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SAFETY REQUIREMENTS FOR TUNNELS REGARDING THE TRANSPORT OF DANGEROUS GOODS (ADR)

Abstract

EU Tunnel Directive 2004/54/EC aims to ensure a minimum level of safety for users in road tunnels in the Trans-European Road Network. EU member states are required to develop, at national level, their own detailed methodology for tunnel risk assessment. Along with that, ADR as the UN regulation in the field of dangerous good transportation by road, contains provisions concerning restrictions on the passage of vehicles carrying dangerous goods in road tunnels. Tunnel category A-E is assigned to each tunnel on the transport route, which regulate the types of dangerous goods to be allowed to go through the tunnel in order to avoid any hazards with major consequences. In this paper, basic principles of risk assessment and categorization of tunnels in accordance.

Keywords: road tunnels, safety measures, dangerous goods, ADR, tunnel category

БЕЗБЈЕДНОСНИ ЗАХТЈЕВИ ЗА ТУНЕЛЕ У ПОГЛЕДУ ПРЕВОЗА ОПАСНИХ МАТЕРИЈА

Сажетак

Директива ЕУ о тунелима 2004/54/ЕЦ има за циљ да обезбједи минимални ниво безбједности за учеснике у саобраћају у тунелима. Од држава чланица ЕУ се захтијева да развију, на националном нивоу, сопствену детаљну методологију за процјену ризика код тунела. Паралелно с тим, АДР као пропис УН у области друмског транспорта опасних материја садржи одредбе које се односе на ограничења проласка возила која превозе опасан терет у друмским тунелима. За сваки тунел на транспортној траси додијељена је категорија тунела А-Е, која регулише врсте опасних материја које треба да прођу кроз тунел како би се избјегле опасности са већим посљедицама. У овом раду су приказани основни принципи процјене ризика и категоризације тунела у складу са АДР, са посебним освртом на регулативу у нашој земљи.)

Кључне ријечиs: друмски тунели, безбједносне мјере, опасне материје, АДР, категорија тунела.

1. INTRODUCTION

Road traffic, especially heavy goods traffic in tunnels increases during years. While most engineering techniques concerning tunnel construction and safety requirements have been continually improving, the problem of dangerous goods transport through tunnels has not been satisfactorily solved yet. Tunnel risk assessment became mandatory for trans-European tunnels via EU Tunnel Directive 2004/54/EC [1] on minimum safety requirements for tunnels in the Trans-European Road Network (TERN), the length of which exceeds 500 meters. Many European countries adopted the requirement for all their tunnels with the goal to have a comparable and uniform safety standard for all tunnels within the TERN. Since EU does not impose a methodology, member states are required to develop, at national level, their own detailed methodology for their country. Managing the risks involved with transporting dangerous goods through road tunnels and finding solutions to these complex problems required varied scientific experience and strong financial support. For these reasons, the OECD's Road Transport and Intermodal Linkages Research Programme and PIARC's Committee on Road Tunnels launched a joint research project, which resulted in the Report [2,3] covering both regulatory and technical aspects of dangerous goods passage through road tunnels. A quantitative risk assessment (QRA) model has been developed as part of that research, which compares the risks of transporting dangerous goods through a tunnel to using an alternative route. A decision support model (DSM) was also developed as part of the research which allows decision makers to combine the results from the QRA with other relevant data. Authors in [4] presented a three step method to categorize Swedish road tunnels according to the regulation ADR-S 2017. The first is a logical decision model which, when followed should lead to well-founded basis for decisions regarding the appropriate categorization. The second is a simplified risk analysis method that can be used in the risk-based categorization of existing and new tunnels. Finally, expert assessment as a method for risk-based categorization is introduced as a third step. Authors in [5] dealt with tunnel hazards due to fires and explosions from a number of sources including transportation of dangerous goods, traffic accidents, combustion of mechanical or electrical installations, sabotage or terrorism. A quantitative risk analysis regarding hourly traffic volume and percentage of heavy goods vehicles in order to assess their impact on the risk level of a directional road tunnel were analyzed in [6]. This paper proposed risk charts useful for quickly assisting in making decisions on the most appropriate traffic control strategies. In Republic of Srpska, Ministry of Transport and Communications adopted the Rule book on minimum security requirements for tunnels [7] which came in force in 2021. This regulation presents the first step authority of our country has taken in managing the risks and safety requirements for tunnels located on road routes which are part of the Trans-European Road Network, the length of which exceeds 500 meters.

