Study on the implementation and effects of Directive 2004/54/EC on minimum safety requirements for road tunnels in the trans-European road network

FINAL REPORT

17 June 2015

ICF International in association with

TRT

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A report submitted by ICF Consulting Services
in association with

TRT Trasporti e Territorio

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Job Number

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Contents

Table of tables

Table of figures

List of abbreviations

AA	Administrative Authority(-ies)
ACC	Advanced Cruise Control
ADB	Automatic Differential Break
ANAS	Azienda Nazionale Autonoma delle Strade
ARZ	Autocesta Rijeka - Zagreb
ASECAP	European Association with tolled motorways, bridges and tunnels
ASFINAG	Autobahnen- und Schnellstraßen-Finanzierungs-Aktiengesellschaft
ASTM	Autostrada Torino Milano
ATIVA	Autostrada Torino Ivrea Valle d'Aosta
BAU	Business as Usual
CCTV	Closed Circuit Television
CETU	Centre d'Etudes de Tunnel
CIRCABC	Communication and Information Resource Centre for Administrations, Businesses and Citizens
COSUF	Committee on Operational Safety of Underground Facilities
DG MOVE	Directorate General Mobility and Transports
DSS	Decision Support System
EC	European Commission
EIB	European Investment Bank
ESCOTA	Autoroutes Estérel Côte d'Azur
ESP	Electronic Stability Program
DARTS	Durable and Reliable Tunnel Structures
EEA	European Economic Area
ETSC	European Transport Safety Council
EU	European Union
EuroTAP	European Tunnel Assessment Programme
EX	Expert(s)
FIA	Fédération Internationale de l'Automobile
FIT	Fire in Tunnels
FP5	5th Framework Programme
HGV	Heavy Goods Vehicle
HMD	Head-Mounted Display
INEA	Innovation and Networks Executive Agency[1]
ITA	International Tunnelling Association
ITS	Information Technology Services
LCC	Life Cycle Cost
L-surF	Large-scale Underground Facility on Safety and Security
NOK	Norwegian Krone
OECD	Organisation for Economic Cooperation and Development
PIARC	Permanent International Association of Road Congresses
QRA	Quantitative Risk Assessment

[1] INEA is the successor of the TEN-T EA (officially started its activities on 1 January 2014).

R.C.E.	Red de Carreteras del Estado
REFIT	Regulatory Fitness and Performance
SafeT	Safe Tunnels
SAFMEA	Statistically Adjusted Failure Mode and Effect Analysis
SALT	Società Autostradale Liguri e Toscana
SAV	Società Autostrade Valdostane
SFTRF	Société Française du Tunnel Routier du Fréjus
SIAS	Società Iniziative Autostradali e Servizi
SIRTAKI	Safety Improvements in Road & Rail Tunnels Using Advanced Information
SITAF	Società Italiana per il Traforo Autostradale del Fréjus
TERN	Trans-European Road Network
TM	Tunnel Manger(s)
ToR	Terms of Reference
TSMS	Tunnel Safety Management Systems
UPTUN	Upgrading of Existing Tunnels for Fire Safety

Executive summary

This report presents a mid-term evaluation of Directive 2004/54/EC

This is the final report of a mid-term evaluation of Directive 2004/54/EC. The Directive was intended to improve the safety of road users in tunnels by preventing critical events that might endanger human life, the environment and tunnel installations, and to reduce the consequences of accidents when they do occur. It was adopted in the wake of a number of serious road tunnel fires that caused significant loss of life.

The main aim of the evaluation is to analyse how Member States have implemented the Directive 2004/54/EC, to assess whether it has served its purposes and to identify its other economic, social and environmental effects. It considers the Directive's overall benefits and costs and looks at practices applied by Member States. The evaluation comes ten years after the Directive entered into force, at a point where the deadline for most Member States to fully implement the Directive's requirements has passed and those Member States that secured an extension need to be making the investments required to secure compliance by the final deadline in 2019. It is an opportunity to take stock and assess the extent to which the measures specified by the Directive have been applied and the Directive's overall objectives achieved.

The study was carried out for the Directorate-General for Mobility and Transport (DG MOVE) of the European Commission ('the Commission') under a contract with ICF International[2]. ICF worked in collaboration with TRT[3]. TRT carried out the larger part of the research.

This summary explains the evaluation method before describing the objectives of the Directive and the results of the evaluation by reference to its main themes.

The evaluation process involved desk-based research and analysis, written consultations and interviews

The terms of reference required the contractor to address a series of evaluation questions relating to the Directive that map onto the Commission's standard evaluation framework - addressing topics of relevance, coherence, effectiveness, efficiency, sustainability and EU added value. At the start of the study the evidence needs, the evidence-gathering approach and analytical approach required to address each evaluation question were determined. The project then moved into an evidence gathering phase that collected and reviewed:

- Data on the safety equipment installed in tunnels as of 2012-2014, as determined by Member States' reports to the Commission;
- Data on accidents and fires in tunnels from 20 Member States for the 2010-2014 period;
- The tunnel safety literature, making use of academic, government and others references (sources for this activity included the CIRCABC repository[4], the PIARC website[5], independent studies, datasets, research papers and presentations to international meetings and symposiums).

Tunnel Managers, Administrative Authorities and tunnel safety experts in the EU, Norway, Switzerland and selected international institutions were then consulted via questionnaires that were distributed by email. In addition, semi-structured interviews were conducted with selected stakeholders. These helped to clarify particular aspects of the implementation of the Directive and to identify good practices. Further research was carried out on five Member States (France, Germany, Greece, Italy and Slovakia) to inform the preparation case studies of the situation and impact of the Directive in these countries.

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[2] www.icfi.com

[3] www.trt.it

[4] CIRCABC is the Communication and Information Resource Centre for Administrations, Businesses and Citizens, established by the European Commission.

[5] PIARC is the World Road Association. Its website is at http://www.piarc.org/en/

In the final phase of the study responses to the evaluation questions were developed based on the totality of evidence gathered. Whilst data availability in many areas of interest to the evaluation was good, in others the scarcity of relevant information imposed constraints on how far specific evaluation questions could be addressed. Particular challenges were faced in relation to: (i) attribution of reductions in accidents in tunnels and of their consequences to the Directive; (ii) determination of the additional costs of the Directive over and above what Member States would otherwise have spent on tunnel maintenance and upgrades. In both cases the information needed to distinguish the impact of the Directive from other drivers of change was absent. These issues constrained responses to questions relating to effectiveness and efficiency of the Directive.

The objective of Directive 2004/54/EC was to establish minimum safety requirements for road tunnels in the trans-European Network

The Directive was designed to improve the safety of road users in tunnels. It applies to tunnels that: are in the trans-European Network; were in operation, under construction, or at design stage as of 30 April 2006; and are over 500 metres in length. Any refurbishment work needed to bring tunnels already in operation up to the prescribed standards had to be completed by 30 April 2014. Seven countries[6] with a higher than average density of tunnels were given an additional five years to complete the refurbishment of tunnels already in operation.

The Directive was intended to: adapt safety requirements to technical progress; achieve a large degree of harmonisation of practice and protection across the designated road network; and lead to the adoption of a harmonised risk analysis method. The Directive requires that safety measures are deployed further to a preliminary risk analysis. It identifies:

- administrative provisions to ensure a ***clear allocation of responsibilities*** amongst the entities involved (i.e., Administrative Authorities, Tunnel Managers, Safety Officers and Inspection Entities);
- ***administrative procedures*** ensuring a sound management of tunnel safety (e.g., periodic inspections); and
- ***safety measures*** including technical requirements and operational measures to ensure that tunnels are safe.

Of the 787[7] EU tunnels identified by the evaluation as being in the scope of the Directive, 548 were in operation as of 30 April 2006 and 239 are "new", i.e. have been, or will be, put into operation after 1 May 2006. 157 of these new tunnels have become operational since 1 May 2006 and the remainder are planned, or are under construction.

The principal conclusion is that the Directive is having a positive influence on road tunnel safety management but the job of bringing all TEN-T road tunnels over 500m into compliance with its requirements is far from complete and so the minimum safety standard prescribed by the Directive is not yet in place. Some Member States have much to do if they are to complete refurbishment programmes by the 2019 deadline.

The evaluation concludes that the Directive:

- Has had a positive effect in the awareness of the problem of tunnel safety.
- Is prompting investments that complement other road safety measures, such as safety campaigns, improvements in vehicle safety and introduction of speed control systems.
- Is credited with improving the capacity of tunnel managers and emergency services to manage dangerous events, and to prevent and mitigate the effects of accidents and fires.

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[6] Italy, Spain, Austria, Greece, Slovenia, Luxembourg and Croatia.

[7] If Norway is included the total number of tunnels in scope is 949.

- Is recognised as having led to a standard to approach regulation in this area since it establishes minimum safety levels;
- Has triggered research into new solutions and technologies.

Greater progress has been made with the operational and procedural aspects of the Directive than the infrastructure measures. These operational and procedural improvements represent the most significant impact of the Directive in the first ten years of its implementation.

Innovative practices have been identified in relation to: research on the causes of the incidents and on the suitable safety measures, identification of cost efficient measures and innovative techniques, cooperation programmes and joint training among the different subjects involved in the management of the incidents.

The Directive is, however, still far from achieving its overall objective of delivering a minimum level of safety in TEN-T road tunnels in the EU. The tunnel refurbishment programme has not been completed in many countries. Some Member States will face significant challenges in meeting their 2019 deferred deadline. These are also the countries that have a large number of tunnels. Action by the Commission to engage with these Member States on this issue is warranted.

The text below provides the findings on: the state of ***implementation***, the ***relevance*** of the Directive's objectives and requirements; its ***coherence*** in the context of EU and other prevailing law; the ***effectiveness*** of the prescribed measures, procedures and arrangements; its **efficiency** (focusing on the additional costs and the results achieved); **sustainability**, considering whether the changes made will have ongoing value, and its EU **added value**.

Implementation: *the 2014 deadline prompted action in many countries but there is still much more to do to achieve full implementation* in *certain Member States*

All the Member States have correctly transposed the Directive into their national legislation. However, nearly a decade since its adoption, the refurbishment of the tunnels in operation by the 30 April 2006 is far from complete. The degree of implementation of the Directive varies widely among Member States.

In those Member States with 2014 deadline, 82% per cent of the tunnels in scope (as measured by total tube length) subject to the 2014 deadline are compliant with the provisions of the Directive. In those Member States with a deadline extension to 2019 only 17% of the tunnels (by tube length) covered by the 2019 deadline are compliant. Considering the EU28 as a whole the overall compliance rate is 30% when assessed on total tube length and 26% when based on the number of tunnels.

The 2014 deadline for the refurbishment works was the most important driver for the implementation of the Directive. The main factor hampering the implementation of the safety requirements was the cost of refurbishing tunnels. The existence of innovative technologies has not been a key driver for implementation. Sixteen derogations have been reported for 13 tunnels, of which half concern water supply. Ten out of the 13 derogated tunnels are in Croatia.

Relevance: *The Directive's objectives and requirements align well to the problems they are intended to address; some adjustments would further improve the fit*

For the Directive to be relevant its objectives and the implementing measures should be appropriate to the identified problems. The Directive was intended to address the causes and mitigate the consequences of road accidents and fires in tunnels through a combination of infrastructure and tunnel management measures. The individual measures in the Directive work in combination to provide a safer road tunnel environment.

Data gathered on traffic accidents and fires in tunnels tend not to link events to specific attributes of tunnel infrastructure but the research suggests that the measures codified in the Directive are consistent with improving the general level of safety in tunnels. The Directive has, for example, enhanced the response of operators and emergency services that can mitigate the negative consequences of an accident. Nevertheless, a number of tunnel safety issues have been identified as insufficiently addressed by the Directive. Examples are flooding, communication inside the tunnel to help tunnel users rescue themselves, the definition of tunnels in particular conditions (e.g. tunnel located in rural areas or far away from emergency services stations), and the detection of high temperatures on heavy vehicles before they enter the tunnel.

Coherence: *Directive 2004/54/EC is a coherent component of the acquis, although there is some support for integration with Directive 2008/96/EC on road infrastructure safety management*

The assessment of coherence considers whether the Directive contradicts other interventions with similar objectives. In general, the provisions of the Directive fit well into the overall regulatory framework for road safety. The change required by the Directive varied widely across the Member States; in some cases its requirements were broadly consistent with pre-existing national standards, in other countries it set standards at a much higher level than had been required before.

A number of the stakeholder and experts consulted were in favour of the integration of Directives 2004/54/EC with Directive 2008/96/EC on road infrastructure safety management. They see benefits in reducing the differences in the approach taken to safety in tunnels of different lengths (i.e. below and above 500 m).

Effectiveness: Some *measures are recognised as having made a particular contribution to reducing the consequences of incidents in tunnels; the aggregate impact of the Directive is harder to determine.*

Evidence on the achievement of the Directive’s operational, specific and global objectives is mixed and in some cases absent. It has reduced the time taken to identify events in tunnels and the time for emergency services to respond. This helps to mitigate the effects of accidents and fires. High impact measures in the Directive include the requirement for a control centre and monitoring systems, and the specification of ventilation, equipment to close the tunnel and fire resistance equipment.

The cumulative impact of the investments and organisational changes triggered by the Directive on the number of incidents, injuries and lives lost in road tunnels cannot be determined with the available data. Road safety has improved significantly across the EU road network over the last ten years, but isolating the contribution of the Directive (where implemented) to the trends seen in specific tunnels, individual Member States and the EU as a whole is not feasible, as it would require a greater depth and consistency of investment and incident data collection at Member State level. Impact is also affected by implementation, which as noted above, is far from complete.

There is evidence to suggest that the Directive has increased the time required for tunnel design. On the operational side, the provisions have changed the managing operations and practices in tunnels, introducing new roles and responsibilities. The general impact of the refurbishment works prompted by the Directive on the environment, local populations and the traffic flows are considered to be minor, but data to quantify them are not available.

Broadening the scope of the Directive to include non-TEN-T tunnels would harmonise the safety and the regulations at national European levels. Taking into account the fact that ordinary roads are often older than motorways included in the Trans European Road Network. The cost of this extension of scope has been provisionally estimated at 1.6-2.4 billion Euro.

Efficiency: *The costs of achieving compliance have been significant in some Member States. Infrastructure costs vary according to factors that include the rigour of pre-existing national standards and the tunnel’s condition. Operational costs are more evenly spread.*

The most costly aspects of the Directive are the tunnel infrastructure requirements. Many tunnels have required upgrading to bring them into compliance. The operational measures of the Directive also imposed significant costs, especially in those countries where risk management was not previously implemented and the Safety Officer role was not in widespread use.

It is not possible to identify the costs generated by the Directive from the budgetary allocations made for maintenance and refurbishment. Similar challenges apply to the identification of expenditure triggered by the Directive's procedural and administrative requirements. The measures undertaken to implement the Directive are estimated to have on average a cost of 2-3 million Euro per kilometre of tube length for the refurbishment of tunnels but there is wide variation. Costs vary by country (based on the pre-existing standards), and by tunnel (according to factors that include tunnel age and physical characteristics).

The main source of financing for tunnel upgrades and maintenance was public funding. Concessionaires' equity and user tolls played a minor role. EU funds were used more extensively in Greece than in other countries.

Sustainability: *The measures required by the Directive continue to add value to tunnel safety, though technological change is reducing the need for fixed communication systems.*

This aspect of the evaluation examined the extent to which positive changes attributable to the Directive are expected to last beyond the period of their implementation. Communication and firefighting systems are the main areas where technologies influence safety measures, while traffic management technologies influences operational measures. Some measures of the Directive are considered obsolete. As an example, developments in communication systems (e.g. GSM coverage and use of smartphones) have reduced the need for emergency stations.

EU Added Value: *The Directive has delivered EU added value, effecting changes that go beyond what might have been achieved by national action alone.*

The evaluation considered the extent to which the Directive has brought about changes that would not have occurred through Member States acting independently, or cooperating bilaterally.

The Directive has delivered EU added value. Operators, ministry officials and road administrators share the view that the Directive, transposed into the national regulations, has had much stronger effects than recommendations or guidelines. It has established a common safety objective for all TEN-T road tunnels in the EU.

There is support for compliance with the Directive being a principle of conditionality for access to EU funds for financing the refurbishment or construction of the new tunnels, including tunnels outside the TEN-T network and outside the EU.

1 Introduction

1.1 This report

This is the final report of an evaluation of the Directive 2004/54/EC on minimum safety requirements for road tunnels in the trans-European road network (TERN), hereinafter 'the study', that was commissioned by the European Commission from ICF International working in association with TRT Trasporti e Territorio Srl.

The main objective of the mid-term evaluation study is to analyse how Member States have implemented the Directive 2004/54/EC.

The evaluation was performed: through: a literature review; the analysis of the responses to a stakeholder consultation exercise and a programme of interviews.

1.2 Evaluation context

The accidents that occurred in the tunnels of Mont Blanc (France-Italy, 1999), Tauern (Austria, 1999) and St. Gotthard (Switzerland, 2001) posed important questions about the safety standards of road tunnels. The tragic events of 1999 prompted work at Member State, EU and international levels.

After the Mont Blanc fire, technical and administrative investigations were undertaken by the French[8] and Italian governments. These resulted in two national reports and a joint bi-national report, providing 41 recommendations to improve the safety of tunnels and including information and training of users and stricter regulations according to the size and flammability of vehicles. In Switzerland a tunnel task force examined the overall safety of road tunnels and made recommendations regarding users, operation, infrastructure and vehicles. Similar steps were taken in other European countries, notably in Austria and Norway.

At European level:

- In order to harmonise the national initiatives, the Western Europe Road Directors created a working group composed of representatives of the Alpine countries and approved common recommendations in September 2000. This work was resumed and enlarged by the Economic Commission for Europe of the United Nations (UNECE) that established a multidisciplinary group of experts on road tunnel safety. The final report, published in December 2001, included recommendations on all aspects of road tunnel safety: road users, operation, infrastructure and vehicles.
- The European Union became involved, further to a request by its Heads of State. In response, the European Commission supported several tunnel safety research projects over the period 2001-2007 under the 5th and 6th Framework Programmes (FPs)[9], with 29 million Euro allocated[10].

At international level the PIARC Technical Committee on Road Tunnel Operation decided to give more emphasis to safety. Its working groups produced new outputs on: cross-section geometry in

8 A check of all tunnels longer than 1 km was carried out within 3 months. A new regulation on road tunnel safety was published a year later, but could only apply to tunnels owned by the State. A law was issued in 2002 in order to apply similar procedures to all tunnels, whoever their owner.

9 The 5th Framework Programme set out the priorities for the European Union's research, technological development and demonstration activities for the period 1998-2002. The 6th Framework Programme (covering 2002-2006) served two main strategic objectives: strengthening the scientific and technological bases of industry and encourage its international competitiveness while promoting research activities in support of other EU policies.

