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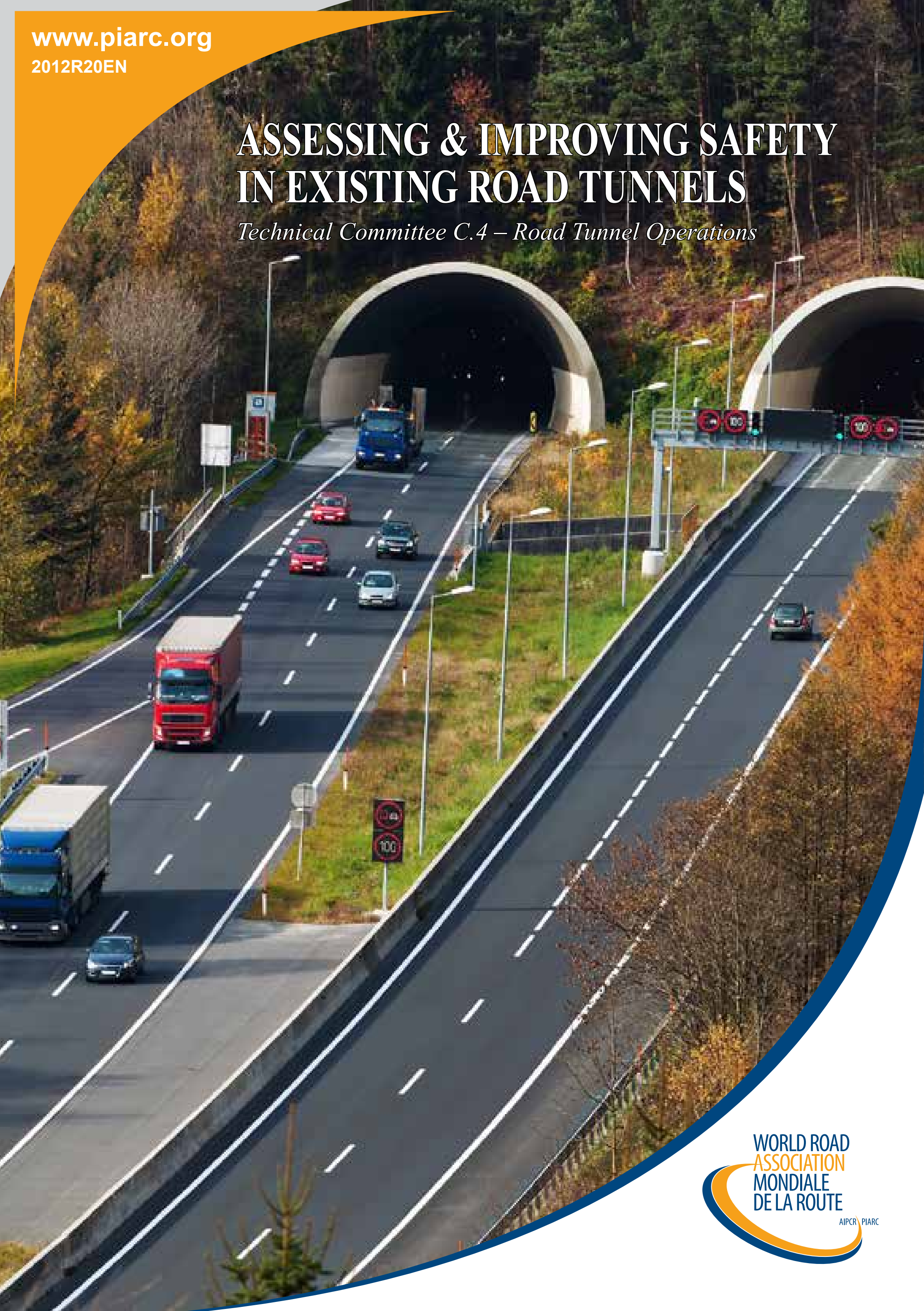
ASSESSING & IMPROVING SAFETY IN EXISTING ROAD TUNNELS

Technical Committee C.4 – Road Tunnel Operations



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STATEMENTS

The World Road Association (PIARC) is a nonprofit organisation established in 1909 to improve international co-operation and to foster progress in the field of roads and road transport.

The study that is the subject of this report was defined in the PIARC Strategic Plan 2008 – 2011 approved by the Council of the World Road Association, whose members are representatives of the member national governments. The members of the Technical Committee responsible for this report were nominated by the member national governments for their special competences.

Any opinions, findings, conclusions and recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of their parent organizations or agencies.

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CONTENTS

SUMMARY

This report provides guidelines for a step-by-step process for the development of a safety upgrade programme for existing road tunnels, ensuring that the required safety levels are achieved.

A five step methodology is proposed:

- **Step 1:** *"establish a safety framework"* to confirm or to prescribe the regulatory framework applicable to the existing tunnel in terms of safety. Safety objectives are defined at this stage.
- **Step 2:** *"investigate current condition"* to obtain a clear view of the current situation.
- **Step 3:** *"evaluate current tunnel safety level"* in order to determine the existing level of tunnel safety.
- **Step 4:** *"define a safety improvement programme"* specific to the existing tunnel and focussed on the deficiencies identified in previous steps.
- **Step 5:** *"evaluate future tunnel safety level"* after the works; to demonstrate the safety benefits obtained through refurbishment works.

The proposed approach allows the assessment of the existing situation within the appropriate regulatory framework, with recommendations that detail an approach to the:

- identification of key issues for an existing tunnel;
- assessment of risk;
- definition of priorities for the implementation of safety measures;
- specification of risk reduction measures.

For tunnels already in operation, the existing condition and level of safety must be assessed to identify whether an upgrade is necessary and to assess how upgrade measures can be best implemented considering the balance between the cost and safety improvement combination. The deficiencies of an existing tunnel should be identified and recorded with possible improvement measures.

A safety improvement programme is developed to address the safety deficiencies identified during the assessment of the existing situation and safety level. The improvement achieved with the proposed refurbishment programme is determined through the assessment of the future tunnel safety level. These steps are iterative, whereby the safety improvement programme is refined and shown to be sufficient to achieve the required safety level.

This report provides a structured methodology for the development of a programme for upgrading the safety level of an existing tunnel, with the identification of example weak spots for existing tunnels and case studies of tunnel improvement programmes provided in appendices. The report is focused on the safety issues of tunnel upgrade works, rather than asset management, maintenance and repair strategies.

It is important to note that each tunnel is unique; solutions for one tunnel may not be simply applied to another. This report aims to provide a common methodology for a holistic approach to the development of renovation programmes that can be adapted and refined taking into account the specific details of the tunnel being considered, the local practice and any specific requirements.

Why upgrade tunnels?

Following construction, tunnel structures and facilities gradually deteriorate and tunnel systems may become obsolete or unreliable. New tunnel systems may also be required for technical reasons or because of changes in the tunnel environment, such as traffic composition. Whatever the trigger for the upgrade of an existing road tunnel, safety is a key consideration.

Following a number of disasters in road tunnels in recent decades (Mont Blanc tunnel fire in 1999, Tauern tunnel fire in 1999 or Gotthard tunnel fire in 2001), the need to establish specific guidelines, guidance and prescriptions for tunnel safety has been identified. Substantial research and analysis followed these incidents, demonstrating that many existing road tunnels require additional and specific means to ensure a safe environment for users. These tunnel fire events raised awareness of risk amongst individuals involved in road tunnels - from authorities' representatives to designers and operators - and demonstrated the need to clarify safety management organisation and to refine operating procedures.

This recognition of the need to make improvements in road tunnel safety led in particular to the European Directive [1] on safety in road tunnels, prescribing minimum requirements to address safety in tunnels. Many countries have their own recommendations adapted to their particular domestic organisation of safety management in road tunnels and to their local practice; and some countries have developed their own regulations to enact the European Directive [1].

In addition to national guidelines and regulations, expert groups (e.g. the PIARC *"Road Tunnel Operations"* technical committee) and workshops are convened to address critical issues regarding the management of safety in road tunnels such as ventilation, risk evaluation or operational issues. These often provide guidance and information that reflects good practice in road tunnel operations both for new tunnels and for existing structures. They provide a scope for safety management in road tunnels and a basis for existing tunnel safety improvement assessment.

Tunnel safety guidance typically addresses the following safety objectives:

- prevent hazards where feasible;
- in case of an incident:

  – avoid critical consequences and escalating situations,
  – facilitate self-evacuation,
  – facilitate emergency services intervention.

With the changing regulatory framework and continual refinement of guidance on road tunnel safety, existing road tunnels may not meet the required standards or target safety levels. Moreover, even if there are not specific changes in the applicable regulations or standards, tunnels may need to be upgraded to address particular changes within their environment. This would be the case for example when:

- there is a traffic change such as an increase of traffic volume or Dangerous Goods Vehicles traffic increase;
- other sensitive structures being constructed near the tunnel, leading to specific refinement of the tunnel fire resistance requirements, the ventilation strategies or even the operational procedures.

Tunnel & Hazard Characteristics

Tunnels are becoming increasingly complex facilities. Firstly, an understanding of the original objectives and design basis for a particular tunnel will provide crucial elements of understanding in the development of upgrade requirements; including:

- functionality: the function of the tunnel within the wider road network;
- local conditions: geological background, topographic issues, environmental constraints, traffic forecast;
- safety objectives.

Secondly, the parameters influencing safety in tunnels depend on the existing and forecast traffic conditions, environment control, tunnel geometrical configuration, structural specificities mechanical & electrical systems functions, operation & maintenance strategies, human factors, staff training etc.

These parameters are interdependent. Focusing solely on one or a small number of parameters may not lead to significant safety improvement or may not represent the most cost-effective solution. A holistic approach to the development of the refurbishment programme is therefore required, taking into account the interaction between all parameters. The holistic approach, illustrated in *figure 1, following page,* enables the proper assessment of influencing hazards and risk events that may occur in existing tunnels; the holistic approach is detailed in PIARC reports *"Risk analysis for road tunnels"* [2] and *"Integrated approach to road tunnel safety"* [3].

FIGURE 1 – HOLISTIC APPROACH TO SAFETY CONSIDERING THE WHOLE TUNNEL SYSTEM

There are hazards associated with the four groups illustrated in *figure 1* as follows:

- **users:** hazards are influenced by human factors and user behaviour;
- **vehicles:** vehicles themselves are hazards, generating possible risk events;
- **operation:** operation and maintenance activities themselves generate hazards; procedures and systems can mitigate risk associated with those hazards;
- **infrastructure:** there are hazards associated with the tunnel configuration and tunnel systems.

Scope of this report

This report addresses the safety aspects to be considered when developing a renovation programme for an existing tunnel; focussing on improvements in the existing tunnel safety systems and procedures. The main objective is to define a specific approach for assessing and improving safety in existing road tunnels to meet the defined safety objectives. Furthermore, the report addresses the development of a refurbishment programme that achieves risk mitigation in terms of reduction in probability of occurrence as well as the reduction of the severity of consequences of undesirable events.