2. DANGEROUS GOODS AND ITS CLASSIFICATION ACCORDING TO THE ADR

Transport of dangerous goods by road is regulated by the UN Agreement concerning the International Carriage of Dangerous Goods by Road (ADR) with its constituent parts, annexes A and B and the act on notification. The aim of this regulation is to permit the free movement of dangerous goods at an acceptable level of safety. ADR is a 1957 UN regulation concerning the international carriage of dangerous goods by road, valid in 54 countries. "ADR" is derived from the French name for the treaty: ***A**ccord relatif au transport international des marchandises **D**angereuses par **R**oute*. Every two years the regulations are updated with the latest version applicable being the ADR 2023.

In ADR, it is stated that, with the exception of certain exceptionally dangerous materials, hazardous materials may in general be transported internationally in wheeled vehicles, provided that two sets of conditions be met:

- Annex A regulates the merchandise involved: a classification system to regroup the large variety of dangerous goods, notably their packaging and labels;
- Annex B regulates the construction, equipment, and use of vehicles for the transport of hazardous materials

Table 1 shows the thirteen different classes and subdivisions of dangerous goods as defined in the ADR [8].

Table 1. Dangerous goods classes according to ADR

Class	Description
1	Explosive substances and articles
2	Gases – Flammable gases – Non-flammable and non-toxic – Toxic
3	Flammable liquids
4.1	Flammable solids, self-reactive substances, polymerizing
4.2	Substances liable to spontaneous combustion
4.3	Substances which, in contact with water, emit flammable
5.1	Oxidizing substances
5.2	Organic peroxides
6.1	Toxic substances
6.2.	Infectious substances
7	Radioactive material
8	Corrosive substances
9	Miscellaneous dangerous substances and article

3. TUNNEL CATEGORIES ACCORDING TO ADR

The categorization of a tunnel is based on the assumption that there are three major hazards that could cause any of the types of harm [8]:

- explosions,
- release of toxic gas or volatile toxic liquid,
- fires.

The main consequences of these hazards and the efficiency of possible mitigating measures, are following [2, 8]:

- "Large explosions", where two levels could be distinguished: 1) "Very large" explosion is 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"); 2) "Large" explosion is 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) would 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) would be more limited, especially regarding damage to the tunnel structure.
- "Large toxic gas releases" can be caused by leakage from a tank containing a toxic gas (compressed, liquefied, dissolved) or a volatile toxic liquid. It would kill all the people near the release zone and in the area where the ventilation (natural or mechanical) would 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 accident.
- "Large fires" could have more or less important consequences (a certain number of victims and limited to serious damage to the tunnel) depending on the tunnel geometry, traffic and equipment.

The order of these hazards: explosion / toxic release / fire, corresponds to the decreasing consequences of an accident and the increasing effectiveness of the possible mitigating measures. From the above assumptions, a system with five groupings is derived, ranked A to E *in order of increasing restrictions* concerning goods permitted in tunnels:

- **Tunnel category A**: All dangerous goods loadings which authorized on open roads (that means there are no restrictions for the transport of dangerous goods). No road sign or additional panel is necessary.
- **Tunnel category B**: All loadings in grouping A except those which may lead to a very large

explosion - “hot BLEVE” or equivalent (that means there are restriction for dangerous goods which may lead to a very large explosion).

- **Tunnel category C**: All loadings in grouping B except those which may lead to a large explosion - “cold BLEVE” or equivalent or a large toxic release (that means there are restriction for the carriage of those dangerous goods which may lead to either a very large explosion, a large explosion, or a large toxic release).
- **Tunnel category D**: All loadings in grouping C except those which may lead to a large fire (that means there are restrictions for the carriage of those dangerous goods which may lead to either a very large explosion, a large explosion, a large toxic release, or a large fire.

Tunnel category E: No dangerous goods are permitted, except those which require no special marking on the vehicle (that means there are restrictions for all dangerous goods other than UN numbers 2919 (nonfissile radioactive material), 3291 (clinical waste), 3331 (fissile radioactive material), 3359 (fumigated cargo transport unit) and 3373 (biological substances)).

Grouping A is the largest category. It contains all loadings which are authorized 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. All loadings in Grouping E are included in Grouping D, all loadings in Grouping D are in Grouping C, and so on.

It is the responsibility of each national authority to categorize its tunnels accordingly and properly label it. Figure 1 shows one example of the tunnel category label.

