# Guidance and Methods for Categorizing Road Tunnels According to Dangerous Goods Regulations (ADR)

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**ABSTRACT**
ADR 2013 contains provisions concerning restrictions on the passage of vehicles carrying dangerous goods in road tunnels. The rules allow routing control for the transport of dangerous goods through tunnels, i.e. either granted passage through the tunnel or refer to an alternative route. Routing control is based on each tunnel is assigned to tunnel category A-E, which to varying degrees regulate the types of goods to be allowed to go through the tunnel in order to avoid accidents with major consequences for human or tunnel construction. In this paper a comprehensive approach for categorizing road tunnels according to ADR 2013 is presented as a three step method. 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.

**KEYWORDS:** Dangerous goods, risk analysis, categorization, ADR, road tunnels

## INTRODUCTION

This paper presents a method to categorize Swedish road tunnels according to the regulation ADR-S 2017, which regulates the transport and carriage of dangerous goods by road. The purpose is to enable and support the categorizing of Swedish road tunnels according to the regulation ADR-S based on risk analysis. This paper takes standpoint in the regulatory conditions that are applied in Sweden and is divided into two parts:

1. Development and presentation of an overall approach to categorize road tunnels in the Swedish regulatory environment. This approach consists of a flow chart decision model, with references to appropriate tools and more detailed risk analysis methods. Furthermore, what types of risk aspects that has to be analyzed when a risk analysis is used as a basis for decision, are presented.
2. Development and reporting of a simplified risk analysis method that can be used in the context of risk-based categorization.

### About transport and carriage of dangerous goods on road

In the preparatory international work established for the regulation of dangerous goods transport, it is clear that the transport of dangerous goods is associated with risks (1). Despite the risks associated with the transport of dangerous goods, international work concludes that it is considered neither reasonable nor sustainable to prohibit such transports in today's society. The strategy laid out in international consensus is instead to manage the risks associated with the transports using a regulatory framework. The purpose of the framework is to prevent, impede and restrict the transport of dangerous goods or unauthorized procedures with such goods, and by doing so reducing the harm caused to people the natural environment (e.g. fragile ecosystems) and/or damage property and infrastructure.

The national regulations governing safety requirements of transport of dangerous goods is based on the so called UN-recommendations, which cover classification, test methods, packaging requirements

etc. The recommendations are implemented in Swedish legislation mainly by law (1), ordinance (2) and regulations (4) ADR-S 2017 regarding transport of dangerous goods.

To reduce the probability and the consequences of a major transport accident, routing control is used to direct the transports to roads engineered to higher standards and to avoid transports through areas where an accident can cause major consequences. Routing control consists of recommended routes and local traffic regulations assigned by the County Administrative Board, which consist of mandatory restrictions or prohibitions. Within the local traffic regulation, prohibition of transport on certain roads is one option.

In addition ADR-S contains specific provisions concerning restrictions on the passage of vehicles carrying dangerous goods in road tunnels. The rules allow routing control for the transport of dangerous goods through tunnels, i.e. either passage is granted through the tunnel or the transport is referred to an alternative route. Routing control is based on that each tunnel is assigned to a tunnel category, A-E, the category regulates the types and the amount of goods to be allowed through the tunnel in order to limit the consequences of an accident regarding life-safety or the tunnel construction, see Table 1. The same tunnel may be assigned to more than one tunnel category, depending on e.g. the weekday and time of day. Tunnel restrictions and alternative routes are displayed on road signs and with alternating traffic signals.

The categorizing of tunnels are based on three main risks, which can cause fatalities or severe damage to the tunnel construction. These risks, or rather accident scenarios, consist of explosion, release of toxic substance and fire.

**Table 1. Meaning of tunnel category A-E (4).**

| Tunnel category | Restriction |
|---|---|
| A | No restrictions for the carriage of dangerous goods. |
| B | Restrictions for the carriage of dangerous goods which may lead to a very large explosion. |
| C | Restrictions for the carriage of dangerous goods which may lead to a very large explosion, a large explosion or a large toxic release. |
| D | Restrictions for the carriage of dangerous goods which may lead to a very large explosion, a large explosion, a large toxic release or to a large fire. |
| E | Restriction for the carriage of all dangerous goods other than UN 2919, 3291, 3331, 3359 and 3373 and all other dangerous goods in accordance if the quantities carried exceed 8 tones total gross mass per transport unit. |

Decisive for the restrictions on the transportation of dangerous goods are the properties of the goods, as well as the type of containment and transported amount. The ADR regulations sets out the considered classification codes, groups, packing groups and UN numbers to meet the criteria for each category (see ADR-S, chapter 1.9.5.2). However, the ADR regulations do not explicitly define the meaning of the terms very large explosion, large explosion, large toxic emissions, etc.

**About categorization**

Countries align to the international ADR agreement are responsible for categorizing their road tunnels in accordance with the ADR regulations. The regulations require that any restriction must follow the directives provided in the regulations, but sets no specific requirements on how to perform the categorization, or what criteria should be used to sort tunnels in different categories. The regulation does not state a criterion for acceptable risk.

International consensus regarding required basis for decisions or which criteria that are to separate each tunnel category are currently lacking. However, considering different countries having varying conditions regarding e.g. number of tunnels but also type of tunnels and their standards and safety

culture, this is understandable. Furthermore, the view on tunnel risks and safety systems is widely varying within the tunnel safety field.

Given this background and conditions, methods to categorize current road tunnels should have a national outset. However, it is expected to be a difference in the dangerous goods approach also within Sweden, and therefore flexibility is required when developing methods for categorizing.

In Sweden the competent authority assigning the tunnel category is the County Administrative Board in their role as decision-makers regarding local traffic regulations for dangerous goods. The formal role as infrastructure manager in charge of operation of the tunnel, e.g. The Swedish Transport Administration, consists of providing documentation for the facilities they are operating and managing so that the County Administrative Board can decide on the tunnel category for each tunnel.

**Limitations**

The methods for categorization presented in this paper focus on aspects related to risk and safety. Decisions regarding tunnel category must however also take into account other aspects, part from risk and safety matters. The occurrence, the character and the meaning of other aspects, e.g. political and economic, can vary a lot and therefore has to be assessed on a case-by-case basis. Access to an alternative route in case of planned and unplanned shutdown is also expected to be an aspect where special consideration is needed. The overall method for categorization presented here can also include other aspects if needed. Risk analysis and assessments based on the methods presented in this paper is to be considered as basis for decisions for the concerned decision-makers.

