SCENARIO-BASED RISK ANALYSIS FOR ROAD TUNNELS

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ABSTRACT
In the French process for tunnel safety management, application of scenario-based risk analysis is used as a complementary tool to prescriptive requirements. For tunnels at design stage, at commissioning stage, or for tunnels in operation, the first major link in safety chain consists in defining reference condition. In this frame, place of scenario-based risk analysis in the safety chain is only complementary. In this paper, the specific aspects of scenario-based risk analyses are described and discussed.

Keywords: risk analysis, scenario, specific hazard investigation, safety documentation, road tunnel

1. INTRODUCTION
When notion of Specific Hazard Investigation has been introduced in French regulation for the first time [4], the question of its contents and objectives was raised. Very rapidly, CETU published a technical note, the objective of which was to define the content of such risk analyses. This definition derived from methodologies for Hazard Investigations conducted in the field of hazardous industries for more than 30 years.

Since that time, European Directive 2004/54/EC on minimum safety requirements for tunnels in the trans-European road network has made mandatory the Specific Hazard Investigation, as part of Safety Documentation.

In the meanwhile, a number of booklet have been published in France, that aim at providing guidelines for elaboration of Safety Documentation [1], of Specific Hazard Investigation [3], and to provide guidance for definition of a reference condition of an existing tunnel [2].

2. PROCESS FOR ROAD TUNNELS SAFETY
In France, for a tunnel at design stage or at commissioning stage, there are generally few discussions about acceptance of its level of safety. It is well defined by prescriptive requirements for new tunnels, as it is in Technical Instruction [4] – TI – for instance. At most, some discussions can arise about organisation for operation and rescue.

On the contrary, prescriptive requirements for new tunnels are not systematically applicable to tunnels in operation. That is why a specific process is required, so as to define a reference condition that can be considered as acceptable regarding safety conditions. In France, this process is defined as illustrated in the following Figure 1. This illustration is derived and extrapolated from [2].
Preliminary General Survey (by tunnel owner)

Existing Condition

- Operating Method
- Field Inspection
- Functional Description

Comparison with Technical Instruction

Needs for improvements

Tunnel Update programme

Reference Condition

Safety documentation (incl. scenario based risk analysis)

Figure 1: Specific process for tunnels in operation, so as to define an acceptable level of safety. Derived from [2]

Process is then made of the following steps:

- **Step 1**: A preliminary overview of tunnel existing condition is conducted by the tunnel owner. This first step aims at sorting between provisions / parts of organisation that do not need any further investigations (for instance: emergency stations have been renewed recently and do not need any further improvements) and provisions / parts of organisation that need detailed investigations (for instance: principle of longitudinal ventilation in a urban 2.1km long tunnel, and potentially congested traffic in peak hours);

- **Step 2**: Detailed investigations are conducted for provisions / parts of organisation that need it, as identified in step 1. Those detailed investigations may necessitate specific analyses of organisation for operation, or specific inspections, for instance to check the conditions for creation of new emergency exits, etc.;

- **Step 3**: Once existing conditions of tunnel are known with an appropriate level of accuracy, a comparison with requirements of Technical Instruction [4] is performed. This comparison aims at giving an idea of existing gaps between the investigated tunnel and a new tunnel of the same type;

- **Step 4**: Based on feasibility studies that contain an estimate for costs and planning, and based on expert judgment, a set of improvements is defined;

- **Step 5**: An update programme is then defined. Reference condition is the result of implementation of update programme;
Step 6: At this stage, tunnel reference condition is provisional. Its consistency has still to be checked, and a Specific Hazard Investigation is performed in this aim.

3. METHODELICAL ASPECTS OF SPECIFIC HAZARDS INVESTIGATIONS

In French approach, Specific Hazards Investigations consist in scenario-based risk analysis, although other methods would have been possible [5]. They are made of the 5 following chapters:

- **Overview of tunnel and environment.** This chapter is dedicated to description of tunnel in its reference condition, with regard to safety.
- **Functional description of tunnel.** This chapter allows description of how civil engineering, equipments, organisation for operation and rescue, etc. work towards safety.
- **Identification of hazards and choice of scenarios.** Contents and objectives of this chapter are described in §3.1 below.
- **Examination of scenarios.** Contents and objectives of this chapter are described in §3.2 below.
- **Conclusions.** This last chapter aims at giving an opinion on reference condition, and to recommend further improvements, if needed.

3.1. Choice of scenarios to be studied

3.1.1. Trigger events

Based on experience, a list of potentially hazardous events is built, in relation with the tunnel studied and its environment. Those potentially hazardous events generally result in a limited number of trigger events:

- Breakdowns,
- Collisions, with or without injuries,
- Fires,
- Accidents with dangerous goods involved. Note that even in a tunnel where dangerous goods are prohibited, such events could be possible, due to trespassing vehicles.