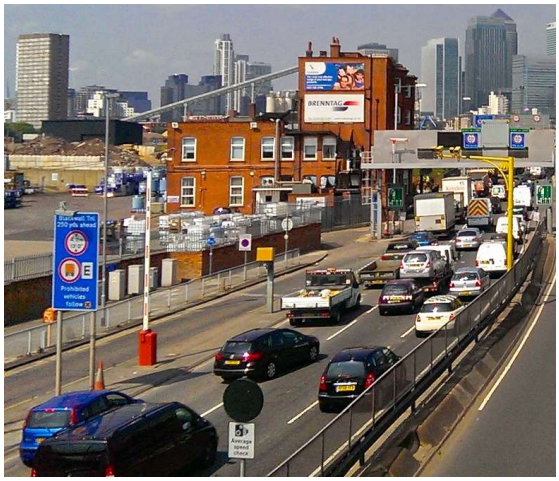

Figure 1. The sign “Class E”, the Blackwall Tunnel approach road, East London [https://en.wikipedia.org/wiki/ADR_(treaty)#/media/File:Towards_Blackwall_Tunnel_(14075187245).jpg]

European countries have different strategies regarding the acceptability of the dangerous goods transport through tunnels on their trunk road networks. For example, France is quite restrictive, while on the other hands, Austria's tunnels have high safety standards. In Spain, there is a designated subset of the road network for the transport of dangerous goods. Sweden also has designated primary and secondary dangerous goods routes [9].

4. A RISK ASSESMENT

The seriousness of damage that can occur during the transportation of dangerous goods through the tunnel can be expressed by the loss of human life, environmental pollution, tunnel damage and interruption of transportation. The types of harm are the same for vehicles transporting dangerous goods as for other vehicles, the difference is only expressed in the potential level of damage. Types of damage which can be analyzed are following [9]:

- Harm to people: People injuries or fatalities are the most important hazard type relating to the assessment of the transport of dangerous goods through tunnels. Statistical fatalities is the most commonly used indicator for the quantitative assessment. Affected people could be: the tunnel users (primary), people situated next to the tunnel, and people (possibly) situated downwind.

- Economic losses: There are the direct capital losses due to the damage caused by the event, and indirect economic losses due to the tunnel closure.
- Impact on the environment: In the case of an accident in the tunnel, even though release of hazardous material is limited to a narrow area in the tunnel, however, the consequences can also occur in the open (pollution of soil, groundwater, habitat destruction, etc).

To managing the risks involved with transporting dangerous goods through road tunnels, it is necessary to perform a risk assessment. The risk assessment is a tool to identify the hazards and analyze the probability and magnitude of damage in order to obtain a quantifiable risk indicator.

Figure 2 illustrates the typical procedure for a risk assessment [9, 10]. The risk assessment procedure includes the stages of risk analysis, risk evaluation and risk reduction. The first step of the risk analysis stage is the description of the tunnel itself (the geometrical and the traffic characteristics along with the operating procedures and the emergency planning are described). Next is the hazard identification step, where all potential hazards that may result in particular risks are identified and categorized. For each potential risk, a frequency and consequence analysis is performed resulting in risk estimation. Following the risk estimation step, a risk evaluation is performed by comparing the risk estimation with the risk criteria. In case the risk criteria are satisfied, the risk level is acceptable. On the other hand, where the risk is above the acceptable level, additional measures are proposed and the procedure of risk assessment is being performed again until the risk falls in levels where acceptable criteria are met [10].

