

Methodology for comparing dangerous goods risks in road tunnels to those on alternative routes

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ABSTRACT: This paper describes a method for comparing the risks of routing dangerous goods (DGs) through a tunnel with the risks of routing the same DGs along an alternative route. This comparative risk assessment method has been made available to jurisdictions to inform decisions on DG carriage through tunnels. The risk assessment looks separately at different DG event scenarios related to different DG classes and subdivisions. The method also allows modifications to the assessment inputs to enable sensitivity assessments to be undertaken.

The wider decision required from a whole-of-government view also includes considerations that are not directly comparable with risks to life or to the asset. The comparative risk assessment outputs derived from this method, when considered alongside community, environmental, and economic issues, provide a standardised basis for examining DG life safety risk in support of a wider DG decision making framework.

1 INTRODUCTION

1.1 *Project deliverables*

Austrroads project ART6122 has established a comparative risk assessment method for assessing whether a tunnel route is safer than a surface route for the road transit of dangerous goods materials. The resultant method has been available to jurisdictions to allow them to inform decisions on dangerous goods routes with respect to tunnel assets.

The project deliverables comprised three complementary reports produced as part of the project. Any application of this Austrroads DG risk assessment method must ensure that the guidance given in all three reports is referenced and applied. The three reports are:

- 1 Best Practice Review (Austrroads, 2023a)

This report reviews best international practice in road tunnel DG risk assessment and provides justification for the selection of the Dangerous Goods Quantified Risk Assessment Model (DG-QRAM) as the tool most appropriate for comparative DG risk assessments.

- 2 Case Study using DG-QRAM in the Australasian context (Austrroads, 2023b)

The Case Study illustrates the stages of the comparative assessment, with incorporation of mitigation measures. It is intended that transport authorities, competent authorities and risk specialists will find the case study a useful demonstration of the intent of the method that is detailed in the Manual.

- 3 Manual for using DG-QRAM in the Australasian context (Austrroads, 2023c)

This report provides background on the development, capabilities and limitations of the DG-QRAM tool as well as providing guidance as to how the DG-QRAM tool should be applied to road tunnels in Australia/NZ.

The resultant comparative risk assessment methodology gives guidance as to the route with the lower risk. Comparative risk is preferred to absolute risk, as it is less susceptible than absolute risk to systemic inaccuracies in either the inputs or the underlying models

1.2 Consultation

Extensive consultation was undertaken delivering this work. Key consultees were the National Transport Commission, the Australian Fire Authorities Council, and the Dangerous Goods Competent Authorities.

1.3 International practice

A review of international practice on risk assessment of dangerous goods in tunnels has produced valuable insights to be considered when developing the Australasian approach to risk-based decisions. The area of risk assessment related to road tunnels is most developed in Europe and so this project drew mostly on experience from there.

The comparative risk assessment gives guidance as to the route of lower comparative risk regardless of how small those risks are. An alternative concept that is applied in Austria, France and Germany is to accept the tunnel route, if the risks from the route fall below an acceptable expected societal risk, which is sometimes expressed in an F-N curve.

1.4 Previous practice in Australasia

Dangerous goods risk assessments of this type are rarely undertaken in Australia, and when they are, the documentation can be tightly held as it is deemed sensitive. The one available Australasian study which took the quantification to the required level for decision seemed unsure whether the decision acceptance criteria should be the establishment of the route of lower risk, or establishing whether all assessed routes achieved a safety level better than a certain threshold. The answer is that no such conclusion is required, with the comparative risk assessment outputs being presented as they are, to be considered alongside community, environmental and economic issues.

1.5 Case study tunnel

The application to a trial tunnel was used to demonstrate the suitability of DG-QRAM, and identified modifications required for Australasia. The onerous requirements for sufficient data on traffic makeup, DG movements and population density to make a detailed assessment may, in future, lead to increased importance of a screening stage, and may also require that appropriate Australasian default values are established for some inputs.

