HIGHLIGHTS

Safety in Tunnels

TRANSPORT OF DANGEROUS GOODS THROUGH ROAD TUNNELS

Association mondiale de la Route

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World Road Association

OECD

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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Pursuant to Article 1 of the Convention signed in Paris on 14th December 1960, and which came into force on 30th September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

- to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
- to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and
- to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The original Member countries of the OECD are Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries became Members subsequently through accession at the dates indicated hereafter: Japan (28th April 1964), Finland (28th January 1969), Australia (7th June 1971), New Zealand (29th May 1973), Mexico (18th May 1994), the Czech Republic (21st December 1995), Hungary (7th May 1996), Poland (22nd November 1996), Korea (12th December 1996) and the Slovak Republic (14th December 2000). The Commission of the European Communities takes part in the work of the OECD (Article 13 of the OECD Convention).

HIGHLIGHTS

Heavy goods traffic in tunnels is increasing, but the problems raised by dangerous goods need to be tackled.

Road traffic (especially heavy goods traffic) in tunnels has continually increased over many years. In addition, with improving construction techniques, tunnels are an increasingly cost-effective engineering solution in many countries, not simply to cross difficult geographic features, but also to traverse urban areas with minimum local environment impact. While most techniques concerning tunnel construction and safety have been steadily improving, the problems raised by dangerous goods need to be tackled through a comprehensive and co-ordinated approach.

A serious incident involving dangerous goods in a tunnel can be very costly …

A serious incident involving dangerous goods in a tunnel can be very costly in terms of human lives, the environment, tunnel damage and transport disruption. On the other hand, needlessly banning dangerous goods from tunnels may create unjustified economic costs. Moreover, it may force operators to use more dangerous routes – such as through densely populated areas – and thus increase the overall risk.

The rules and regulations for the transport of dangerous goods in tunnels vary considerably among countries and even within countries. The definition of "local rules and regulations", decision taking, responsibility and enforcement are left to local or provincial authorities and politicians, the tunnel owners, or "expert" opinions. For the most part, there are no general rules or regulations that are applicable to all road tunnels at the national level.

… and highlights the need for systematic international regulation.

The lack of systematic regulation is in part the result of limited tools to assess risks and make decisions. This project is a comprehensive package covering both regulatory and technical issues. A system for international regulations has been devised using a scientific approach. A number of tools have been developed which are needed to decide on the regulations for each specific tunnel.

Proposed regulations

Regulations are often difficult to understand and apply.

Currently, planning the transport of dangerous goods requires reference to different regulations, each with different lists of loadings which are authorised or banned in various tunnels, assuming that the carrier is even aware of the existence of such restrictions. The regulations are not always well respected, a main reason being that they are difficult to understand, check and enforce.

Common groupings of dangerous goods are proposed…while national authorities are left free to set their own regulations.

Under the system proposed in this report, authorities are free to set the regulations that are suitable for the tunnel in question. However, the regulations will be expressed in the same way everywhere, referring to the same lists of dangerous goods loadings which are authorised or banned. These common "lists" are called "groupings of dangerous goods loadings" (or more simply "groupings").

A common grouping system would enhance safety and facilitate international transport operations.

The adoption of the proposed system would improve safety because harmonised regulations would be easier to comply with and easier to enforce. In addition, it would facilitate the organisation of international transport and thus eliminate technical barriers to trade and rationalise international transport operations.

Under the system proposed in this report, all dangerous goods loadings would be split into a small number of groupings. This should be done in such a way that all loadings referred to in the same grouping could be accepted together in the same tunnel. The number of groupings must remain reasonably low for the system to be practicable.

The three major hazards: explosions; releases of toxic gas or volatile toxic liquid; fires.

The proposed grouping system is based on the assumption that there are three major hazards in tunnels which may cause numerous victims and possibly serious damage to the structure: explosions; releases of toxic gas or volatile toxic liquid; fires.

The main consequences of these hazards, and the efficiency of possible mitigating measures, are roughly as follows:

Large explosions…

Two levels of large explosions can be distinguished:

- "Very large" explosion, typically the explosion of a full loading of LPG in bulk heated by a fire (Boiling Liquid Expanding Vapour Explosion – BLEVE – followed by a fireball, referred to as "hot BLEVE"), but other explosions can have similar consequences.

- "Large" explosion, typically the explosion of a full loading of a non-flammable compressed gas in bulk heated by a fire (BLEVE with no fireball, referred to as "cold BLEVE").

A "very large" explosion ("hot BLEVE" or equivalent) will kill all the people present in the whole tunnel or in an appreciable length of tunnel and cause serious damage to the tunnel equipment and possibly its structure. The consequences of a "large" explosion ("cold BLEVE" or equivalent) will be more limited, especially regarding damage to the tunnel structure. There are generally no possibilities to mitigate the consequences, particularly in the first case.