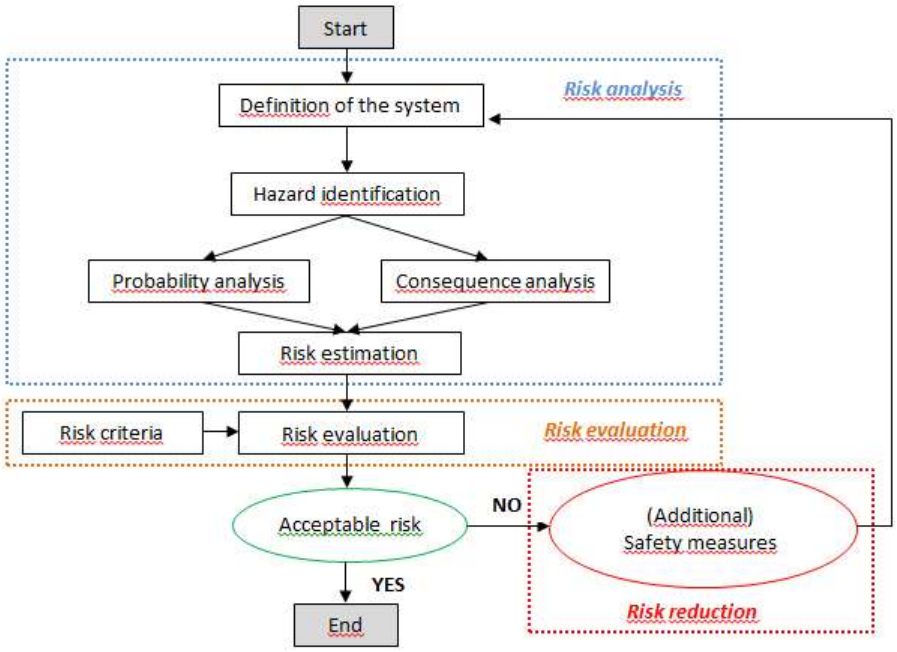

Figure 2. Risk assessment flowchart [9, 10]

There are two approaches to analyze a risks regarding dangerous goods in a tunnel: quantitative or qualitative, or combined it. Qualitative methods are paying particular attention to the interaction and the interdependence of events. On the other hand, quantitative methods are based on the calculation of characteristic risk values. However, due to the lack of sufficient data for complete quantitative analysis, it is applicable to combine qualitative and quantitative components.

4.2. THE QUANTITATIVE RISK ASSESSMENT MODEL (QRAM)

As the numerous factors and variables influence probabilities and consequences of accidents involving dangerous goods, it is very demanding to quantify a risk, both into and outside tunnels. A comprehensive model, named quantitative risk assessment model (QRAM) [2], was developed through international co-operation and can be used in all countries. The QRAM aims to quantify the risks regarding transport of dangerous goods on given routes of the road system, as well as to compare one route including a tunnel with an alternative route in the open area. Components relevant for the developing of the QRA model are as follows:

- Indicators
- Accident scenarios
- Evaluation of accident probability
- Determination of physical consequences, structural and environmental damage
- Evaluation of consequences on humans (open and tunnel sections)
- Uncertainty/sensitivity analysis
- Validation

A complete assessment of the risks regarding transport of dangerous goods could require the consideration of many variables: variety of dangerous materials, variety of meteorological conditions, variety of type of accidents, sizes of breaches, vehicles fully or partially loaded, etc. It is almost impossible to consider all of it, so some simplifications need to be made. The model is based on consideration of 13 accident scenarios, presented in Table 2, which are representative of the groupings described in the proposed regulations. The use of QRAM software for conducting tunnel categorization according to ADR agreement as proposed by the developers of the QRAM software can be made by assigning the proper scenarios to each tunnel category.

Table 2. Scenarios representative of each grouping in the QRA model [2]

Grouping	Scenario No.	Description
E	1	Heavy Goods Vehicle fire with no dangerous goods (20 MW)
	2	Heavy Goods Vehicle fire with no dangerous goods (100 MW)
D		*In addition to scenarios for Grouping E*:
	3	BLEVE of Liquid Petroleum Gas (LPG) in cylinders
	4	Release of acrolein in cylinders
C		*In addition to scenarios for Grouping D*:
	5	Pool fire of motor spirit in bulk
	6	Vapour Cloud Explosion (VCE) of motor spirit in bulk
B		*In addition to scenarios for Grouping C*:
	7	Release of ammonia in bulk
	8	Release of chlorine* in bulk
	9	Release of acrolein in bulk
	10	BLEVE of carbon dioxide in bulk (not including toxic effects)
A		*In addition to scenarios for Grouping B*:
	11	BLEVE of Liquid Petroleum Gas (LPG) in bulk
	12	Vapour Cloud Explosion (VCE) of LPG in bulk
	13	Torch fire of LPG in bulk

BLEVE: Boiling Liquid Expanding Vapour Explosion, LPG: Liquefied Petroleum Gas
*Chlorine is considered in countries where its transport is allowed in appreciable quantities on roads

4.3. THE DECISION SUPPORT MODEL (DSM)

In decision making process about which groupings are to be permitted in tunnels, it must be taken in consideration that the goods not allowed in the tunnel should be transported on some alternative route. One of the primary aims for the decision on which grouping to permit in a tunnel is to minimize the risk to human life, but there are other factors that need to be taken into account. The features that are evaluated and weighted by a decision support model (DSM) are following [2]:

- Injury and fatality risks to road users and the local population using the indicators from the QRAM.
- Material damage due to possible accidents on tunnel or alternative route.
- Environmental impact due to an accident on tunnel or alternative route.
- 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 accident (time lost during repair works after an incident in the tunnel).
- Annoyance to local population (environmental impact of dangerous goods traffic, with the exclusion of possible accident consequences, but possibly including psychological impact).