The methods presented provides assistance in the categorization process. The use of the methods does not in itself guarantee a high quality of either the risk analysis or the decision-making basis. Good practices and other recommendations regarding implementation of the risk analysis as a basis for decision-making, e.g. regarding competence and quality assurance, must be followed, documented and reported according to many standard risk analysis procedures. This also applies to the simplified risk analysis method.

Decisions regarding tunnel category are based, consciously and unconsciously, on what is perceived and considered an acceptable risk. This paper also use the abbreviation acceptable risk in several places. It is important to note that this does not mean a specific absolute or relative risk criterion is being specified, given that no such criteria is set in the Swedish legislation and no such criterion have been evaluated within this work. Instead, it is meant by risk assessment analysts and/or decision-makers to consider what acceptable risk is defined as in the specific case.

This paper assumes that a restriction against the passage of dangerous goods through road tunnels is only implemented to improve the tunnel safety, i.e. to reduce the level of risk for the people and objects protected in close vicinity to the tunnel, whose level of risk is directly affected by the location and configuration of the tunnel. This means that a tunnel restriction is not implemented to reduce the level of risk to people exposed, e.g. residents, or protected natural and cultural environments of value along other parts of the stretch of road involving a tunnel passage. This limitation applies to the case when an alternative route has been referred and it is relatively far away from the tunnel and its area of influence in regards to risk and safety.

In practice, this means that the road section including the tunnel passage also includes part of the surface road network. The road used for re-routing from the tunnel does not have to be the same as the alternative route. In the simplified risk analysis method, risk impact on the road used for re-routing used when the tunnel is shutdown is not included. However, the same method applied to the alternative route can be used to determine the risk exposure from the road used for re-routing, but aspects such as the amount of traffic and how often the road section is used, has to be considered.

## COMPREHENSIVE METHOD FOR CATEGORIZATION

This section presents the comprehensive method for categorization of road tunnels in accordance to ADR 2017. The method is considered to be a logical decision model which, when followed, should lead to a well-supported basis for decision regarding the appropriate categorization. More detailed descriptions of suitable risk analysis methods that can be used within the comprehensive method is referred to within this section.

The categorizing of a tunnel is a complex decision where many aspects of objectives and prerequisites has to be considered. The fundamental issues to consider are:

- What tunnel category is suitable given the underlying risk and safety aspects? This includes the tunnel safety but also the safety of the transport of dangerous goods by road in general and on the surface road network.
- What tunnel category is desirable given the overall societal assessment taking into account every relevant aspects of the decision? Those aspects can consist of a socio-economic assessment, practical and political consideration etc.

Tunnel safety can simplified be described by the safety concept of the tunnel. A road tunnel's safety concept consist of the technical and administrative actions intended to reduce the probability of an accident and/or reduce its consequences to an acceptable level. What is considered an acceptable risk level is often defined within a safety objective. A common safety objective is to meet the general qualitative requirements in the Swedish legislation. In general, the safety concept implies an acceptable risk level with respect to human life/health, natural environment and property. In developing the safety concept also considered is the resulting costs for society at large, e.g. costs for traffic disruptions and reconstruction.

A road tunnel's risk level and its safety concept are in many ways dependent on the types and amounts of dangerous goods transported through the tunnel. There are many different categories of transports of dangerous good; transports that are not labeled (not classified as dangerous goods), mixed cargo groupage with small amounts of goods, combination packaging with different types of goods and larger transports of single substances.

The comprehensive method for categorization should be useful and provide support irrespective of the objectives and prerequisites associated with an individual decision on categorization. This means that the method has to be general in terms of its ability to give suitable advice on any tunnel and can include different standpoints and preferences. The method is therefore focusing on giving advice about the decision-making process and what aspects must be considered, instead of focusing on what is a right or wrong decision in regards to a specific category for a tunnel. The method includes steps where it may be appropriate to introduce risk mitigating measures. The possibility to make different considerations for existing and new tunnels is therefore given as well.

With support from the comprehensive method, the required basis for a decision about a suitable category range can be obtained. Depending on what tunnel that is to be categorized, the basis for the decision will be different, especially regarding the access to information and documentation. This also means that how the basis for a decision is to be obtained depends on different aspects, e.g. the available time for collecting information and making the assessment. Possible ways to obtain the basis for a decision is mainly by investigation (risk analysis) or expert judgement. The method does not specify in detail what is required in the basis for decisions or how this is to be obtained, however recommendations are given. Risk analyzes can generally be conducted in a variety of ways and with different levels of detail, but must address the correct aspects of risk and answer the right questions.

A simplified process of how a decision about a categorization is made can be described with three options, permitting all, part of, or no dangerous goods transports to go through the tunnel. If part of or no dangerous goods are permitted through the tunnel, the transports are instead referred to an alternative stretch of road.

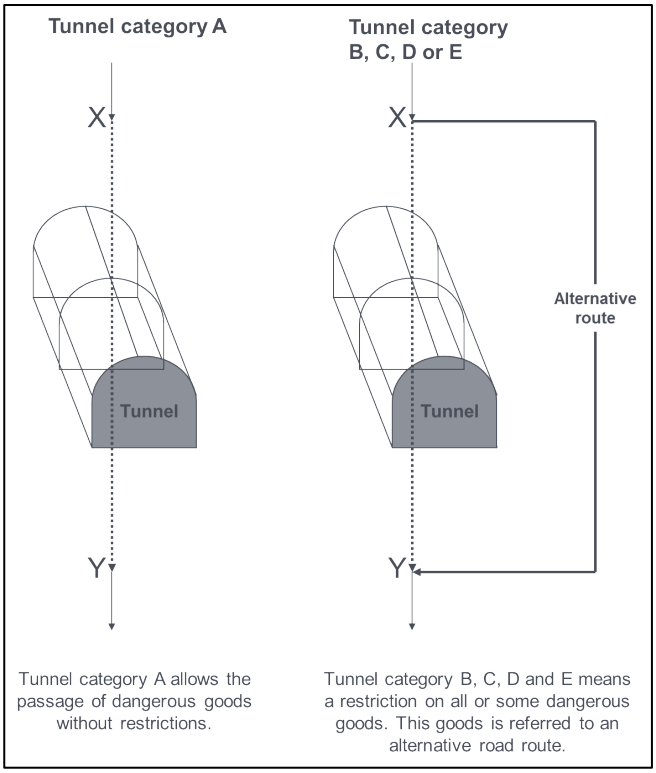
Figure 1 shows how the transport of dangerous goods can be made from a point X to a point Y on the road section though the tunnel and/or on an alternative road section. If a tunnel is categorized with category A all goods are permitted through the tunnel, meaning no risk impact on any alternative road section. However, if the tunnel is given a restriction, i.e. category B-E, the transports redirected on the alternative road section will expose the surroundings to an increased level of risk.