10 Of which 27 million Euro under the 5th Framework Programme and 2 million Euro under the 6th. The EuroTAP project has been funded by the European Commission over the years 2005-2007, but outside the 6th Framework Programme. The main findings of these projects are reported in Appendix 3

unidirectional road tunnels (2001), transport of dangerous goods through road tunnels (2001) and reports issued by specific Working Groups[11].

In the Communication COM(2003)311, the European Commission acknowledged that many of Europe's road tunnels had been built several decades previously, when traffic density and vehicle characteristics were different from what they are today. Application of a minimum safety standard across the EU's tunnels would require investment in the infrastructure and changes to tunnel safety management arrangements.

The European Union identified the need for a Directive on minimum safety requirements for tunnels in the Trans-European Road Network[12] to better achieve common measures at European level. In adopting the Directive 2004/54/EC the Member States implicitly recognised the value-added of the EU action in this area, in compliance with the principle of subsidiarity, as set out in Article 5 of the Treaty.

The Directive was designed to ensure the safety for road users in tunnels by preventing critical events that might endanger human life, the environment and tunnel installations and the identification of protection measures in case of accidents. It was specifically intended to:

- contribute to the achievement of a uniform, constant and high level protection of road tunnel users through the deployment of measures in line with technical progresses achieved and with a flexible and progressive timetable;
- strengthen the level of harmonisation as regards risk analysis methods and road users interfaces for tunnels on their territory;
- support the prevention of more serious consequences of the accidents occurred and ensure that the deployment of emergency services can act effectively and protect the environment, as well as limit material damage;
- foster and provide recommendations for the implementation of comparable safety levels for road tunnels located in territory that do not form part of the TERN.

The intervention logic of the Directive is summarised below.

Table 1.1 Directive intervention logic

Problems	Objectives	Output	Results	Impacts
■ Provide a response to tragic events in tunnels (in particular accidents occurred in the road tunnels of the Mont blanc (1999), Tauern (2001) and St. Gotthard (2001)) ■ Need of a common minimum level of safety in the road tunnels.	■ To ensure safety in tunnels by preventing critical events that might endanger human life, the environment and tunnel installations (material damage). ■ To alleviate consequences of such events, providing protection in	■ Installation of safety measures in existing TEN-T tunnels ■ Enhancement to administrative arrangements to ensure a clear allocation of responsibilities amongst entities involved (Administrative authorities, Tunnel Managers,	■ Reduction in the number of accidents and severity of accidents in TEN-T road tunnels ■ Mitigation of the consequences of accidents due to enhanced monitoring and response ■ Reference standard established for road-tunnel safety	■ Fewer deaths and injuries in TEN-T tunnels within scope ■ Reduced economic and social impact of accidents on tunnels within scope ■ Spillover impacts on accidents in tunnels beyond immediate scope of the Directive as the result of its influence on

[11] Operation, Human factors of safety, Communication systems and geometry, Dangerous goods and Fire and smoke control.

[12] Also referring to the conclusions of the study carried out by ICF International (2002) in collaboration with TRT.

Problems	Objectives	Output	Results	Impacts
■ Costs of refurbishing existing tunnels varies considerably amongst Member States.	case of accidents. ■ To adapt safety requirements to technical progress. ■ To achieve a large degree of harmonisation and adopt harmonised risk analysis method. ■ To identify a flexible and progressive timetable for the completion of most urgent works. ■ To encourage Member States to implement comparable safety levels for road tunnels outside the scope of the Directive.	Safety Officers, Inspection Entities). ■ Enhancement of tunnel safety management procedures (e.g. periodic inspections). ■ New tunnels designed and managed to at least a common minimum standard		tunnel design and operational practices elsewhere

This mid-term evaluation study is tasked with analysing the level of implementation achieved and demonstrate the effects generated in economic, environmental and social terms. Although the Directive was adopted ten years ago, the information anticipated on the level of implementation has highlighted that a considerable number of tunnels in operation still needs refurbishment works to be compliant with the provisions laid down.

The Directive applies to tunnels in operation, under construction, or at design stage with a length of over 500 metres[13]. It requires that any refurbishment work needed to bring tunnels already in operation up to the prescribed standards must be completed by 30 April 2014. Certain countries with higher than average density of tunnels within their borders[14] were given the option of taking an additional five years to complete the refurbishment works of tunnels already in operation[15].

The Directive also prescribes that safety measures have to be deployed, further to a preliminary risk analysis, inasmuch as minimum standards are met. The standards depend on: total traffic volume (per day, current or forecasted), percentage of heavy vehicles and geometry parameters (primarily length and longitudinal gradient). In this respect, the main categories of works identified were: structural (e.g. geometry of the tunnel, escape routes); lighting; ventilation; emergency stations; water supply; road signs; monitoring systems; equipment to close the tunnels; communication systems; emergency power supply; fire resistance of equipment. A summary of the minimum safety requirements set by the Directive is shown in Table A2.1.

[13] See Article 1.2.

[14] Greece, Spain, Italy, Luxembourg, Austria and Slovenia. Croatia, EU member since 2013, was also given the extended deadline to 2019.

[15] See Article 11.7.

With respect to the organisation the Directive defines certain roles and functions - the Administrative Authority (AA), the Tunnel Manager (TM), the inspection entity and the Safety Officer. On the operational side it sets the responsibilities of such entities for tunnel operation: safety documentation, inspections, exercises. Figure A2.1 shows the organisation defined by the Directive, with the entities, their main roles and interactions.

1.3 Evaluation purpose

The purpose of the evaluation is to provide the Commission with information on the progress made in the refurbishment and determine the overall effects of the provisions on tunnels under construction, or planned. On the basis of this evidence the evaluation is required to comment on the level of harmonisation achieved and its implications, highlighting any critical issues that emerged from the research, whether in respect of technical measures or with regard to management and operations..

In particular, the evaluation was commissioned to provide:

- An evaluation of the improvement in road tunnels safety, obtained by preventing critical events that might endanger human life, the environment and tunnel installation, also with the adoption of harmonised risk method;
- Analysis of how Member States implemented the Directive, both in terms of scope and provisions (administrative and technical requirements);
- An assessment of the results, consequences and impacts of implementation;
- An assessment of the effects regarding costs induced and benefits yielded;
- Details of best practices applied by Member States.

It was asked to consider the Directive's performance with respect to:

- **Implementation**: the extent to which the provision of the requirements stipulated in the Directive are applied by Member States.
- **Relevance**: the extent to which the objectives and implementing measures of the Directive are appropriate to address the identified problems.
- **Coherence**: the extent to which the Directive does not contradict other interventions with similar objectives.
- **Effectiveness**: the extent to which the operational, specific and global objectives of the Directive have been achieved, i.e. to what extent the effects correspond to the objectives.
- **Efficiency**: the relationship between financial inputs and identifiable outcomes, i.e. whether the effects have been achieved at a reasonable cost.
- **Sustainability**: the extent to which positive changes attributable to the implementation of the Directive may be expected to last beyond the period of their implementation.
- **Added Value**: the extent to which interventions or activities supported at the EU level bring about changes that would not have occurred through Member States acting independently, or cooperating bilaterally.

The terms of reference defined a set of evaluation questions, as listed in Table 1.2.

Table 1.2 Evaluation criteria and evaluation questions

Evaluation criterion	Evaluation question	
Implementation	1	Has the refurbishment of tunnels in operation been completed? What is the state of implementation in countries where the work is not yet completed?

Evaluation criterion		Evaluation question
	2	How many new tunnels were planned and constructed? Have the requirements of the Directive been applied to them?
	3	How many tunnels were inspected? How were these inspections carried out?
	4	Which factors might have hampered or slowed down the implementation of the Directive?
	5	How have technological developments affected the application of the Directive 2004/54/EC, especially in terms of safety, operational and organisational measures?
	6	To what extent were the derogations, notably concerning structural requirements, innovative techniques and safety measures laid down by Directive 2004/54/EC applied in the different Member States?
	7	To what extent were the technical measures implemented?
Relevance	8	To what extent is the Directive 2004/54/EC addressing the causes of accidents and fires in tunnels? Are other possible safety issues in tunnels sufficiently addressed?
	9	Is the scope of the Directive, i.e. tunnels of over 500m on the TEN-T network in all EU Member States and EEA plus Switzerland, adequate?
Coherence	10	The analysis on the coherence should evaluate the links of Directive 2004/54/EC with other objectives of the EU transport policy. In particular, the contractor should assess whether Directive 2004/54/EC is coherent with the objectives of transport externalities and road safety
Effectiveness	11	To what extent has Directive 2004/54/EC contributed to prevention of accidents and mitigations of the consequences of accidents? What have been the effects of the Directive on the planning and construction of new tunnels?
	12	To what extent has the Directive 2004/54/EC affected existing managing operations and practices in tunnels? Has this resulted in an improvement in terms of effectiveness of operations?
	13	What effects has the need of refurbishing existing tunnels had on the environment, local population and on the traffic flows?
	14	Has Directive 2004/54/EC had other indirect or unexpected effects?
	15	To what extent did the Directive 2004/54/EC have an effect outside the trans-European network and outside the EU? Did it have an impact outside the EU? In particular, what are the positive experiences and spill-over generated outside the EU and beyond EEA and Switzerland?
	16	To what extent could the effects identified be increased by broadening the scope of the Directive 2004/54/EC to include non-TEN-T tunnels?
Efficiency	17	What are the costs of measures undertaken to implement the Directive 2004/54/EC?
	18	At what costs were the procedures (commissioning, safety inspections, safety exercises, etc.) and other administrative arrangements described in the Directive established?
	19	To what extent did the use of derogations generate costs and/or benefits?
	20	Have measures related to budget planning been adequate for ensuring the minimum level of safety in tunnels?
Sustainability	21	The evaluation should estimate the long and medium term effects of the Directive and in particular: How technological development might affect the application of the Directive 2004/54/EC, especially in terms of safety, operational and organisational measures.
EU added value	22	Due to accidents and fires in the Mont Blanc, Taurern and Gothard tunnels, in 2004 the added value of EU action for ensuring a minimum level of safety was clear and practically self-explanatory. Is it still justified to maintain and possibly extend EU action for road tunnel safety?
	23	Would it be justified to apply the conditions established by Directive 2004/54/EC as principle

Evaluation criterion		Evaluation question
		of conditionality for acceding to EU funds for financing partially or totally, the works, refurbishment or construction of new tunnels, also outside the TEN-T network and outside the EU?

1.4 Report structure

The report is organised as follows:

- Section 2 describes the methodology used to determine the extent of implementation of the Directive 2004/54/EC, its results and its impacts ten years on. The scope encompasses safety measures on technical and operational requirements[16], administrative procedures to ensure sound management of tunnel safety[17] and administrative provisions on the allocation of responsibilities[18]. The process was conceived and structured to give an answer to each evaluation question. Section 2 describes the tools used to carry out the analysis. The work included a review of the literature, the scrutiny of the reports and documents made available in the CIRCABC repository and a stakeholder consultation. The preliminary scan of the data showed that there are gaps in the data available on road tunnels refurbishment works and on the accidents and fires that occurred. The stakeholder consultation helped to fill such information gaps and, consequently, supported the evaluation and the preparation of responses to the evaluation questions. The data on the tunnels were collected in a database for analysis.
- Section 3 presents the quantitative and qualitative assessment of the Directive in terms of results achieved and impacts generated by the adoption of its provisions. The structure of the assessment follows the methodology designed to answer the evaluation questions and provides an account of the counter-factual scenario (wherein the Directive would not have been deployed) against the current situation (in which the provisions have been in force for nearly a decade).
- Section 4 presents the conclusions of the report and section 5 lists the references used.
- The final section of the report gathers three appendixes on: the focus countries (France, Greece, Germany, Italy and Slovakia), tables and figures referring to the other main sections of the report and the descriptions of previous EU studies and additional literature sources reviewed.

[16] Article 3 and Annex I.

[17] Article 9 and Annex II.

[18] Articles from 4 to 7.

2 Method

This section describes the method adopted for the study.

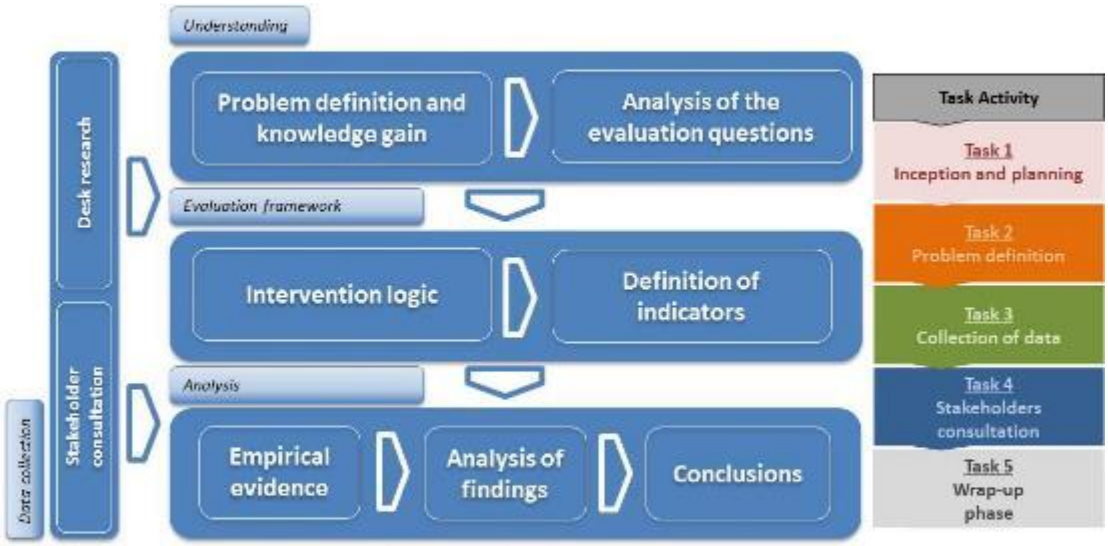
After an inception phase the project moved into a task focused on the development of an analytical framework focused on the evaluation questions defined the terms of reference. An evaluation matrix was developed which set out how each question[19] would be addressed during the study. For each question the evidence needs, evidence-gathering approach to be adopted and the analytical approach to be taken were defined.

The principal research and analytical tasks that followed were:

- The collection of data and literature review;
- Stakeholder consultations;
- A wrap-up phase in which the evaluation synthesis was prepared.

The basic structure of the method is illustrated in Figure 2.1.

Figure 2.1 Structure of the analysis, project tasks



2.2 Description of the analytical framework

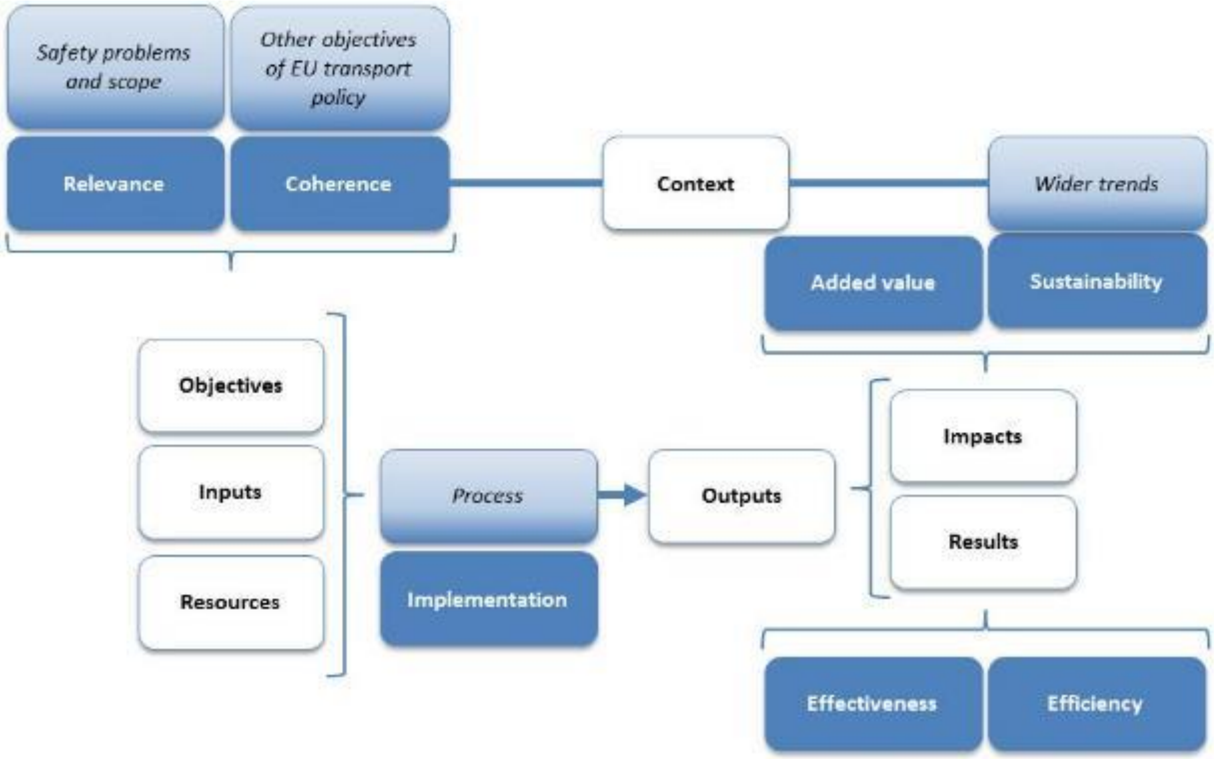
The evaluation questions are grouped under themes that explore the Directive's implementation, relevance, coherence, effectiveness, efficiency, added value and sustainability. Figure 2.2 describes the relationship between the various components of the evaluation. It shows the links identified amongst the evaluation criteria and illustrates the structure in which the thematic analysis of the Directive as a whole is elaborated.

The evaluation matrix is reproduced in Table A2.2 in Appendix 2. This:

- identifies what each evaluation question aims to measure and the indicator best fitting this purpose;
- shows the sources of information (e.g. stakeholders to whom the question is addressed);
- describes the methodology implemented to obtain the evaluation needed.

19 See paragraph 3, on page 3.

Figure 2.2 Schematic representation of the relationship between the components of the evaluation



2.3 Data collection and literature review

The first research task involved the collection of data and literature to support the evaluation. The data used in the study that ICF and TRT undertook in 2002[20] were taken as a starting point. The main findings of the nine previous EU studies conducted in the field of tunnel safety, over a period of nearly ten years, were then reviewed. More recent sources were then assessed to fill information gaps.

