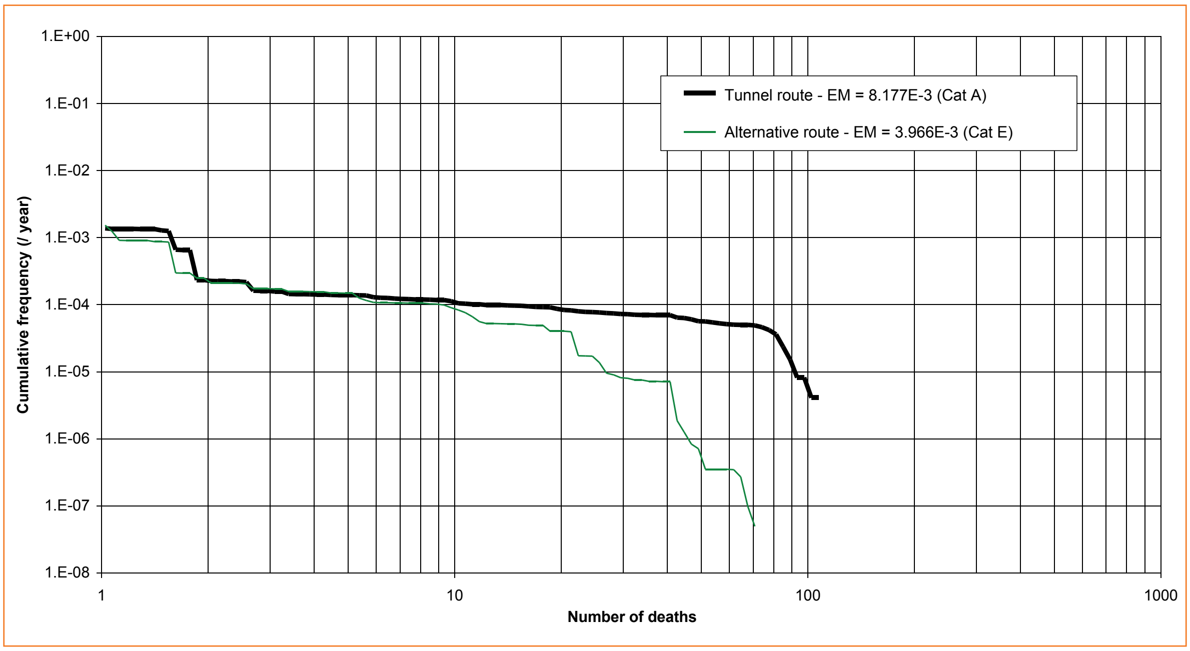

Figure 8: Comparison of F-N curves between two categories

In the example shown in Figure 8, the two curves intersect:

- in terms of the risk of causing a mass casualty accident (more than 10 victims), with the first category having the highest frequency,
- in terms of the risk of causing a smaller number of deaths (less than 10 or so), with both categories having very similar frequencies and the curves intersecting.

The ME for the first category ($8x10^{-3}$ deaths) is double the ME for the second ($4x10^{-3}$ deaths). This difference is not large enough to conclude that there is a significant difference in risk between the two categories being compared here, given the uncertainties in the input data and the model.

As part of the analysis, the curves may also be viewed in different ways. Each of these methods should be interpreted with caution. Only those curves that provide useful insights for the analysis should be included in the final report.

25 To recap, the dangerous goods taken into account on alternative routes are only those which would have been able to go through the tunnel, but which are prohibited from doing so due to the category considered. Vehicles carrying dangerous goods travelling on alternative routes, whether authorised to use the tunnel or not, should not be taken into account.