The implementation of a restriction therefore must be based on an evaluation and possibly a comparison of both the road section with the tunnel and the alternative road section.

**Scope of work for risk analysis in accordance with ADR**

The extent and content of risk analysis required in different contexts is generally based on why the risk analysis is established and what it intends to highlight, that is to say its purpose and objective. One common purpose is that the risk analysis should form a part of the basis for a decision, which can vary in terms of scope and content depending on the governing regulations. In this case, the regulation ADR-2017 is governing and its purpose and objective is decisive for the scope and the content of the risk analysis. The regulations scope and objective can be described as:

- reduce the level of risk associated with transport of dangerous goods to human life and health, natural environment and property,
- prevent and limit accidents (with following fire, explosion or dispersion of toxic substance) in tunnels leading to a many fatalities and/or severe damage to the tunnel construction, and
- guide transports to roads engineered to higher standard and avoid transports through areas with valuable natural and cultural environments (residential areas, vulnerable ecosystems, critical societal functions etc.)




Given the purpose and the objective of the regulations, risk analysis for categorization should take into account the impact of accidents in tunnels on people and tunnel construction, i.e. what is often referred to as tunnel safety, and also, the impact on the surroundings (human life/health, natural environment and property) along the roads where dangerous goods are transported. What types of accidents should be included is clearly presented in the regulations regarding categorization, fire, explosion and release of toxic gas and volatile toxic liquids or substances. All types of dangerous goods transported, or that can be transported in a vehicle on the given road section are expected to lead to an inherent risk of accidents and should be included in the risk analysis. To decide where the transport of dangerous goods is most suitable to minimize the risks, it is not enough to only take into account the safety in the tunnel.

**Figure 1. Overview of tunnel categories and the consequence of the choice of different tunnel categories.**

The risk exposure to humans, natural environment and property along the surface roads also has to be considered. Depending on if all transports will go through the tunnel or if a restriction means that some transports will be guided to the surface road network, the level of risk for the given road section has to be compared for different individual groups (passengers, people in the surroundings and other valuable objects or environment), before a decision can be made about where and how the transports will take place.

Altogether the following aspects are considered central to obtain the purpose and objective of the regulation:

- All relevant classes of dangerous goods has been considered.
- The impact of accidents on objects required to be safe-guarded in the tunnel (human life and health and tunnel construction) has been considered.

- The impact of the accidents on object worthy of protection in the surroundings (human, natural environment and property) has been considered.

**Work flow**

The comprehensive method for categorization is presented as a flow chart and shows in what order each step in the method is to be carried out, see Figure 2.

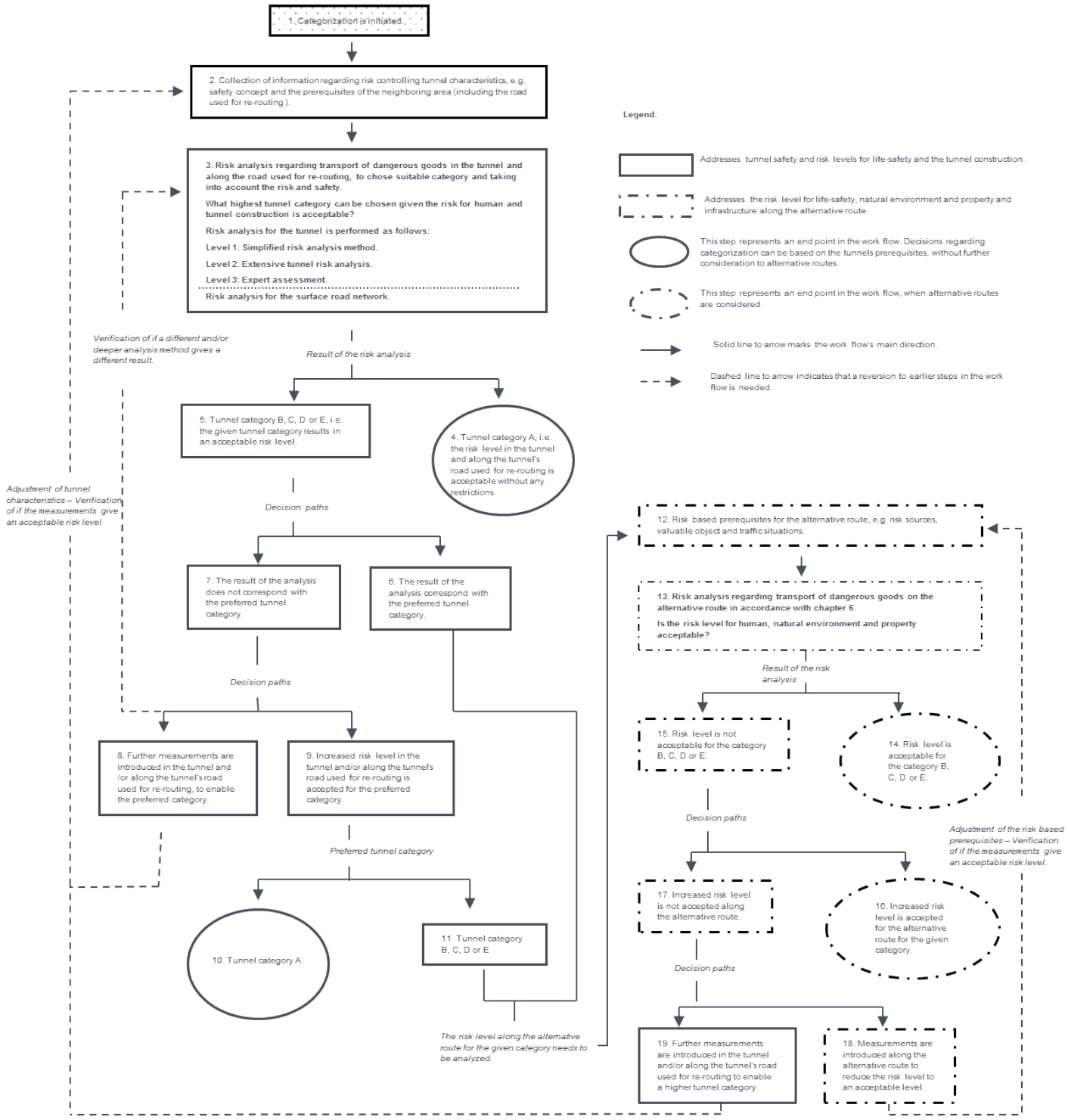



**Figure 2. A comprehensive method for categorization as a flow chart, describing the workflow of the method. The numbering in the figure shows in what principal order each step is to be carried out.**