In decision making process, the decision maker must determine which features are relevant and how these should be weighted against each other. A computerized tool has been developed, making it possible to take account of the mentioned features in a rational manner.

4.4. RISK REDUCTION MEASURES

In order to reduce either the probability or the consequences of an accident in a tunnel, there are several measures that could be implemented in tunnels. A number of these measures are included in the QRAM. Using qualitative and quantitative methods for the analysis of the effects of risk reduction measures, it is possible to assess the effects of these measures for a given tunnel. For each tunnel, the results of measures and related costs are specific, depending on the traffic characteristics and local circumstances. Also, costs can differ notably if the measures are implemented during the initial design and building stage compared to the cost of retrofitted measures. Risk reduction measures classified according to their main purpose are listed in Table 3.

Table 3. Risk reduction measures classified according to their main purpose [2]

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	

5. TRANSPORTATION OF DANGEROUS GOODS THROUGH TUNNELS IN THE REPUBLIC OF SRPSKA

In our country, Republic of Srpska, Ministry of Transport and Communications declared the Rule book on minimum security requirements for tunnels [7] which entered into force in 2021. In order to provide traffic in the tunnel to be safe, it is necessary to undertake infrastructural safety measures and measures related to the use of the tunnel. The Rulebook prescribes that safety measures are based on the following basic parameters: 1) the length of the tunnel, 2) number of tunnel pipes, 3) number of traffic lanes, 4) cross-sectional geometry, 5) harmonization of vertical and horizontal road elements and road facilities with tunnel elements, 6) type of construction (tunnel and roadway) and surface characteristics of the roadway structure, 7) one-way or two-way traffic, 8) traffic load per tunnel tube (including time distribution), 9) risk of traffic congestion (daily or seasonal), 10)

response time of emergency services, 11) percentage of heavy goods vehicles in the total traffic in the tunnel (expressed as a percentage), 12) percentage share of vehicles that transport dangerous goods substance and type of hazardous substance, 13) construction and traffic characteristics of access roads, 14) traffic lane width, 15) vehicle speed, 16) geographical environment and meteorological conditions.

A risk analysis is a detailed risk assessment for a specific tunnel, taking into account all project factors and traffic conditions that affect safety, especially the characteristics and type of traffic, the length and geometry of the tunnel, as well as the predicted number of heavy goods vehicles per day. By risk analysis, additional safety measures are determined in order to increase safety, that is, reducing the risk in a given tunnel (reducing the evacuation route, reducing the distance of cross roads by emergency services, increasing the fire resistance of building structures and equipment, positioning of the fire station services with the definition of special equipment, additional traffic signaling, integral management of safety systems in accidents and the like). Risk analysis is a mandatory part of the documentation in the procedures for obtaining construction and use permits for tunnel.

When it comes about transporting the dangerous goods through the tunnel, this Rule book prescribes the regulation governing the transportation of dangerous goods (ADR) should be applied. Also, following measures should be taken:

- to perform a risk analysis before defining conditions and ways of transporting dangerous goods through tunnels,
- placement of appropriate traffic signs on entrances to the tunnel, i.e. before the tunnel at a sufficient distance, to enable drivers to choose alternative routes direction,
- to determin a special operational measures whose purpose is to reduce risks during the transportation of dangerous goods through the tunnel.

6. CONCLUDING REMARKS

Safety measures to be applied in road tunnels are based on a systematic consideration of all aspects including: tunnel infrastructure, works in tunnels, users and vehicles. If there are additional characteristics which must be taken in account, such as the transport of dangerous goods through tunnel, a detailed risk analysis must be carried out to determine if there is a need for additional safety measures and/or additional equipment to ensure a high level of tunnel safety. Risk analysis is applied both in the design of new tunnels and for existing ones. The risk analysis must take into account possible accidents, which clearly affect the safety of road users in tunnels, and which could happen during tunnel operation, and the nature and magnitude of their possible consequences. On the basis of the risk analysis for the transport of dangerous goods through tunnels, the categorization of tunnel is done (A - E), regulating the types of dangerous goods to be allowed to go through the tunnel, in order to avoid any hazards with major consequences. Categorization is a complex process where it is necessary to address the risks in the tunnel, the risks along the alternative route for loadings restricted for passing the tunnel and what risk reducing measures that are practically applicable. The decision making regarding categorization of tunnels can be structured using quantitative and qualitative approaches, known as the quantitative risk assessment model (QRAM) and the decision support model (DSM), or combining these two.

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