Notes

Choice of alternative routes

In stage 2 of the risk assessment, a choice needs to be made as to the alternative routes to be used for category comparison purposes.
In order for the alternatives routes under consideration to be relevant, they must of course be suitable for the passage of dangerous goods vehicles, and for trailer trucks in particular. Some routes may already be closed to this type of transport or vehicles (city centre crossings, other tunnels, restricted clearance structures, tonnage restrictions, etc.). Yet it may be relevant to include these routes in the comparison as they could offer a safety advantage over the passage of dangerous goods through the tunnel. They should therefore be included in the comparison. The owner may wish to consult the competent authorities in order to arrive at an informed decision. It is important to remember that the final chosen category might actually reinforce the prohibition as opposed to challenging it.
In some cases, the routes to be included in the assessment may be self-evident. This is especially true for a planned tunnel on a new route, where the alternative route will naturally be the one historically used by vehicles carrying dangerous goods. Other cases may, however, prove more complex (see Figure 9). Here, it will be a matter of anticipating as best as possible what decisions dangerous goods carriers will make and, therefore, the likely shifts in traffic, for each possible category.[26]
The question may also look very different depending on the type of dangerous goods vehicle traffic, and on its origins and destinations. For instance, the relevant alternative routes for heavy transit and local service may differ significantly in length, with large distances between the decision points in relation to the reference route.

Being able to choose the alternative routes therefore relies on having sufficient data on the composition of dangerous goods vehicle traffic, and on its origins and destinations.

In the case of long-distance transport, such as heavy transit, the alternative route can sometimes originate a long way upstream of the tunnel, making the diversion of such vehicles almost regional in scope. It is therefore important to bear in mind that the longer the routes being compared, the less influence the tunnel itself will have on the ME value for the route as a whole. In other words, the comparison tends to encompass considerations beyond the tunnel alone.[27]

When choosing alternative routes, it is recommended to prioritise those nearest to the tunnel. The investigation should only be expanded if there is a demonstrated need. In any event, there is generally no benefit in selecting and analysing more than two alternative routes. Where possible and appropriate, it is advised to select just one.

[26] Routes that are likely to accommodate little shift may be excluded from the outset. Note that the comparative analysis is concerned solely with traffic shifts. Consequently, dangerous goods vehicles that do not pass through the tunnel anyway (e.g. for local service reasons) are not included in the analysis, even through they are part of the overall traffic on the alternative route in question.

[27] For extremely long routes, the ME values tend to be high but with little difference between them (almost proportional relationship to journey length in the open air).

Choice of alternative routes: example of the Dullin and Épine tunnels on the A43 motorway

Initially, the investigation looked at locally available opportunities to bypass the Dullin and Épine tunnels on the A43 motorway between Lyon and Chambéry (the reference route). Two alternative routes were identified, each involving a diversion of around 30 km using national roads.

Figure 9: Example of alternative routes

Alternative route 1, shown in dark green, should be eliminated immediately due to the presence of the Chat tunnel, a category E tunnel whose classification is unlikely to be challenged.
Alternative route 2, shown in blue, is worth further investigation despite the presence of the Echelles tunnel and the fact that it passes through built-up areas on sometimes narrow and winding roads (albeit not impassable for trailer trucks).

Annexe D

Type "C" accidents: calculating the mathematical expectations of death

The mathematical expectation of death from type "C" accidents is the average number of deaths per year from accidents of this type involving dangerous goods vehicles. It is calculated using the following formula:

$ME(X) = \sum i \; R_{acc\text{-}HGV}(i)*Conv*N_{death/pers\text{-}inj\text{-}acc\text{-}HGV}(i)*R_{traf\text{-}DGV}(i)*365*L(i)$ where:

- X is one of the four possible tunnel categories.
- $R_{acc\text{-}HGV}(i)$ is the rate of accidents involving at least one HGV on route i.
- $Conv=R_{pers\text{-}inj\text{-}acc\text{-}HGV}(i)/R_{acc\text{-}HGV}(i)$ enables us to obtain, for route i, the rate of personal injury accidents involving at least one HGV ($R_{pers\text{-}inj\text{-}acc\text{-}HGV}(i)$) from the rate of accidents involving at least one HGV ($R_{acc\text{-}HGV}(i)$);
- $N_{death/pers\text{-}inj\text{-}acc\text{-}HGV}(i)$ is the number of people killed per personal injury accident involving at least one HGV on route i.
- $R_{traf\text{-}DGV}(i)$ is the annual daily average traffic (ADAT) of all dangerous goods vehicles (DGVs) authorised to drive on route i in view of the category X in question.[28]
- L(i) is the length of route i.