The principal sources used were:

- the Communication and Information Resource Centre for Administrations, Businesses and Citizens (CIRCABC) repository;
- the PIARC web site[21];
- previous EU studies in the field of tunnel safety, independent studies, datasets, research paper and presentations of international meetings and symposiums (see Appendix 3);

Data submitted to the European Commission according to Art.15 of the Directive are stored on the CIRCABC repository (see section 2.3). This was used as a reference for the requirements of articles 13 (Risk analysis) and 15 (Reporting) of the Directive. Table A2.3 in Appendix 2

[20] ICF Consulting. (2002). Costs and Benefits of Rehabilitating Road Tunnels in View to Enhance Safety, Final Report (with TRT Trasporti e Territorio).

[21] PIARC Technical Committee on Road Tunnel Operation was created in 1957. PIARC is not in charge of the constructional aspects, which instead are managed by the International Tunnelling Association (ITA).

summarises the reports[22] available and their date. These information were used to assess implementation and accident/fire data.

The information obtained from CIRCABC was integrated with findings from PIARC and EU studies and used to build the database described in section 2.5. It represents a key source for the evaluation presented in section 3.

Risk analysis methods analysed cannot be used for the evaluation process. This analysis is mainly used in two ways:

- to trade-off amongst alternative measures, when dealing with technical solutions that cannot be implemented, or that are feasible only at disproportionate costs;
- to prioritise the refurbishment works, by selecting tunnels with higher risk. .

Furthermore, in this respect, although the EC recommended the adoption of a harmonised approach, the EU funded SafeT project concluded that none of the methods developed "*gives the perfect solution for every risk assessment problem*". As highlighted also in PIARC (2008), a combination of methods seems more appropriate, depending on the context.

2.4 Stakeholder consultation

The stakeholder consultation involved:

- The distribution of questionnaires to TMs, AAs and experts (see section 2.4.1.2) from across the EU, Norway, Switzerland and selected international institutions (ASECAP, ETSC, FIA, ITA and PIARC);
- Semi-structured interviews with key stakeholders of five focal countries (Italy, Germany, France, Slovakia and Greece, see section 2.4.2) to highlight which measures have been taken and how the works have been organized in each of these states.

The consultation process is described in more detail below.

2.4.1 Questionnaires

2.4.1.1 Definition of the questions

The scrutiny of the CIRCABC repository and previous EU studies provided a fairly comprehensive overview that informed the preparation of the questionnaire for stakeholder consultation. The evaluation questions were fine-tuned in order to fill the remaining gaps of information and according to the following criteria:

- adapting the evaluation questions where the information was available but needed to be verified and updated;
- introducing additional questions and sub-questions in order to fill missing information according to the methodology proposed in the evaluation framework (see Appendix 2).

To simplify their presentation in the questionnaire, questions were rearranged by the main recurring topics, namely:

- Transposition;
- State of implementation;
- Periodic inspections;
- Cost of implementation;

[22] Reports on fires and accidents (Art. 15.1), forms on the state of implementation of the Directive (Art. 15.2), list of the new tunnels (not mandatory).

- Sources of financing;
- Derogations;
- Safety Issues;
- Innovative techniques;
- Indirect, or unexpected effects;
- Scope of the Directive.

The core set of evaluation questions was supplemented with a number of additional questions that the team of experts considered useful to improve the quality of the evaluation.

As not all the questions were applicable to every stakeholder, three different questionnaires were distributed, one for each stakeholder category: Administrative Authorities (AA), Tunnel Managers (TM) and Experts (EX).

2.4.1.2 Identification of stakeholders

AAs and TMs were identified during the review of forms and reports submitted by Member States. A total of 69 AAs and 97 TMs were recorded on a database. The experts were selected from:

- World Road Association (PIARC), Technical Committee 3.3 Road Tunnel Operations;
- users of the CIRCABC repository;
- Road Tunnel Safety Group of Experts;
- participants in the European Tunnel Safety Officers Forum.

During the consultation, it was found that some AAs at regional level, such as the Länder in Germany, also act as TMs. Furthermore, three Member States asked for a special questionnaire that combined the three versions. Therefore two additional versions were prepared, combining the questions of the basic versions (“AA+TM” and “AA+TM+EX”).

More than 300 questionnaires were sent out. For some entities the questionnaire were sent to multiple persons in order to reach the person who was able to provide the necessary information.

The provisions of the Directive are applied in 30 countries: the 28 Member States, plus Norway and Switzerland. The obligation to report[23] to the European Commission on fires and accidents and on the state of implementation of the Directive is not mandatory for the latter two countries; the available data are provided on a voluntary basis. During the stakeholder consultation no new data were provided for the Norwegian tunnels in addition to those already available, while no information is available for the tunnels in Switzerland. For this reason, the analysis in this report refers to the Member States and to a lesser extent to Norway.

Amongst the 28 Member States, four countries[24] were not consulted because they do not have tunnels in the scope of the Directive in operation, under construction or planned.

2.4.1.3 Response rates

Table A2.5 in Appendix 2 reports the number of questionnaires answered. Most of the AAs provided their contributions, in some cases in combination with the unique TM as mentioned above. The response attributed to the United Kingdom refers only to the AA of one county, Kent. Germany appointed the Federal Highway Research Institute (BASt) to officially answer the questionnaire, but limited its reply to the Expert questionnaire. Slovenia answered the combined version AA+TM of the questionnaire but did not complete the spreadsheet provided, thus some

[23] Art. 15 of the Directive.

[24] Estonia, Latvia, Lithuania and Malta.

technical data on its tunnels were not updated. No responses were supplied from Belgium, Bulgaria, Poland or Portugal.

Overall, 31 questionnaires were completed for specific countries. In addition, three questionnaires for experts not linked to any specific country were answered by members of ETSC and FIA, giving 34 answered questionnaires in all. The three responses of France, Germany and the Netherlands were provided on behalf of, in total, 67 AAs and TMs.

2.4.2 Interviews

In-depth research on how the Directive has been implemented was undertaken for five Member States as selected in the ToR: Italy, France, Greece, Germany and Slovakia. This analysis highlighted which measures have been taken and how the works have been organized in each of these states. The consultation was further complemented with a number of direct interviews involving key stakeholders and experts to examine in depth some topics of the study.

The interviews helped to clarify particular aspects of the implementation of the Directive and to identify best practices.

2.5 Tunnels database

Details of the tunnels in the scope of the Directive, listed in the forms submitted to the European Commission by the Member States, were collected in a database. For each record, the following attributes were recorded:

- country;
- number of the road;
- tunnel name;
- administrative authority;
- tunnel manager;
- tunnel length in metres;
- total tube length in metres;
- traffic volume (annual average daily traffic per lane);
- status (in operation, under construction or planned);
- year of opening to public traffic;
- year of the last inspection;
- actual compliance.

Some 27 additional fields were used to associate the compliance of the tunnels with the 27 groups of provisions of the Directive (see Table A2.1 in Appendix 2).

The geographical coordinates (latitude/longitude) of each tunnel were recorded. A preliminary geolocation was carried out using tools from various web services, namely: Google Maps, OpenStreetMap, Nominatim, Motorways - Exit Lists, Wikimapia and Foursquare. These services provide a geolocation that can be searched by name and address (so-called reverse geocoding). Each tunnel was searched by its name, checking by road number and length of the tunnel. During the stakeholder consultation, the actual geolocation of some tunnels, or missing information, was provided by AAs and TMs.

2.6 Data and other limitations

As with any evaluation, data and methodological constraints influenced the breadth and depth of evidence available.

The availability of data on the state of implementation of the Directive was comparatively good. Data from the period 2012-2014 were available for 18 out of 28 Member States for tunnels in operation by the 30 April 2006. For two Member States the data are older (2006 for Ireland and 2010 for Portugal). Data for new tunnels were available for the period 2010-2014 for 20 Member States. Four Member States do not have tunnels within the scope of the Directive and Croatia only recently joined the EU.

The response rate to the questionnaires distributed for this study was good, with 34 returned, covering AA and TM in 20 Member States. Information is, however, missing for five Member States (Belgium, Bulgaria, Czech Republic, Poland and Portugal). For Germany and France the questionnaires were not returned by the Administrative Authorities but rather by the national research centres (i.e. BASt and CETU) who acted on behalf of the local administrative authorities (Länder and Départements).

Data on accidents and fires in tunnels were available for 20 Member States. Figures were unavailable for three Member States (Cyprus, Poland and Romania). The absence of reports for these countries may be related to the small number of tunnels within scope of the Directive in these countries. However, determination of the impact of the Directive on safety was difficult due to factors that included:

- Significant changes in road safety across the EU over the period in question, both in tunnels and on the wider highway network;
- Lack of data that would facilitate comparison of safety performance in tunnels that had undergone refurbishment as compared to those that had not, either on a before/after basis for specific tunnels or across the total stock of tunnels in any given Member State;
- Differences among Member States in the approach to recording incidents and, in some cases, changes in the methodology used by individual Member States over the evaluation period. Though the Directive requires that “any significant incident or accident occurring in a tunnel shall be the subject of an incident report” (Art. 5.3) and “Member States shall compile reports on fires in tunnels and on accidents which clearly affect the safety of road users in tunnels” (Art. 15.1), the definition of significant incident does not seem sufficiently clear, hence a number of Member States adopted different definitions

These factors have an impact on the analysis of effectiveness.

Few data were available on the incremental costs incurred by Member States in meeting the requirements of the Directive. Investment costs for tunnels in operation and for new tunnels were returned by eight countries and data on maintenance costs provided by seven countries. However, it is very difficult to determine for any individual Member State, what costs are incremental over and above what would otherwise have been incurred in maintaining or upgrading tunnels in the absence of the Directive. For some Member States the Directive requirements were similar to those of pre-existing national standards, for others they represented a significant change. Some Member States have a large number of old tunnels that would require refurbishment and upgrading in the absence of the Directive, for others the tunnels are comparatively new. In addition, accounting methodologies and cost classifications are not standardised. These issues make the analysis of efficiency very difficult; the sound data needed to support a robust analysis are not available.

In addition, the benefits of specific measures required under the Directive cannot be assessed individually as it is the package of measures that is supposed to ensure the right level of safety in tunnels. Detailed analysis of the individual provisions of the Directive was not part of the scope of the evaluation.

3 The Evaluation

3.1 Introduction

This section presents the quantitative and qualitative assessment of the effects generated by the implementation of the Directive. The evaluation follows the seven criteria defined by the Commission:

- Implementation;
- Relevance;
- Coherence;
- Effectiveness;
- Efficiency;
- Sustainability;
- EU added value.

Each element of the evaluation consists of one or more evaluation questions, as reported in Table 1.2. For each criteria the general findings are presented, followed by the analysis of the relative evaluation questions.

3.2 Implementation

This section presents the assessment of the extent to which the provision of the requirements stipulated in the Directive have been applied by Member States.

3.2.1 Summary findings

All the Member States have correctly transposed the Directive into their national legislation (see Table A2.6 in Appendix 2). However, nearly a decade since its adoption, the refurbishment of the tunnels in operation by the 30 April 2006 is far from complete.

Table 3.1 reports the number of tunnels in the scope of the Directive for each country based on the data collected from Member State reports and information provided to this study by stakeholders. Considering the EU28, 787 tunnels with a total tube length of 2,045.5 km, are considered in the present study (705 in operation, 37 under construction and 45 at planning stage). Of these, 548 were in operation by the 30 April 2006. Thirty per cent of the tunnels in the scope of the Directive are "new", i.e. have been or will be put into operation on or after 1 May 2006 (239 out of 787 tunnels). Of these, 157 have become operational since 1 May 2006 and the remainder are planned or are under construction. Considering Norway in addition to the EU28, 949 tunnels fall in the scope of the Directive, with a total tube length of 2,284.0 km.

Figure 3.1 shows the location of "old" (i.e. in operation by the 30 April 2006) and "new" tunnels in the scope of the Directive. A location has been assigned to 771 tunnels, of which 738 are in operation, 18 are under construction and 15 are planned.

Very different levels of implementation of the Directive are observed across the EU (as measured by the share of tunnels that are fully compliant with the provisions of the Directive). Whilst 2014 was set as the default implementation deadline, seven Member States with a higher density of tunnels on the TEN-T (Italy, Spain, Austria, Greece, Slovenia, Luxembourg and Croatia) were given a later implementation deadline of 2019. Eighty two per cent of the tunnels (measured by total tube length) subject to the 2014 deadline are compliant with the provisions of the Directive, but only 17% of the tunnels covered by the 2019 deadline are currently compliant. The overall EU28 compliance rate is therefore 29% on total tube length and 26% on number of tunnels (see Table 3.2 and EQ 1). The provisions of the Directive have not been fully applied in at least 11 of the new (in operation post-30/4/2006) tunnels (see Table 3.2 and EQ 2).

Art. 12 of the Directive requires that the tunnels have to be inspected by the Inspection Entities[25] at least every six years to verify their compliance with the provisions of the Directive. For 251 out of 705 tunnels (36%) in operation in the EU the year of the last inspection was provided. In most cases it falls in the period 2012-2014. In general, the inspection criteria and frequency have been defined at national level. The AA acts as Inspection Entity in half of the countries (EQ 3).

The 2014 deadline for the refurbishment works was cited as being the most important driver for the implementation of Directive's provisions (EQ 4). The cost of refurbishing tunnels has been identified as the main factor hampering the implementation of the Directive. The existence of innovative technologies has not been a key driver for implementing the Directive, though technology development has affected the available solutions for some specific measures, namely communication systems, monitoring and control centres (EQ 5).

Sixteen derogations have been reported for 13 tunnels (see EQ 6). Half of the derogations concern water supply (point 2.11 of the Annex I of the Directive). Ten out of the 13 derogated tunnels are in Croatia.

Estimates of compliance with specific measures have been derived from the stakeholder consultations and not from the reports submitted to the Commission. These data provide more details but are less complete than those describing the overall compliance of the tunnels. In few cases it was observed that the general state of compliance reported to the Commission does not correspond to information provided the compliance with the single measures, data showing this inconsistency were checked and fixed in the database. There is compliance across all of the 705 tunnels in operation for only three of the measures prescribed by the Directive. The measure least respected relates to point 2.10 of Annex I ("Emergency stations"): 40% of the tunnels in operation are non-compliant with that requirement. The analysis for the Member States that had a 2014 refurbishment deadline shows a maximum rate of non-compliance for specific provisions of 4% (see EQ 7).

Table 3.1 Number of tunnels in the scope of the Directive by country[26]

Country	Tunnels in operation by 30 April 2006		New tunnels		Total	
	Number of tunnels (A)	Total tube length (km) (B)	Number of tunnels (C)	Total tube length (km) (D)	Number of tunnels (A+C)	Total tube length (km) (B+D)
Member States with deadline 2014						
BELGIUM	5	10.3	0	0.0	5	10.3
BULGARIA	5	8.8	0	0.0	5	8.8
CYPRUS	1	1.8	4	9.8	5	11.6
CZECH REPUBLIC	1	1.0	17	44.8	18	45.8
DENMARK	3	10.7	0	0.0	3	10.7
FINLAND	0	0.0	6	12.4	6	12.4
FRANCE	28	67.2	2	4.3	30	71.5
GERMANY	25	84.7	4	6.5	29	91.2
HUNGARY	0	0.0	4	14.8	4	14.8
IRELAND	1	1.2	2	10.4	3	11.7
NETHERLANDS	8	15.2	5	32.8	13	48.0
POLAND	0	0.0	12	32.0	12	32.0
PORTUGAL	3	6.5	1	11.3	4	17.8
ROMANIA	0	0.0	8	16.7	8	16.7

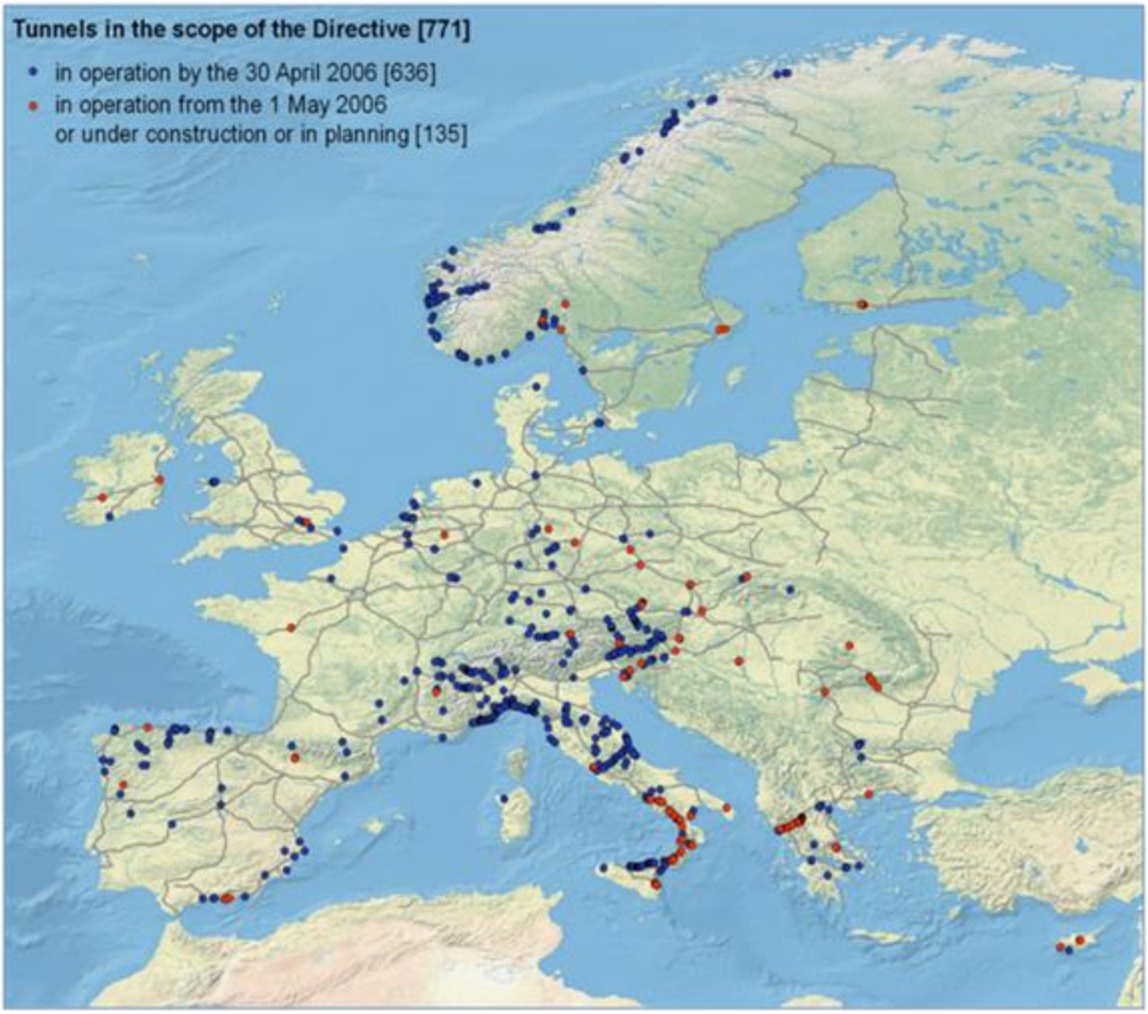
[25] Inspection Entities are defined by Art. 7 of the Directive.