Refurbishment programmes should address each individual safety parameter as well as the global tunnel systems. Control of the interaction between parameters enables the development of a coherent and efficient renovation programme. The approach proposed in the present report allows the following:

- identification of key issues for an existing tunnel;
- definition of priorities for the implementation of the safety measures required;

- selection of the most appropriate improvement programme including, if necessary, potential risk mitigation measures.

The challenge in the upgrading of existing tunnels is the development of practicable solutions considering the existing physical constraints and the individual tunnel safety characteristics, which may vary significantly from tunnel to tunnel. Nevertheless, two main topics are generally applicable to all tunnels and have to be addressed when preparing a renovation programme:

- firstly, a current situation assessment is required in order to obtain a clear view of the tunnel in its current state; providing a snapshot of the tunnel safety condition at the beginning of the analysis. The objective here is to be able to define the current safety level of the tunnel. This provides a baseline for comparison with a reference safety level that may be defined by a regulatory framework. From these initial assessments and analyses, actions required can be further developed and prioritised;
- secondly, the future situation of the tunnel can be defined by developing a renovation programme. The safety level for the future situation may then be defined and shown to be acceptable with regards to the tunnel safety level objective.

This report includes in appendix A, identification of typical weak points and specific technical issues in the upgrading of existing tunnels. In appendix B, case studies are provided on the upgrade of existing tunnels in Europe, describing the strategy adopted for the renovation works and the alternative risk reduction measures implemented.

Major structural repairs or refurbishment of life expired systems are also necessary to ensure a safe environment for tunnel users. These represent management of the asset with periodic maintenance and upgrade works required to extend the tunnel operational life. These aspects are not the main focus of the present report but do, nevertheless, have to be considered and managed as part of a holistic approach to tunnel refurbishment.

Proposed approach

In this report, a proposal for a structured approach is presented with key steps on each topic. A chronological procedure is presented, including actions required for the analysis of the existing safety condition of a tunnel and for preparing the associated renovation programme.

In each main topic, a specific step by step process is proposed to identify, assess and prepare the required renovation works. The arrangement and objectives of each step are illustrated in *figure 2, following page.*

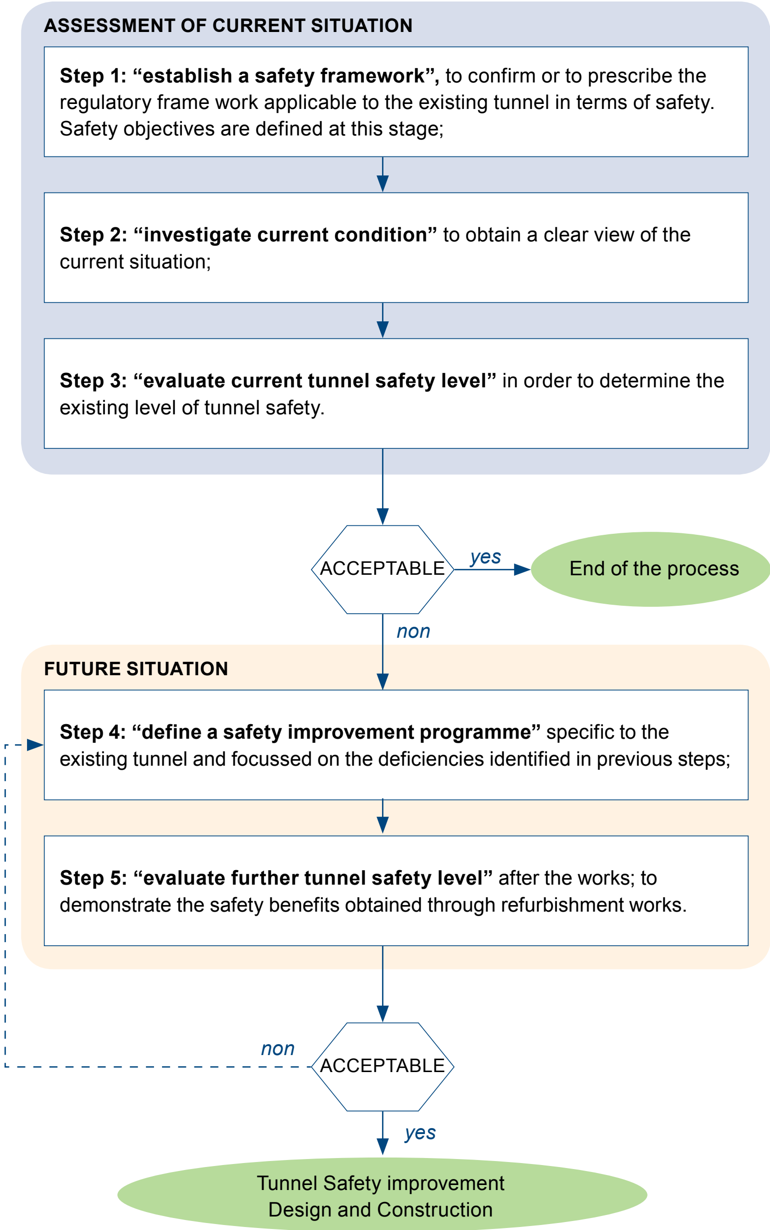

FIGURE 2 – DEFINITION OF STEP-BY-STEP PROCESS

This report is structured with one chapter for each step, presenting different possible situations and the associated methods needed to meet the objectives of each step. Of course, this conceptual step-by-step approach may be adapted and amended considering the specific situation being addressed, local practice and previous experience of tunnel refurbishment works. For example, depending on the situation, the process may be stopped after step 3 if the analysis is demonstrating that the safety level target and objectives set at step 1 are already achieved.

It is also the output from step 3 that may highlight the need for short term risk mitigation measures: such as implementation of tunnel closure barriers, signalling or simple traffic control measures. These measures may be implemented immediately to reduce risk in the short term in advance of putting long term renovation measures into place. Refining operating procedures is a useful means of temporary risk reduction. For example, when a tunnel's safety level is judged to be below the minimum for safe operation, temporary operational measures may be implemented, such as restricting access to specific vehicles; such a mitigation measure may then be cancelled after the tunnel has been upgraded.

Temporary operational measures may also allow the tunnel to continue in safe operation for a period, enabling the owner to delay the renovation plan to allow appropriate time for the design and planning required for any heavy civil works for example.

The development of a renovation specification for a tunnel is an iterative process; it requires the consideration of a combination of technical issues, safety measures, costs implications and phasing constraints. Steps 4 and 5 may therefore be undertaken several times to obtain an optimised refurbishment programme.

The step-by-step process for the tunnel safety assessment and the preparation of the renovation programme is summarised in the diagram in *figure 2* which describes the functional links between each step and the respective outputs.

The comparison between the safety level in the current situation and the future state of the tunnel (after renovation works) in step 3 and step 5 should provide a clear illustration of the safety benefits provided by the renovation works which can be easily communicated to stakeholders.

Occasionally, step 3 might not be necessary if the safety level is clearly far below that which is acceptable; in this case, a confirmation of the improved safety level at step 5 only would be necessary.

After step 5, design activities for the refurbishment works would then start with clear objectives to be achieved with the refurbishment programme.

1. STEP 1 - ESTABLISH A SAFETY FRAMEWORK

1.1. GENERAL

The first step in the process of upgrading tunnel safety is to identify the reference standard or the regulatory framework to be applied. This includes establishing what standards and regulations were used in the original design.

Where regulations exist, the safety standard can be defined and identified either by:

- prescriptive definition of the safety requirements or;
- performance based definition of the safety requirements (invariably including prescriptive elements as there are no regulations based purely on a performance based approach).

Depending on the circumstances and the tunnel characteristics, individual safety objectives can also be defined for a specific tunnel. Indeed, in some cases it may be necessary to prescribe refined safety objectives, either:

- in addition to existing guidelines: where the guidelines are technical design recommendations which implement safety aspects only indirectly; or
- because there are no existing guidelines.

For such particular cases, it would be necessary to conduct specific assessments to highlight and communicate risk and safety issues and enable stakeholders to make informed decisions about safety objectives.

1.2. SAFETY REQUIREMENTS IN ACCORDANCE WITH EXISTING REGULATIONS

1.2.1. Prescriptive definition of requirements

Prescriptive safety standards will stipulate specific requirements and safety features or actions to be implemented. Such guidelines are often enacted by national regulations.

The stipulation of requirements or guidelines may be developed in different ways. Typically, prescriptive requirements for safety will have been determined through expert judgment that is informed by experience or by scientific research.

A prescriptive, checklist-type process provides advantages for tunnel assessment (steps 3 and 5):

- the requirements for tunnel refurbishment can be demonstrated quickly through an assessment of compliance with the standard;
- issues such as cost-effectiveness of individual measures should have already been assessed at the time of developing the prescriptive requirements; it is implicit in prescriptive requirements that the measures that are mandated are cost-effective;
- prescriptive measures are recognised by the responsible authority; as that authority is generally involved in the development, approval and updating of the requirements.

On the other hand, in most cases, prescriptive requirements do not allow alternative mitigation options but may include possibilities for derogation. Where prescriptive requirements do not allow for alternatives, the cost implications for tunnel upgrades can be significant, for example where additional emergency exits are required.

1.2.2. Performance based approach with prescriptive elements

A performance, or risk, based approach requires the specification of overall safety performance, without being prescriptive about how this may be achieved. This usually requires the assessment of tunnel safety and comparison with predefined safety objectives such as risk acceptance criteria.

With the increasing complexity of tunnel projects and the need to provide economically viable safety features and performance that is focused on the specific conditions, needs and issues at a particular tunnel, performance based approaches are often preferred.

In the past the assessment of alternative safety measures has typically been based on qualitative criteria, and derogation from the design standard only permitted in exceptional cases. Since the introduction of European Directive [1] and other similar regulations, this approach has changed fundamentally to allow, in certain cases, the application of a performance based approach. With such an approach, the safety level or the safety standard is typically still described in a prescriptive way but with an acceptance of derogation if alternative measures or a combination of measures can be shown to provide an equivalent level of safety. With this approach, the responsible Authority may accept alternative risk reducing measures in place of the prescriptive requirements, especially if compliance with the prescriptive requirements can only be achieved at disproportionate costs.

The demonstration of the equivalence of safety performance requires the application of a precise, clearly-defined, transparent risk analysis methodology which shows the level of safety that can be achieved by the individual measures selected. Recently developed national methodologies for risk analysis are therefore often based largely on quantitative approaches, to ensure an objective assessment of the measures.