For each route i, the local values of the accident rate ($R_{acc\text{-}HGV}(i)$) and number of deaths per personal injury accident ($N_{death/pers\text{-}inj\text{-}acc\text{-}HGV}(i)$) should be used as a priority, subject to the conditions indicated below. Firstly, these values should be based on local accident data covering a period of at least three years. Secondly, it must be possible to calculate them for each of the routes in question. If it is possible to calculate the rate of personal injury accidents on each route i directly using this data, then these rates ($R_{pers\text{-}inj\text{-}acc\text{-}HGV}(i)$) replace the values calculated using the conversion factor ($R_{acc\text{-}HGV}(i)*Conv$).

If the local data do not meet the conditions described above, default values are used for each of the routes i:

- $R_{acc\text{-}HGV}(i)$ is based on the values used in the latest version of the QRA software. These values can be found in the AccRates.xls file at the time of publication of this guide.
- $N_{death/pers\text{-}inj\text{-}acc\text{-}HGV}(i)$ is based on Table 5.5, possibly updated with national data collected at the time of the study.

[28] To recap, the dangerous goods taken into account on alternative routes are only those which would have been able to go through the tunnel, but which are prohibited from doing so due to the category considered. Vehicles carrying dangerous goods travelling on alternative routes, whether authorised to use the tunnel or not, should not be taken into account.

Type of road	Number of deaths per personal injury accident involving at least one HGV
Motorways under private management	0.181
Motorways not under private management	0.041
All motorways	**0.108**
National roads in open countryside	0.298
National roads in urban areas	0.135
All national roads	0.245
Departmental roads in open countryside	**0.283**
Departmental roads in urban areas	0.142
All departmental roads	0.235
Other road categories	0.072
All networks	0.165

Table 5.5: Number of deaths per personal injury accident involving at least one HGV[29]

Existing and default values for $R_{acc\text{-}HGV}$, $R_{pers\text{-}inj\text{-}acc\text{-}HGV}$, and $N_{death/pers\text{-}inj\text{-}acc\text{-}HGV}$ should not be used together in the same analysis. If there is at least one route where there is insufficient data to establish local values, then the default data should be used for all routes.

The QRA software uses a Conv factor of 6.6. This factor can be used with both local and default values.

[29] Source: *Les poids lourds et la sécurité routière en France en 2005* – National Interministerial Road Safety Observatory.

Annexe E

Example of a multi-criteria analysis (step 2 of the method)

This appendix provides a sample multi-criteria analysis for a fictitious tunnel. It follows step 2 of the method, as presented in sections 4.2.a to 4.2.e.

The tunnel route is an express bypass around a small town, passing through an industrial area. The busiest alternative route has some outstanding natural areas and some industry, but no areas of significant population concentration. It carries a high volume of traffic, with significant accident-prone junctions. The comparison tables for the death-related criteria have been defined arbitrarily, but in a manner consistent with the assumptions for the fictitious tunnel and its alternative routes. The aim is merely to illustrate the process behind this part of the method. These tables are normally compiled following the calculations and analyses outlined in sections 4.2.a to 4.2.e.

E.1. Step 2: Comparing categories by criterion – multi-criteria analysis

E.1.1. Criterion 1: Risk of death from type "M" accidents

Table 5.6 shows the comparison of mathematical expectations of death (ME)[30] for type "M" accidents. Only those comparisons for which the differences are significant are included.

Compared categories	B	C	D/E
A	Non-significant difference	Non-significant difference	Significant difference ME(D/E)<ME(A)
B		Non-significant difference	Indeterminate difference ME(D/E)<ME(B)
C			Non-significant difference

Table 5.6: Type "M" accidents - ME of death - comparison of categories

30 For the sake of brevity, "ME(category X)" is shortened to "ME(X)" in the table.

E.1.2. Criterion 2: Risk of death from type "C" accidents

Table 5.7 shows the comparison of mathematical expectations of death for type "C" accidents.