[26] Estonia, Latvia, Lithuania and Malta do not have tunnels in the scope of the Directive.

Country	Tunnels in operation by 30 April 2006		New tunnels		Total	
	Number of tunnels (A)	Total tube length (km) (B)	Number of tunnels (C)	Total tube length (km) (D)	Number of tunnels (A+C)	Total tube length (km) (B+D)
SLOVAKIA	2	5.6	2	4.8	4	10.4
SWEDEN	1	3.2	2	63.0	3	66.2
UNITED KINGDOM	7	11.2	1	1.0	8	12.2
Total MS 2014	**90**	**227.3**	**70**	**264.6**	**160**	**491.9**
Member States with deadline 2019						
AUSTRIA	58	236.9	10	31.1	68	268.0
CROATIA	11	25.5	23	57.6	34	83.1
GREECE	24	41.3	44	131.7	68	173.0
ITALY	282	627.7	67	132.8	349	760.4
LUXEMBOURG	2	4.4	0	0.0	2	4.4
SLOVENIA	9	24.9	4	9.6	13	34.5
SPAIN	68	147.4	21	48.1	89	195.5
Total MS 2019	**454**	**1,108.0**	**169**	**410.9**	**623**	**1,518.9**
Binational tunnels*	4	34.7	0	0.0	4	34.7
Total EU	**548**	**1370**	**239**	**675.5**	**787**	**2,045.5**
NORWAY	119	235.9	43	2.6	162	238.5
Total EU + Norway	**667**	**1,605.9**	**282**	**678.1**	**949**	**2,284.0**

** Tunnels located on the territory of two Member States: Fréjus (FR/IT), Karawanks (AT/SI), Mont Blanc (FR/IT), Somport (ES/FR).*

Figure 3.1 Location of tunnels in the scope of the Directive[27]



3.2.2 Response to the evaluation questions

EQ1: Has the refurbishment of tunnels in operation been completed? What is the state of implementation in countries where the work is not yet completed?

The state of implementation and compliance is available at 2014 for all Member States except Bulgaria. Information for Belgium and the United Kingdom are older (dating from 2006 and 2010 respectively).

The data show that the implementation of the Directive is far from complete. Only 26% of the tunnels in operation by the 30 April 2006 (29% if calculated on the basis of tube length) are fully compliant with the Directive. Excluding the tunnels in Member States that benefit from Article 11.7 (extension of the refurbishment deadline to 2019) the percentage rises to 78% (82% in

[27] The indicated numbers refers to the tunnels which could be located.

The Trans-European Road Network adopted by the European Parliament and the Council in December 2013 is Copyright 2014 DG MOVE. The up-to-date version of the TERN is provided by TENtec Public Portal (http://ec.europa.eu/transport/infrastructure/tentec/tentec-portal). The basemap is made with Natural Earth (http://www.naturalearthdata.com).

terms of total tube length). The remaining tunnels are either not compliant or their state of compliance is unknown.

A summary of the minimum safety requirements set by the Directive is provided in Table A2.1 in Appendix 2.

51% of the EU tunnels in operation by the 30 April 2006 are located in Italy. Italy spent 940m Euro on tunnel refurbishment between 2007 and 2013 and a further expenditure of 1,784 million Euro is programmed. 70% of the investment has been allocated to refurbishment of electrical plants and lighting, escape routes and emergency exits. Most of tunnels are compliant with respect to the lighting and power supply requirements of the Directive. Lay-bys are available in longer tunnels, while an emergency lane is provided only in new tubes. Escape routes and emergency exits are installed in most tunnels longer than 1 km. Despite all these improvements, which are considered to bring to acceptable safety levels in the majority of tunnels, only 4% of the tunnels are fully compliant with the Directive.

Despite the implementation plan foreseeing a full compliance by 2019, in the case of Italy, the State of Implementation Plan delivered in 2014 indicates that:

- for some tunnels, included in the TEN-T network only in 2013, the deadlines is deemed to be postponed;
- tunnel managers will adopt operational and management operations in the medium term while for heavy infrastructure interventions, there will be the possibility to apply for derogations and or finding alternative solutions (guaranteeing comparable safety levels according to risk analysis);

In the EU 28 the compliance status is higher for tunnels with two or more tubes than for single tube tunnels (27% against 19% for the single tube tunnels), as illustrated by Figure 3.2[28]. As an explanation of this fact, it must be noted that refurbishment works in single tube tunnels, are more complex, as they imply a partial or full closure of the tunnel Of the 548 tunnels that were open as of 30 April 2006, 74 have a single tube. 40 of these are located in Italy and are not compliant. Similarly, 231 out of the 342 (67%) of the non-compliant tunnels with two or more tubes are located in Italy. This highlights that Italy accounts for a large share of EU28 tunnels in the scope of the Directive, hence the relevance of specific analyses carried out for the Italian case (see EQ 11 and EQ 17).

[28] The number of tubes in each tunnel in the database was assessed based on comparison of the recorded length and the total tube length.

Figure 3.2 State of compliance per number of tubes of the EU28 tunnels in operation by 30 April 2006

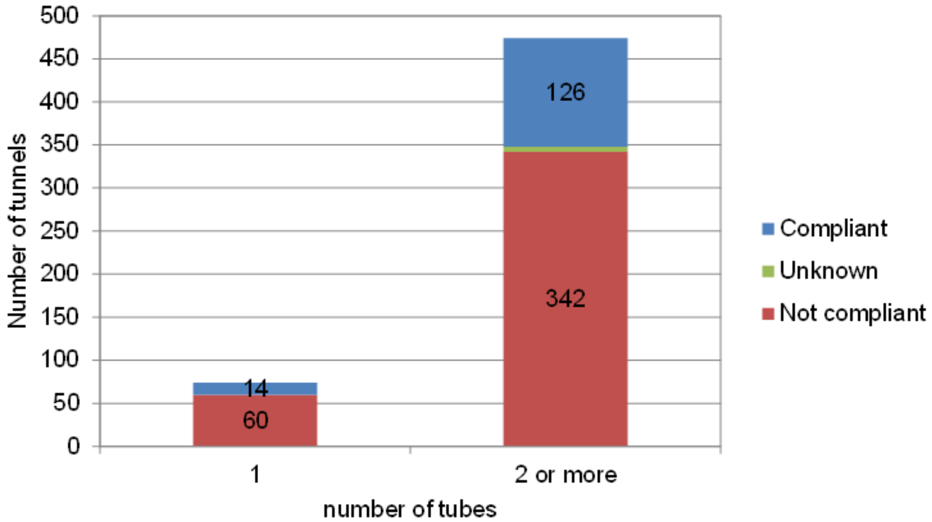


Table 3.2 provides an overview at country level of the state of implementation of the Directive, showing compliance by number of tunnels and total tube length. Finland, Hungary, Poland and Romania are not listed because they had no tunnels in the scope of the Directive as of 30 April 2006. Figure 3.3 provides a map of compliance status[29],[30].

The full available information is reported in the tunnels database compiled and annexed to this report.

[29] A database of compliance status will be supplied to the Commission as one of the deliverables of the current study.

[30] The total tube length for Norway is not known.

Table 3.2 State of implementation of the Directive per country for the tunnels in operation by 30 April 2006[31]

Country	Number of tunnels					Total tube length (km)				
	Total (A)	Compliant with the Directive (B)	Not compliant with the Directive (C)	State of compliance unknown (D)	Ratio (B)/(A)	Total (E)	Compliant with the Directive (F)	Not compliant with the Directive (G)	State of compliance unknown (H)	Ratio (F)/(E)
Member States with a 2014 deadline										
BELGIUM	5	2	3	0	40%	10.3	4.7	5.7	0.0	45%
BULGARIA	5	0	0	5	0%	8.8	0.0	0.0	8.8	0%
CYPRUS	1	1	0	0	100%	1.8	1.8	0.0	0.0	100%
CZECH REPUBLIC	1	1	0	0	100%	1.0	1.0	0.0	0.0	100%
DENMARK	3	2	1	0	67%	10.7	9.3	1.4	0.0	87%
FRANCE	28	25	3	0	89%	67.2	59.4	7.9	0.0	88%
GERMANY	25	22	3	0	88%	84.7	75.6	9.1	0.0	89%
IRELAND	1	1	0	0	100%	1.2	1.2	0.0	0.0	100%
NETHERLANDS	8	8	0	0	100%	15.2	15.2	0.0	0.0	100%
PORTUGAL	3	3	0	0	100%	6.5	6.5	0.0	0.0	100%
SLOVAKIA	2	2	0	0	100%	5.6	5.6	0.0	0.0	100%
SWEDEN	1	1	0	0	100%	3.2	3.2	0.0	0.0	100%
UNITED KINGDOM	7	2	5	0	29%	11.2	2.3	8.9	0.0	21%
Total MS 2014	**90**	**70**	**15**	**5**	**78%**	**227.3**	**185.6**	**32.9**	**8.8**	**82%**
Member States with a 2019 deadline										
AUSTRIA	58	8	50	0	14%	236.9	50.7	186.3	0.0	21%
CROATIA	11	9	1	1	82%	25.5	19.4	5.1	1.1	76%
GREECE	24	14	10	0	58%	41.3	28.9	12.4	0.0	70%
ITALY	282	11	271	0	4%	627.7	25.4	602.3	0.0	4%
LUXEMBOURG	2	1	1	0	50%	4.4	3.2	1.2	0.0	73%
SLOVENIA	9	6	3	0	67%	24.9	17.6	7.3	0.0	71%
SPAIN	68	18	50	0	26%	147.4	44.4	103.0	0.0	30%
Total MS 2019	**454**	**67**	**386**	**1**	**15%**	**1,108.8**	**189.5**	**917.4**	**1.1**	**17%**
Binational tunnels*	4	3	1	0	75%	34.7	26.8	7.9	0.0	77%
Total EU	**548**	**140**	**402**	**6**	**26%**	**1370.0**	**401.9**	**958.2**	**9.8**	**29%**

[31] Estonia, Finland, Hungary, Latvia, Lithuania, Malta, Poland and Romania did not have TEN-T road tunnels open by 30 April 2006.

Country	Number of tunnels					Total tube length (km)				
	Total (A)	Compliant with the Directive (B)	Not compliant with the Directive (C)	State of compliance unknown (D)	Ratio (B)/(A)	Total (E)	Compliant with the Directive (F)	Not compliant with the Directive (G)	State of compliance unknown (H)	Ratio (F)/(E)
NORWAY	119	20	99	0	17%	235.9	35.2	200.7	0.0	15%
Total EU + Norway	**667**	**160**	**501**	**6**	**24%**	**1,605.9**	**437.1**	**1,159.0**	**9.8**	**27%**

** Tunnels located on the territory of two Member States: Fréjus (FR/IT), Karawanks (AT/SI), Mont Blanc (FR/IT), Somport (ES/FR).*

Figure 3.3 Current compliance status of the tunnels that were operational by the 30 April 2006[32]

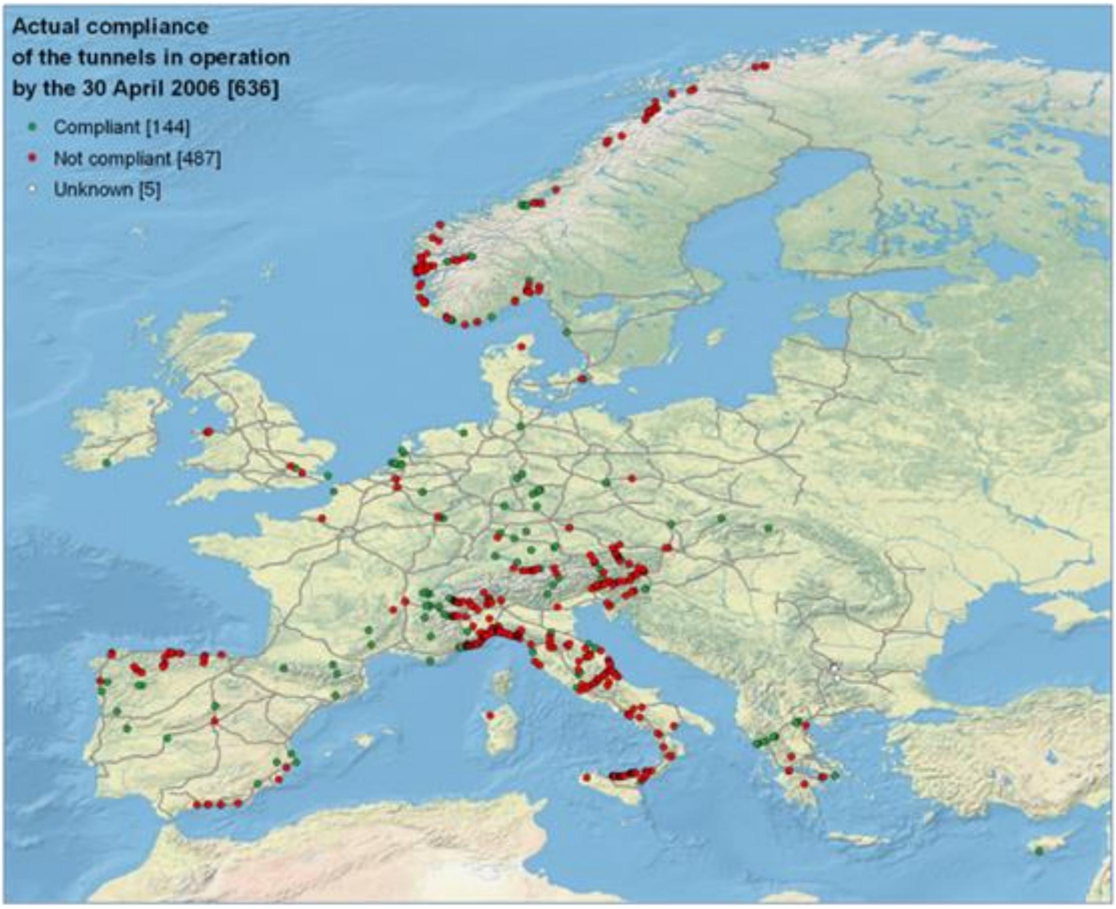


Table A2.5 in Appendix 2 shows the tunnels in operation as of 30 April 2006 and their state of compliance by reference to the tunnel manager (TM). Five TMs manage 56% of the tunnels in the scope of the Directive that were operational as of 30 April 2006. Three of these are Italian, while the other two operate in Austria and in Spain. Autostrade per l'Italia (IT) is the TM with largest number of tunnels. It manages 110 tunnels, nearly twice as many as ASFINAG (AT), the second-ranked tunnel manager. When assets are measured by total tube length, the ranking of these two organisations is reversed; ASFINAG manages 244.8 km of tunnels (18% of the total EU length) and Autostrade per l'Italia manages 204.8 km (15% of the EU total). The Norwegian Statens vegvesen Region vest is the fourth largest TM, associated with 50 tunnels (127.6 km of total tube length). Only 9% of the tunnels of the top five EU TMs are compliant; 14% when measured by total tube length.

EQ2: How many new tunnels were planned and constructed? Have the requirements of the Directive been applied to them?

Across the EU28, 157 new tunnels have been put in to operation since 1 May 2006. A further 37 tunnels are under construction and 45 are still at planning stage. In at least 11 tunnels that are in operation the provisions of the Directive were not fully applied, while for 9 of them the status in not known. The EU compliance rate is therefore 87% in terms of number of tunnels and 91% in terms of total tube length.

[32] The indicated numbers refers to the tunnels which could be located. See footnote 27 for the credits.

Table 3.3 shows the number and total tube length of new tunnels for each country. Overall, 239 new tunnels in EU Member States (operational and planned) fall under the scope of the Directive, with a total tube length of 675.5 km. When Norway's new tunnels are added, the total increases to 282 tunnels - 30% of the total in the scope of the Directive. Figure 3.1 shows the location of the new tunnels (red points) and the tunnels in operation as of 30 April 2006 (blue points). Table 3.3 reports the state of compliance of the new tunnels in operation by country.

In the EU28, at least 137 of the 157 tunnels that have become operational since 1 May 2006 are fully compliant with the Directive. The state of implementation for nine tunnels is unknown, while 11 are not fully compliant. The latter, nine of which are in Italy, consist of tunnels falling under Art. 10 of the Directive, i.e. "tunnels whose design has been approved but which are not yet open". The level of risk related to the non-compliance with a number of provisions of the Directive was assessed to be lower than the level of risk generated by the closure of the tunnels, in particular due to a lack of appropriate alternative routes. In terms of total tube length, and considering only the Member States with 2014 as deadline for the refurbishment works, at least 85% of the tunnels are compliant with the Directive.

Table A2.8 and Table A2.9 analyse the new tunnels and their state of compliance per TM. ANAS (IT) is the tunnel manager with the largest number of new tunnels (56, accounting for 111.9 km of tube length), most of which are already in operation (54 tunnels). 87% of the new tunnels managed by ANAS are fully compliant with the Directive. The non-compliant new tunnels are managed by nine out of the 36 tunnel managers that have new tunnels in operation. Data on the state of compliance was not provided by four TMs that have new tunnels in operation.

The tunnels database compiled for this study includes the new tunnels, with the corresponding state of compliance, in the scope of the Directive.

Table 3.3 New tunnels per country[33]

Country	Number of tunnels				Total tube length (km)			
	Total	in operation	under construction	planned	Total	in operation	under construction	planned
Member States with deadline 2014								
CYPRUS	4	0	0	4	9.8	0.0	0.0	9.8
CZECH REPUBLIC	17	2	1	14	44.8	6.4	1.2	37.2
FINLAND	6	5	1	0	12.4	11.4	1.0	0.0
FRANCE	2	2	0	0	4.3	4.3	0.0	0.0
GERMANY	4	4	0	0	6.5	6.5	0.0	0.0
HUNGARY	4	2	0	2	14.8	4.4	0.0	10.4
IRELAND	2	2	0	0	10.4	10.4	0.0	0.0
NETHERLANDS	5	2	2	1	32.8	10.6	22.2	0.0
POLAND	12	1	0	11	32.0	0.7	0.0	31.3
PORTUGAL	1	0	1	0	11.3	0.0	11.3	0.0
ROMANIA	8	0	0	8	16.7	0.0	0.0	16.7
SLOVAKIA	2	2	0	0	4.8	4.8	0.0	0.0
SWEDEN	2	1	0	1	63.0	13.0	0.0	50.0
UNITED KINGDOM	1	1	0	0	1.0	1.0	0.0	0.0
Total MS 2014	**70**	**24**	**5**	**41**	**264.6**	**73.5**	**35.7**	**155.4**
Member States with deadline 2019								
AUSTRIA	10	2	6	2	31.1	3.4	20.0	7.7
CROATIA	23	23	0	0	57.6	57.6	0.0	0.0
GREECE	44	26	16	2	131.7	69.8	51.4	10.6
ITALY	67	62	5	0	132.8	120.6	12.2	0.0
SLOVENIA	4	3	1	0	9.6	5.4	4.2	0.0
SPAIN	21	17	4	0	48.1	41.8	6.3	0.0
Total MS 2019	**169**	**133**	**32**	**4**	**410.9**	**298.5**	**94.0**	**18.3**
Total EU	**239**	**157**	**37**	**45**	**675.5**	**372.0**	**129.8**	**173.8**
NORWAY	43	27	16	0	2.6	2.6	0.0	0.0
Total EU + Norway	**282**	**184**	**53**	**45**	**678.1**	**374.6**	**129.8**	**173.8**

Source: TRT analysis of the questionnaires and of the reports submitted to the Commission

[33] Belgium, Bulgaria, Denmark and Luxembourg are not listed because they have no new tunnels in the scope of the Directive. Cyprus, Portugal and Romania do not have new tunnels in operation. The total tube length of the tunnels in the Netherlands and in Norway is only partially known (in the Netherlands the length of a planned tunnel is unknown). Greece and Poland have both one tunnel whose construction is suspended, but it is however still considered as a tunnel under construction.