Large toxic gas releases…

A large release of toxic gas can be caused by leakage from a tank containing a toxic gas (compressed, liquefied, dissolved) or a volatile toxic liquid. It will kill all the people near the release and in the zone where the ventilation (either natural or mechanical) will push the gas. A part of the tunnel may be protected but it is not possible to protect the whole tunnel, especially in the first minutes after the incident.

Large fires.

Depending on the tunnel geometry, traffic and equipment, a large fire will have more or less important consequences, ranging from few victims and limited damage to several dozens of victims and serious damage to the tunnel.

Five groupings correspond to increasing restrictions on goods permitted in tunnels.

The order of these hazards: explosion, toxic release (gas or volatile toxic liquid), fire, corresponds to the decreasing consequences of an incident and the increasing effectiveness of the possible mitigating measures. From the above assumptions, a system with five groupings can be derived, ranked A to E in order of increasing restrictions concerning goods permitted in tunnels:

Grouping A: All dangerous goods loadings authorised on open roads.

Grouping B: All loadings in grouping A except those which may lead to a very large explosion ("hot BLEVE" or equivalent).

Grouping C: All loadings in grouping B except those which may lead to a large explosion ("cold BLEVE" or equivalent) or a large toxic release (toxic gas or volatile toxic liquid).

Grouping D: All loadings in grouping C except those which may lead to a large fire.

Grouping E: No dangerous goods (except those which require no special marking on the vehicle).

Grouping A is the largest category; it contains all loadings which are authorised for road transport, including the most dangerous ones. Grouping E is the most restrictive one, containing only those loadings which do not require a special marking on the vehicle, *i.e.* the least dangerous ones. Further restrictions (such as banning dangerous goods in any quantities) are impossible for authorities to enforce: there is no way for authorities to differentiate loadings in Grouping E (which do not require exterior placards) from vehicles without dangerous goods short of stopping the vehicle for verification. All loadings in Grouping E are included in Grouping D, all loadings in Grouping D are in Grouping C, and so on. These groupings can be the basis for differentiated regulations, for example:

– *Grouping C (6:00 to 22:00) - Grouping A (22:00 to 6:00).* This means that loadings in grouping A and not in grouping C are authorised from 22:00 to 06:00 only, while loadings in Grouping C may be transported anytime.

– *Grouping C (free passage) - Grouping B (under escort).* Loadings in Grouping A and not in Grouping B are forbidden, loadings in Grouping B and not in Grouping C are authorised with an escort only, loadings in Grouping C can go through the tunnel freely.

For mixed loadings of dangerous goods on the same transport unit, the grouping for each type of dangerous goods is identified. For the whole loading, the first alphabetical grouping is used.

The quantitative risk assessment model (QRAM)

Calculating risk is extremely difficult, both within and outside tunnels…

Quantification of risk is difficult because numerous factors and variables influence probabilities and consequences of incidents involving dangerous goods both within and outside tunnels. Even with expert knowledge, it is therefore difficult to assess risk for all circumstances, environments, weather conditions, etc. Computer calculations are an indispensable tool for developing a sound rational approach to the problem.

…a quantitative risk assessment model was therefore developed.

In order to rationally evaluate the risks and set regulations, a comprehensive model is needed to deal with both tunnels and the open road. Due to the complexity of developing such a model, the task was best carried out through international co-operation. The resulting quantitative risk assessment model (QRAM), developed as part of this project, is a unique tool which can be used in all countries.

This model can produce risk indicators for 13 accident scenarios.

A complete assessment of the risks involved in transporting dangerous goods would require the consideration of all kinds of dangerous materials, all possible meteorological conditions, all possible incidents, sizes of breaches, vehicles fully or partially loaded and many other variables. Since all circumstances are impossible to consider, simplifications have to be made. The model currently considers 13 accident scenarios which are representative of the groupings described in the proposed regulations. If the groupings permitted in a tunnel change, the possible accident scenarios change. The QRAM can produce risk indicators for the various groupings and provide a scientific basis for the regulations. The 13 scenarios considered by the model are:

Grouping E: Heavy Goods Vehicle fire with no dangerous goods (20 MW)
Heavy Goods Vehicle fire with no dangerous goods (100 MW)

Grouping D: ***In addition to scenarios for Grouping E:***
Boiling Liquid Expanding Vapour Explosion (BLEVE) of Liquid Petroleum Gas (LPG) in cylinders
Release of acrolein in cylinders

Grouping C: ***In addition to scenarios for Grouping D:***
Pool fire of motor spirit in bulk
Vapour Cloud Explosion (VCE) of motor spirit in bulk