1.3. SAFETY REQUIREMENTS WHERE NO EXISTING REGULATIONS EXIST

If no national regulations on safety requirements exist, the target safety level can be defined by the principles of internationally applicable regulations such as:

- international minimum requirements (for example in accordance with European Directive 2004 [1]) or;
- best practice guidelines (e.g. PIARC reports [3] & [4] or SAFE-T report [5] or FIT report [6]) or;
- regulations followed by other countries.

In these cases, the selection of other existing frameworks has to be carefully considered with regard to the relevancy of their application to the country in question. With no specific baseline safety requirements, like those described in chapter 1.2, a safety strategy and associated objectives first need to be established. Individually defined safety objectives for specific tunnels may also be an acceptable approach. Objectives would be derived from international standards and good practice guidelines and agreement reached with stakeholders on their local applicability.

In the assessment of the required overall safety objectives, the following considerations are recommended:

- account should be taken of the general extent of tunnel safety in the respective country or region. This should be considered as an indication of the acceptability of safety levels given the local social, economic and transportation policy circumstances;
- if special regulations regarding tunnel safety exist in neighbouring countries, it is recommended that their local applicability be assessed;
- the generally accepted international regulations or guidelines concerning tunnel safety should be considered but the appropriateness of their local application should be scrutinised to avoid the possibility of an unreasonably high or to a too low safety level being adopted without question;
- regulations from technically related areas or from other modes of transport could also be helpful. From these, generally accepted safety standards could be deduced which could allow a conclusion to be drawn on an appropriate tunnel safety level. However, in these cases the transferability of the regulations must be assessed.

The proposed guidelines or standards should be approved by the responsible authority. Specific safety measures can then be derived from the definition of the safety objectives. In the selection or specification of measures, it must be considered how they apply to the tunnel's specific needs and if they represent the state-of-the-art technology in the country.

In the assessment of the applicability of guidelines from other countries, it should be noted that regulations (particularly those with prescriptive requirements) typically go through a long development or creation process, in order to achieve the optimum combination of safety measures having given due consideration to economic issues. Therefore, the measures specified in national regulations can represent a complete package, where the combination of measures provides the required level of safety. If the selection of measures to be used in a country without its own national requirements is to be based on a mix of different national or international regulations, then the effects of the measures may no longer entirely fulfil their purpose and the safety level aimed for may not be achieved; in such cases, expert knowledge and advice should be sought.

The following basic recommendations for action can be derived from the above mentioned considerations. If no national regulations exist:

- guidance should be sought through international minimum requirements, best practice guidelines or regulations followed by other countries;
- the transferability of regulations from neighbouring countries or from regulations for technically related areas within the country and other modes of transport should be assessed;
- before using regulations from other countries, it is recommended to establish a national version;
- should regulations of other countries be used, the regulations should not be a mix of individual prescriptions or a selection of the overall strictest requirements from regulations of other countries and the potential interactions of individual measures must be taken into account. In any case, expert knowledge must be sought;
- the proposed guidelines should be agreed by the responsible authority;
- a safety strategy should then be established from which the requirements for retrofitting / improvement can be derived. The objective should be to develop a strategy which is achievable in terms of the operational organisation capabilities.

2. STEP 2: INVESTIGATE CURRENT SITUATION

The objective of step 2 is to generate a description of the current tunnel condition (with a focus on safety rather than asset management) in terms of:

- systems and equipment: checking the condition and performance;
- safety documentation and existing procedures;
- tunnel operation (organisation, training and quality assurance);
- structural aspects (condition and performance).

Guidance on safety inspections for road tunnels has been published in PIARC Technical Committee 3.3 technical report: *"Tools for Tunnel Safety Management"* [7] which also provides details about the European Directive requirements on Safety Inspections of Road Tunnels. The methodology presented in the present report describes a more general approach.

The first part of the procedure is to identify the current condition of the tunnel with regards to safety. This assessment may be performed separately from the inspection of the structure but has to be coordinated with the safety aspects of the structural condition and configuration.

2.1. GENERAL APPROACH

The objective is to generate a description of the condition in a format usable for the subsequent steps 3 to 5, in particular:

- a description of the structural elements, configuration and existing systems;
- a description of the physical condition;
- a description of the functional condition;
- an estimate of the reliability, availability and maintainability of the function.

All data available on the tunnel should first be collected; from the as-built drawings, the design and the technical specifications for the equipment and structural arrangement. A complete inventory of data allows an understanding of the structure, equipment and the functions of the tunnel in general. The initial desktop data collection and assessment will serve to focus the specification for the site inspection on aspects of particular interest; on suspected weak points for example. Advice on the site inspection stage is given in PIARC Technical Committee 3.3 technical report: *"Tools for Tunnel Safety Management"* [7].

In planning the inspection, the following key questions should be considered:

- what qualifications and certifications should the inspectors have?
- is there cooperation between organisations involved (tunnel owner, tunnel manager, inspection body, safety body)?
- what would be the best contracting strategy?
- shall the investigations been done independently of the representatives of the tunnel (owner, operator, etc.)?
- how should the inspection be programmed?
- what are the access restrictions for inspection works?
- what are the needs / means for assisting the inspector (equipment, protection, lifts, lighting, and tunnel closure)?

Inspection reports should provide descriptions and data sufficient to enable the assessment of the existing safety level in the tunnel.

2.2. SPECIFIC APPROACH FOR SYSTEMS AND EQUIPMENT

A systematic assessment of the working order and performance of all mechanical and electrical equipment in the tunnel should be made, including the following key points:

- age and degree of obsolescence of the equipment
- links to the tunnel control system (for e.g. SCADA);
- maintenance records;
- assessment of the working state and identification of any problems in function;
- existence of spare parts;
- assessment of degree of protection from fire.

The performance and reliability of the equipment should be assessed:

- check the actual performance of each critical system: e.g. ventilation systems, monitoring and communications, CCTV, lighting etc.;
- evaluate the reliability of the systems;
- define and perform integrated tests to check the overall system response and compliance with objectives.

The result of the assessment would be a detailed description of the functional performance and reliability of the individual and collective tunnel systems.

2.3. CHECK OF SAFETY DOCUMENTATION

The set of safety documents may include: previous risk analyses, management procedures, emergency response plans, incident records, maintenance procedures, etc.

A check of the documents highlights safety issues for the tunnel and how they are addressed in the safety documentation. Assessment should include traffic analysis, reports on incidents, feedback on experience and analysis of mandatory exercises carried out. Assessment should also include interviews with key people such as the rescue services and operating staff; with particular regard to the effectiveness and relevance of the emergency response plan.

2.4. CHECK OF TUNNEL MANAGEMENT AND OPERATING PROCEDURES

The objective is to examine the existence and functioning of overall policies, organisation, planning, procedures, monitoring and review and training of the staff. This includes the analysis of the tunnel management organisation; providing a description of the tunnel operator role as well as the emergency services, maintenance support team, road assistance and rescue units.

For the case where the tunnel has a control room and an associated tunnel control system, an assessment of the following should be made:

- **redundancy principles –** minimum operating conditions (if any);
- **systems performance –** functional analysis & transmission of information;
- **human-machine interface –** ergonomy.

2.5. INVESTIGATION OF STRUCTURAL ASPECTS

Structural elements are typically inspected at regular intervals and classified according to their observed condition. Structural condition is a key consideration in the management of the tunnel structure. The structural inspector is typically required to provide a description of the physical and functional condition. The functional condition may be presented with reference to condition classes which reflect how well the different structural elements meet the performance requirements specified in the design. Standards for tunnel inspection and the condition classification classes may vary between different countries.

An assessment of the structural arrangement of the tunnel enables a check of the current situation against *"as-built drawings"* if they exist. If such records do not exist, sufficient records should be created as part of the planning for the refurbishment programme. During assessment of the structural arrangement, assessment of the current state of the structural elements which directly affect tunnel safety should be made. This could be the fire resistance of some tunnel parts, provision of emergency exists, configuration and condition of the ceiling or ventilation ducts etc.

3. STEP 3: EVALUATE CURRENT TUNNEL SAFETY LEVEL

The approach to the assessment of the safety level of a tunnel in its existing condition depends on the details of the existing regulations, as assessed in Step 1. An assessment at this stage can be made of whether the initial safety level has decreased because of changing operating conditions such as an increase in traffic volume and increased frequency of congested conditions; or changes in the use of the tunnel by heavy goods vehicles; or the construction of nearby infrastructure that indirectly affects tunnel safety. As described in step 1, two main types of regulations exist: prescriptive and performance based regulations, for which the approaches to evaluation of tunnel safety level are described separately below.

3.1. EVALUATION OF THE CURRENT SAFETY LEVEL BASED ON PRESCRIPTIVE REGULATIONS

Where detailed prescriptive regulations exist, the evaluation of the safety level of the tunnel can be made by direct comparison between these regulations and the current state of the tunnel. This will highlight the basic non-compliances with standards and identify critical weak points.

It is presupposed that the prescriptive regulations are set in order to assure a sufficient safety level, corresponding to the actual state of the art, and that a tunnel which complies with these regulations is considered to have an acceptable safety level.

A systematic approach to the comparison between the existing provisions and the requirements of standards will facilitate the choice of the refurbishment measures to be taken. All factors influencing safety in the tunnel should be considered in the evaluation.

These factors could include the following:

- tunnel structure and equipment such as:
  - emergency exits and escape routes,
  - lay-bys,
  - emergency stations and emergency phones,
  - fire extinguishers,
  - radio broadcasting system,
  - ventilation systems,
  - lighting (normal and emergency),
  - status and incident detection,
  - signing;

- maintenance and operation:
  - maintenance and operation of tunnel and equipment,
  - contingency planning and emergency exercises,
  - tunnel monitoring and control systems,
  - operation schemes,
  - traffic management and control,
  - emergency services response.

For all the above factors, the comparison between existing regulations and the current situation is required so that deficiencies may be listed and classified to define a set of corresponding measures that are focused on upgrading the tunnel to achieve a sufficient safety level.

3.2. EVALUATION OF THE CURRENT SAFETY LEVEL USING A RISK BASED APPROACH

Although the comparison of the existing tunnel safety provisions with prescriptive standards allows a qualitative assessment of the deficiencies in tunnel safety, it does not allow the assessment of the effective level of safety of the tunnel and the effective safety gain brought by each chosen upgrade measure. This can only be done by using a risk based approach.

It may also be the case that risk analysis is required by the standards; indeed for a strict prescriptive regulatory system, the risk assessment is implicit in the regulations. For practical purposes, most countries use a combination of prescriptive regulations and performance requirements; in these cases, there is always a need for a risk assessment.

If the safety objectives are expressed in terms of performance requirements then, in addition to specific prescriptive regulations, the level of safety has to be assessed using a risk based approach. The PIARC reports on Risk Analysis [2] and Risk Evaluation [8] describe in detail the practical application of a risk based approach methodology. For completeness, some general information, taken from these reports, is provided below.