1. Categorization is initiated, i.e. a decision is made for a specific tunnel that it should be categorized to a tunnel category. The underlying basis for the decisions should be stated and included in this step, e.g.:
    a. Whom is the competent authority assigning the tunnel category?
    b. What organizations should be included in the decision through consultation and referral procedure?
    c. Economical limits?
    d. Timeframes?
    e. Who is to carry out the risk analysis?
    f. Etc.
2. When the underlying basis for decisions have been stated, information about the tunnel and its surroundings is obtained. The information can consist of technical information regarding e.g. tunnel characteristics and safety, drawings, assessments, risk analysis, safety documentation, fire safety documents etc.
3. Based on the risk characteristics of the tunnel, the highest possible tunnel category, given that risk for human life and health and tunnel construction is acceptable, is analyzed. The risk along the alternative route in case of a shutdown is also included. It is recommended that the risk analysis regarding transport of dangerous goods in the tunnel is made in accordance with the simplified risk analysis (level 1) and if necessary in accordance with the in-depth risk analysis (level 2) described later on or other similar method. An expert assessment should only be used when level 1 or level 2 for any reason cannot be applied.
4. If the tunnel, according to the risk analysis, can be categorized as an A-tunnel, no further assessment is needed. It is assumed that the decision-maker prefers the tunnel category without restrictions if possible, i.e. A is the preferred category. In case the tunnel, according to the risk analysis, is categorized as an A-tunnel, but this category by any reason does not reflect the requests and preferences of the decision-maker, an analysis of an alternative route is needed. In this case, move to the overall method, step 11.
5. If the risk analysis shows that the tunnel and/or its alternative route should be subject to a restriction, i.e. categorized as and B-, C-, D-, or E-tunnel, the next step depends on if the proposed category can be accepted by the decisions-makers.
6. The risk analysis propose a tunnel category equivalent to the decisions-maker's requests.
7. If the risk analysis propose a tunnel category not equivalent to the decision-makers request, the result (and category) of an in-depth, or other, analysis should be compared with the first result and category, see section about level 1-3 in step 3 above. If the new analysis does not result in a different category, decisions has to be made about either introducing further safety precautions to reduce the risk and enable the desired category, or to accept a higher risk level in the tunnel and/or along the alternative route.
8. If further safety precautions are introduced to enable the desired category, an adjustment is made to the prerequisites of the initial risk analysis. Move back to the overall method step 2.
9. If a higher risk level is accepted in the tunnel and/or along the alternative route, the next step depends on what category is desirable.
10. If the tunnel is to be categorized as an A-tunnel, no further assessment is needed. See the overall method step 4.
11. If the tunnel is to be categorized as a B-, C-, D- or E-tunnel, the risk level has to be acceptable along an alternative route. An alternative route is chosen for further analysis. In case there are more than one possible route sections, these are assessed separately with the same method. The same assessment is repeated for each road section. When the tunnel is the only connection and if by any reason there are no alternative routes, the tunnel is handled separately.

12. Collection of information regarding the alternative route. Relevant information is for example road- and traffic standard, traffic situation, transport of dangerous goods, protected regions of cultural heritage or environment value and sensitive hazardous installations, property or infrastructure and other objects of protection along the route section.
13. Based on the risk prerequisites, the possible category is analyzed based on the assumption that the risk for human life and health, natural environment and property should be acceptable. The risk analysis can be obtained with different methods, levels of detail etc.
14. This category is proposed if the risk analysis concludes that the risk level of the alternative route is acceptable for the given category B-E.
15. If the risk analysis instead concludes that the risk level not acceptable, the increased risk level has to be accepted or not.
16. If an increased risk level is accepted along the alternative route for the desired category, no further assessment is needed.
17. If an increased risk level is not accepted along the alternative route, risk mitigation measures are to be introduced in the tunnel and/or along the alternative route.
18. If further safety precautions are introduced in the tunnel and/or along the alternative route to enable the desired category, an adjustment is made to the prerequisites of the initial risk analysis. Move back to the overall method step 2.
19. By introducing further precautions along the alternative route, the risk level may be reduced and enable the desired category. This is verified by new analysis in accordance with step 12 and forth from there.

**Categorization of new tunnels**

Both the Planning and Building Act (4) and The Swedish Environmental Act (5) specify that risks for e.g. human health and the natural environment must be considered when a new area is planned, including the planning and designing of roads and road tunnels. The planning process for a new road consists of three stages; initial study, feasibility study and road plan (including preliminary design). This is followed by a detailed designing process resulting in construction documents. The need for risk analysis varies depending on the different stages. The planning process and its stages for e.g. road projects and the need for risk analysis is described in (6).

A new road tunnel and its safety concept shall, part from the above legislation, also fulfill the Road Act (7), The act on safety in road tunnels (8), The Civil Protection Act (9) and Transport of Dangerous Goods Act (2). It is important to be aware that all laws are independent and each tunnel has to consider and fulfill all legal requirements (11). The most detailed requirements and guidelines regarding safety measurements are found in the Act on Safety in Road Tunnels (8) and the requirements 2016:0231 (13) and recommendations 2016:0232 (13) from the Swedish Transport Administration. The two last ones applies to all tunnels belonging to The Swedish Transport Administration, no matter what length, and tunnels managed and maintained by others made out of steal or concrete when the length exceeds 100 m.

Decision regarding the categorization of road tunnels should not be made formally until all relevant prerequisites are known. Examples of those prerequisites are knowledge about the safety concept and traffic situation. For new tunnels, this means that the decision can not formally be made until the tunnel is ready to put into use, i.e. in a late stage of the planning process.

Prerequisites regarding the transport of dangerous goods, e.g. restrictions, are important aspects when designing a tunnel's safety concept. Given this, it should be possible to implement a restriction of dangerous goods as part of the safety concept, when needed. Therefore, it is important that a categorization decision is predictable and can be agreed upon among all involved parties during the planning process. Given this, it is noted that the basis for a decision regarding tunnel category has to be obtained during the planning and designing of new tunnels and this should be coordinated with other risk management in the specific project.