1.6 Wider decision-making framework

As noted above, the wider context of transport route decisions may determine the question of how to judge or act on a quantitative risk assessment. The quantitative methods that are a primary focus of this document are not an end in themselves, but a decision aid within a decision that is often more complex and judgement-based. Besides the risk to life from the QRA, a complete decision on routing might need to consider environmental risks (including to water supply catchments), community and social benefits, economic benefits, and economic risks. There is no magic formula for converting all risks to one measure (e.g. dollars, lives, or ecological cleanliness) and so judgement will still be necessary. Because the big picture cannot be entirely quantitative, the risks of both routes may be considered within the wider decision, and so perhaps it matters less whether, within the risk model, we compare risks to a benchmark, or prefer only the lowest, following a SFAIRP approach. That is: the outputs may be considered within the holistic decision without necessarily being placed into either framework.

1.7 Limitations of quantitative risk assessment

There are many approximations in risk assessment calculation methods. For DG risk assessment methods, the simplifications and approximations in the methodology, as well as the uncertainties in the inputs will always limit the accuracy of any risk estimate. First, the theoretically possible events and chains of events are so numerous and situation dependent, that considering them all correctly is simply not feasible. Thus, in any DG risk assessment, quantitative or qualitative,

approximations and assumptions are inevitable. Quantitative risk assessment results are a statistically-based approximation to what could most likely happen in reality. It will always be only an approximation to reality and never a foretelling of exactly what will happen in a specific event.

Second, it seems logical that the more encompassing an assessment is (e.g. by covering many scenarios), the more realistic the results will be. However, the accuracy of any risk estimation is obviously limited by the completeness and correctness of the initial information and input data processed. One must therefore be cautious to not produce tremendously detailed analyses delivering results to many decimal places and pretending a precision that is outrunning both the initial data quality and the modelling approximations. Hence, the level of detail should be truncated where the assessor's knowledge of the inputs determines that no further accuracy or certainty can be achieved.

1.8 *Focus of this paper*

The focus of this paper is on the best practice review which provided justification for the selection of DG-QRAM as the tool most appropriate for comparative DG risk assessments.

2 TYPES OF HARM

The types of harm are the same for DG-carrying vehicles as for other vehicles, perhaps with differences in the potential level of harm. In general, four different types of harm can be investigated:

- Harm to people (including injuries as well as fatalities)

This is the most important hazard type relating to the assessment of the transport of dangerous goods through tunnels. The most commonly used indicator for the quantitative assessment is statistical fatalities. The primary affected people are the tunnel users. However, people situated next to the tunnel portals and possibly also those downwind and even above the tunnel (for shallow urban tunnels) could be affected. Emergency responders may be at risk in responding to incidents. There is also a low probability that some maintenance related inspection might be underway at the time of an incident. For surface routes, the two affected groups are the road users, and the people close to the route or downwind or downstream. DG-QRAM does not include risk to emergency responders, as that risk may be completely different depending on the different approaches to emergency response that may be used. Responders will undertake risk assessments in addressing each incident and adjust their response accordingly.

- Economic losses

Two types of economic loss may be distinguished. There are the (direct) capital losses due to the damage caused by the event, and there are the (indirect) economic losses due to the tunnel closure (longer or slower travel and transport routes, higher travel and transport costs, affected business losses, possible loss of toll revenue, etc.).

- Impact on the environment

The impact on the environment may also be relevant to the transport of dangerous goods. Whilst the environmental pollution expected from an event in a tunnel is normally limited by capture of in-tunnel spillage and suppression water, the consequences of a liberation of noxious substances in the open can be significant (pollution of soil, groundwater, habitat destruction, etc.). The routes may also vary significantly in the required vehicle fuel use and resultant emissions.