In a risk based approach, the risk assessment process includes the following main three elements:

- **risk analysis:** systematic approach to analyse sequences and interrelations in potential incidents or accidents, identifying weak points in the system;
- **risk evaluation:** risk criteria have to be defined and it has to be determined whether a given risk level is acceptable or not;
- **risk reduction:** if the estimated level of risk is considered as not acceptable, additional safety measures have to be proposed.

In risk analysis, different types of risk can be investigated: harm to a specific group of people, loss of property, economical loss, damage to the environment, damage to immaterial values. Risks can be addressed in a quantitative or in a qualitative way. Qualitative methods typically focus on the functional analysis of the sequence of events and the interaction of people, systems and procedures, whereas with quantitative methods, characteristic risk values can be calculated.

In some cases, the risk analysis may address different upgrading stages, if the local conditions require phased reopening of the tunnel; for example if particular operating conditions or procedures are imposed to mitigate risk.

In practice, there are various different approaches to the evaluation of the current tunnel safety level using a risk based approach. In particular, the following approaches to risk evaluation may be taken:

- **qualitative approach:** checklists, safety audits, expert assessments, etc.
- **farmer diagram (or FN diagram):** quantitative frequency-consequences plots showing the cumulative frequencies (F) of incidents involving N or more units of damage. The consequences are most often expressed in terms of fatalities;
- **expected value (EV):** long-term average number of statistically expected fatalities per year due to a particular hazard and for a particular tunnel. The fatality rates of all relevant events may be summed to give the total EV for the accident type or the system as a whole;
- **monetary risk:** the criteria for acceptability may be based on the principle of the optimal allocation of available resources.

The evaluation of the current safety level can be made by applying absolute or relative criteria.

Application of absolute criteria: a widely used strategy of risk evaluation is based on the comparison of the resulting risk estimation for a tunnel with a defined maximum threshold, defining the level of acceptable risk. As long as the assessed risk evaluation is comparable or lower than the defined threshold the, risk for the tunnel may be evaluated as acceptable. The application of absolute criteria is simple but the determination of acceptability thresholds requires a commitment of all involved stakeholders, including the responsible legal authorities if the criteria are included in a legal basis.

Application of relative criteria: the results of a risk analysis for a specific tunnel may be compared to the results from the application of same risk analysis methodology for a reference tunnel or a reference condition. The reference tunnel is normally a tunnel similar to the tunnel to be investigated which is fully compliant with the applicable standards and requirements. The assessed results for the reference tunnel may be used as a target for the risk evaluation. The expected risk value of the tunnel under assessment should be below or equal to this target value. All relative risk evaluation strategies rely on the concept of a *"reference tunnel"* which may be difficult to define consistently. However, this approach provides a means to *"translate"* the prescriptive approach into the concept of a performance-based risk assessment (by quantifying the risk which is related to a tunnel which completely fulfils the relevant prescriptive regulations).

As illustrated in *figure 2*, from the results of this step 3, the need to continue with steps 4 or 5 may be established.

4. STEP 4: DEFINE A SAFETY IMPROVEMENT PROGRAMME

The phases of the definition of a safety improvement programme for step 4 are:

- review the deficiencies and propose different solutions;
- review the different options for the improvement programme globally;
- develop the chosen solution.

The phasing of renovation works also needs to be considered carefully as it directly influences the safety level evolution for the tunnel. There may also be constraints on the allowable closure periods and works that can be carried out at different times that will influence the options evaluation for the renovation works.

Urgent mitigation measures may also be considered during this phase; if immediate measures are proposed, they need to be integrated within the overall renovation programme as a holistic approach is required to obtain a coherent and refined overall scope of works.

4.1. DEVELOPMENT OF AN IMPROVEMENT PROGRAMME

The development of an improvement programme is an iterative process that requires the definition of different tunnel configurations that are aimed to satisfy the deficiencies identified in step 3. The improvement programme options should be based on the results of step 3 where objectives have been clarified. Of course, simple solutions can be defined for simple cases; the following paragraphs are for more complex solutions.

The preliminary definition of the improvement programme requires:

- the identification of the minimum requirements to be satisfied (from Step 3),
- the identification of possible alternative measures to minimum requirements,
- the identification of possible integrative measures,
- the definition of one or more tunnel configuration options.

The formulation of the improvement programme may require the following information:

- analysis of deficiencies with respect to minimum requirements (from Step 3),
- risk level of the existing tunnel in terms of risk values (from Step 3),
- feasibility study of structural measures,
- analysis of alternative measures in terms of risk reduction performance,
- definition of two or more alternative solutions,
- cost estimation.

The criteria on which the definition of the improvement programme should be based are:

- compliance with prescriptive requirements where feasible;
- compliance with risk acceptance criteria, if applicable.

The first criterion requires the results of step 3 which will identify noncompliance with respect to the regulations. Alternative measures should be considered to balance noncompliance. The second criterion needs the results of a preliminary risk analysis that should be taken into account in order to define if the tunnel requires additional risk mitigation measures. Furthermore, cost-effectiveness should be considered while developing improvement options.

The selection of alternative measures should be aimed at achieving compliance with the fixed risk acceptance criteria (e.g. tolerability, acceptance limits) and with the risk reduction requirements. An overview and a discussion on risk evaluation criteria can be found in the PIARC report on risk evaluation [8].

The definition of the performance and characteristics of the safety improvement measures (structural measures, safety systems, etc.) should be aimed at risk reduction criteria compliance and focussed on the optimisation of safety provision. If the defined tunnel configuration options do not achieve the safety level targets and criteria, the configurations should be reviewed and further options proposed.

In the case where safety targets are not achieved and there are non-compliance with prescriptive minimum requirements, it may be possible to:

- adopt safety measures required for tunnels with higher length or traffic volume;
- adopt alternative and/or additional safety measures derived from good practice;
- adopt innovative design solutions and/or safety systems.

Example options for alternative solutions for different cases are provided in appendix 2 with a focus on potential mitigation measures for structural aspects, safety equipment and operational measures.

This outcome of this stage is the definition of distinct solutions for the different aspects of the improvement programme for the tunnel. Further assessment is required of how these solutions are integrated globally, discussed in the following section.

4.2. REVIEW THE IMPROVEMENT PROGRAMME OPTIONS HOLISTICALLY

After the development of a feasible improvement programme with various options identified to increase the safety level in the tunnel, an analysis should be performed to globally assess options and decision criteria in order to plan the optimum refurbishment programme.

A number of issues shall be considered with regard to the improvement programme options, the main topics are:

- phasing the works:
  - identification of the nature of the tunnel closure needed for the refurbishment schedule; e.g. total closure or night closure, single lane or full bore closure etc.,
  - consideration of the impact of disturbance of traffic during works; especially in urban tunnels or routes of strategic importance to the road network. Consideration to whether alternative routes can be easily utilised;
- financial constraints:
  - affordability of the refurbishment works,
  - consideration of losses associated with tunnel closure and disruption, even temporarily during refurbishment works,
  - impact of the improvement programme on future operational costs such as increase in maintenance requirements, increase in energy consumption, increase in surveillance requirements (increase of the number of tunnel staff required);
- operational constraints:
  - implementation of specific mitigation measures during works (adaptation of the minimum operating conditions),
  - consideration of whether intermediate operational procedures are feasible and easy to implement;
- emergency means:
  - establish whether a specific Emergency Response Plan can be implemented and be effective during the works,
  - determine if the refurbishment programme is temporarily decreasing the safety level of the tunnel and whether this can be accepted.

A holistic approach is recommended here in order to properly assess risk and opportunities in the evaluation of the refurbishment programme options. By considering the broader issues described above, a cost beneficial solution can be developed that meets the safety level target. An improvement programme can then be defined that achieves the required safety level whilst limiting the economic impact of tunnel operations and enabling suitable planning for the operational and emergency response procedures during and after the refurbishment. Technical solutions that do not consider the broader issues can lead to extensive economic impacts or difficult operating conditions.

Some of the main criteria in the assessment of options are shown in *figure 3*:

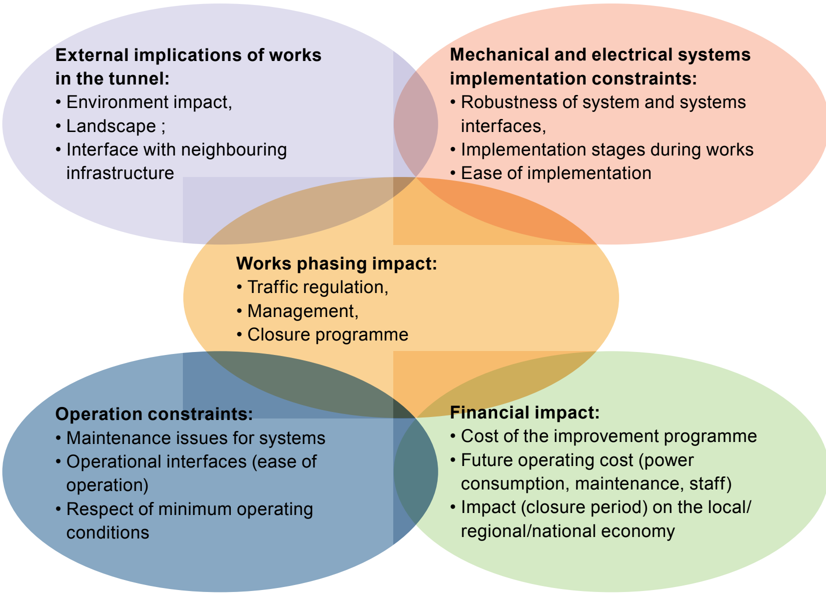

FIGURE 3 - MULTIPLE CRITERIA IN THE ASSESSMENT OF REFURBISHMENT PROGRAMME OPTIONS

4.3. PREFERRED CHOICE FOR THE IMPROVEMENT PROGRAMME

The different improvement programme options can be assessed and classified to help define the details of the alternative configurations for the tunnel refurbishment project; to inform a choice of one refurbishment programme from all technically feasible options. A ranking method may be a simple approach to this process. Such techniques do not, however, take into account the mutual influences between safety systems; only a complete risk analysis can help define the risk reduction potential of different safety systems. It is for this reason that steps 4 and 5 (where the assessment of the safety improvement is made) are iterative; the ranking method here would be a complementary tool to organise technical issues on the different improvement programme options.

The circumstances for each particular tunnel will be different so the option classification should be tailored to the particular issues at that tunnel and its critical weak points. For example, in urban tunnels, fire resistance of the structure may be considered crucial for safety in the tunnel, but also for ensuring the stability of overlying structures and the safety of those outside the tunnel; so the impact of this measure may be significant in the consideration of options.

Again, the choice of the solution for the refurbishment programme should be assessed globally taking into account wider issues, in addition to safety. Upgrading tunnel safety is an iterative process that requires the results of risk analysis and the application of a risk evaluation method to support decisions. The chosen configurations should be verified through the use of risk analysis and risk evaluation.