The risk analyses required and carried out in the planning process in Sweden today are expected to meet the requirements of a risk analysis needed to categorize a tunnel. However, an earlier study (15) states that the risk analyses carried out until todays date, do not meet the requirements of the basis for decisions regarding tunnel categories for existing tunnels. The costs to update and adjust the analyses to the required standard are, however, expected to be very small, given that the analyses contain the correct information and answer the correct questions.

In this context, it is important to say that a decision regarding tunnel category and dangerous goods restrictions is an administrative measurement, and has to be able to vary over time depending on future conditions. The reasons to reconsider a decision can be many, e.g. a new traffic situation or settlements. These new conditions can change either during the planning process or during operation.

**Categorization of existing tunnels**
An earlier study (15) states that the risk analyses carried out until todays date, do not meet the requirements of the basis for decisions regarding tunnel categories for existing tunnels. The identified deficiencies mainly consist of:

- The risk analysis does not include all current classes of dangerous goods, only focusing on transport of flammable liquids (class 3).
- Alternative routes are not assessed.

Although a risk analysis does not represent a complete basis for decision, it can still be used as part of a bigger basis for decision. When no earlier risk analysis is present, or when the quality is too low, a new analysis is to be obtained. The categorization of existing tunnels can be made in accordance with the method and recommendations presented in this paper.

**Documentation of decisions**
The categorization decision of road tunnels can, and is recommended to, be based on risk analysis, including relevant risk and safety aspects. In societal planning as a whole, many other aspects also needs to be considered. Regardless of how, when, where, by whom, why and on what grounds and the available basis, the decision has to be documented. The documentation enable the decision to be evaluated and, when needed in the future, reconsidered.

## LEVEL 1 – SIMPLIFIED RISK ANALYSIS METHOD

This section presents a simplified risk analysis method that can be used when categorizing existing and new road tunnels, with a risk-based approach. The simplified risk analysis method is recommended to represent the first step, here called level 1, in a risk analysis regarding transportation of dangerous goods in tunnels when choosing appropriate tunnel category in accordance with the comprehensive method. In the simplified method, the technical prerequisites and other conditions in the specific tunnel and its surroundings are considered to decide the highest tunnel category (i.e. with the least restrictions) that results in an acceptable risk level for people in the tunnel and its construction. Note that the risk impact from a possible alternative route used in case of a shutdown is not included in the method. The same method as the one presented further down in this article can be used for this purpose, but has not been developed further within this scope of work.

The method takes into account the required safety measurements in the Act on Safety in Road Tunnels (8) and Tunnel 16 (13) (13), which is the requirements and recommendations from the Swedish Transport Administration. The intention is that the method shall describe relevant requirements on existing and new tunnels in a correct way.

The method is based on the approach that a few risk parameters can be linked in a relative simple way to a suitable safety concept and an expected risk level, and therefore also a suitable tunnel category for each object. The method is presented as a checklist with specific tunnel characteristics and is carried out step by step. By answering the questions in the checklist, the method leads to a proposed highest tunnel category. If the checklist results in a category A-tunnel, the risk analysis can be used as a basis for decision when deciding on the tunnel category. Otherwise (tunnel category B-E), the risk

level for the alternative route has to be assessed and can be accepted in regards to human life and health, natural environment and property.

**Step 1 – Verification of general conditions**
In this step, a few general conditions are verified in accordance with what is normally expected in a road tunnel context. If one or more of the listed general conditions for the specific tunnel are not met, the tunnel should continue to be categorized as an E-tunnel, unless the results of an assessment in accordance with risk analysis level 2 or 3 shows something else.

All general conditions listed below shall be met to move to the simplified risk analysis method step 2:

1. Traffic and road standard, i.e. vertical and horizontal alignment (inclination), reference speed, number of lanes etc., shall for new tunnels be in accordance with "high standard" in the Swedish Association of Local Authorities and Regions and The Swedish Transport Administration's requirements for road design, VGU (16). For existing tunnels, the traffic and road standard in all relevant aspects meet these requirements, with few exceptions. If a deviation is reasonable it has to be decided on a case-by-case basis.
2. There are no reversible lanes in the tunnel.
3. The rescue service's capacity to perform a rescue mission in the specific object is expected to be satisfactory. The following aspects should be central for the assessment of the rescue capacity:
    a. evacuation strategy (normally consisting of self evacuation),
    b. resource availability,
    c. time of arrival (normally less than 10 minutes),
    d. equipment availability,
    e. level of education/competence,
    f. tactical knowledge and preparation (including training), and
    g. the characteristics of the access roads.
4. The traffic situation/possible traffic jams (daily or seasonal): The risk of traffic jam and/or slow moving traffic should be low. Busy tunnels and/or city tunnels should normally, without taking into account traffic management measurements be associated with a high risk for traffic jam and congestion. Other indicators of risk of traffic jam can be when the traffic flow is in level with the capacity the road/tunnel is designed for, lack of capacity on surrounding road network, inadequate traffic or signal controlling, pedestrian crossings or bridge openings. Non busy and/or tunnels in rural areas should normally be associated with low risk of traffic jams.
5. The potential consequences of an accident are not big, i.e. the tunnel is not situated under water and not immediately under buildings or just next to other densely populated areas. The tunnel is not situated next to important societal services, e.g. a central power line.