Grouping B: ***In addition to scenarios for Grouping C:***
Release of ammonia in bulk
Release of chlorine in bulk (chlorine is considered in countries where its transport is allowed in appreciable quantities on roads)
Release of acrolein in bulk
BLEVE of carbon dioxide in bulk (not including toxic effects)

Grouping A: ***In addition to scenarios for Grouping B:***
BLEVE of Liquid Petroleum Gas (LPG) in bulk
Vapour Cloud Explosion (VCE) of LPG in bulk
Torch fire of LPG in bulk

The decision support model (DSM)

No shortcuts are possible when making rational decisions for the safe transport of dangerous goods…

Decision support methodologies have been studied theoretically for many years and are applied in various fields. A survey and evaluation of proven state-of-the-art decision support tools was carried out, and concluded that there are no shortcuts to making rational decisions for the safe transport of dangerous goods. The various, potentially conflicting, objectives must be subject to a mutual weighting – no matter how delicate it may seem to quantify these objectives and weights. In cases where no formalised decision support tool is used, the weighting is made instinctively.

…and goods prohibited in the tunnel must be transported on some alternative route.

When making decisions about which groupings are to be permitted in tunnels, decision makers must keep in mind that the goods prohibited in the tunnel must be transported on some alternative route. The risk and inconvenience on the alternative route will directly influence which grouping is the best from a societal point of view. This implies that it might not be rational to give the same grouping to two identical tunnels carrying the same traffic if the alternative routes differ significantly, *e.g.* in terms of length and population density along the route.

Primary objective: minimising the risk to human life.

One of the primary objectives for the decision on which grouping to permit in a tunnel is to minimise the risk to human life. Apart from the risks to human life, there are several other factors that need to be taken into account when taking a decision on the routing of dangerous goods. The decision process is a complex procedure and a decision support model (DSM) is therefore required to ease and assist rational decision making. The attributes that are evaluated and weighted by the DSM include:

A decision support model (DSM) can evaluate and weight: risks to road users and the local population; material damage; damage to the environment …

- Injury and fatality risks to road users and the local population using the indicators from the QRAM. The DSM helps the decision maker to weight his concerns (for example, a risk-adverse decision maker considers one incident with 100 fatalities less acceptable than 100 incidents with one fatality in each).
- Material damage due to possible incidents on tunnel or detour route.
- Environmental impact due to an incident on tunnel or detour route. The environmental output from the QRAM is limited, giving only approximate indicators for environmental risk. The DSM can be expanded to accept more detailed environmental information.
- Direct expenses (investment and operational cost of tunnel risk reduction measures as well as possible additional costs in the transport of dangerous goods).
- Inconvenience to road users due to a possible incident (time lost during repair works after an incident in the tunnel).
- Nuisance to local population (environmental impact of dangerous goods traffic, with the exclusion of possible incident consequences, but possibly including psychological impact).

…as well as other risks.

Any other attribute found relevant by the decision maker can also be included in the decision problem. In order to make a decision, the decision maker must determine which attributes are relevant and how these should be weighted against each other. These choices must reflect the preferences of the decision maker.

By evaluating risk in a rational manner, the DSM frees decision makers to concentrate on policy decisions.

A computerised tool has been developed, making it possible to take account of the above attributes in a rational manner. The DSM includes the option of choosing between the classical Bayesian decision methodology and multi-attribute methodologies. The DSM utilises the QRAM output directly. Other technical data is used as input, for example, reparation costs following an accident or additional costs for transporting dangerous goods by a longer route. The decision-maker thus has all the technical input and must provide only the policy-based preferences.

Risk reduction measures

Measures can be implemented which reduce the probability or the consequences of an incident in a tunnel.

There are several measures that can be implemented in tunnels which will reduce either the probability or the consequences of an incident in a tunnel. These will influence the regulations governing the restriction of dangerous goods transport through a tunnel. Extensive studies were carried out to determine the effectiveness of these measures as part of this project.

The QRAM could be extended to include other safety measures…

A number of these measures are included in the QRAM. The model can be used to examine the effects of introducing these measures into a tunnel. In addition, a number of other measures were examined and procedures described which would permit an extension of the existing QRAM to include safety measures that were not part of the original model specification.

… and can be used in tandem with other risk reduction measures.

Both qualitative and quantitative methods for the analysis of the effects of risk reduction measures are presented in this report. Using the QRAM together with these methods, it is possible to assess the effects of these measures for a given tunnel.

Every tunnel is unique …

… and the effectiveness (and the cost) of risk reduction measures will vary for each.

The effects of measures are unique to each tunnel, depending on the traffic characteristics and local circumstances. A general effect of the measures applicable to all tunnels could therefore not be generated. Likewise, the costs of measures vary for each type of tunnel. Costs will also differ considerably if the measures are incorporated during the initial design and building stage compared to the cost of retrofitted measures. The costs are therefore best estimated for each particular tunnel case so that the efficiency or cost effectiveness ratio of the measures can be properly evaluated for the specific case.