5. STEP 5 - EVALUATE FUTURE TUNNEL SAFETY LEVEL

This step requires the assessment of the future safety level, after the upgrade works, to check whether the upgraded tunnel condition meets the defined safety objectives. This requires a risk based approach. The characterisation of the future risk level provides information to aid communication with stakeholders to demonstrate the impact of the proposed upgrade measures. This will allow suitable decisions to be made about the alternative design configurations identified in step 4 and enable confirmation of the choice of the improvement programme to be adopted.

This safety analysis of the future state of the tunnel after renovation can be refined with the improvement programme optimisation in step 4. This is an iterative process undertaken whilst making sure that the relevant criteria are met, including the constraints, discussed in *Section 4*. The analysis should take into account the function of the tunnel facilities as well as their interaction. The ranking method of assessment of refurbishment programme options in step 4 can then be completed with estimated safety benefits. This assessment should be performed holistically.

For consistency, the approach to the risk-based evaluation of the future tunnel safety level should be the same as that used for the evaluation of the safety level in the existing tunnel, described in *section 3.2*. There are many ways to analyse and evaluate risk. In practice, it is often the case that combinations of methods and principles are applied. A risk based approach allows assessment of:

- the effective level of safety of the tunnel;
- the effective safety gain brought by each chosen upgrade measure;
- the most cost-effective upgrade measures;
- the extent of safety deficiency due to possible inability to apply particular upgrade measures that are not technically feasible;
- the relative merits of competing upgrade options.

Risk assessment can also help to inform decisions on the appropriate temporary mitigation measures and the development of the intervention safety plan with the fire services for the period prior to the full upgrade works. The risk analysis should be compared with the one carried out on the current state of the tunnel (before upgrading) to show the benefits of temporary risk mitigation measures and ultimately the benefits of transition to the upgraded condition.

At the end of this process, there may be a need to reiterate step 4 to establish an alternative improvement programme for comparison or to ensure the required safety level is achieved. Given the results of step 4 (upgrade proposals) and step 5 (future safety level achieved) as well as a plan for the refurbishment strategy, design activities can be progressed with clear objectives and solutions that are aligned to the specific needs of the existing tunnel.

6. REFERENCES

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APPENDIX A: TYPICAL WEAK POINTS AND POSSIBLE UPGRADE MEASURES

The list below is not exhaustive; but provides some examples to show how solutions may be very different from case to case. These examples shall not be considered as a check list but as indicative examples only.

A.1. DRAINAGE SYSTEMS

Safety issue description: these two cases describe the typical problem of adapting drainage systems in existing road tunnels in order to deal with Dangerous Goods Vehicles incidents (spillage or fire scenarios).

A.1.1. Construction of slot gutter with siphons, flame traps and gulley

Objective:
- reduce the pavement surface spread in case of leakage, mostly with Dangerous Goods;
- reduce the fire intensity (fire size, time development, spread, etc.);
- avoid fire spreading inside drainage system;
- no monitoring system required.

Construction conditions:
- possible implementation during night closures in closing only one lane – if possible;
- low impact on traffic;
- low inconvenience for users;
- temporary reinforcement of signalling and patrol;
- drainage system has to be entirely renewed.

Operational consequences:
- additional maintenance procedures for new system.

A.1.2. Construction of storage tanks

Objective:
- safety improvement at portals,
- environmental protection of water resources.

Construction conditions:
- construction outside of traffic space,
- no inconvenience for users,
- temporary reinforcement of signalling and patrol.

Operational consequences:

- maintenance requirement,
- SCADA impact (new sensors' back up onto the existing system),
- adapt emergency response plan.

A.2. FIRE PROTECTION

Safety issue description: Structure and mechanical & electrical systems have to be protected in order to maintain operating conditions in the case of a fire. These examples deal with cases where the structure and cable fire resistance is insufficient.

A.2.1. Structure fire resistance

Objective:

- protection of the structure.

Construction stage impact:

- in the case of complex work associated with heavy civil repairs: closure of a tube is needed;
- in the case of fixing protection boards or spraying techniques: night closures. Closure period depends on the method and organisation;
- impacts on traffic;
- inconvenience for users.

Operational consequences:

- emergency Response Plan refinement,
- the protection implementation may require removing / putting back some systems (lighting, CCTV, etc.).

A.2.2. Cable fire protection

Objective:

- protection of cables.

Construction conditions for cable protection:

- construction of a trough or additional material;
- usually complex: cables have to be temporarily removed – their function has to be maintained;
- construction may be possible during night time lane closures;
- part of the work requires tunnel closure. Closure period depends on the method and organisation;
- impacts on traffic;
- inconvenience for users.

Operational consequences:

- emergency Response Plan refinement.

A.3. USUAL RENOVATION ISSUES WHICH REQUIRE MONITORING & CONTROL SYSTEMS

Safety issue description: it may be the case that appropriate monitoring systems and a SCADA network are not implemented in old existing road tunnels. The objective here would be to implement such systems to comply with regulatory standards and objectives in terms of operation and emergency response plans. If these are implemented, some adaptations may have to be realised due to other systems modifications.

A.3.1. Signalling systems

Objective:

- improve signalling and communication with the users,
- improve guidance to escape routes,
- improve traffic management,
- signs to stop traffic entry to tunnel and inside tunnel (barriers, lights),
- monitoring by the control centre.

Construction stage impact:

- signalling on the side wall: construction possible during night by lane closure;
- signalling above traffic space: preparation outside – implementation during night, short closure of the tube for lifting and fixing;
- cables for supply and remote: during night with a lane closed;
- low impact on traffic;
- low inconvenience for users;
- temporary reinforcement of signalling and patrol;
- test during low traffic periods.

Operational consequences:

- emergency Response Plan refinement;
- SCADA Software update required.

A.4. EMERGENCY EXITS

Safety issue description: these cases illustrate the issue of implementing new emergency exists to reduce distance between egress points to comply with prescriptive requirements.

A.4.1. Example for twin tube tunnels

Tunnel situation:

- unidirectional tunnel 2 tubes,
- good ground conditions.

Construction conditions:

- if closing a tube is acceptable:
- no particular difficulties, system can be established to reopen each morning in time;
- if closing one tube is not acceptable:
- construction during the night,
- closure of left lane and width reduction of right lane,
- short temporary closures.

Alternative solutions:

- cross Passages,
- creation of a parallel escape gallery.

Operational consequences:

- emergency Response Plan adaptation (access of rescue team),
- monitoring means (SCADA upgrade),
- potentially operating in Minimum Operating Condition during the works.

A.4.2. Example for a single bore tunnel

Tunnel situation:

- bidirectional tunnel 1 tube, 2 lanes.

Construction conditions:

- special connections needed from shelters,
- particular operating procedures.

Alternative solutions:

- construction of new safety exits,
- parallel gallery as escape route from shelters,
- use of existing tunnel bore space for new, fire-protected escape passage (for example in the crown, side or invert.

Operational consequences:

- emergency Response Plan adaptation (access of rescue team and evacuation of users),
- monitoring (SCADA upgrade),
- complete tunnel closure during works.

A.5. VENTILATION SYSTEMS

Safety issue description: these cases illustrate the typical issue of upgrading ventilation systems in existing tunnels to meet safety objectives. This would be the case where the existing tunnel has been constructed prior to the regulation update or an assessment of significant changes in terms of traffic has been made.

A.5.1. Example for simple unidirectional tunnel with 2 tubes

Tunnel situation:
- unidirectional tunnel 2 tubes,
- existing ventilation system: longitudinal,
- traffic increase and fire conditions require more air flow or higher air flow velocity,
- solution: add additional fans.

Construction conditions:
- new fans may be installed during short tunnel closures,
- complementary power supply may be installed during night with one lane closed,
- modification of SCADA, may be tested during low traffic period.

Alternative solutions:
- alternatively, but most costly, Saccardo nozzles can be implemented at portals or fan rows at portals in elevated crown,
- intermediate shafts, especially for urban tunnels,
- according to the length, smoke exhausts at intervals may be required.

Operational consequences:
- emergency Response Plan adaptation (access of rescue team).

In case of a complex situation (e.g. regular traffic jams, ramps in the tunnel etc.), further refurbishment requirements would be required, e.g.:

- control and management of longitudinal airflow,
- particular consideration of aspects such as work phasing and corresponding refinement of emergency plans and operating conditions.

Tunnel situation:
- unidirectional tunnel 2 tubes,
- existing ventilation may be longitudinal or semi transverse,
- numerous traffic jams,
- particular atmospheric conditions at portal, with strong natural air flow inside the tunnel.

Refurbishment requirements:
- control and manage longitudinal air velocity,
- Create or keep smoke extraction (smoke exhaust, dampers).

Civil works implications:
- investigation of all possible conditions,
- very detailed construction method analysis, in order to target construction time with precision of less than one day,
- strategy of works staging with regard to closure possibility,
- in case of staging – evaluation of the safety conditions when temporary reopening between two construction stages,
- tight survey and control of the upgrade works in order to respect the programme.

Solutions for controlling air velocity:
- the implementation of boosters at each portal;
- the installation of jet fans or injectors:
- build recess to install jet fans,
- adapt the power supply and the data transmission network,
- modify the SCADA;
- organisation of upgrading works:
- civil for recess needs closure of the tube,
- other works as for previous example.

It may also be the case that the ventilation control system is not automated or implemented. In some of these cases, if a specific ventilation response is required, an operator has to instigate manually; or the ventilation control requires detailed information from sensors that require upgrade. Also, in some existing tunnels it may be necessary to upgrade the fans in order to increase their fire resistance.

A.5.2. Ventilation control

Objective:
- to provide or improve the automatic ventilation control during normal operation and in case of a fire emergency.

Construction conditions:
- anemometers may be required;
- study of the fans' real thrust and its reaction time;
- real scale tests would require tunnel closure for short periods, preferably at night or during low traffic periods;
- low impact for users;
- SCADA modifications.

Operational consequences:
- emergency Response Plan adaption;
- SCADA modification.

A.5.3. Pollution sensors and anemometers

Objective:
- to equip the tunnel with a higher number of pollution sensors and anemometers;
- to increase the information about the air quality inside the tunnel and improve the resilience of the system to a sensor failure.

Construction conditions:
- new devices can be installed during a very short lane closure;
- this can be carried out at night or during low traffic periods;
- very low consequences for users;
- requires SCADA modifications;
- it may require changes in signal acquisition devices.

Operational consequences:
- maintenance;
- SCADA modification (new signals).

A.5.4. Heat resistance of fans

Objective:
- to equip the tunnel with heat resistant fans;
- includes cable protection if necessary.

Construction conditions:
- fans can be replaced during short tunnel closures;
- SCADA must be tested;
- low impact for users;
- low consequences on traffic;
- temporary reinforcement of signalling and patrol;
- test during low traffic periods.