Table 3.4 State of compliance of the new tunnels per country[34]

Country	Number of tunnels					Total tube length (km)				
	Total in operation (A)	Compliant with the Directive (B)	Not compliant with the Directive (C)	State of compliance unknown (D)	Ratio (B)/(A)	Total in operation (E)	Compliant with the Directive (F)	Not compliant with the Directive (G)	State of compliance unknown (H)	Ratio (F)/(E)
Member States with deadline 2014										
CZECH REPUBLIC	2	0	0	2	0%	6.4	0.0	0.0	6.4	0%
FINLAND	5	5	0	0	100%	11.4	11.4	0.0	0.0	100%
FRANCE	2	1	0	1	50%	4.3	1.0	0.0	3.4	22%
GERMANY	4	4	0	0	100%	6.5	6.5	0.0	0.0	100%
HUNGARY	2	2	0	0	100%	4.4	4.4	0.0	0.0	100%
IRELAND	2	2	0	0	100%	10.4	10.4	0.0	0.0	100%
NETHERLANDS	2	2	0	0	100%	10.6	10.6	0.0	0.0	100%
POLAND	1	0	0	1	0%	0.7	0.0	0.0	0.7	0%
SLOVAKIA	2	2	0	0	100%	4.8	4.8	0.0	0.0	100%
SWEDEN	1	1	0	0	100%	13.0	13.0	0.0	0.0	100%
UNITED KINGDOM	1	0	1	0	0%	1.0	0.0	1.0	0.0	0%
Total MS 2014	**24**	**19**	**1**	**4**	**79%**	**73.5**	**62.1**	**1.0**	**10.4**	**85%**
Member States with deadline 2019										
AUSTRIA	2	2	0	0	100%	3.4	3.4	0.0	0.0	100%
CROATIA	23	18	0	5	78%	57.6	51.7	0.0	5.9	90%
GREECE	26	26	0	0	100%	69.8	69.8	0.0	0.0	100%
ITALY	62	53	9	0	85%	120.6	106.4	14.2	0.0	88%
SLOVENIA	3	3	0	0	100%	5.4	5.4	0.0	0.0	100%
SPAIN	17	16	1	0	94%	41.8	40.3	1.4	0.0	97%
Total MS 2019	**133**	**118**	**10**	**5**	**89%**	**298.5**	**277.0**	**15.6**	**5.9**	**93%**
Total EU	**157**	**137**	**11**	**9**	**87%**	**372.0**	**339.1**	**16.6**	**16.3**	**91%**
NORWAY	27	26	1	0	96%	2.6	2.6	0.0	0.0	100%
Total EU + Norway	**184**	**163**	**12**	**9**	**89%**	**374.6**	**341.7**	**16.6**	**16.3**	**91%**

Source: TRT analysis of the questionnaires and of the reports submitted to the Commission

[34] Belgium, Bulgaria, Denmark, Estonia, Latvia, Lithuania, Luxembourg and Malta do not have new TEN-T road tunnels. Cyprus, Portugal and Romania do not have new tunnels in operation.

EQ3: How many tunnels were inspected? How were these inspections carried out?

The year of the most recent inspection was available for 251 of the 705 tunnels operational in the EU. Most of these inspections occurred in the period 2012-2014. The inspections of the tunnels may have been carried out either as required by Art. 12, to ensure that the tunnels comply with the Directive (periodic), or to verify the functionality of the structure and its management[35]. Table 3.5 shows the number and the total tube length of the tunnels that have been reported as inspected and Figure 3.4 gives the share of the tunnels on the basis of the year of their last inspection. The tunnels database compiled for this study includes the year of last inspection for each tunnel as of December 2014.

Table A2.10 in Appendix 2 lists the Inspection Entities per country. The methodology of the inspections is mostly defined at national level. In at least eight countries, the AAs also perform the role of Inspection Entity.

The TMs consulted indicated the frequency of the inspections for: highway infrastructure; mechanical and electrical infrastructure; tunnel structure; and geotechnical infrastructure.

The highway infrastructure is inspected every year in Greece (Egnatia Odos), Luxembourg and Sweden, every two years in Austria, every five in Spain and six in the Netherlands. In France, it is inspected during tunnel commissioning and then every three years.

The mechanical and electrical infrastructure is inspected annually in Austria, Greece (Egnatia Odos, while for the Attiki Odos it depends on the equipment) and Italy (ANAS), while the frequency is set at five years for Spain and six for France, for the Mont Blanc tunnel, the Netherlands and Sweden.

Tunnel structures are inspected annually for the Greek Attiki Odos and the Italian ANAS, while the frequency is every two years in Austria. For the Greek Egnatia Odos the frequency is every five years, while in France, in the Mont Blanc tunnel, in the Netherlands and in Sweden the inspection of this area is carried out every six years. In Spain such inspection is done when necessary.

Geotechnical infrastructure is inspected ‘when necessary’ in Spain and every 1-2 years in Greece (Egnatia Odos) and Austria. In France and Sweden the frequency is every six years.

Inspections intended to check compliance of the tunnels with the provisions laid down by Art. 12, are reported to be carried out every six years by Austria, Denmark, the Mont Blanc tunnel and Slovenia.

[35] Responses indicated the last year of inspection. No distinction was made in the questionnaire between inspections commissioned under Art. 12 to ensure that the tunnels comply with the Directive and those verifying the functionality of the structure and its management, so no distinction is made in the reported inspection data.

Table 3.5 Tunnels in operation inspected per country[36]

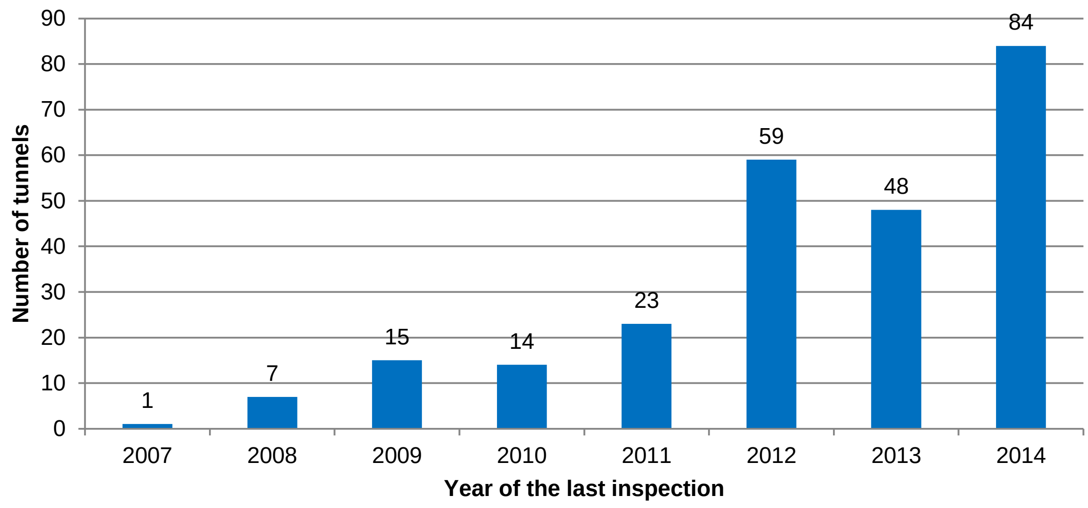
Country	Number of tunnels in operation			Total tube length in operation (km)		
	Total tunnels in operation (A)	Inspected tunnels (B)	Ratio (B)/(A)	Total tube length (km) (C)	Total tube length inspected (km) (D)	Ratio (D)/(C)
Member States with deadline 2014						
BELGIUM	5	0	0%	10.3	0.0	0%
BULGARIA	5	0	0%	8.8	0.0	0%
CYPRUS	1	1	100%	1.8	1.8	100%
CZECH REPUBLIC	3	0	0%	7.4	0.0	0%
DENMARK	3	1	33%	10.7	8.1	76%
FINLAND	5	1	20%	11.4	3.0	27%
FRANCE	30	0	0%	71.5	0.0	0%
GERMANY	29	1	3%	91.2	1.2	1%
HUNGARY	2	2	100%	4.4	4.4	100%
IRELAND	3	2	67%	11.7	10.3	88%
NETHERLANDS	10	6	60%	25.8	18.4	71%
POLAND	1	0	0%	0.7	0.0	0%
PORTUGAL	3	0	0%	6.5	0.0	0%
SLOVAKIA	4	4	100%	10.4	10.4	100%
SWEDEN	2	1	50%	16.2	3.2	20%
UNITED KINGDOM	8	1	13%	12.2	0.8	7%
Total MS 2014	**114**	**20**	**18%**	**300.8**	**61.6**	**20%**
Member States with deadline 2019						
AUSTRIA	60	60	100%	240.3	240.3	100%
CROATIA	34	20	59%	83.1	58.8	71%
GREECE	50	35	70%	111.1	80.2	72%
ITALY	344	53	15%	748.3	135.8	18%
LUXEMBOURG	2	0	0%	4.4	0.0	0%
SLOVENIA	12	0	0%	30.3	0.0	0%
SPAIN	85	60	71%	189.1	139.2	74%
Total MS 2019	**587**	**228**	**39%**	**1,406.5**	**654.3**	**47%**
Binational tunnels*	4	3	75%	34.7	28.1	81%
Total EU	**705**	**251**	**36%**	**1,742.0**	**744.0**	**43%**
NORWAY	146	0	0%	238.5	0.0	0%
Total EU + Norway	**851**	**251**	**30%**	**1,980.5**	**744.0**	**38%**

** Tunnels located on the territory of two Member States: Fréjus (FR/IT), Karawanks (AT/SI), Mont Blanc (FR/IT), Somport (ES/FR).*

Source: TRT analysis of the questionnaires

[36] MS 2014 and MS 2019 are Member States with deadline 2014 and 2019 for the refurbishment works, according to Art. 11.6 and 11.7 of the Directive. MS 2019 include Austria, Croatia, Greece, Italy, Luxembourg, Slovenia and Spain. Estonia, Latvia, Lithuania, and Malta do not have new TEN-T road tunnels. Romania does not have tunnels in operation in the scope of the Directive.

Figure 3.4 Year of last inspection



Source: TRT analysis of the questionnaires

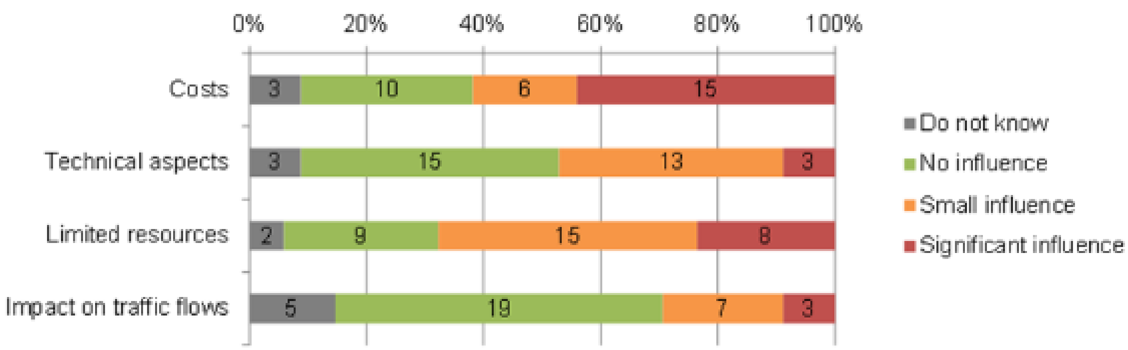
EQ4: Which factors might have hampered or slowed down the implementation of the Directive?

Four main factors were defined in the evaluation framework as possibly having hampered the implementation: costs for refurbishment of existing tunnels, technical aspects linked to the feasibility of the works, the limitedness of resources allocated and the impact on traffic flows. During the consultation few other factors were added to the analysis as reported below.

The consultation results indicate that refurbishment costs were the most significant constraint on implementation of the Directive, followed by the limited resources allocated by Governments / TMs. The two factors partially overlap: cost and scarcity of resources are both affordability constraints. The research suggests that no specific factors favoured implementation: the principal driver for refurbishment was the legislative deadline.

Figure 3.5 shows the perceived influence of the proposed factors on the basis of the 34 answers provided by all stakeholders (AA, TM and EX). The importance of costs as a constraint is confirmed for key countries such as Italy and Austria where the refurbishment of a high number of tunnels has required the allocation of significant funds.

Figure 3.5 Frequency and ranking of importance of the factors having hampered the implementation of the Directive



Source: TRT analysis of the questionnaires (34 answers)

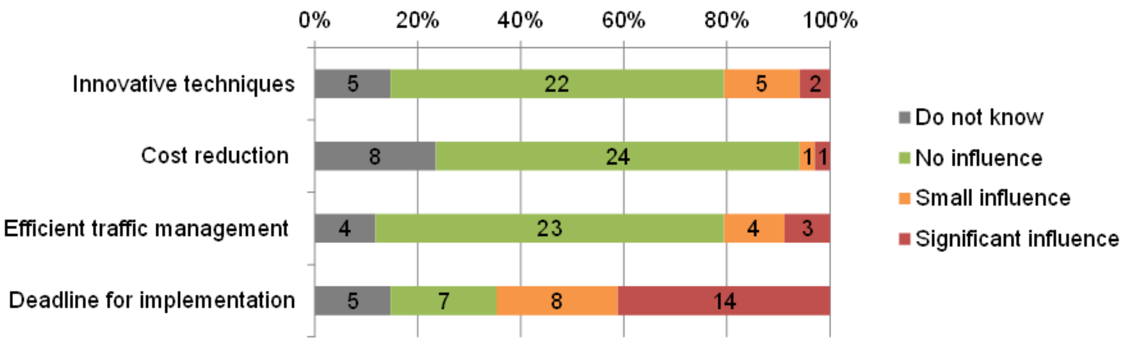
The other negative factors mentioned include the difficulty in arranging the new management arrangements defined by the Directive. In Greece, for example, delays in the transposition of the Directive into the national regulation (2007) and the subsequent setting up of the institution of the AA, affected the operations of the other stakeholders. The general inertia of the entities (included the TMs) is cited as factor affecting the speed of implementation of the Directive. Political will and unproductive discussions are also mentioned among the side effects.

Responses from Italy illustrate the variety of factors that impacted on the implementation of the Directive. Stakeholders variously cited:

- the economic crisis;
- scarcity of alternative routes due to the Italian orography;
- lack of prioritisation of the identified interventions;
- high number of tunnels;
- high density of tunnels;
- EU funds not available;
- complexity of the state authorization for public works involving areas outside the road.

Similarly, four factors were also indicated in the consultation as having possibly supported the implementation of the Directive: innovative techniques, cost reduction, efficient traffic management and deadline for the implementation. The deadline is cited as being the largest driver for the implementation of Directive's provisions (Figure 3.6). Another positive factor cited is the role of the Administrative Authority itself in relation to inspections and tests.

Figure 3.6 Frequency and ranking of importance among the factors that favoured the implementation of the Directive

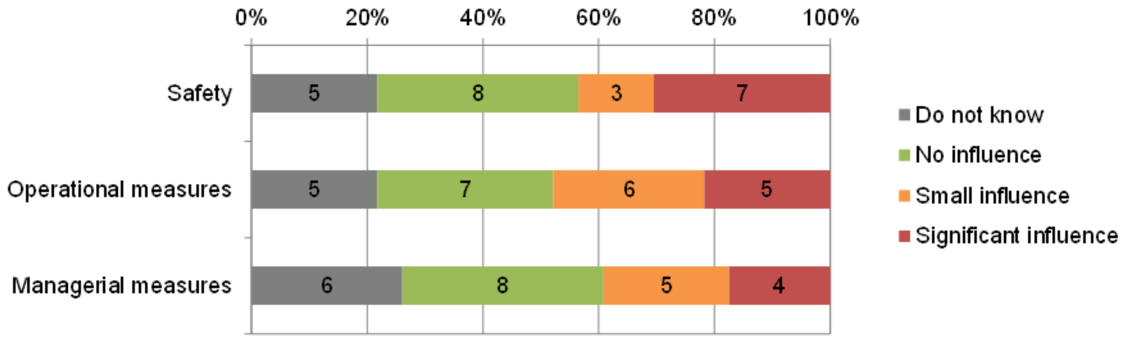


Source: TRT analysis of the questionnaires (34 answers)

EQ5: How have technological developments affected the application of the Directive 2004/54/EC, especially in terms of safety, operational and organisational measures?

Stakeholders do not consider innovative techniques to have had a large supporting influence on implementation of the Directive (Figure 3.7). However technology has evolved and the technical solutions available have changed over time. This allowed AAs and TMs in various countries to develop and install new technical solutions. This is especially true for operational measures (e.g. man-machine-interfaces, traffic management systems), and all requirements needing monitoring and communication systems.