Compared categories	B	C	D/E
A	Non-significant difference	Non-significant difference	Significant difference ME(A)<ME(D/E)
B		Non-significant difference	Significant difference ME(B)<ME(D/E)
C			Non-significant difference

Table 5.7: type "C" accidents - ME of death - comparison of categories

E.1.3. Criterion 3: Vulnerability of routes in relation to accidents involving vehicles carrying dangerous goods

Table 5.8 shows the comparison of categories for the criterion "vulnerability of routes":

Compared categories	B	C	D/E
A	Non-significant difference	Non-significant difference	Significant difference A<D/E
B		Non-significant difference	Significant difference B<D/E
C			Non-significant difference

Table 5.8: economic impact, vulnerability of routes – categories presenting significant advantages

E.1.4. Criterion 4: Economic implications of the decision

Table 5.9 shows the comparison of categories for the criterion "economic impact".

Compared categories	B	C	D/E
A	Non-significant difference	Non-significant difference	Significant difference A<D/E
B		Non-significant difference	Non-significant difference
C			Non-significant difference

Table 5.9: economic impact, vulnerability of routes – categories presenting significant advantages

E.2. Multi-criteria analysis – proposed category

Table 5.10 outlines the findings of the category evaluation for each of the criteria, showing significant differences for all criteria and indeterminate differences for the risk of death from type "M" accidents.

Category	Type "M" accident	Type "C" accident	Vulnerability of routes	Economic impact
A		**Significant** difference ME(A)<ME(D/E)	**Significant** difference A<D/E	**Significant** difference A<D/E
B		**Significant** difference ME(B)<ME(D/E)	**Significant** difference B<D/E	
C				
D/E	**Significant** difference ME(D/E)<ME(A) **Indeterminate** difference ME(D/E)<ME(B)			

Table 5.10: Findings of the category evaluation according to each criterion

Category A presents a significant advantage compared with category D/E for the three criteria: "risk of death from type "C" accidents", "vulnerability of routes" and "economic impact". It nevertheless presents a more significant risk than category D/E for the "risk of death from type "M" accidents".

Category B presents a significant advantage compared with category D/E for the criteria "risk of death from type "C" accidents" and "vulnerability of routes". Category B presents a greater risk of death than category D/E for type "M" accidents, but sensitivity analyses have not been able to determine whether the difference is significant or not. Category B presents no significant disadvantage for any of the criteria compared with the other categories. Category B is therefore considered the most advantageous in terms of risk related to DGT.

Notes

Annexe F

DGT-related risk reduction measures: effectiveness and application

F.1. Passage in escorted convoys

F.1.1. Different types of escorted convoys and the value of the concept

Escorted convoys of dangerous goods vehicles can be organised in different ways. These arrangements fall into three distinct categories:
- convoy travelling on a route that is closed to other vehicles,
- convoy travelling on a route that has only one lane per direction and is kept open to all or some other types of traffic,
- convoy travelling on a route that has more than one lane per direction and is kept open to all or some other types of traffic.

From the outset, it is clear that the third type of arrangement is of extremely limited benefit. The only reason to organise a convoy is to reduce the probability of accidents occurring, as well as their potential severity. Yet this benefit is soon lost when other vehicles can move freely "around" the convoy. Consequently, this particular arrangement will not be discussed further.

In each case, the convoy consists of vehicles carrying dangerous goods and escort vehicles. There are also associated traffic rules that, for example, specify:
- the maximum number of dangerous goods vehicles permitted in a convoy,
- the maximum permitted speed,
- the distance between vehicles while moving,
- the distance between vehicles while stationary (if applicable).

One of the most common objections to convoys concerns the potential for an accident to spread and to trigger a so-called "domino effect"[31]. This disadvantage, which can be partly reduced by strict adherence to the distances between vehicles, is offset by significant advantages as described below.

[31] The domino effect is the spread of a disaster from vehicle to vehicle or from vehicle to facility.

F.1.2. Reducing the frequency of occurrence of accidents involving dangerous goods vehicles

In a convoy, all vehicles adhere to a reduced speed limit and maintain a set distance between themselves and other vehicles. Since traffic travels in only one lane, it is impossible for other vehicles to overtake dangerous goods vehicles. It is therefore clear that the likelihood of an accident with serious consequences is greatly reduced.