Risk reduction measures classified according to their main purpose

MEASURES TO REDUCE THE PROBABILITY OF AN ACCIDENT		
Related to tunnel design and maintenance		
Tunnel cross section and visual design	Alignment Lighting (normal)	Maintenance Road surface (friction)
Related to traffic and vehicles		
Speed limit Prohibition to overtake	Escort Distance between vehicles	Vehicle checks
MEASURES TO REDUCE THE CONSEQUENCES OF AN ACCIDENT		
Alarm, information, communication of operator and rescue services		
Close-circuit television Automatic incident detection	Automatic fire detection Radio communication (services)	Automatic vehicle identification *Emergency telephone*
Communication with users		
Emergency telephones *Radio communication (users)*	Alarm signs/signals	Loudspeakers
Evacuation or protection of users		
Emergency exits Smoke control	*Lighting (emergency)* Fire-resistant equipment	Failure management
Reduction of accident importance		
Fire-fighting equipment Rescue teams	Drainage *Road surface (non-porous)*	Emergency action plan *Escort*
Reduction of the consequences on the tunnel		
Fire-resistant structure	Explosion-resistant structure	

Policy recommendations

Implementation of a consistent regulatory and technical framework

The results are applicable in all countries with tunnels.

The results from this project are applicable in all countries with tunnels. The analysis of risks and the development of decision support tools achieved through this project provide road administrations with options to improve the transport of dangerous goods through road tunnels:

☞ **Recommendations**

It is strongly recommended that administrations which allow the transport of dangerous goods through road tunnels implement the "groupings of dangerous loadings" system as the basis of regulations. This system should be implemented at both the national and international levels.

It is recommended that through the adoption of these regulations all tunnels are assigned a grouping of goods that are permitted. This will require new sign-posting, both at the tunnel approach and alternative routing signs.

The adoption of the "groupings" system requires a systematic and scientific basis for decision making. To this end, the QRAM and the DSM developed as part of the project are currently the state of the art in the field and are recommended for use in all countries to support the adoption of the proposed groupings system.

International regulatory framework

The United Nations should be designated as the guardian, promoter and developer of the grouping system.

As a global body, the United Nations Committee of Experts for the Transport of Dangerous Goods is the most appropriate body to act as the guardian, promoter and developer of this system of groupings. It is *recommended that the system be included in the UN's Model Regulations and promoted in all regions of the world*. This represents an important mechanism to promote global transport efficiency through the implementation of a consistent and harmonised regulatory framework.

Recognising that the United Nations Committee of Experts for the Transport of Dangerous Goods deals with multimodal regulations, which are non-mandatory, the most viable road specific alternative is the United Nations Economic Commission for Europe Working Party No. 15 on the transport of dangerous goods. This Working Party is responsible for the European Agreement concerning the *International Carriage of Dangerous Goods by Road (ADR)*, which is applied throughout 34 contracting states and which is the basis for national legislation throughout the European Union. However, many non-European states are likely to wish to adopt these regulations and will therefore have a strong interest in how the regulations evolve in the future.

☞ **Recommendation**

It is recommended that the relevant United Nations Committee should be charged with developing the signs necessary for the implementation and enforcement of the regulations.

Model application and development

The quantitative risk assessment and decision support models require extensive inputs and require a sound understanding of the models and their functions.

☞ **Recommendations**

A database on applications containing all experiences with the QRAM, accessible by Internet. This database should contain the results of all available national runs of the model.

A network of experienced model users who can be contacted if problems cannot be solved by the users themselves.

Meetings of new user groups to be arranged in order to develop further expertise in use of the models throughout the world.

This collection of experiences and results can form a basis for further improvements of the quantitative risk assessment software and the reference manual. The target is to improve the quantitative risk assessment software in a continuous process, involving all users and their experiences.

Expected benefits

The likely benefits for road transport and infrastructure management …

This project has focused on the safe transport of dangerous goods by road. It is likely to generate the following benefits to road transport and infrastructure management flowing from the implementation of the recommendations and the adoption of the tools developed:

- Reduction in the cost of damage to road infrastructure arising from possible incidents in tunnels or on detour routes.
- Reduction in the environmental impact due to an incident in tunnels or on detour routes.
- Improvement in network efficiency by implementing consistent and harmonised regulations for the transport of dangerous goods through tunnels.
- Improvement in overall transport efficiency through reduction in the time costs to road users associated with a possible incident (time lost arising from the incident itself, detour routes and during repair works after an incident in the tunnel).
- Increased efficiency in the deployment of funds invested in upgrading/constructing tunnel infrastructure, management systems and risk reduction measures.
- Increased efficiency of road transport operations arising from compliance with regulations and correct routing of vehicles.

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