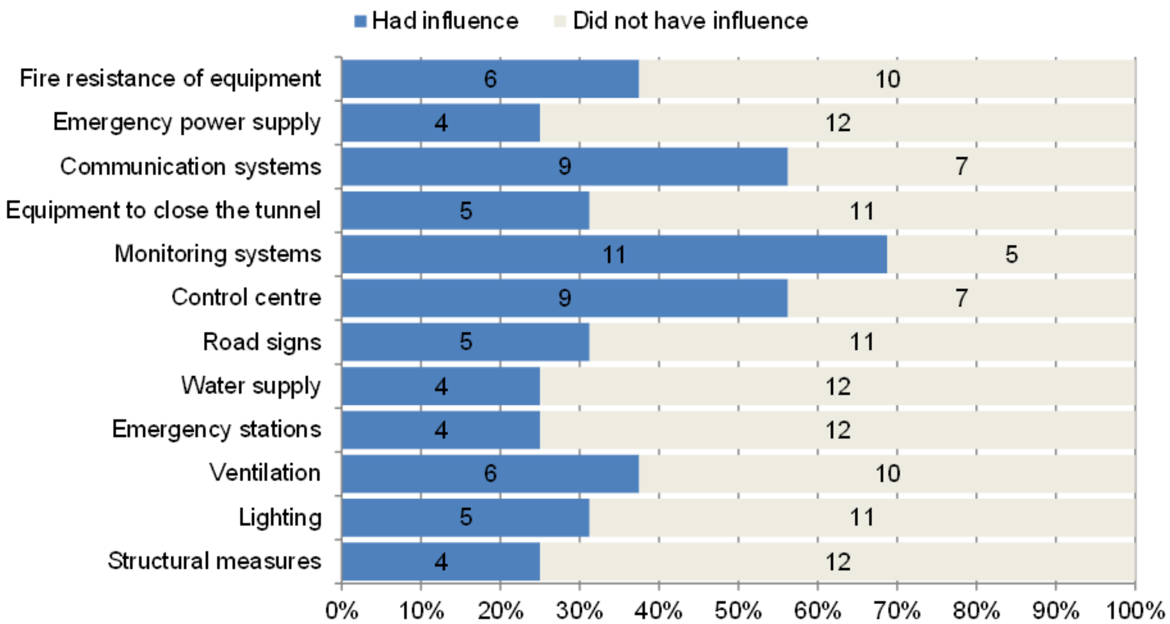
Figure 3.7 Degree of influence of the technological developments on the implementation of the Directive



Source: TRT analysis of the questionnaires (23 answers)

Technological change has had most impact on the solutions available for communication systems, monitoring and control centres (Figure 3.8).

Figure 3.8 Degree of influence of the technological developments on each safety requirement



Source: TRT analysis of the questionnaires (23 answers)

Technological developments considered include innovations that allow for a better performance of the existing measures but also alternatives to some equipment. Communication and fire protection systems and operational measures are the main areas covered.

Communication:

- New technologies can limit the traffic noise for the roadside telephones, reducing the need of acoustic hoods at emergency niches. The spread of GSM coverage in tunnels and of the use of mobile phones reduces reliance on emergency phones. SOS cabins can then be replaced by push buttons on the walls. Loudspeaker systems can now be used zonally to give different messages depending upon where users are located in the tunnel.

- Information technology systems should facilitate improved safety by monitoring and informing vehicle occupants as they travel, even before they reach the tunnel. Similarly (though it is not specifically linked to tunnel safety equipment) speed control on the whole road network could help to reduce the number of accidents in tunnels.

Fire protection systems:

- Fixed fire-extinguishers could replace fire hydrants, with the exception of those installed on tunnel portals. Smoke detectors could replace temperature detectors. In more general terms, the passage from analogue to digital has seen an improvement in fire detection devices.

Operational measures:

- Man-machine-interfaces (MMI) support the operators in the control centre. Technological development involves both software and hardware that constitute such MMI, therefore it indirectly influences the operations of the staff: if incident detection systems enable a faster response; automated emergency responses help to minimize human errors while they speed up the response.
- Traffic management systems (TMS) have been developed that are especially useful for long, or multiple successive tunnels. Predefined traffic management scenarios can be developed and, when an accident occurs, the operator can select the most suitable and get suggestions and assistance.
- The use of virtual reality for the training of operators (to simulate incident scenarios) is another example of technological development that indirectly improves procedures. The EU project Virtual Fires developed a simulator allowing for the training of fire fighters in the efficient mitigation of fires in a tunnel using a computer generated virtual environment.
- Technological aids can also help in extending the management of operations in case of emergency to senior officers that cannot be actually present in case of incidents (e.g., the virtual "silver command" post[37]).
- LED lighting systems can reduce maintenance and operating costs.

Further technology-related issues are discussed under the response to EQ 21, concerning the "sustainability" of the Directive and the effects of the technological developments on its application.

EQ6: To what extent were the derogations, notably concerning structural requirements, innovative techniques and safety measures laid down by Directive 2004/54/EC applied in the different Member States?

The available information suggests few derogations have been applied by the Member States. Altogether, 16 derogations are reported (collectively affecting 13 tunnels). However Italy foresees that more derogations will be applied as it looks to achieve compliance by the 2019 deadline.

Table 3.6 shows the number of derogations and the provisions for which they were applied. Ten of the 13 tunnels involved are Croatian, while the remaining three belong to Sweden, Denmark and Greece. All tunnels are in operation, the oldest one dating from July 2000 (the Øresund tunnel), whilst five of the Croatian tunnels become operational in 2008 and two in 2009.

[37] A gold–silver–bronze command structure is used by emergency services of the United Kingdom to establish a hierarchical framework for the command and control of major incidents and disasters. The Silver Commander is the tactical commander who manages tactical implementation following the strategic direction given by Gold and makes it into sets of actions that are completed by Bronze.

Table 3.6 Derogations granted per provision

Provision	Total EU	Total MS 2014	Total MS 2019
Tunnel geometry (§2.2)	1	1	0
Emergency exits (§2.3.3-.2.3.9)	1	0	1
Drainage (§2.6)	1	1	0
Emergency stations (§2.10)	4	0	4
Water supply (§2.11)	8	0	8
Road signs (§2.12)	1	0	1
Total	**16**	**2**	**14**

Source: TRT analysis of the questionnaires

Examples of derogations and their justification are provided below.

A derogation was granted in relation to the requirement on drainage for flammable and toxic liquids (point 2.6 of the Annex I) for the Øresund tunnel (4,050 m long) in Denmark for technical and economic reasons. The implementation of the requirement would have required extensive modifications that would have had a large impact on the availability of the tunnel.

A derogation in Greece for the tunnel Agia Varvara (700 m long, in operation before the 30 April 2006) which does not have an emergency exit at least every 500m (point 2.3.3-.2.3.9 of the Annex I). The derogation was granted on the basis that:

- there is no congestion risk, so in case of fire no people are expected ahead of the fire;
- the ventilation system has been upgraded in order to manage heat and smoke from a 100 MW fire;
- the tunnel has a control centre beyond the minimum requirements of the Directive;
- the excavation of a connecting gallery in a very weak and already loaded geomaterial has significant uncertainties and would introduce unacceptable risk on the existing structure.

In Greece, Italy and Slovenia in some cases alternative measures were adopted instead of resorting to derogations. For example:

- Transport of dangerous goods through 32 tunnels (in the scope of the Directive) on the Egnatia Odos, a highway in northern Greece, is forbidden as their drainage systems are not designed to prevent fire and flammable and toxic liquids from spreading inside the tubes (point 2.6 of the Annex I). A number of violations of the prohibition have been registered by the TM.
- The ventilation and fire protection systems were upgraded to provide an equivalent or higher level of protection than the emergency exits in the tunnel Vrilision in Greece and in the tunnel Golovec in Slovenia. The same occurred for the Appia Antica road tunnel in Italy.

EQ7: To what extent were the technical measures implemented?

The data on the implementation of each measure of the Directive are less complete than those describing the overall compliance of the tunnels. As a matter of fact, while information on the general state of compliance can be gathered from the reports provided by the Member States to the Commission (see section 2.3), information on the compliance with the specific requirements had to be collected directly from AAs and TMs, which was not provided for all countries. The tunnels database compiled for this study includes the detail on the state of compliance of each tunnel with the single measures of the Directive.

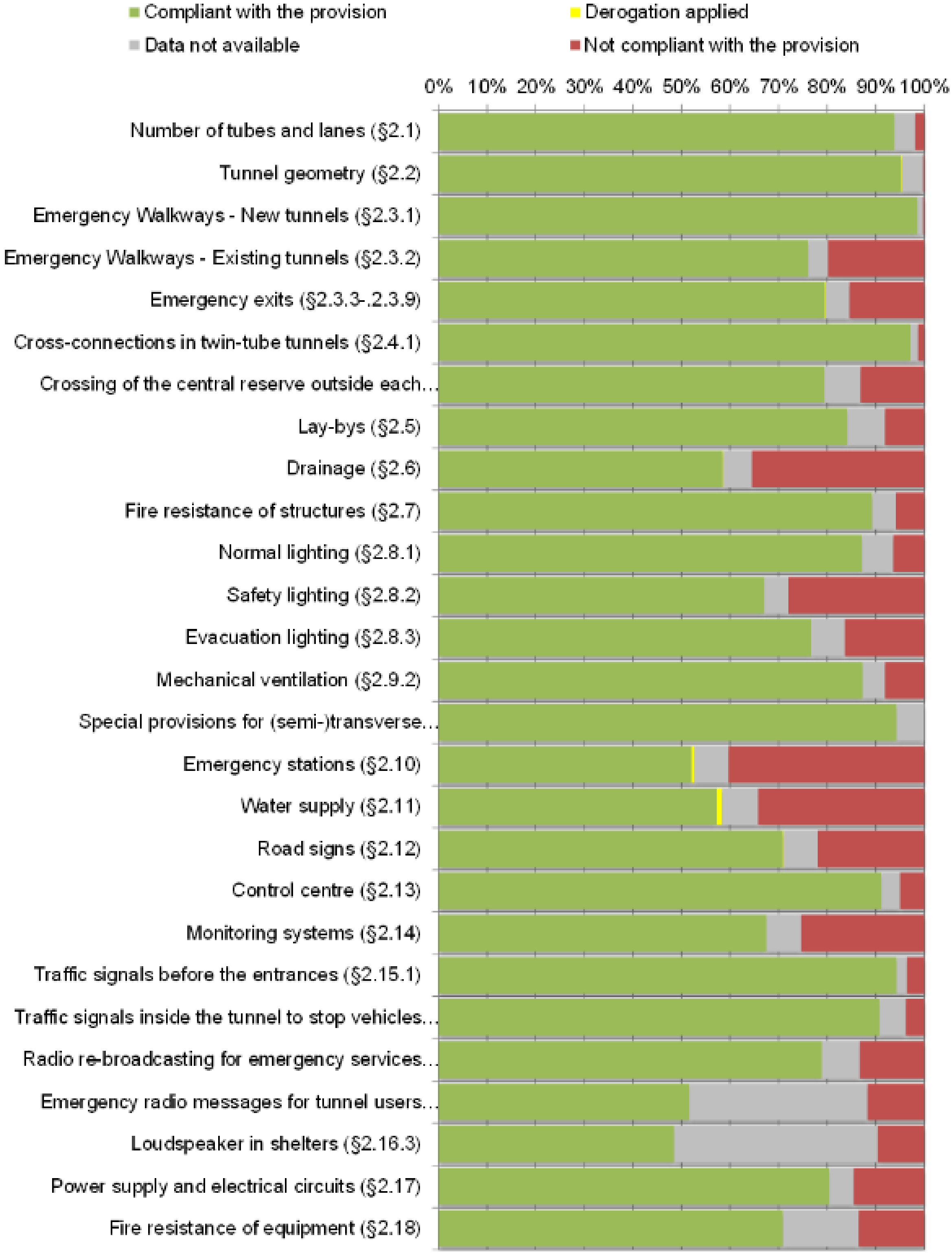
Error! Reference source not found. shows the state of implementation for each provision of the Directive according to the data provided by AAs and TMs in the EU. The data covered 705 tunnels that were either open to public traffic by 30 April 2006 or which have opened since from 1 May 2006. The percentage of tunnels which comply with each measure is indicated.

Only for three measures are all tunnels compliant. The measure least respected relates to point 2.10 of Annex I ("Emergency stations"): 40% of the tunnels in operation are non-compliant. Around 35% of the tunnels are not compliant with provisions relating to "drainage" (point 2.6) and "water supply" (point 2.11). Such percentages are due to the tunnels belonging to countries with deadline 2019, which also have a higher share of older tunnels. **Error! Reference source not found.** The corresponding analysis for the Member States that had a 2014 deadline (Figure 3.10) shows that, the maximum rate of non-compliance for any specific provision is 4%.

Looking across all measures, information is missing for 8% of the tunnels on average. There are three measures for which the data gaps are much more significant: "loudspeaker in shelters" (42%); "emergency radio messages for tunnel users" (37%); and "fire resistance of equipment" (16%). Again, the highest percentages of missing information involve countries with a 2019 compliance deadline. Some of this missing information refers to tunnels reported as fully compliant.

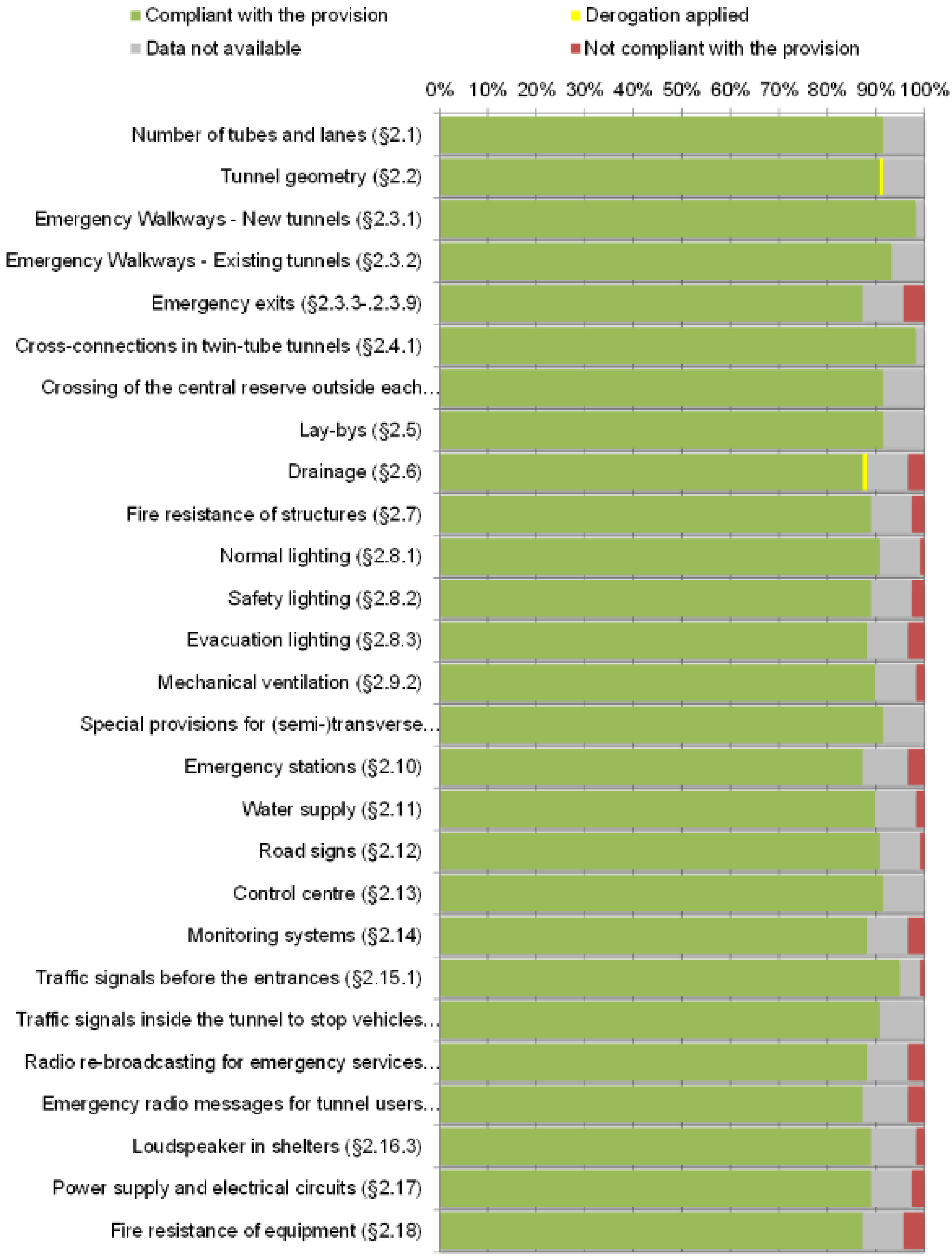
Derogations have been applied in few cases (tunnel geometry and drainage).

Figure 3.9 Compliance with specific provisions of the Directive, all tunnels



Source: TRT analysis

Figure 3.10 Compliance with specific provisions of the Directive, Member States with a 2014 deadline for refurbishment works



Source: TRT analysis

3.3 Relevance

This section presents the assessment of the extent to which the objectives and implementing measures of the Directive are appropriate to address the identified problems.

3.3.1 Summary findings

The Directive was intended to address the causes and mitigate the consequences of road accidents in tunnels through a combination of infrastructure and tunnel management measures. The individual measures in the Directive work in combination to provide a safer road tunnel environment. Data on traffic accidents in tunnels tend not to link events to specific attributes of tunnel infrastructure.

Some insight into causes of accidents is provided by a published analysis of 502 accidents in Austria over the 1999-2005 period. The main causal factors highlighted were various categories of human error – inappropriate driver behaviour (e.g. not maintaining a safe distance from the vehicle in front), misinterpretation of the traffic situation or driving conditions, lack of vigilance (with distractions, fatigue, alcohol, etc. as contributory factors) and excessive speed. The Directive does not address all these causal factors directly but overall the implementation of its requirements is effective at improving the level of safety in tunnels and containing the consequences when a problem occurs.

A number of tunnel safety issues are insufficiently addressed by the Directive. These include flooding, communication inside the tunnel to enhance the self-rescue of the users, definition of tunnels in particular conditions (e.g. tunnel located in rural areas or far away from emergency services stations), and the detection of high temperatures on heavy vehicles before they enter the tunnel (EQ 8).

The Directive provides a minimum safety level at the European level for tunnels over 500 m on the TEN-T, but may lead to differences at the national level, in terms of: (i) safety in tunnels shorter than 500 m and those not on the TEN-T; and (ii) responsibilities. 48% of the consulted AAs and experts consider it useful/feasible to include the non-TEN-T tunnels in the scope of the Directive, while the 38% have the same opinion with regard to the tunnels shorter than 500 m (EQ 9).

3.3.2 Response to the evaluation questions

EQ8: To what extent is the Directive 2004/54/EC addressing the causes of accidents and fires in tunnels? Are other possible safety issues in tunnels sufficiently addressed?

The main causes of accidents in tunnels include: wrong behaviour, misinterpretation, lacking vigilance and speed. A useful analysis is reported in the 2014 report on fires and accidents[38] on the cause of 502 accidents in tunnels that occurred in the period 1999-2005.