Some incidents involving dangerous goods are not caused by a road traffic accident but instead by a breach or a spontaneous fire. Yet a convoy can even help to mitigate the risk of incidents attributable to non-traffic-related causes. This is because, when travelling in a convoy, vehicles carrying dangerous goods typically:

- stop in a waiting area pending formation of the convoy,
- are escorted as they pass through the tunnel.

These factors allow the vehicles' engines to cool before they arrive at the tunnel, and cause drivers to take extra care as they pass through. In addition, in some cases, the vehicles may be visually inspected before the convoy moves off.

F.1.3. Reducing the severity of incidents

If the route is fully or partially closed to other traffic, there will likely be fewer road users in the vicinity of a potential accident. Moreover, the presence of the escort vehicle means that incidents involving one or more dangerous goods vehicle(s) on the convoy will be detected more quickly, allowing for a rapid response and early warning of the operations centre. The escort can therefore significantly reduce the time that passes between the incident starting and it being reported. This faster response has benefits for both prevention and protection.

F.1.4. Accounting for escorted convoys in the QRA model

Frequency of occurrence

There are two ways to account for convoys in the QRA model:

- A reduction in accident rates: after analysing the causes of accidents, it is possible to identify and eliminate those causes that no longer apply because the vehicles are travelling in a convoy.
- A change in the “conditional probability” of a particular scenario following an accident (although this assumes that sufficient statistical data is available).

Severity

The current version of the QRA model does not take into account the decrease in severity following the formation of convoys. This is because traffic is always defined as continuous, which is not the case with convoys. One way to improve the modelling is to set time periods that correspond to times when vehicles travel in convoys. This idea should be applied with caution and requires a thorough understanding of how the QRA software works.

F.2. Time restrictions

The QRA model supports the use of different time periods. This approach only makes sense if the input data actually show marked variations over time, whether hourly, weekly, seasonal, etc. These variations can concern both traffic (dangerous goods vehicles and/or other vehicles) and the environment (variation in the population in the vicinity of the tunnel).

The model calculates the risk (in the form of an F-N curve or mathematical expectation) specific to each of the defined periods and then aggregates these risks. Even if one category is less risky overall than the others, it is possible that it may be more risky over a given period. Restricting the passage of dangerous goods vehicles at specific times, if done appropriately, can therefore reduce the overall level of risk.

As an example, consider the following situation, where category A is compared with category D/E[32]. In this case, there is only one alternative route and it is in the open air (i.e. there are no tunnels). Traffic is divided into three periods, with significant variations in traffic and population throughout the day.

It is assumed that the use of either route does not change the hourly distribution of traffic.

Mathematical expectation – type "M" accident	Off-peak period	Normal period	Peak period	All periods combined
Category A	0.1×10^{-3}	0.4×10^{-3}	1.5×10^{-3}	2×10^{-3}
Category D/E	7×10^{-3}	2×10^{-3}	1×10^{-3}	10×10^{-3}

This may occur if, for example:

- The off-peak period is characterised by low traffic levels but high resident population numbers along the alternative route (e.g. at night).
- The peak period has high traffic on the tunnel route and low population densities (commuting periods).

Let us also assume, given the traffic levels and population densities on the routes, that road users make up the majority of casualties on the tunnel route, and that local residents account for the majority of casualties on the open-air route. Here, the riskiest period for the tunnel route is the peak period (heavy traffic), whereas the riskiest period for the open-air route, if used by dangerous goods vehicles, is the off-peak period (high population density). As a result, consideration may be given to assigning the tunnel category E status in peak periods only. In the above example, the results are thought-provoking but the ME values are not sufficiently different to support a clear decision in favour of a time restriction.

In conclusion, time restrictions can be accounted for in the QRA model. Yet such measures are only relevant in situations where traffic volumes and/or population numbers vary to a significant degree.

[32] As a reminder, the QRA model cannot distinguish between categories E and D.

Notes

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Table of contents

This document is the second version of Booklet 3, the first version of which was published in December 2005. Information about the background to these versions, and the contributors to them, can be found below.