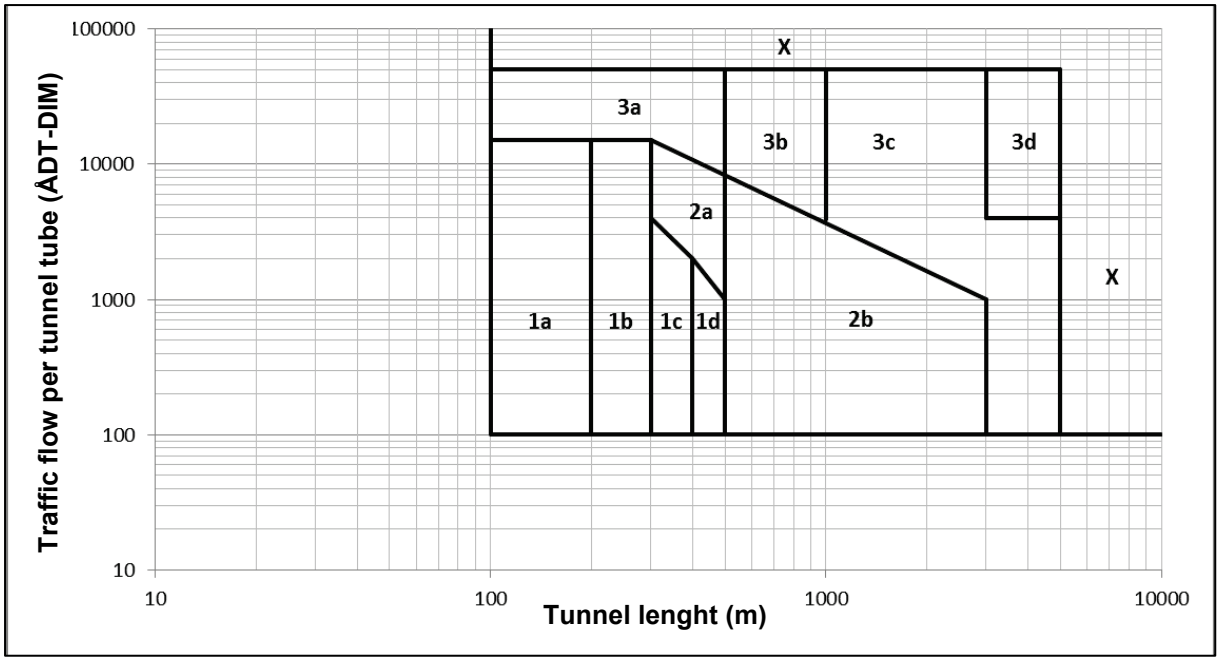



**Figure 3. Basis for selection of risk category for double tube tunnels, one-way traffic.**

**Step 2 – The tunnels risk category**

Each tunnel is given a risk category with help of Figure 3 (showing double tube tunnels, one-way traffic), based on the parameters traffic flow and tunnel length. A similar graph has also been derived for single tube tunnels with two way traffic, but is not presented in this paper. These two parameters are expected to give a good description of the total risk for a tunnel and is also used as a prerequisites

in Tunnel 16 (13) to decide on a tunnel category. Together with requirements in TSFS 2015:27 (16), they are used to set the requirements for the safety concept.

The traffic flow in this instance means the designed annual average daily traffic per tunnel tube. If the amount of heavy trucks exceeds 15 % of the ÅDT_DIM, the traffic flow used should be increased in accordance with the following formula: 0,6*(percentage of heavy traffic-15) (16).

The tunnel length means the length of the tunnel including covered road outside the tunnel, e.g. light shields. Single tube tunnels with a partition is seen as a double tube tunnel.

**Step 3 – Technical standard**

Step 3 describes the technical standard, beyond the overall prerequisites, needed in the safety concept for each category and highest suitable category for 1a – 3d.

Note that the safety concept is based on today's safety requirements on tunnels. These requirements should also apply to existing tunnels; however, the plausibility of the existing tunnels to fully meet the requirements has to be taken into account. An assessment of whether the tunnel in all relevant aspects meet the technical and administrative requirements or not should be made.

Every category in Figure 3 cannot be described in detail due to length restrictions, but the technical requirements are to be found in the reference documents and are developed further in (17).

**Step 4 – Risk based categorization**

A tunnel, whose safety concept includes the technical and administrative requirements in accordance with the specified risk category 1a, 1b, 2a, 2b, 3a, 3b, 3c or 3d can, with no further risk assessments, be categorized as a C-tunnel (or D or E). The same tunnel can, with no further risk assessment, be categorized as an A-tunnel (or B) if the following requirements are met:

Risk of fire and explosion has been considered in particular, and necessary safety precautions have been implemented. The need for implementing more preventive measures have been evaluated, and if

it is reasonable to implement these. A selection of suitable precautions to implement is presented below:

- Rigorous requirements regarding the protection of load bearing structures in case of a fire.
- Increased requirements regarding separating components explosion load absorption capacity.
- Installation of a fixed extinguishing system.
- Special precautions to minimize the risks with some or all vehicles transporting dangerous goods, e.g. declaration before entering the tunnel, convoy transportation escorted by a vehicle, the shutdown of other traffic or to control the traffic to specific times (the tunnel's category vary with time of day).

For tunnels in risk category X (see Figure 3), the risk is so complex that the tunnel, regardless of the technical standard, must be further investigated. Without investigation, the tunnel should be regarded as an E-tunnel

Note that the presented tunnel categories are based on risk and safety aspects, in accordance with the comprehensive method for categorization. There are also other aspects that has to be considered as part of the category decision.

The level for what is considered enough safety precautions is not clearly specified. To some extent, it is possible to make a decision based on other basis than a risk analysis. If there is not enough experience and basis for a decision, it is necessary to obtain a risk analysis in accordance with level 2 or 3 in this method, to be able to motivate a decision of a tunnel category A (or B).

### LEVEL 2 – EXTENSIVE TUNNEL RISK ANALYSIS

This section describes risk analysis of road tunnels and tunnel safety, in accordance with the comprehensive method for categorization. It is recommended that such a risk analysis, herein referred to as level 2, is used as a second step when the simplified risk analysis (level 1) for some reason, e.g. the tunnels complexity or expected risk level, does not result in the desired tunnel category. The focus in the descriptions of the level 2 risk analysis is on the overall aspects that need to be considered within the analysis. The exact form of the risk analysis, e.g. types of methods, level of detail etc., has to be based on the requirements of the specific object.

#### Introduction to risk analysis as a basis for decision

Risk analysis is used as a tool to identify, assess and evaluate risks in a systematic way, with the purpose to, when needed, implement suitable risk reduction measurements, e.g. restrictions on the transportation of dangerous goods. Risk analysis is not in itself a solution to a safety issue, but facilitates risk identification and analysis. The practical value in a risk analysis consists of the decisions based on said analysis. These decisions are inevitably inherently affected by the decisions maker's values, e.g. the decision makers might be risk averse or the opposite. There is not a specified acceptance value or acceptance criteria for risks related to the transportation of dangerous goods in Sweden. To be able to use the risk analysis as a basis for decision, it is crucial to present the values (safety targets), value criteria and acceptance criteria resulting in the analysis's result. Value and acceptance criteria simplifies the communication of relevant risks between involved parties. It is important that the risk analysis's level of detail, its method and limitations are chosen in a way that relates to the chosen criteria.

Given the lack of value and acceptance criteria, it is practically impossible to, via risk analysis, show or verify that a specific tunnel design results in an acceptable risk level in accordance with current legislation.

Suitable literature to learn more about risk analysis as a basis for decisions are for example Handbok för riskanalyser (18), Olycksrisker och MKB (15) and Värdering av risk (20).