- Reputational damage

Spectacular events causing higher damage (to people and/or property) attract a high media attention, causing public discussions and reactions at political level. A major road tunnel incident may result in significant damage to a tunnel operator's reputation. In comparison to conventional tunnel risks, like collisions or vehicle fires not involving dangerous goods, incidents involving the release of dangerous substances in a tunnel are characterized by very low probabilities but very high potential consequences. Even minor spills of the material could close a tunnel for some time, generating similar media interest. The harm under this heading could include loss of trust in the asset owner or authorities (with unduly high expenditure on changes to recover trust),

reduced tolls, reduced economic use of the tunnel, or difficulty in gaining acceptance for new tunnel projects. Similar risks apply if the decision is taken to exclude DGs from a tunnel and a high consequence event occurs on the surface route.

The risks linked to these types of harm can be analysed either quantitatively or qualitatively, or both. In comparison to qualitative methods, which are mostly focussing on the interaction and the interdependence of events, quantitative methods enable the calculation of characteristic risk values. Often, due to the lack of sufficient data for complete quantitative analysis, qualitative and quantitative components might be combined in practical applications. For potential high-profile incidents, a closer look at reputational damage is required. Due to the specific influence of risk perception described above, in the process of risk evaluation, special attention is to be paid to incidents with potentially very high consequences (Kohl & Krieger, 2012).

3 RESPONSIBILITY OF THE ROAD AUTHORITY

The reader is directed to the best practice report which contains a comprehensive review of the responsibilities of the road authority. Some key points of that review are re-produced here.

It is generally accepted in all Austroads legal jurisdictions that each member of the public is entitled, as of right, to pass along a public road (whether on foot, in a vehicle or otherwise) and to drive stock or other animals along the public road. Any restriction on the passage of goods through road tunnels is a restriction of that right. Typically, such restrictions will be imposed by a road authority, dangerous goods transport regulator or a combination of statutory authorities which may have overlapping jurisdiction. The regulation of the transport of goods prescribed as dangerous, or otherwise worthy of transportation restrictions, is an exercise of power to restrict the general rights of passage of the public and must therefore be exercised in accordance with law.

Because each State in Australia is a different legal entity, and because each of the States has transferred some of its powers to the Commonwealth of Australia, and because New Zealand is a separate country, the exact identity of the authorities with power, or which claim to have power, over dangerous goods transport varies from place to place and time to time.

Tunnels are, by their nature, prone to creating hazards for users, vehicles and goods. The hazards are uniquely the responsibility of road authorities and could not reasonably be expected to be within the knowledge or control of other regulatory authorities. The unique physical properties of a tunnel when combined with a road transportation function make the regulation of dangerous goods through tunnels a responsibility of road authorities.

A decision to regulate the passage of dangerous goods through tunnels by a road authority must be both reasonable and not negligent. The requirements for a 'reasonable' decision for the regulation of dangerous goods and the requirement that a road authority not be 'negligent' are separate legal requirements. This means that a road authority must be mindful of both its statutory obligations as an authority and its civil responsibilities not to do harm. The determination of legal unreasonableness is heavily fact dependent and inherently sensitive to context. It is therefore not capable of reduction to a formula and no single legal test of unreasonableness can be stated.

A road authority that can clearly articulate its statutory powers and obligations to an identified and transparent framework for making decisions about the regulation of dangerous goods through tunnels is in an extremely strong position to demonstrate the legal reasonableness of its actions.

It is within this articulation of 'unreasonableness' that the methodologies for considering comparative and absolute assessment for the acceptability of risk through risk analysis techniques must be analysed. While the tools for risk analysis may be used in multiple overseas jurisdictions, it does not follow that their use by Austroads members would withstand a reasonableness test if the outcomes appear to abandon common sense. Similarly, if there are alternative tools that both meet Australasian reasonableness and common-sense requirements, road authorities could choose either according to their preference.

It must be noted that the concept of reasonableness is not within European law (the legal framework within which DG-QRAM and other models evolved). This means that the application of European methodologies in an Austroads context needs to be challenged and verified for local regulatory and factual conditions.