It shows that 42% of the accidents were due to various categories of human error: the inappropriate driver behaviour, unsafe distance to the vehicle in front (18% of all accidents analysed), overtaking manoeuvres, failure to remain within the marked lane and other driving failures. 36% of the accidents were associated with a lack of vigilance, generated by distraction (15% of all cases), fatigue (9%), blinding or consumption of alcohol or drugs. Excessive speed was the cause of accidents in 4% of the cases, more relevant in unidirectional tubes than in bidirectional tubes. Some accidents were caused by “misinterpretation” of the situation (e.g. vehicles in front driving slow or stationary, the state of the road pavement or on the weather including sudden fog, rain or wind, while exiting a

[38] Report 2014 on fires and accidents of Austria.

tunnel). Five per cent of the events considered related to other causes, such as mechanical failures, unexpected events and suicides.

The causes of accidents not properly addressed by the Directive mentioned by respondents to the survey are:

- obstacles inside the tunnel, as refurbishments, stopped vehicles, falling equipment and spillages onto road surface, drivers leaving their vehicle, congestion / traffic jams;
- poor driver behaviour, lack of understanding of dangers posed by an enclosed space as opposed to the open road, safety distance between vehicles;
- over-sized vehicles;
- "near fire" accidents, such as vehicles burning excess oil and producing thick white smoke inside tunnels such that visibility is much reduced, cameras views are obscured, air pollution sensors are activated, and other drivers prompted to stop or reverse.

The two main causes of tunnel fires are technical defects and accidents. Technical defects include vehicle breakdowns and overheated vehicles or vehicle parts (brakes, tires, motor, etc.), in particular in tunnels with steep gradient. Another source of fires can be identified in heavy goods vehicles with loads not classified as dangerous goods, but highly flammable (e.g. new energy carriers like Ethanol and biogas)[39].

Summing up, the Directive is effective in improving the level of safety in tunnels but it does not directly address all the causes of accidents and fires. In case of an event, however, a number of provisions (e.g. monitoring systems) facilitate a quick response by the operators and emergency services that can prevent the negative development of the situation. The effectiveness of the measures provided by the Directive is discussed in EQ 11.

EQ9: Is the scope of the Directive, i.e. tunnels of over 500m on the TEN-T network in all EU Member States and EEA plus Switzerland, adequate?

On a qualitative basis, the scope of the Directive is adequate with regard to the number of tunnels where the provisions are applied. However, the same standards of the Directive were incorporated into the national legislation and applied to tunnels also outside the original scope of the Directive.

Two possible extensions of the scope were considered: the inclusion of tunnels outside the TEN-T and the inclusion of tunnels shorter than 500 m. Few data are available to assess the effects of either.

In the first scenario (inclusion of tunnels outside the TEN-T), the number of the tunnels involved would be at least equal to 1,486. Table 3.7 reports the number of tunnels with tube longer than 500 m outside the scope of the Directive, grouped by tube length. 537 tunnels were identified, but the data are incomplete for some countries[40]. The Directive is currently applied to 949 tunnels (Table 3.1). These correspond to the 64% of total number of tunnels in the hypothetical scope considered.

In the second scenario (inclusion of tunnels shorter than 500 m) the total number of tunnels involved would be higher than in the previous scenario, but fewer data are available. In Italy, figures for 2011[41] show that the State-owned road operator ANAS manages 1,235 tunnels: 98 tunnels are already within the scope of the Directive (Table A2.7 and Table A2.8 in Appendix 2), while 266 are non-TEN-T tunnels longer than 500 m (Table 3.7). Hence, the

[39] Lönnermark A. (2010). New Energy Carriers in Tunnels. Fourth International Symposium on Tunnel Safety and Security.

[40] For Spain the numbers refer to tubes, but it is not specified if they correspond to tunnels as well. The tunnels of Italy are reported by TM ANAS. The figures reported by the Swedish AA and TM differ slightly, thus they were combined. For the United Kingdom the data includes only the tunnels in Kent.

[41] Valente A. (2012).

assets of ANAS alone would add 871 tunnels shorter than 500 m to the list if the scope of the Directive was broadened in this way

Table 3.7 Number of tunnels outside the scope of the Directive per country and per class of total tube length

Country	In operation			Planned/under construction			Total
	500-1000 m	1000-3000 m	> 3000 m	500-1000 m	1000-3000 m	> 3000 m	
AUSTRIA	30	35	6	3	1	0	75
CROATIA	2	2	1	0	1	0	6
GREECE	3	2	0	1	0	0	6
SPAIN*	36	14	3	0	0	0	53
FINLAND	1	0	0	1	1	0	3
FRANCE	42	29	7	4	2	0	84
HUNGARY	0	0	0	0	0	1	1
ITALY**	127	123	16	0	0	0	266
LUXEMBOURG	2	1	0	1	2	0	6
NETHERLANDS	5	4	1	3	4	0	17
ROMANIA	1	0	0	0	0	0	1
SWEDEN***	4	5	1	3	1	0	14
SLOVENIA	0	1	0	2	1	0	4
UNITED KINGDOM****	1	0	0	0	0	0	1
Total	**254**	**216**	**35**	**18**	**13**	**1**	**537**

* Tubes are specified

** Anas

*** Mixed from AA and TM

**** Kent

Source: elaboration of literature and questionnaires

Several requirements of the Directive were already applied in a number of countries before its introduction, although the refurbishment of the existing tunnels was not required. After the introduction of the Directive, these provisions have been applied also to tunnels outside the trans-European network in at least seven countries (Austria, Greece, Finland, Hungary, Luxembourg, the Netherlands and UK). Specific examples of measures being applied beyond the scope of the Directive are:

- Austria: the same standards will apply to tunnels outside the TEN-T on highways and expressways by 2029;
- Germany: all existing and new road tunnels are built, equipped and managed according to the requirements of the Directive, as established by the national RABT 2006 guidelines;
- Finland: all the tunnels are constructed to be compliant with the requirements mentioned in the Directive;
- Spain: the transposition of the Directive concerns also tunnels on the Central Road Network that have a length of less than 500 m.
- Italy: the State-owned road operator applies the requirements of the Directive to all tunnels of the National Road network with a length greater than 500 m.

- the Netherlands: most of the requirements of the Directive were applied to all road tunnels longer than 250 m.
- UK: many TMs (also outside TEN-T) consider the Directive as best practice that should be adhered to.
- France: the role of the Safety Officer is highly valued, and the measures suggested by Safety Officers are used as reference by Tunnel Managers of tunnels with a length > 300 m as well.

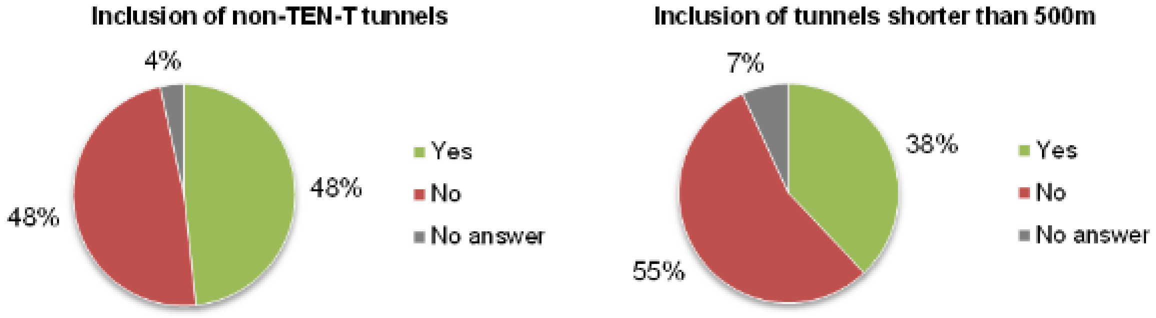
Table A2.11 and Table A2.12 in Appendix 2 report, for each country, the measures in the Directive that are applied to tunnels outside the TEN-T and to TEN-T tunnels shorter than 500 m. In consultations few data were provided on the number of tunnels that are beyond the scope of the Directive that had been refurbished to meet its standards. Data returns suggest that four tunnels in Austria and six in Luxembourg meet its requirements.

The number of measures applied to the two groups of tunnels is generally the same, except in three countries (Austria, Cyprus and France). In Austria a larger number of provisions are applied to tunnels outside the TEN-T, while in Cyprus and in France the requirements of the Directive concentrate on TERN tunnels shorter than 500 m. In Finland, Hungary, Luxembourg and in the Netherlands all, or almost all the measures of the Directive are applied in both types of tunnels outside the scope of the Directive.

Figure 3.11 shows the views of the AAs and experts on extension of the scope of the Directive to non-TEN-T-tunnels and to tunnels shorter than 500 m. With regard to the first scenario (extension to non-TEN-t tunnels), opinions are fairly split: 48% of respondents are in favour and 48% against. Respondents cited the heterogeneity[42] of non-TEN-T tunnels as a reason for not including them. 38% of the respondents were in favour and 55% against the second scenario (extension to tunnels short than 500m).

The research suggests that safety measures should be identified case by case and using the related accident rate as baseline (in terms of both frequency and type).

Figure 3.11 Share of respondents that consider useful/feasible to extend the scope of the Directive



Source: TRT analysis of the questionnaires (29 answers)

Support for extension of the scope of the Directive has been related to the expected benefits associated with the increased safety and the simplified legislation. It has been remarked that if the scope of the Directive remained unchanged this would potentially create a difference in standards between tunnels on the basis of their TEN-T or non-TEN-T status. The extension

[42] Heterogeneity relates to parameters that include: year of construction; type of traffic; tunnel operator; type of tube (twin-tube tunnel, unidirectional or single tube unidirectional, bidirectional tubes); cross section of the road; type of control system; context (urban and extra-urban); type of users.

of the scope of the Directive would apply uniform safety levels, procedures and responsibilities with a clear regulatory framework.

Consultees noted about the costs of implementation, both in terms of both financial and human resources. The administrative burden would be increased by the requirement to report on the compliance status and on accidents and fires. These costs would be even greater where several AAs act in one country.

3.4 Coherence

This section presents the assessment of the extent to which the Directive does not contradict other interventions with similar objectives.

3.4.1 Summary findings

In general, the provisions of the Directive fit well into the overall regulatory framework for road safety, but improvements can be suggested. For example, as confirmed also by a number of consulted stakeholders and experts, the integration of Directive 2004/54/EC and Directive 2008/96/EC should be discussed, as this could reduce the differences in the approach taken to safety in tunnels of different lengths (below and above 500 m).

3.4.2 Analysis of the evaluation question

EQ10: The analysis on the coherence should evaluate the links of Directive 2004/54/EC with other objectives of the EU transport policy. In particular, the contractor should assess whether Directive 2004/54/EC is coherent with the objectives of transport externalities and road safety.

The most important objective of the Directive is the improvement of road safety in tunnels. This is consistent with the objective of not only reducing the number of accidents but, more importantly, reducing the consequences of the accidents and the impacts as measured in terms of human lives lost, and social and environmental costs. It is concluded (based on data gathered and expert judgement) that the Directive has improved the overall safety of tunnels (perceived and real) and therefore helped to reduce transport externalities.

This opinion is consistent with the analysis on EQ11 which shows that the number of accidents and fires occurred in tunnels fell during the period in which the Directive has been in force, though it is not possible to attribute this result to the Directive itself. A qualitative analysis was carried out on the basis of stakeholder responses and an assessment of the effectiveness of the main measures introduced.

Different points of view were raised during the consultation. The extent to which the Directive helped to improve safety and reduce externalities is linked to the legislative framework in which it was placed, which varied from country to country.

In Germany, the incremental improvement of safety levels was relatively low as most of the measures (structural and operational) required by the Directive were already mandatory before 2004. Similarly, the safety levels of tunnels in the Netherlands were already higher than those required by the Directive. Marginal improvements have been introduced even after its entry into force, such as the identification of emergency exits. In Austria, by contrast, stakeholders attributed a high impact to the Directive as it led to tunnel safety standards being tightened.

As a general opinion shared by different experts and stakeholders is that operators are now more involved and coordinated, while safety is now better integrated in tunnel operations. The systemic approach proposed by the Directive is one of the bases for a coherent safety policy. It is concluded that the provisions of the Directive are a good fit to the overall regulatory framework for road safety. Improvements have been suggested by a number of respondents.

With regards to the integration of Directive 2004/54/EC and Directive 2008/96/EC on road infrastructure safety management, different opinions were expressed by the stakeholders. The two Directives do not overlap as they refer to different problems, the first one is applied for tunnels longer than 500 m, the second one for shorter tunnels, but they apply in different ways. The former prescribes a number of minimum requirements to be applied everywhere on infrastructures in its scope, while the latter requires the establishment and implementation of procedures relating to road safety impact assessments, road safety audits, the management of road network safety and safety inspections by the Member States and finally provides indication on how to intervene to improve safety on the road network. As confirmed by a number of respondents, clear rules for the harmonization of the two Directives would be useful and the proposals[43] made by the working group of PIARC seem to be feasible and applicable: “the principles set out in Directive 2008/96 should be preserved and carefully adapted to the specific context of road tunnels”, focusing on the importance of safety documentation, of safety inspection and audits and of evaluations also within the application of Directive 2004/54.

Minor duplications and contradictions, not causing major problems, were highlighted by a number of stakeholders. For example, in Italy the national regulation, which is stricter than the Directive, wa complemented by a special article , the so called “overdesign” norm, which was introduced in a decree law in 2014, to prevent entities from requiring stricter requirements than those established by the European Directives without a prior analysis of the additional costs and time of implementation[44].

One expert called for more balanced intervention and harmonisation of rules for tunnels and the road network. His view was that too much focus and investment was been given to tunnel safety at the expense of road safety in general (and in a context where most accidents occur on local roads).

3.5 Effectiveness

This section presents the assessment of the extent to which the operational, specific and global objectives of the Directive have been achieved, i.e. to what extent the effects correspond to the objectives.

3.5.1 Summary findings

The Directive increased the level of safety in the tunnels of the trans-European road network and, in a number of countries (see EQ 9), outside the TEN-T network. The measures provided, in particular those that enhance the response time for the identification of the events and the intervention of the emergency services, mitigate the effects of accidents and fires.

The analysis of the contribution of the Directive to the prevention of accidents and fires and mitigation of their effects assessed the highly valued effectiveness of the control centre and of the monitoring systems on the prevention of both accidents and fires and on the mitigation of their effects. An even more considerable role in the mitigation of the fires’ effects is attributed to the ventilation requirements, together with other measures, like the equipment to close the tunnel and the fire resistance equipment (EQ 11).

The research suggests that the Directive has increased the time required for tunnel design. Increases in construction costs are concentrated in countries where the national regulations previously in place did not cover the requirements of the Directive.

[43] “PIARC Recommendation regarding the approach to take into account Directive 2008/96/EC in the context of road tunnels”, PIARC Technical Committee 3.3, http://www.piarc.org/en/Technical-Committees-World-Road-Association/Technical-Committee-Road-Tunnels-Operations

[44] Art. 14 of Decreto Legge 12 settembre 2014, n. 133.

The Directive has changed the managing operations and practices in tunnels, introducing new roles and responsibilities. Such changes are in general considered having improved the effectiveness of the operations (EQ 12).

The general impact of the refurbishment work prompted by the Directive on the environment, local populations and the traffic flows are considered to be minor, but no data were provided to quantify them (EQ 13).

Other indirect effects generated by the Directive and mentioned by experts concern the cost of risk analysis and the additional costs levied on tunnel users (via tolls) to support the investments of the road concessionaries (EQ 14).

The broadening of the scope of the Directive to include non-TEN-T tunnels would mainly harmonise the (perceived) safety and the regulations at national level and then at European level (EQ 16). On the other hand, it would increase the costs of implementation. The additional cost is estimated to be in the range of 1.6-2.4 billion Euro, taking into account that ordinary roads are often older than motorways included in the TERN.

3.5.2 Response to the evaluation questions

EQ11: To what extent has Directive 2004/54/EC contributed to prevention of accidents and mitigations of the consequences of accidents? What have been the effects of the Directive on the planning and construction of new tunnels?

The Directive increased the level of safety in the tunnels of the trans-European road network and, in a number of countries (see EQ 9), outside the TEN-T network. The measures provided, in particular those that enhance the response time for the identification of the events and the intervention of the emergency services, contribute to mitigate the effects of accidents and fires.

The available data on the accidents and fires that have occurred in the tunnels in the scope of the Directive do not allow for a quantitative analysis of the effects of the Directive and on the causes of such events. The period of time is comparatively short, there are missing data and the data do not distinguish between refurbished and non-refurbished tunnels. Furthermore, the criteria followed in recording the data vary from country to country, and in some cases even in the same country during the period considered. For example, the data of Austria for the period 2012-2013 cannot be directly put in comparison with the data of the previous periods, due to a change in the gathering methodology. The Directive requires that “any significant incident or accident occurring in a tunnel shall be the subject of an incident report” (Art. 5.3) and “Member States shall compile reports on fires in tunnels and on accidents which clearly affect the safety of road users in tunnels” (Art. 15.1). The definition of significant incident does not seem sufficiently clear, hence a number of Member States adopted stricter definitions, mainly derived from that provided by PIARC[45], i.e.:

- An accident involving at least one injured party (requiring medical attention or hospitalisation, even for a short period);
- An accident involving at least one fatality;
- A fire in a vehicle which began to burn in the tunnel but was able to exit without assistance;
- A fire in a vehicle which burnt (totally or partly) within the tunnel;
- A leakage or loss of dangerous goods (whether dangerous goods are authorised or not).

The different types of incidents considered affect the homogeneity of the data available. There is, however, evidence that supports a qualitative assessment of the impact of the Directive.

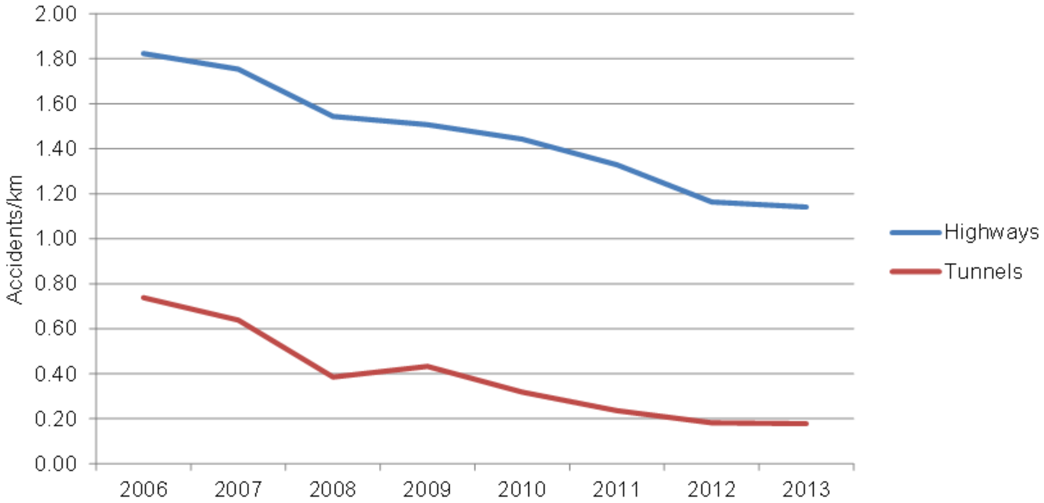
[45] PIARC Technical Committee 3.3 Road Tunnel Operations (2009). “Tools For Tunnel Safety Management”.