Operational consequences:
- maintenance;
- Emergency Response Plan adaption.

A.6. CLOSED CIRCUIT OF TELEVISION AND AUTOMATIC INCIDENT DETECTION SYSTEM

Safety issue description: it may be the case that the Closed Circuit TV and/or the Automatic Incident Detection System are not implemented in old existing road tunnels. The objective here would be to implement such systems to comply with regulatory standards, and to improve the response time in case of incident in the tunnel. In existing tunnels with a CCTV system, it may be necessary to upgrade it and/or replace the cameras if a new AID system is going to be installed.

A.6.1. Proper location of the cameras

Objective:

- to avoid dazzling the cameras by outdoor lighting. Placing the last camera oriented towards the interior;
- to make the detection by the AID system easier. Proper spacing between cameras;
- to avoid a large number of images in the Control Centre. Proper spacing between cameras;
- to provide 100% coverage.

Construction conditions:

- consequences on traffic, due to the closure of a lane or the whole tunnel;
- possible implementation during night time and closure of a lane.

Operational consequences:

- video Server re-configuration;
- new masks generation and AID system reconfiguration;
- re-programming and re-configuring the SCADA system;
- Emergency Response Plan adaptation.

A.6.2. Automatic Incident Detection (AID)

Objective:

- to immediately detect any incident, in order to efficiently manage the emergency;
- to automate the Emergency Response Plan.

Construction conditions:

- if it is necessary to modify the transmission system of the cameras, or to add new equipment for this purpose, it can be carried out during night time and closure of a lane;
- new equipment in technical rooms at the tunnel portals and in the Control Centre.

Operational consequences:

- re-programming and re-configuring the SCADA system;
- Emergency Response Plan adaptation.

A.7. CONTROL SYSTEM

Safety issue description: in some existing tunnels, it may be necessary upgrade the control system because it doesn't have redundancy at network level, at equipment level and/or at SCADA level.

A.7.1. Control system redundancy

Objective:

- to protect the control system against the break of the communication network, against the failure of the equipment (switches, PLC, servers, etc.) or against computer problems.

Construction conditions:

- if the installation of new fibre optic wiring is required, it will be done in a cable tray or in a duct under road or pavement. Construction possible during night by closing a lane;
- if new equipment installation is required, it will be done in the technical rooms and in the Control Centre, so traffic will not be significantly affected;
- if the updating of the control computer system is required, it will be done only in the Control Centre, so it will not have repercussions for traffic.

Operational consequences:

- emergency Response Plan adaptation;
- re-programming and re-configuring the SCADA system.

A.8. COMMUNICATIONS SYSTEM

Safety issue description: it may happen that radio communication system and/or public address system are not implemented in old existing road tunnels. The objective here would be to implement such systems to comply with regulatory standards and objectives.

A.8.1. Radio communication

Objective:

- to provide a communication system in the tunnel interior to the emergency services, in case of emergency;
- to help the tunnel users to maintain normal driving conditions, by providing FM radio rebroadcast.

Construction conditions:
- the leaky feeder cable will be installed in the ceiling, requiring complete tunnel closure;
- antennae and amplification equipment must be installed in the vicinity of the tunnel portals;
- tests can be done in normal traffic conditions.

Operational consequences:
- operating personnel and emergency services must be provided with terminals, in order to communicate in the tunnel interior;
- emergency Response Plan adaptation.

A.8.2. Public-address system

Objective:
- to offer a straight information system for tunnel users in an emergency situation, assisting evacuation.

Construction conditions:
- speakers are usually installed in the tunnel sidewalls, so it may be done with lane closure;
- few disadvantages for users;
- few consequences for traffic.

Operational consequences:
- emergency Response Plan adaptation;
- programming and reconfiguration of the SCADA system.

A.9. ELECTRICAL SUPPLY SYSTEM

Safety issue description: as a consequence of the incorporation of new equipment with an increased electrical load in an existing tunnel (ventilation systems, water pumps for fire fighting systems, lighting system, etc.), an extension of the electrical supply system might be required. In some cases it is necessary to provide the tunnel with additional UPS to ensure the operation of the emergency equipment.

A.9.1. Extension of the electrical supply system due to increasing the power demand

Objective:
- to provide the necessary electrical supply to the new equipment installed.

Construction conditions:

- first of all, an estimation of the new equipment power consumption must be completed;
- consultation with the Electricity Board to ensure that the present electrical network is able to support the extension, or else an extension of the network is needed;
- an evaluation of which electrical equipment must be upgraded or replaced must be done (transformer, electrical cabinets, wires, etc.);
- an extension of the technical rooms, where electrical supply system equipment is placed, might be required in order to house the new electrical equipment;
- some of these works could be completed during night time, with low impact on traffic (for example, an electrical transformer replacement). However, other works could have a higher impact (for example, a technical room extension).

Operational consequences:

- additional maintenance procedures;
- SCADA impact (more signals must be controlled).

A.9.2. Installation of a secondary source of electrical supply

Objective:

- To provide the tunnel with a secondary source of power supply, to ensure the operation of the safety equipment in case of an electrical failure.

Construction conditions:

- estimation of required power and consultation with the Electricity Board;
- establish the tunnel equipment to incorporate (transformers, electrical panels, connections switching system, etc.);
- possible technical room extension to hold the new equipment;
- some of these works can be done at night, with limited impact on users (e.g. the replacement of a transformer). Other works, however, would have a greater impact (e.g., the extension of a technical room could cause the cut of the power supply for a few days).

Operational consequences:

- additional maintenance procedures;
- SCADA impact (more signals must be controlled).

A.9.3. Installation of an Uninterruptible Power Supply (UPS)

Objective:

- to provide the tunnel with a secure power supply, to ensure the continued operation of emergency equipment (control system, closed-circuit television, etc.).

Construction conditions:

- estimate required power, to choose the appropriate UPS;
- changes in low voltage electrical cabinets (upstream and downstream of the UPS);
- these works can be done at night.

Operational consequences:

- additional maintenance procedures;
- SCADA impact (more signals must be controlled).

A.10. LIGHTING SYSTEM

Safety issue description: new regulations for lighting requiring systems in some existing tunnels to be upgraded.

A.10.1. Lighting system upgrade

Objective:

- to improve the driver's visual comfort,
- to fulfil the lighting regulations in those existing tunnels where lighting system is poor or insufficient.

Construction conditions:

- installation of new cable trays and an extension of main electrical cabinet could be needed,
- lamp replacement is possible during night time, with a lane closure,
- consequences on traffic,
- inconvenience for users.

Operational consequences:

- additional maintenance procedures,
- SCADA impact (more input/output signals).

APPENDIX B – CASE STUDIES

B.1. CASE N°1: BI-DIRECTIONAL TUNNEL IN FRANCE

TUNNEL CHARACTERISTICS		
	before renovation	**evolution after renovation**
General description		
Location:	France	
Length (m):	1,752	1,752
Number of tubes:	1	1 + parallel evacuation gallery
Uni-directional or bi-directional traffic:	Bi-directional	
Urban:	Yes	
Traffic:		
annual average daily traffic volume:		
- per tube:	26,000	26,000
- per lane:	13,000	13,000
- indicate volume for peak hours:		
- risk of congestion (daily or seasonal):	Yes (daily)	
- presence and percentage of heavy goods vehicles:	no HGV, no Trucks	Vans in existing tunnel and Buses in parallel gallery
- presence, percentage and type of dangerous goods - traffic (% of HGV): - category according to EDR:		
Environment – operation:		
- particular geographical and meteorological environment:	urban tunnel in historical area - continental	
- characteristics of the access roads: numerous, close to the portals:	interchange at one portal	
- speed limit (km/h):	50	50
- permanent surveillance:	Yes	Yes
- strong influence of the emergency services:	Yes	Yes

RENOVATION CHARACTERISTICS		
Equipment	**State of the tunnel**	
	before renovation	**evolution after renovation**
Geometry: cross-section for a tube (join a scheme):		
- number of lanes:	2 x 2	2 x 2
- emergency lane and width:	No	
- width of slow and fast lane:	2.70 m and 2.55	
- separation space for bidirectional and width:	1.10 m – Yes	
- width of emergency walkways, easily accessible:	0.75 m – Yes	
- vertical alignment (slope):	close to zero	
- horizontal alignment: dangerous curves:		
Infrastructure measures:		
Emergency exits:		
- type (direct, cross connections: second tube or emergency gallery, shelters):	None	Evacuation gallery parallel to the existing tube with 11 cross passages
- inter distance:		150 m
- suitable for the use of emergency services.		Yes
- clear identification by the user:		Yes
Lays-bys:		
- presence:	None	None
- number:		
Drainage:	Yes	Yes
- slots gutters:		
- siphoids gullys:		
Ventilation system:		
- longitudinal:	No	Yo
- smoke exhaust shaft - number:	Yes - 5 shafts	Yes - 5 shafts
- semi -transverse:	Yes	No
- smoke extraction dampers - interdistance:	None	No
- longitudinal air flow control:	No	Yes
Safety equipment:		
Emergency stations:		
- interdistance:		
Water supply:		
- interdistance hydrants:	200 m	150 m
Lighting:		
- good lighting conditions:	Yes	Yes

RENOVATION CHARACTERISTICS (follow)		
Equipment	**State of the tunnel**	
	before renovation	**evolution after renovation**
Monitoring systems:		
- video:	Yes	Yes
- automatic incident detection:	No	Yes
- automatic fire detection:	No	Yes
Tunnel closing equipment (barriers):		
- outside tunnel:	Yes	Yes
- inside tunnel:	No	No
- signals:		
Communication:		
- radio:	Yes	Yes
- fire services broadcasting:	Yes	Yes
- loud speaker:	Yes	Yes
Operation issues:		
- personal training:	Yes	Yes
- emergency response plans:	Yes	Yes
- specific measures concerning DGV:		
- safety exercises:	Yes	Yes
- special traffic regulations (distances, etc.):	No	Yes

MAIN CONCLUSIONS	
Risk analysis of the current state	**Key Improvements**
• Main influence parameters: - Traffic flows - Urban constraints (works under operation)	• Derogation (regarding local regulations)
• Main deficiencies pointed out: - No escape route except by the portals - Inefficient ventilation system performance regarding safety objectives	• Additional - compensating measures: - Creation of a second tube for bus use only - Creation of an escape route at the same time • Innovative techniques: - Use of the safety tube for bus traffic as well as cyclist and pedestrian crossing - Reinforcement of the longitudinal ventilation system with control of the longitudinal air flow and extraction facilities