4 EXAMPLES OF NATIONAL STANDARDISED RISK ASSESSMENT METHODS

Typically, the risk assessment and evaluation procedure for dangerous goods transports consists of two levels:

- At the policy/overview level, there is the procedure of risk assessment and risk evaluation, including the risk acceptance approach and criteria.
- The detailed level is the choice of risk model that is applied for the quantitative investigation. In fact, there are only a limited number of models which find use in practice.

In order to evaluate the ADR category that should be assigned to a tunnel, a (quantitative) risk assessment is necessary. Note that ADR is the UN treaty concerning the International Carriage of Dangerous Goods by Road, not the Australian Design Rules. Experience has shown that submitting a tunnel to a complete examination is an extensive task and requires a large amount of data. It is time and cost expensive.

To reduce this expenditure, and in view of the large diversity of tunnels (regarding tunnel parameters, equipment and traffic parameters), some national authorities decided to divide the process into several steps. The use of quantitative models form steps or parts of steps required in their respective national risk assessment methods. The particular procedures, although similar, differ from country to country. Nevertheless, the main principle is to end the tunnel assessment as soon as it is proven that sufficient tunnel safety measures have been included such that no restriction on the transport of dangerous goods is necessary. Alternative routes are evaluated only in a last step. This is conceptually different to the proposed framework for Australasia, in which parallel assessments of the tunnel and surface route are compared.

In general, acceptance criteria are not harmonised within Europe. In fact, the definition of the acceptability limits or boundary curves for the F-N diagrams is often a complicated (national) long-term process involving multiple stakeholders. Adopting a comparative approach with F-N curves for a risk-based comparison of alternatives is useful but needs to be done carefully, as the interpretation – especially where curves intersect – is a highly sophisticated task. The complexities of all this make it attractive to apply a ‘deemed to satisfy’ approach in the US.

The use of F-N curves to judge acceptability against criteria, is also a point of difference with the ‘SFAIRP’ approach to risks that is common in Australasia. If we follow the SFAIRP approach to risk reduction, we need to see if we could reasonably reduce risk further by using the alternative route for DG, even if it has already been made ‘acceptable’ against some criterion. European approaches generally are satisfied if the tunnel route meets the criteria set, whether or not it is theoretically possible to reduce risk further. Only if the tunnel route does not meet the criteria is the comparison with alternative routes required, to decide which is preferred. Whether criteria are met or not, the French approach allows other parameters to be considered in the decision (environment, economic, non-DG incidents), alongside DG risk outcomes.

The best practice report describes and assesses the methodologies applied in France, Germany and Austria as well as reference to methodologies applied in Italy and Switzerland. It confirms that in other countries such as the USA, Great Britain and Ireland the methodology to be applied is decided on a case-by-case basis as there are not standard national approaches.

US federal regulations require a risk assessment for DG in tunnels, but specifically do not suggest a recommended risk model. This allows and forces the states to select their own model. The US lack of centralized DG regulations and therefore adoption of a preferred national risk model, is a direct result of the individual states requirements superseding federal requirements. In general, full quantitative risk assessment (QRA) for fires and dangerous goods in tunnels or surface routes is hardly used in the US. It is conventional to comply with codes and standards to fulfil the mandatory requirements, as they correspond to an assumed level of risk. These are commonly used as the benchmark for setting the initial bar.

5 DANGEROUS GOODS QUANTITATIVE RISK ASSESSMENT MODEL (DG-QRAM)

This quantitative risk assessment model (DG-QRAM) for the transport of dangerous goods was first developed in a joint project of OECD and PIARC almost 20 years ago. It is a commercial software, which is widely used and serves often as a basis for a country-specific method for the

risk-based assessment of the transport of dangerous goods through tunnels or on tunnel routes. Importantly for the present work, DG-QRAM was developed as a tool for deciding whether to forbid or authorise, partly or totally, the dangerous goods traffic through tunnels. It is intended to be used for this purpose only. The risk model is not suitable for a general risk assessment study for road tunnels. There are several reasons for this limitation such as:

- The model does not deliver a complete picture of the overall tunnel risk, as it does not include incidents (collisions / fires etc) from a range of non-DG transports (i.e. passenger cars).
- The model includes a lot of different DG-scenarios, therefore to reduce complexity the consequence sub-models in DG-QRAM for each individual scenario are rather coarse. This is particularly relevant to fire and smoke propagation modelling inside a tunnel. Other modern tunnel risk models (like TuRisMo) offer a much better and realistic representation of these effects, because they use complex combined and transient 1D/3D CFD modelling.
- There are limitations in assessing the positive effects of many quite effective tunnel safety measures – related to ventilation, evacuation, FFFS or organisational measures influencing the timeline of reactive actions in fire incidents.

The tool's general structure allows an assessment of the tunnel alone, as well as the assessment of an open-air route in comparison with the tunnel route. This is a valuable feature, as this allows either a comparative risk assessment or an absolute risk assessment or both. Furthermore, the tool allows the user to select between the option of calculating fatalities plus injuries or fatalities only, and to select between the consideration of road users plus local populations, or road users only, or local population only. One part of the model consists of a quantitative frequency analysis. DG-QRAM encompasses an analysis of the sequence of events or occurrences that stem from an initial DG event, to a set of consequence scenarios including the respective probabilities of occurrence.

Thirteen scenarios representing the hazards most threatening to human life have been defined. Scenarios of other dangerous goods primarily affecting the environment are not considered, as the main focus is on human well-being. Within modern Australasian tunnels, the environmental impact of the release of polluting substances seems negligible, as all are equipped with sumps that capture spillage and either store it for disposal or transfer it to surface storage. For every scenario there is a probability implemented in the model, distinguishing between the different boundary conditions (tunnel or open air, urban area or rural area, etc.).

The consequences of scenarios involving those DGs not appearing in the DG-QRAM scenario list is taken as being similar, or less significant than the consequence of one already in the list. The chosen substances are representative of all other dangerous goods. The exceptions are large quantities of explosives, and radioactive materials, which are not addressed by DG-QRAM and are also regulated differently. Depending on the detonation assumption (rapid or delayed) more moderate explosive loads could be considered through BLEVEs or vapour cloud explosions of the appropriate size. It may not be appropriate to use those scenarios to model military quantities of explosives.

The general procedure to obtain a scenario's probability of occurrence is to combine the route's HGV incident rate (or a national default value) with the traffic and the DG HGV ratio among that traffic along the (tunnel) road, as well as the conditional probability of occurrence of the scenario. Those specific probabilities are preset in the software and are a function of the dangerous goods traffic's composition. The probabilities used are based on a comprehensive (400-page) study by the University of Waterloo (Canada), which was an annex to the original work documentation. The probability can be adjusted by aggravating or diminishing factors related to the tunnel's or/and the route's characteristics, such as being an urban or rural road, the presence of exit or on-ramps, the existence of crossroads, etc. For the tunnel, it is of course important to know whether it is single tube or twin tube. A detailed description of the model is given in the DG-QRAM reference manual (PIARC 2019).

6 PREVIOUS PRACTICE IN AUSTRALASIA

We have been provided with and have reviewed risk assessments for several specific Australasian projects. We are aware of others that cannot be specifically referenced as the information is tightly

held. Of the reports that are available to the authors, we refer to one that had the depth of analysis sufficient for a comparative QRA. That report is discussed briefly here.

The transport of DG was looked at for the M5 East tunnel in 1995, as part of the planning and design. The report (Parsons Brinckerhoff Quade & Douglas, 1995) noted a lack of detail in prior work looking at DG risk in tunnels, and the paucity of data with which to make assessments. The study compared the risk in tunnels against that on alternative surface routes, and emphasised the sensitivity of the result to values and assumptions which might tend to favour the open air or the tunnel cases. The method applied was a full quantitative method, considering frequency and consequences for representative DG loads, reaching distinct conclusions on the preferred route for each DG class. The spectrum of DG loads was simplified in a manner similar to that done in DG-QRAM.