First version (December 2005)

The French Centre for Tunnel Studies (CETU) formed a working group, at the request of the Road Tunnel Safety Assessment Committee (CESTR), to develop a guide for all parties with an interest in road tunnel safety documentation.

The working group comprised representatives of government technical departments, public bodies, consulting firms, owners and operators. Several members of the CESTR also took part. The Mines ParisTech engineering school (ENSMP) provided methodological and operational support to the group.

Below is a list of working group meeting attendees:

Michel Vistorky (Area), Pierre Kohler (Bonnard et Gardel SA), Yves Trottet (Bonnard et Gardel S.A.), Éric Cesmat (CSTB), Pascal Beria (DDE 13), Marilou Marti (DDE 13), Philip Berger (Docalogic Inflow), Romain Cailleton (DTT-MTMD), Daniel Fixari (ENSMP-CGS), Philippe Cassini (Ineris), Raphaël Defert (Ineris), Emmanuel Plot (Ineris), Emmanuel Ruffin (Ineris), Johann Lecointre (Ligeron SA), Philippe Pons (Ligeron SA), Eric Boisguerin (Scetauroute), Anne-Sophie Graipin (Scetauroute), Michel Legrand (Scetauroute), Pierre Merand (Scetauroute), Raymond Vaillant (Setec TPI), Pierre Carlotti (Cetu), M. Deffayet (Cetu), François Demouge (Cetu), Nelson Gonçalves (Cetu), Didier Lacroix (Cetu), Claude Moret (Cetu), Michel Pérard (Cetu), Philippe Sardin (Cetu), Marc Tesson (Cetu).

Second version (December 2018)

CETU created a second working group to work on a new version of the booklet in order to bring it in line with the ADR and to update the methodological guidance based on practical experience gained over the previous decade.

The group comprised representatives of government technical departments and consulting firms, as well as several members of the French National Commission for the Safety Assessment of Highway Engineering Structures (CNESOR). CETU proposed a new risk analysis and assessment method. This method was fine-tuned by the working group and subsequently approved by CNESOR. CETU prepared the second version of the booklet on this basis.

Below is a list of working group meeting attendees:

Raphaël Defert (BG), Philippe Pons (BG), Michel Legrand (EGIS), Marie Lerat (EGIS), Florianne Quezel-Ambrunaz (EGIS), Alexis Boncour (SETEC), Jean Michel Vergnault (SETEC), Didier Lacroix, Marie-Noëlle Marsault (CETU), Marc Tesson (CETU), Christophe Willmann (CETU).

Centre
d'Études
des Tunnels

25, avenue
François Mitterrand
69500 Bron Cedex
Tel.:
33 (0) 4 72 14 34 00
Fax:
33 (0) 4 72 14 34 30
Email: CETU
@developpement-
durable.gouv.fr
Website:
http://www.cetu.
developpement-
durable.gouv.fr/

Guide to Road Tunnel Safety Documentation:

- Booklet 1 — The role of safety documentation in safety procedures (forthcoming)
- Booklet 2 — In-service tunnels: "from inventory to reference state"
- ➤ **Booklet 3 — Assessing risks related to the carriage of dangerous goods**
- Booklet 4 — Specific Hazard Investigations (SHIs)
- Booklet 5 — The Emergency Response Plan (ERP)

The decision as to whether to allow vehicles carrying dangerous goods to pass through a tunnel is based on a two-stage risk assessment.

Stage 1 involves assessing the intrinsic risk posed by these vehicles travelling through the tunnel in question.

Where this risk exceeds a certain threshold, stage 2 involves carrying out a comparative risk assessment between different possible tunnel categories.

In 2005, the French Centre for Tunnel Studies (CETU) formed a working group, at the request of the Road Tunnel Safety Assessment Committee (CESTR), to prepare an initial version of Booklet 3 in the Guide to Road Tunnel Safety Documentation series.

In 2018, CETU prepared this second edition of the booklet, including updates to reflect the new arrangements introduced under the European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR). The updated version was drawn up with input from a working group and with the agreement of the French National Commission for the Safety Assessment of Highway Engineering Structures (CNESOR).

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