3.1.2. Analysis of frequencies and consequences

Considering the above mentioned trigger events, and the different categories of vehicles admitted in a tunnel, an estimate of frequency and severity is performed, and situated on pre-formatted scales:

- **Quantitative frequency analysis:** Frequencies are calculated, as a function of several factors as tunnel length, traffic volume, accident rates, etc. In most cases, calculation is based on an analysis of accident data (collection of local incident data) or based on default values (case of tunnels at design or commissioning stages). The calculated figures are then placed in a A (one event per year or more) to F (one event per 10 000 year or less) scale;
- **Qualitative consequence analysis:** Each trigger event is estimated to be of a given class of severity, from I (only material damages) to V (50 fatalities or more).

3.1.3. Frequency x Severity matrix

Based on the preceding estimate, a Frequency x Severity Matrix is built, in order to support the choice of scenarios to be studied, as shown on Figure 2 below.
Figure 2: Frequency – Severity Matrix, according to [4]

Scenarios to be studied are derived from the most potentially severe and/or frequent trigger events. On Figure 2 above, the corresponding trigger events appear in red colour. Note that, French guidelines [4] make imperative the selection of "standardised" trigger events, such as:

- 30MW Heavy Goods Vehicle (HGV) fire,
- 200MW HGV carrying Dangerous Goods (DG) fire,
for tunnels where HGV carrying DG are admitted.

At this stage, a choice of scenarios among the selected trigger events has to be done. Those scenarios are defined by a context, made of specific meteorological conditions, specific level of traffic, specific conditions for operation, specific human behaviour, etc.

So as to avoid the study of an excessive number of contexts, a few representative situations must be considered, together with a sensitivity study on main parameters.

3.2. Examination of scenarios

Once a few scenarios have been selected, possible consequences are estimated for people, with support of 1D or CFD modelling, depending on required level of accuracy. Figure 3 below gives an overview of possible representation of scenarios, based on time-space graphs.
Figure 3: Representation of consequences for people of a fire in tunnel

On this graph:

- Distance, in meters, from upstream portal, is represented from right to left, in X-coordinates,
- Time, in minutes, is represented in Y-coordinates,
- Average temperatures in a given section of tunnel are represented from a blue colour (low temperatures) to a red colour (high temperatures),
- Possible or expected movements of people are represented by means of blue/black arrows. On this graph, several behaviours, expected or not, are investigated: people that move escaping, people that move toward the fire, people that stay in their car, etc.

So as to represent people behaviour (including: tunnel operator, road users and evacuating people), the following standardised assumptions are made, according to [4]:

- Drivers respect the speed limits;
- Drivers are not supposed to respect interdistance when they stop, if any;
- If there are red traffic lights inside the tunnel (typically every 800m), drivers are not supposed to respect them;
- If there are intermediate barriers inside the tunnel, drivers are supposed to respect them;
- It is generally considered that people begin to evacuate when they can themselves perceive danger. For instance if they are in smokes, or if they see other people evacuating;
- Once danger is perceived, starts a 1.5 minutes delay for people to effectively evacuate vehicles – 5min in case of a bus / coach;
• If any, the effect of systems of alert can be checked, by reducing time to perceive danger: messages in vehicles transmitted by radio, flash lights around emergency exits, messages enforcing evacuation on variable message road signs, etc.;
• People know that they are expected to go to an emergency exit when evacuating;
• People that have reached shelters are not supposed to come back into the tunnel, for instance in order to help other people, or to retrieve their belongings;
• Tunnel operator (if any) reacts in line with his guidelines and operates available systems correctly.

In addition, a sensitivity study is generally performed to test effect of main parameters regarding behaviour of people, fire size, meteorological conditions, etc. on scenarios. If relevant, more sophisticated methods to represent behaviour of people against conditions in tunnel can be used [6].

In the end, level of safety is checked, and further improvements can be recommended, for instance if the conclusions of study of scenarios show that conditions would be much worse than in case of a new tunnel.

4. CONCLUSIONS

As shown above, French approach to road tunnels safety is mostly based on prescriptive requirements [4] and expert judgment. In this frame, scenario-based risk analysis is performed mainly so as to validate organisation for operation and general functioning of defined system – tunnel reference condition -, rather than to make easier a choice between different possible provisions for safety. Indeed, for a tunnel in operation, the choice of a set of safety provisions is required before performing a Specific Hazard Investigation, the scenario-based risk analysis. Therefore, such risk analyses rather aim at verifying whether the reached level of safety can be considered as acceptable or not.

Moreover, and so as to allow for comparability, methodical aspects and assumptions of such scenario-based risk analyses have been specified in guidelines [3]. This includes specifications for road users’ behaviour. That is why misunderstanding of human behaviour is of less importance as it would have been if a scenario-based risk analysis is used to decide on safety provisions, in the absolute.

In this frame, improvements in understanding human behaviour are more useful if they are used to update prescriptive requirements for safety provisions and operation, rather than if they are used to increase relative accuracy of risk analyses.

5. REFERENCES