The likelihood and consequence analysis appears to have been done in some detail, although the specifics of the consequence analysis are not given. The methodology of assessing the alternative route consequences is not readily deduced.

7 CONCLUSIONS

PIARC's DG-QRAM is selected as the most appropriate quantitative tool to use within an Australasian approach, with the suggestion that a screening assessment, as is common in Europe, be applied first. The purpose of a screening assessment would be to shorten the assessment where the comparative risk result is so clear that a simple approach is sufficient, and the time and expense of a more detailed approach is unnecessary. If such an assessment is considered, it may use the same methodology, but with approximated or notional input data, appropriate to the screening function and shorter time availability.

Currently there is no standardized risk assessment approach in Australia or New Zealand. Experience shows that this lack of a uniform methodology and an associated validated assessment model has led to a certain grade of arbitrariness in the evaluation of the permissibility of the transport of dangerous goods through tunnels.

European countries have developed methodologies for assessing DG risk. While those methodologies may at first appear quite different, when reviewed in detail they have much in common:

- They all have as their basis a quantitative risk assessment;
- They are all based on the ADR;
- Most of the methods include a multi-stage approach; and
- Most rely on DG-QRAM.

This DG-QRAM (dangerous goods quantitative risk assessment model) has in fact been developed specifically for the needs of a QRA for the transport of dangerous goods. It has been developed in an international context (PIARC/EU/OECD) and encompasses the statistical background of various countries. Further, it enables “direct” comparison of the tunnel route and an alternative route. As the categorization system of dangerous goods in the ADR is the same as in Australia, a closer examination of DG-QRAM in the Australasian context seems reasonable.

Governments must consider many aspects, such as social and community benefit, risks to environment, including water supplies etc. Within that broader context, the fine details of a very detailed model may lose impact. Depending on the legal context applying to each road authority, the distinction between acceptable risk and the SFAIRP approach for model outputs may lose relevance, as the overall method outcome cannot be assessed one dimensionally.

Finally, there are differences between jurisdictions that need to be considered in the methodology. These include:

- Infrastructure differences
 - Fixed fire-fighting systems (deluge or water-mist)
 - Egress provisions (i.e. cross-passage spacing)
- Dangerous goods fleet differences
 - Bulk diesel (i.e. whether diesel is identified as a DG)
 - B-double trucks (B-doubles not permitted to carry DGs in Europe)

- Driver training
- Seasonal transports
- Operational differences
 - Lane use restrictions
 - Time of day

8 REFERENCES

- Austroads. 2023a. *Methodology for Comparing Dangerous Goods Risks in Road Tunnels to Those on Alternative Routes – Best Practice Review*. Sydney: Austroads.
- Austroads. 2023b. *Methodology for Comparing Dangerous Goods Risks in Road Tunnels to Those on Alternative Routes – Case Study Using DG-QRAM in the Australasian Context*. Sydney: Austroads.
- Austroads. 2023c. *Methodology for Comparing Dangerous Goods Risks in Road Tunnels to Those on Alternative Routes – Manual for Using DG-QRAM in the Australasian Context*. Sydney: Austroads.
- Kohl, B. & Krieger, J. 2012. *Current Practice for Risk Evaluation for Road Tunnels*. Paris - La Défense: PIARC World Road Association.
- Parsons Brinckerhoff Quade & Douglas. 1995. *M5 Motorway East: Transport of Dangerous Goods - Supplement to M5 East Motorway Environmental Impact Statement in Working Papers Vol 2 of 3*.
- PIARC. 2019. *Transport of Dangerous Goods through Road Tunnels: Quantitative Risk Assessment Model (v. 4.04) - Reference Manual*. Paris: PIARC - World Road Association.