#### Risks with dangerous goods in road tunnels compared to the surface road network

Accidents involving dangerous goods in road tunnels are associated with other prerequisites compared to if the same accident happened on the surface road network. These prerequisites can be positive in the sense that the consequence might be lessened by them, e.g. the possibility to evacuate the hazard

area (passengers) is sometimes easier and the protection of third person (people in surrounding buildings) is in many cases better. In other instances the prerequisites work in the opposite way, e.g. the potential consequences in case of a fire are bigger. However, one cannot draw general conclusions when comparing the risks of transporting dangerous goods in tunnels with transports on the surface road network, there are too many uncertainties within each scenario. All roads are associated with a specific, unique design and different goods and amounts are transported, and is therefore associated with specific, unique prerequisites and risks. In addition, the surroundings, e.g. the design of buildings in the vicinity of the road, can be more or less suitable to limit the consequences of an accident involving dangerous goods. Further examples of such specific conditions are if a road tunnel is situated close to a densely populated area and/or a decking-type construction is located on top of the tunnel. These examples of conditions result in that no general conclusions can be made regarding a comparison of the risks with dangerous goods in road tunnels and on the surface road network.

**Prerequisites to consider for a risk analysis regarding tunnel safety**

The measurements needed as part of a tunnels safety concept depends on the following overall prerequisites, which together determine the expected risk: the physical design of the tunnel, the geographical location of the tunnel (surrounding aspects), type of traffic (cars, trucks and dangerous goods transports), the amount of traffic and the conditions for rescue operations. Risk analysis conducted with the purpose to act as a basis for decision for categorization in accordance with ADR-2017, should include these overall aspects.

The Ordinance on Safety in Road Tunnels (16) specifies what risk factors should be included in the risk analysis when it is acting as a basis for the safety concept. The ordinance regulates in the 2:nd chapter. 1 § that, the safety precautions in the tunnel should be based on a systematical assessment of all the relevant system aspects, i.e. infrastructure, operation, passengers and vehicles. The legislation specify the following risk factors/parameters to be included in such an assessment: tunnel length, number of pipes, number of traffic lanes and their width, the tunnel's cross section geometry, vertical and horizontal alignment, one way or two way traffic, traffic flow in relation to time of day, speed, risk of traffic jam (daily or seasonal), percentage of heavy trucks, percentage and type of dangerous goods, the tunnel's type of construction, time for the rescue service to reach the tunnel and their capacity to conduct a rescue mission, the characteristics of the roads used by the fire service and the geographical and metrological prerequisites.

If a tunnel has a particular design given certain risk factors (length etc.), the ordinance states that a risk analysis should be made to determine if more safety precautions or extra equipment is needed to determine if the safety level in the tunnel is acceptable or not.

In the requirements on safety in road tunnels (16) it is stated that the safety measures taken for tunnels should be the result of an overall assessment. The assessment should take into account for example proportion and type of transport of dangerous goods.

Advisable suitable measurements to minimize the risks can for example be declaration before entering the tunnel, transport in a convoy escorted by a vehicle, shut down of all other traffic or to control the traffic to certain hours. These operational measurements can also be implemented in accordance with the ADR-regulation and shall therefore be considered in a risk analysis acting as a basis for decision for categorization.

It is also important that, when categorizing a tunnel, temporary and permanent as well as planned and unplanned shutdowns of the tunnel and how unique transport, e.g. those transported with a dispensation, are considered.

Suitable literature to learn more about risk analysis for road tunnels are: Integrated Approach to Road Tunnel Safety (21), Combined Qualitative and Quantitative Fire Risk Analysis – Complex Urban Tunnels (21), Veileder for risikoanalyser av vegtunnlar (revidert) (22), Riskanalysmetoder (23), Riskvärdering (25), Tunnel 16 (13) (13), Towards Development of a Risk Management Approach (26), Risk Analysis for Road Tunnels (27), and Current Practice for Risk Evaluation for Road Tunnels (28).

There is also useful information in the documentation from the two research projects UPTUN (Upgrading of existing tunnels) and FIT (Fire in tunnels) and at the PIARC: website for tunnel safety.

**Risk analysis for categorization of road tunnels**

There are many methods, both in Sweden and internationally, for risk analysis whose purpose in particular is to assess risks associated with transportation of dangerous goods in road tunnels and/or to categorize road tunnels in accordance with the ADR-regulations. However, there are no international agreements on how these risk analyses should be carried out, but there is a large amount of information and material that can be used from these methods, e.g. from project reports such as The Nothern Link in Stockholm (15) where an extensive event- tree analysis is used.

The risk analysis method named DG-QRAM ((Dangerous Goods – Quantitative Risk Assessment Model) should be mentioned in particular. It was developed in parallel with the new EU-directives and should act as a support when categorizing tunnels with dangerous goods.

DG-QRAM is a software developed by INERIS (France) and WS Atkins (UK) in a cooperation with the Institute of Risk Research from University of Waterloo (Canada). The work has been supervised and followed up by a coordination committee formed by OECD (Organization for Economic Co-operation and Development) and PIARC (World Road Association). The purpose of DG-QRAM is to calculate the risks with transport of dangerous good on the surface road network and/or in road tunnels and should be used to compare different solutions or as a comparison of acceptance criteria.

The model is only studying the extra risk inherent in dangerous goods transports. Risk associated with "normal" traffic accidents on the surface road network or in tunnels are excluded. The model is based on 13 predefined scenarios. The first two covers fires in trucks (no dangerous goods). The rest covers accidents with dangerous goods class 2 (flammable and toxic gas) and class 3 (flammable liquid). Other dangerous goods classes are not included. Additional development of software for tunnel risk analysis has been financed by The Norwegian Public Road Administration which has resulted in the model Transit (28) but it is not publicly available at the moment.