B.2. CASE N°2: BI-DIRECTIONAL TUNNEL IN AUSTRIA

TUNNEL CHARACTERISTICS		
	before renovation	**evolution after renovation**
General description:		
Location:	Austria	
Length (m):	1,311	1,311
Number of tubes:	1	1
Uni-directional or bi-directional traffic:	Bi-directional	Bi-directional
Urban:	Yes	Yes
Traffic:		
annual average daily traffic volume:		
- per tube:	13,614	15,225
- per lane:	6,807	7,613
- indicate volume for peak hours:		
- risk of congestion (daily or seasonal):	daily	daily
- presence and percentage of heavy goods vehicles:	Yes (6%)	Yes (6%)
- presence, percentage and type of dangerous goods - traffic (% of HGV): - category according to EDR:	0.33 % of heavy good vehicles A	0.33 % of heavy good vehicles A
Environment – operation:		
- particular geographical and meteorological environment:		
- characteristics of the access roads: numerous, close to the portals:		
speed limit (km/h):	80	80
permanent surveillance:	Yes	Yes
strong influence of the emergency services:	Yes	Yes

RENOVATION CHARACTERISTICS		
Equipment	**State of the tunnel**	
	before renovation	**evolution after renovation**
Geometry: cross-section for a tube (join a scheme):		
- number of lanes:	2	2
- emergency lane and width:	No	No
- width of slow and fast lane:	3.75	3.75
- separation space for bidirectional and width:	No	No
- width of emergency walkways, easily accessible:	width:1.00 m – Yes	width:1.00 m – Yes
- vertical alignment (slope):	1.2%	1.2%
- horizontal alignment: dangerous curves:	No	No
Infrastructure measures:		
Emergency exits:	Yes	Yes
- type (direct, cross connections: second tube or emergency gallery, shelters)	1 emergency exit	1 emergency exit
- inter distance:	495 m/818 m	495 m/818 m
- suitable for the use of emergency services.	No	No
- clear identification by the user:	Yes	Yes
Lays-bys:		
- presence:	Yes	Yes
- number:	2	2
Drainage:		
- slots gutters:	Yes	Yes
- siphoids gullys:	No	No
Ventilation system:		
- longitudinal:	Yes	Yes
- smoke exhaust shaft - number:	No	No
- semi -transverse:	No	No
- smoke extraction dampers - interdistance:	No	No
- longitudinal air flow control:	Yes	Yes
Safety equipment:		
Emergency stations:	7	7
- interdistance:	178-255 m	178-255 m
Water supply:		
- interdistance hydrants:	<250 m	<250 m
Lighting:		
- good lighting conditions:	Yes	Yes (higher luminance level)

RENOVATION CHARACTERISTICS (follow)		
Equipment	**State of the tunnel**	
	before renovation	**evolution after renovation**
Monitoring systems:		
- video:	Yes	Yes
- automatic incident detection:	No	Yes
- automatic fire detection:	Yes	Yes
Tunnel closing equipment (barriers):	CO and visibility sensors	CO and visibility sensors
- outside tunnel:		
- inside tunnel:	No	No
- signals:	No	No
Communication:	Yes	Yes
- radio:		
- fire services broadcasting:	Yes	Yes
- loud speaker:	Yes	Y
Operation issues:	Yes (in lays bys and portals)	Yes (in lays bys and portals)
- personal training:		
- emergency response plans:	Yes	Yes
- specific measures concerning DGV:	Yes	Yes
- safety exercises:	No	No
- special traffic regulations (distances, etc.):	Yes	Yes

MAIN CONCLUSIONS	
Risk analysis of the current state	**Key Improvements**
• Main influence parameters: - Ventilation in case of fire	• Derogation (regarding local regulations) - new ventilation system with new regulation - renewing the traffic control and traffic supervision - renewing of the tunnel lighting - new emergency call system - evaluation of the fire response plan (first step) - LED on both hard shoulders
• Main deficiencies pointed out: - emergency exit spacing too great - structural fire protection (apartment buildings are over the tunnel)	• Additional - compensating measures: - installation of a water mist system (ordered by an official notification based on a risk analysis) - reducing the distance between the emergency exits (ordered by an official notification)

B.3. CASE N°3: BI-DIRECTIONAL TUNNEL IN AUSTRIA

TUNNEL CHARACTERISTICS		
	before renovation	**evolution after renovation**
General description:		
Location:	Austria	
Length (m):	2,135	Length of each tube: 2,135 (right - existing) and 2,102(left – new))
Number of tubes:	1	2
Uni-directional or bi-directional traffic:	Bi-directional	Uni-directional
Urban:	No	No
Traffic:		
annual average daily traffic volume:		
- per tube:	12,255	12,586
- per lane:	6,128	3,147
- indicate volume for peak hours:		
- risk of congestion (daily or seasonal):	congestion only on specific weekends, especially on winter time	No in general and practically
- presence and percentage of heavy goods vehicles:	Yes (17%)	Yes (21%)
- presence, percentage and type of dangerous goods - traffic (% of HGV): - category according to EDR:	2.2 % of heavy good vehicles A	2.2 % of heavy good vehicles A
Environment – operation:		
- particular geographical and meteorological environment:		
- characteristics of the access roads: numerous, close to the portals:		
speed limit (km/h):	80	100
permanent surveillance:	Yes	Yes
strong influence of the emergency services:	Yes	Yes

RENOVATION CHARACTERISTICS		
Equipment	**State of the tunnel**	
	before renovation	**evolution after renovation**
Geometry: cross-section for a tube (join a scheme):		
- number of lanes:	1x2	2x2
- emergency lane and width:	No	No
- width of slow and fast lane:	4.25	4.25/3.75
- separation space for bidirectional and width:	No	
- width of emergency walkways, easily accessible:	width:1.00 m – Yes	width:1.00 m – Yes
- vertical alignment (slope):	Maximum 1.41%	Maximum 1.41%
- horizontal alignment: dangerous curves:	Yes	Yes
Infrastructure measures:		
Emergency exits:	Yes (1)	Yes
- type (direct, cross connections, second tube or emergency gallery, shelters):		5 cross connections and 1 emergency exit
- inter distance:		330 - 365 m
- suitable for the use of emergency services.		Yes
- clear identification by the user:	Yes	Yes
Lays-bys:		
- presence:	Yes	Yes
- number:	1	1 and 2 in the new tube
Drainage:	No Separate system for road surface liquids	There is separate system with siphons
- slots gutters:	Yes	No
- siphoids gullys:	No	Yes
Ventilation system:		
- longitudinal:	injector ventilation	Yes
- smoke exhaust shaft - number:	No	No
- semi -transverse:	No	No
- smoke extraction dampers - interdistance:	No	No
- longitudinal air flow control:	Yes	Yes (3 per tube)
Safety equipment:		
Emergency stations:	11	11 and 19 (new tube)
- interdistance:	212 m	For the new tube interdistance 96 -127 m
Water supply:		
- interdistance hydrants:	Maximum 212 m	For the new tube interdistance 96 -127 m

RENOVATION CHARACTERISTICS (follow)		
Equipment	**State of the tunnel**	
	before renovation	**evolution after renovation**
Lighting:		
- good lighting conditions:	Yes	Yes (higher luminance level)
Monitoring systems:		
- video:	Yes	Yes (new, distance of the cameras 106 – 115 m)
- automatic incident detection:	No	Yes
- automatic fire detection:	Yes	Yes
Tunnel closing equipment (barriers):	CO and visibility sensors	CO and visibility sensors
- outside tunnel:		
- inside tunnel:	No	No
- signals:	No	No
Communication:	Yes	Yes
- radio:		
- fire services broadcasting:	Yes	Yes
- loud speaker:	Yes	Yes
Operation issues:	Yes (in lays bys, cross connections and portals)	Yes (in lays bys, cross connections and portals)
- personal training:		
- emergency response plans:	Yes	Yes
- specific measures concerning DGV:	Yes	Yes
- safety exercises:	No	No
- special traffic regulations (distances, etc.):	Yes	Yes

MAIN CONCLUSIONS	
Risk analysis of the current state	**Key Improvements**
• Main influence parameters: - high percentage of heavy goods vehicles	• Derogation (regarding local regulations) - new ventilation system with better regulation - new fire detection system - new drainage system - new emergency call system - new lighting system - information panels
• Main deficiencies pointed out: - low luminance level - no fire protection of the structure	• Additional - compensating measures: - LED on both hard shoulders - new emergency call system - new radio system - new lighting system - information panels

B.4. CASE N°4: UNI-DIRECTIONAL TUNNEL IN SPAIN

TUNNEL CHARACTERISTICS		
	before renovation	**evolution after renovation**
General description:		
Location:	Spain	
Length (m):	940 (tube I) and 560 (tube II)	940 (tube I) and 560 (tube II)
Number of tubes:	2	2
Number of lanes per tube	2	2
Uni-directional or bi-directional traffic:	Uni-directional	Uni-directional
Urban:	No	No
Traffic:		
annual average daily traffic volume:		
- per tube:	16,500	16,500
- per lane:	8,250	8,250
- indicate volume for peak hours:	1,075 veh/h per tube	1,075 veh/h per tube
- risk of congestion (daily or seasonal):	Yes	Yes
- presence and percentage of heavy goods vehicles:	18.9%	18.9%
- presence, percentage and type of dangerous goods traffic (% of HGV): category according to EDR:	Yes 0.53%	Yes 0.53%
Environment – operation:		
- particular geographical and meteorological environment:	interurban tunnel, dry warm Mediterranean	interurban tunnel, dry warm Mediterranean
- characteristics of the access roads: numerous, close to the portals:		interchange at both portals
speed limit (km/h):	80	100
permanent surveillance:	No	Yes
strong influence of the emergency services:	No	No

RENOVATION CHARACTERISTICS		
Equipment	**State of the tunnel**	
	before renovation	**evolution after renovation**
Geometry: cross-section for a tube:		
- number of lanes:	2 x 2	2 x 2
- emergency lane and width:	No	No
- width of slow and fast lane:	3.5 m and 3.5 m	3.5 m and 3.5 m
- separation space for bidirectional and width:	No	No
- width of emergency walkways, easily accessible:	0.75m – Yes	0.75m – Yes
- vertical alignment (slope):	average 2%	average 2%
- horizontal alignment: dangerous curves:	No	No
Infrastructure measures:		
Emergency exits:		
- type (direct, cross connections, second tube or emergency gallery, shelters):	No	Yes - one cross connection, one emergency gallery
- inter distance:		400 m
- suitable for the use of emergency services.		Yes
- clear identification by the user:		Yes
Lays-bys:		
- presence:	No	No
- number:		
Drainage:		
- slots gutters:	No	continuous slot
- siphoids gullys:	No	every 100 m
Ventilation system:		
- longitudinal:	Yes	Yes (four additional jets in tunnel II)
- smoke exhaust shaft - number:	No	No
- semi -transverse:	No	No
- smoke extraction dampers - interdistance:	No	No
- longitudinal air flow control:	No	Yes
Safety equipment:		
Emergency stations:		
- interdistance:	Yes - 180 m	Yes - 180 m (upgraded)
Water supply:		
- Presence:	No	Yes
- interdistance hydrants:		50 m

RENOVATION CHARACTERISTICS (follow)		
Equipment	State of the tunnel	
	before renovation	evolution after renovation
Lighting:		
- good lighting conditions:	No	Yes - Lighting control units and emergency lighting
Monitoring systems:		
- video:	Yes	fixed cameras, fibre optic
- automatic incident detection:	No	Yes
- automatic fire detection:	No	Y
Tunnel closing equipment (barriers):		
- outside tunnel:	No	Yes
- inside tunnel:	No	No
- signals:	Yes	Yes
Communication:		
- radio:	Yes (out of service)	Yes
- fire services broadcasting:	Yes (out of service)	Yes
- loud speaker:	No	Yes
Operation issues:		
- personal training:	Yes	Yes
- emergency response plans:	Yes	Yes (improved)
- specific measures concerning DGV:	No	No
- safety exercises:	No	Yes
- special traffic regulations (distances, etc.):	No overtaking	Security distance: 70 m

MAIN CONCLUSIONS	
Risk analysis of the current state	**Key Improvements**
• Main influence parameters: - Emergency exits - Ventilation control - Heavy goods vehicles traffic volume	• Derogation (regarding local regulations)
• Main deficiencies pointed out: - Insufficient Lighting - Emergency Lighting - Radio Signal not available in the whole tunnel - Emergency phones out of service - No established emergency routes - Toxic waste drainage inexistent - No safety exercises - No fire alarm	• Additional - compensating measures: - Cross connections - Emergency radio service

B.5 CASE N°5: BI-DIRECTIONAL TUNNEL IN GREECE

TUNNEL CHARACTERISTICS		
	before renovation	**evolution after renovation**
General description:		
Location:	Greece	
Length (m):	1,399	Length of each tube: 1,399 (right - existing) and 1,403 (left – new))
Number of tubes:	1	2
Uni-directional or bi-directional traffic:	Bi-directional	Uni-directional
Urban:	No	No
Traffic:		
annual average daily traffic volume:		
- per tube:	12,800	7,150
- per lane:	6,400	3,575
- indicate volume for peak hours:	1,580 (16 and 23 August 2009)	
- risk of congestion (daily or seasonal):	No in general (congestion only on specific 4 or 5 days e.g. holy Thursday and good Friday, Monday and Tuesday after Easter, the fifteenth of August)	No in general and practically (congestion provided only a running lane (for whatever reason) only on specific 4 or 5 days e.g. as next and some other holidays))
- presence and percentage of heavy goods vehicles:	Yes	Yes (5%)
- presence, percentage and type of dangerous goods	No DGV	Yes for the new tube, No for the existing old (renovated) tube, for the present Note: For the existing tube, the decision is mainly influenced by the presence of loads with liquid fuels DGV tanks (unlike the new tube where there are mostly empty DGV tanks) and the absence of flame traps of the separate drainage system for road surface liquids. As risk analysis concludes, after implementation of flame traps DGV will be allowed without restrictions, and the tunnel will be ADR category A for renovated tube.

TUNNEL CHARACTERISTICS (follow)		
	before renovation	**evolution after renovation**
- traffic (% of HGV):		
- category according to EDR:	E	A (new tube) and E (existing renovated tube) Note: After implementation of flame traps both tubes will be in category A.
- particular geographical and meteorological environment:	Rural tunnel – continental Mediterranean	
characteristics of the access roads: numerous, close to the portals:		
speed limit (km/h):	60	80
permanent surveillance:	Yes	Yes
strong influence of the emergency services:	Yes	Yes

RENOVATION CHARACTERISTICS		
Equipment	**State of the tunnel**	
	before renovation	**evolution after renovation**
Geometry: cross-section for a tube:		
- number of lanes:	1x2	2x2
- emergency lane and width:	No	No
- width of slow and fast lane:	3.75	3.75
- separation space for bidirectional and width:	No	
- width of emergency walkways, easily accessible:	width:1.08 m – Yes	width:1.08 m – Yes
- vertical alignment (slope):	Maximum 0.94%	Maximum 0.94%
- horizontal alignment: dangerous curves:	No	No
Infrastructure measures:		
Emergency exits:	No	Yes
- type (direct, cross connections, second tube or emergency gallery, shelters):		cross connections second tube (3 cross connections)
- inter distance:		380 m maximum
- suitable for the use of emergency services.		The mid cross connection is suitable for the use of emergency services.
- clear identification by the user:	Yes	Yes
Lays-bys:		
- presence:	Yes	Yes
- number:	1	1 for each tube
Drainage:	Separate system for road surface liquids but no flame traps	There is separate system with flame traps (siphons) , which prevents the spread of fire, for the new tube. Separate system, no flame traps for the old (renovated) tube. For this renovated tube there is provision for construction of flame traps in distances every 50 m in the near future (after peak traffic of summer months).
- slots gutters:	Yes	Yes
- siphoids gullys:	No	Yes for the new tube

RENOVATION CHARACTERISTICS (follow)		
Equipment	**State of the tunnel**	
	before renovation	**evolution after renovation**
Ventilation system:		
- longitudinal:	Yes	Yes
- smoke exhaust shaft - number:	No	No
- semi -transverse:	No	No
- smoke extraction dampers - interdistance:	No	No
- longitudinal air flow control:	No	Yes
Safety equipment:		
Emergency stations:		
- interdistance:	Maximum 200 m	For the new (left) tube interdistance 50 m, for the existing (right) tube maximum interdistance 200 m
Water supply:		
- interdistance hydrants:	Maximum 200 m	For the new (left) tube interdistance hydrants 50 m, for the existing (right) tube maximum interdistance hydrants 200 m
Lighting:		
- good lighting conditions:	No	Yes
Monitoring systems:		
- video:	Yes	Yes
- automatic incident detection:	No	Yes
- automatic fire detection:	Yes (conventional analogic detectors distributed in 7 zones)	Yes [linear heat sensor (optic fibre cable)]
- air quality control:	CO and visibility sensors	CO, NO_x, and visibility sensors, system for measurement of direction and velocity of the air
Tunnel closing equipment (barriers):		
- outside tunnel:	No	No
- inside tunnel:	No	No
- signals:	Yes	Yes
Communication:		
- radio:	No	No
- fire services broadcasting:	No	Yes
- loud speaker:	No	Only into cross connections

RENOVATION CHARACTERISTICS (follow)		
Equipment	State of the tunnel	
	before renovation	evolution after renovation
Operation issues:		
- personal training:	Yes	Yes
- emergency response plans:	Yes	Yes
- specific measures concerning DGV:	No DGV	No
- safety exercises:	Yes	Yes
- special traffic regulations (distances, etc.):	No	interdistance for cars 45 m, for HGV 90 m

MAIN CONCLUSIONS	
Risk analysis of the current state	**Key Improvements**
• Main influence parameters: - Composition of traffic load (for renovated tube, presence of loads with liquid fuels DGV tanks (unlike the new tube where there are mostly empty DGV tanks) and the possibility of spreading the fire from liquid spillage)	• Derogation (regarding local regulations) - There are not any derogations regarding local regulations and requirements of European directive 2004/54/EC
• Main deficiencies pointed out:	• Additional - compensating measures: - Tunnel control centre is not mandatory but required on the basis of results of risk analysis for transport of DGs

B.6. CASE N°6: UNI-DIRECTIONAL TUNNEL IN ITALY

TUNNEL CHARACTERISTICS		
	before renovation	**evolution after renovation**
General description:		
Location:	Italy	
Length (m):	1,669	
Number of tubes:	2	
Uni-directional or bi-directional traffic:	Uni-directional	
Urban:	No	
Traffic:		
annual average daily traffic volume:		
- per tube:	50,000	
- per lane:	12,500	
- indicate volume for peak hours:	5,000	
- risk of congestion (daily or seasonal):	Yes (daily)	
- presence and percentage of heavy goods vehicles:	Yes	
- presence, percentage and type of dangerous goods - traffic (% of HGV): - category according to EDR:	Yes 20% A	
Environment – operation:		
- particular geographical and meteorological environment:	urban tunnel	
- characteristics of the access roads: numerous, close to the portals:		
speed limit (km/h):	130	50
permanent surveillance:	No	Yes
strong influence of the emergency services:	No	No

RENOVATION CHARACTERISTICS		
Equipment:	**State of the tunnel**	
	before renovation	**evolution after renovation**
Geometry: cross-section for a tube:		
- number of lanes:	2 x 2	2 x 2
- emergency lane and width:	No	
- width of slow and fast lane:	3.75 m	3.75 m
- separation space for bidirectional and width:	No	
- width of emergency walkways, easily accessible:	0.75m – Yes	
- vertical alignment (slope):	1.5%	
- horizontal alignment: dangerous curves:		
Infrastructure measures:		
Emergency exits:		
- type (direct, cross connections, second tube or emergency gallery, shelters):	None	Cross connections
- inter distance:		300 m
- suitable for the use of emergency services.		Yes
- clear identification by the user:		Yes
Lays-bys:		
- presence:	No	No
- number:		
Drainage:	Yes	Yes
- slots gutters:	No	No
- siphoids gullys:	No	No
Ventilation system:		
- longitudinal:	No	Yes
- smoke exhaust shaft - number:	No	No
- semi -transverse:	No	No
- smoke extraction dampers - interdistance:	No	No
- longitudinal air flow control:	No	Yes
Safety equipment:		
Emergency stations:	No	Yes
- interdistance:		150 m
Water supply:		
- interdistance hydrants:		150 m
Lighting:		
- good lighting conditions:	No	Yes

RENOVATION CHARACTERISTICS		
Equipment:	**State of the tunnel**	
	before renovation	**evolution after renovation**
Monitoring systems:		
- video:	No	Yes
- automatic incident detection:	No	Yes
- automatic fire detection:	No	Yes
Tunnel closing equipment (barriers):		
- outside tunnel:	No	No
- inside tunnel:	No	No
- signals:	No	Yes
Communication:		
- radio:	Yes	Yes
- fire services broadcasting:	No	Yes
- loud speaker:	No	Yes
Operation issues:		
- personal training:	Yes	Yes
- emergency response plans:	No	Yes
- specific measures concerning DGV:	No	Yes
- safety exercises:	No	Yes
- special traffic regulations (distances, etc.):	No	Yes

MAIN CONCLUSIONS	
Risk analysis of the current state	**Key Improvements**
• Main influence parameters: - Traffic Volume - HGV percentage	• Derogation (regarding local regulations)
• Main deficiencies pointed out: - Open cross connections - Ventilation - Lighting	• Additional - compensating measures: - Compartmentalization and ventilation of cross connections - Longitudinal ventilation with air velocity control - LED ordinary and evacuation lighting - innovative techniques: - LED Visual guide for lighting and signalling - Prefabricated intelligent cross connection module (Ventilation, Lighting, signalling, communications, PLC)