**Pre-defined scenarios in DG-QRAM**

1. Heavy Goods Vehicle fire with no dangerous goods (20 MW)
2. Heavy Goods Vehicle fire with no dangerous goods (100 MW)
3. Boiling Liquid Expanding Vapour Explosion (BLEVE) of Liquid Petroleum Gas (LPG) in cylinders
4. Pool fire of motor spirit in bulk
5. Vapour Cloud Explosion (VCE) of motor spirit in bulk
6. Release of chlorine in bulk
7. BLEVE of LPG in bulk
8. VCE of LPG in bulk
9. Torch fire of LPG in bulk
10. Release of ammonia in bulk
11. Release of acrolein in bulk
12. Release of acrolein in cylinders
13. BLEVE of carbon dioxide in bulk (not including toxic effects)

As a support for categorization on level 2 extensive literature regarding certain aspects are available and can be incorporated in the framework presented here. The following documents are international guidance documents based on risk analysis to categorize road tunnels: Safety in tunnels – Transport of dangerous goods through road tunnels (28), Verfahren zur Kategorisierung von Straßentunneln gemäß ADR 2007 (29) (freely translated: Method for categorizing road tunnels in accordance with ADR 2007), Risk analysis relating to dangerous goods transport (32), Current practice for risk evaluation for road tunnels (28), Guide to Road Tunnel Safety Documentation (31) and Methodological Approaches for Tunnel Classification According to ADR Agreement (33).

### LEVEL 3 – EXPERT ASSESSMENT

This section gives an overall expert assessment method for risk based categorization. The expert assessment regarding suitable tunnel category should only be used when the other methods for some reason cannot be used.

The Expert Assessment means an assessment based on experience and is qualitative. The expert assessment is a subjective assessment carried out by one or several persons with relevant knowledge about the subject. It is important to note that all risk analyses contain subjective elements, i.e. elements of expert assessments. The expert assessment described here refers to a more straightforward

expert assessment, without support from an explicit risk analysis method, e.g. leve 1 or level 2 approach.

The advantages of using an expert assessment compared to a risk analysis method are that it is usually a fairly simple process and it requires less resources. However, the disadvantages are many. For example it is difficult to carry out the assessment in a systematical way and present the facts behind the assessment. To document an expert assessment is also therefore important, some examples of what the documentation may include are: The compositions of the expert group, the purpose and target of the assessment and the available facts. It is crucial that the expert group have the necessary knowledge about the tunnel and its surroundings, and the competence to perform the assessment.

## RISK ASSESSMENT FOR SURFACE ROAD NETWORK

All cases with a restriction on transport of dangerous goods in tunnels, i.e. categories B-E, needs documentation as a basis for the decision of a category. The documentation regarding the category decision should include an assessment of risk level for the surroundings and along the alternative road used for goods not allowed in the tunnel. The alternative road is here assumed to be a surface road, which should be the normal case.

This guiding document does not include further development or descriptions of specific risk assessment methods to assess the risk exposure from an alternative surface network. However, this section gives an orientation of the aspects needed to be included in any such risk analysis. The corresponding method should be useful when studying the risk impact from the road used for re-routing when the tunnel is shut down, even if the prerequisites can be different.

The current legislation's requirements on risk management, e.g. who is to be protected and area specific conditions regarding for example objects and environment required to be safe-guarded, risk objects, risk sources etc. mainly determine the scope and the level of detail of the risk assessment covering the surface road network acting as the alternative road section.

### Scope of work

The applicable legislation is, in this case, the Act of Transport of Dangerous Gods (1). The purpose of the legislation is to increase the safety when transporting dangerous goods, by minimizing the probability of an accident and to limit the consequences for human life and health, natural environment and property. One way of acquiring knowledge about the probability of, and consequences of an accident on the alternative road section, is to, in a systematical way with help from a risk analysis method, identify, assess and evaluate the risk impact from the redirected transports on adjacent protective objects, i.e. human life and health, environment and property.

To be able to use the risk assessment as a suitable basis for decision, it is important that it covers the risk objects, risk sources and objects worthy of protection, that are covered in the legislation.

### Choice of method and level of detail

As for the assessment of the tunnel safety, the choice of method and the level of detail in a risk assessment for the surrounding along the alternative road section has to be adjusted to every specific case. An important factor is the assessment's overall purpose, e.g. if it is to act as a basis for the evaluation between different road sections or if it should determine the need for measurements along the section. Likewise, the complexity of the current risk is an aspect to consider when choosing the method and level of detail. Whatever method and level of detail the assessment should, in a well-supported way, answer the questions described above in the scope of work section of this paper. If the alternative road section runs through unpopulated areas, it may be enough to state that the accidents have little to no effect on the people in the surroundings and to document why it can be considered an acceptable risk when diverting the dangerous goods transports. If the location of the tunnels is adjacent to a protected region of environmental or cultural value, or a highly populated area, this may lead to the need of a more detailed risk assessment, to determine the need of measurements or a different location.

### Risk assessment in spatial/land-use planning

It is common to address the risk impact along roads with dangerous goods, when assessing the risks in the land-use planning process, where the transports on road often represents the risk object. Risk

assessments in land-use planning usually only covers how accidents involving dangerous goods may affect a limited part of the area along the road section, i.e. along a specific detailed development plan. In these risk assessments, carried out for different local plans, it is ensured that enough consideration is taken regarding risks for the planned land use from adjacent roads and other risk sources. This is done by implementing different risk mitigating measurements regarding e.g. configuration of the detailed development plan or the design of the buildings. For older buildings, there are usually no such risk consideration.

A number of guiding documents are carried out for these risk analyses, in which requirements of content and quality are described, to approve as basis for decision. Documents of general character and specific documents for the planning and development of new buildings are listed below. It is important to note the difference in scope depending on what legislation or what requirements are governing in different situations. Therefore, the documents should only act as guiding in each specific case.

Examples on guiding documents regarding risk management in land-use planning: Riskanalyser som beslutsunderlag (32), Handledning – Riskanalys vald vägsträcka (36), Fördjupning – Riskanalys vald vägsträcka (34), Riktlinjer för riskhänsyn i samhällsplaneringen – Bebyggelseplanering intill väg och järnväg för transport av farligt gods (36), Riskhantering i detaljplaneprocessen. Riskpolicy för markanvändning intill transportleder för farligt gods (39), Riskanalyser i detaljplaneprocessen – vem, vad, när & hur? (37), Riskhantering vid ny bebyggelse intill vägar och järnvägar med transport av farligt gods och bensinstationer (38), samt Säkerhetshöjande åtgärder i detaljplaner (39).

## CONCLUSIONS

Categorization is a complex process where it is necessary to address the risks in the tunnel, the risks along the alternative route for transports considered to be restricted from the tunnel and what risk reducing measures that are practically applicable. The decision regarding categorization can be structured with a decision model in which risk analysis plays a central part. The risk analysis model can be executed with different level of complexity depending on the prerequisites for both the analysis, the risk reducing measures possible to apply and the level of conservatism that is applicable. Independently of the method chosen the documentation of the method and the prerequisites together with the quality of the assessment carried out is very important.

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