The literature suggests that the frequency of road accidents in tunnels is generally lower than in open sections of road. This is because weather conditions have less effect on driving conditions in tunnels and the level of attention of road users is usually higher. The cases of Italy and Austria seem the most appropriate to corroborate this conclusion, as the records available consist of significant values, cover the entire period of observation and data collection is more reliable. Accidents with personal injuries registered in the Italian tunnels in the scope of the Directive represent about 48% of the events reported in EU28 for the period 2006-2013 (1,798 out of 3,709).

Figure 3.12 shows the trend of the accidents per kilometre recorded in the Italian TEN-T tunnels (in red) and in the whole Italian highway network (in blue). About the 92% of Italian tunnels in the scope of the Directive, in terms of total tube length, belong to the highway network. The average rate of accidents in tunnels is well below the rate measured on the whole network. Over the period 2006-2013 traffic on the highway network dropped by 8%[46] (in terms of millions of vehicles-km) and accidents/km fell by 37%. The reduction of the accidents/km in tunnels over the same period is more significant at 76%. The extent to which this decrease can be attributed to the Directive cannot be determined. However, as also mentioned in the report 2014 on accidents and fires submitted by Italy, the main factors that contributed to the reduction in the number of accidents are:

- focused refurbishment interventions identified on the basis of risk analyses (e.g. road signs, lighting, ventilation);
- a reduction in traffic volumes (since 2009);
- improvement of the vehicle fleet, especially in terms of safety related equipment;
- improvement in user behaviour induced by a continuous speed control along the whole highway network.

Figure 3.12 Trend of the accidents per kilometre for the Italian tunnels and motorways



Source: TRT analysis of AISCAT's data 2013 and of the report on accidents and fires of Italy

In Austria, the trend is more volatile but still decreasing over the period considered. Again, the average rate for tunnels is lower than that recorded on the entire motorway network.

The two situations cannot be compared, as the registered events in Austria include accidents in tunnels longer than 200 m both on highways and expressways (the Directive applies to tube lengths above 500 m)

46 Notiziario trimestrale 3-4/2013, Associazione Italiana Società Concessionarie Autostrade e Trafori - AISCAT

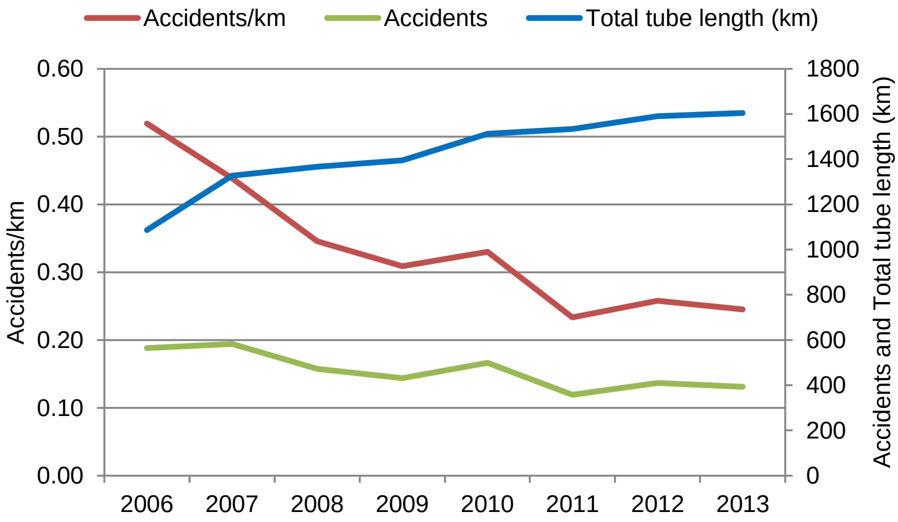
Gaps in the data and variation in the methods used in collection of information across the Member States mean that a generalisation of the results is not possible. Figure 3.13 charts the change in accidents per kilometre based on elaborations of the available data. The trend shows a positive diminution driven by the trend recorded in the countries weighing more (Italy and Austria in particular).

Table 3.8 Frequency of accidents in tunnels in the scope of the Directive

Country	2006	2007	2008	2009	2010	2011	2012	2013
AUSTRIA	69	96	84	60	75	48	110	99
BULGARIA	55	23	27	27				
CZECH REPUBLIC				3	1	2		
DENMARK	0	2	2	2	5	0	0	1
FINLAND				2			5	4
FRANCE	12	13	22	8	16	17	24	15
GERMANY	48	47	46	46	50	49	29	67
GREECE					3	6	10	8
HUNGARY					0	2	28	21
IRELAND		1	0	0	2	0	0	0
ITALY	372	322	194	219	240	178	140	133
LUXEMBOURG		1	4	1	7			
NETHERLANDS			3	2	5	0	2	5
PORTUGAL	4	3	1	0	5	0	7	5
SLOVAKIA	4	6	10	14	13	11	1	2
SLOVENIA		58	64	36	64	34	45	29
SPAIN		10	13	10	11	10	9	3
SWEDEN	0	0	2	1	2	1	0	2
Total EU	**564**	**582**	**472**	**431**	**499**	**358**	**410**	**393**

Source: TRT analysis of the questionnaires and of the reports on accidents and fires of the Member States

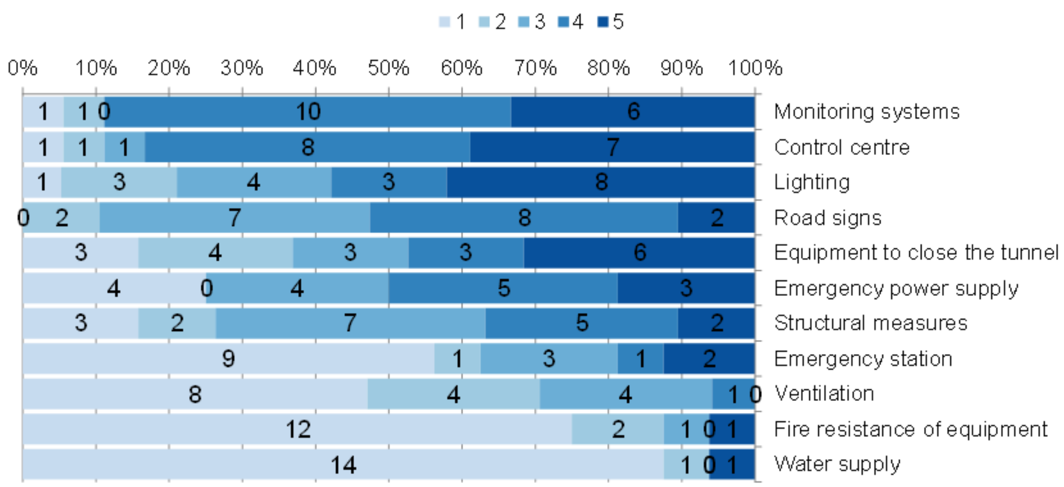
Figure 3.13 Trend of the accidents per kilometre for the tunnels of the Member States



Source: TRT analysis of the questionnaires and of the reports on accidents and fires of the Member States

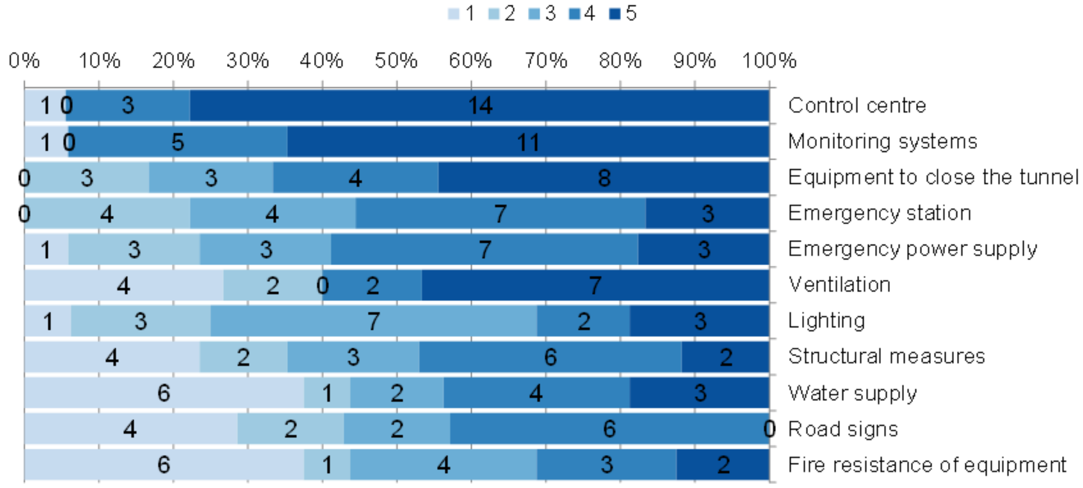
In the absence of detailed quantitative data the effect on prevention and mitigation of effects has been addressed through qualitative research with stakeholders. Tunnel managers and experts assessed the importance of measures specified in the Directive in the prevention of accidents and fires and the mitigation of their effects by assigning a rank (from 1 (low) to 5 (high)) to each measure. Figure 3.14 and Figure3.15 show the results, ordered by the perceived effectiveness. Control centres and monitoring systems are considered to be the most effective measures both for the prevention of accidents and the mitigation of their effects. With respect to the prevention, lighting and road signs follow, while the equipment to close the tunnel play an important role in mitigating the effects of accidents. An average rank is attributed to the contribution of the structural measures (which are the most expensive ones) both in the prevention and in the mitigation.

Figure 3.14 Stakeholder ranking of the contribution of measures specified in the Directive to the prevention of accidents (1 is low, 5 is high)



Source: TRT analysis of the questionnaires (23 answers)

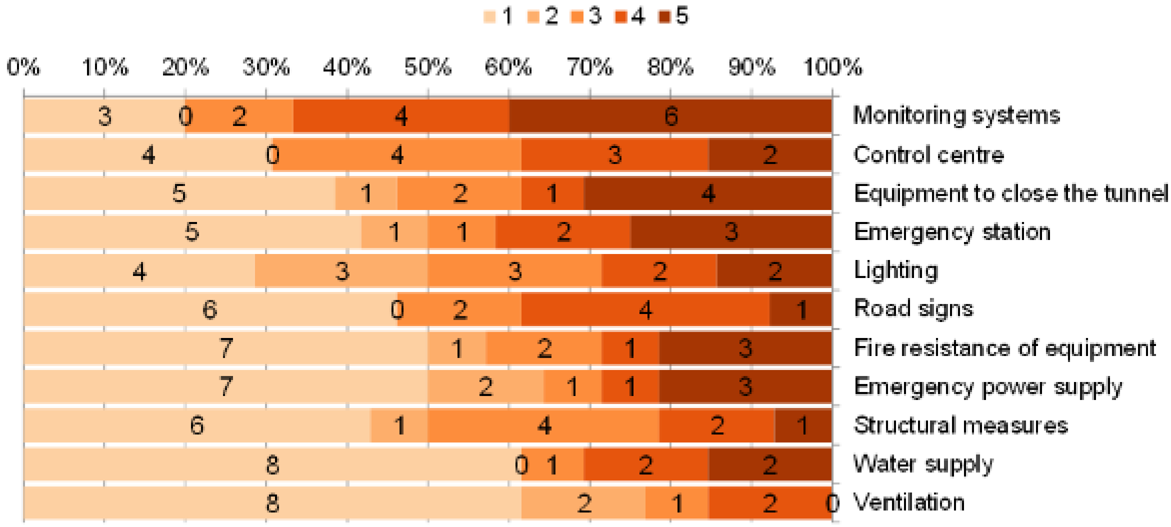
Figure 3.15 Stakeholder ranking of the contribution of measures specified in the Directive to the mitigation of the effects of accidents (1 is low, 5 is high)



Source: TRT analysis of the questionnaires (23 answers)

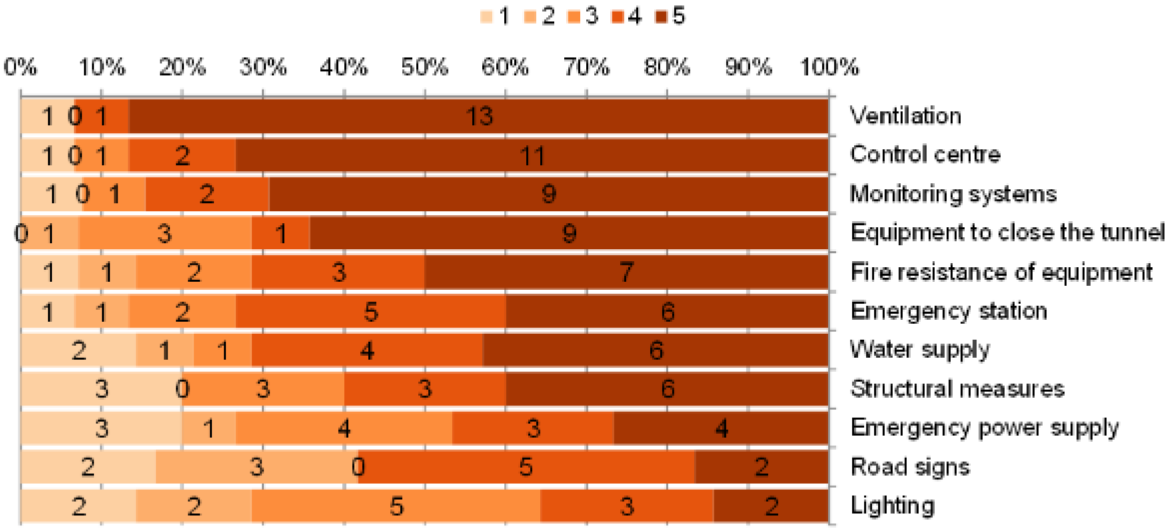
The analysis for fire prevention and mitigation is shown in Figure 3.16 and Figure3.17. Monitoring systems are ranked most important, followed by control centres. Stakeholders perceive the most important measures for the mitigations of the effects of fires to be ventilation, the control centre, monitoring systems, equipment used to close the tunnel and fire resistance of equipment. All were given an average rating of more than four out of five.

Figure 3.16 Stakeholder ranking of the contribution of measures specified in the Directive to the prevention of fires (1 is low, 5 is high)



Source: TRT analysis of the questionnaires (23 answers)

Figure 3.17 Share of the ranks of the contribution of the measures to mitigate fires' effects (1 is low, 5 is high)



Source: TRT analysis of the questionnaires (23 answers)

Additional comments provided by the stakeholders help to explain the rankings.

- In Italy a national standard for lighting was already in force[47], thus the contribution of the corresponding measure provided by the Directive was ranked at '1';
- In France the requirements of the Directive are similar to those provided by the national regulations, so it was not possible to identify contributions. Accidents and fires were not considered separately in the rankings assignment. The contribution of ventilation to the mitigation was ranked at '5' for its effectiveness in case of accidents involving the transport of dangerous goods. The road signs were ranked at '4' for mitigation, considering the signs dedicated to the self-evacuation of users.
- For the Netherlands accidents and fires were considered at the same time, since the prevention often concerns collisions resulting in fire. According to the consultees, there are no measures in the tunnel for preventing a single cause of fire, like overheated engines, overheated break discs, etc.
- For Sweden the high rank assigned to the structural measures refers to the significant enhancement of safety provided by the addition of tunnel tubes.
- For Spain the equipment to close the tunnel was highly valued as road users are not always conscious of the danger derived from accidents or fires.

An analysis presented in the report by Mante (2011) shows the effectiveness of three measures in case of fire: closing down the tunnel, ventilation and emergency exits. The report shows that the three measures do not need to be all effective at the same time to assure safety. For instance, in case of fire the closing down of the tunnel prevents potential casualties, but if the ventilation system works correctly, the consequences of failure of the equipment used to close the tunnel is less severe. On the other hand, if the ventilation fails, the consequences are less severe when many emergency exits are available (100 m is the distance required for the emergency exits in the Netherlands). In general, the larger the distance between the emergency exits, the more reliable and effective the ventilation needs to be.

[47] It requires checks and upgrading of lighting systems inside existing, or new tunnels.

Consultees suggest that there should be further studies on the effectiveness of each measure in preventing accidents and fires and mitigating their effects. Such studies, it was proposed, should calculate the value of the Crash Modification Factors (CMF) of each safety measure.

Additional suggestions on safety measures and their contribution to prevention and mitigation include:

- communication with drivers (ranked '5' on both prevention and mitigation);
- traffic guidance constructions, in the form of barrier profiles against the tunnel wall (so-called step-barriers), have a low prevention effect but a high rank for the mitigation;
- passive fire protection contributes to mitigation of structural damage, but it little impact on safety for road users, since the evacuation phase is relatively short;
- a safe road design (ranked '5' for prevention and '3' for mitigation effectiveness).

The importance of the latter issue, safe road design, can be illustrated by the following two examples: an incident in 2012 in the Sierre tunnel (Switzerland) and a number of suicides in tunnels in Slovenia. Both involve the design of the lay-bys. The incident in the Sierre tunnel was caused by a coach crashing against the wall of the tunnel and finishing in a lay-by that was built with the end wall perpendicular to the lane. In Slovenia a number of crashes against the end wall of the lay-bys were identified as suicides. In short, the existence of perpendicular and unprotected walls at the ends of the lay-bys should be considered highly dangerous.

Safety issues that stakeholders identified as being insufficiently addressed by the Directive are:

- flooding, chemical, biological, radiological, nuclear or explosive events;
- provisions to hasten the evacuation process, in particular its starting phase, giving to the drivers and road users correct and convincing information (e.g. through variable message signs inside tunnels);
- more detailed requirements about appropriate means of preventing smoke and heat from reaching the escape routes;
- dedicated fire services in very long tunnels (over 4000 m), where the fire brigade is stationed far away;
- the detection of high temperatures on heavy vehicles before they enter the tunnel;
- continuity of mobile communications inside long tunnels and other V2I (vehicle to infrastructure) safety technologies (e.g. eCall, an electronic safety system that automatically call emergency services in case of a serious accident[48]);
- control sections inside the tunnel, with signals locations matched to emergency exits, to stop the vehicles already inside the tunnel when the event occurs, as far away as possible from the location of the event (especially for very long tunnels);
- standardisation of the tunnel signage within a Member State (e.g. blinking of traffic signs, the same colour for emergency exits, SOS lay-bys);
- requirements of the Directive 2008/96/EC on Road Safety, currently applied only to tunnels shorter than 500 m.

Finally, the Directive had clear impacts on the planning and construction of new tunnels. This impact was stronger in countries where pre-existing regulations were not as strict as those in the Directive (see also EQ 9). Major changes concerned the equipment (significantly increased), and the geometry structural requirements (for example, the need for emergency

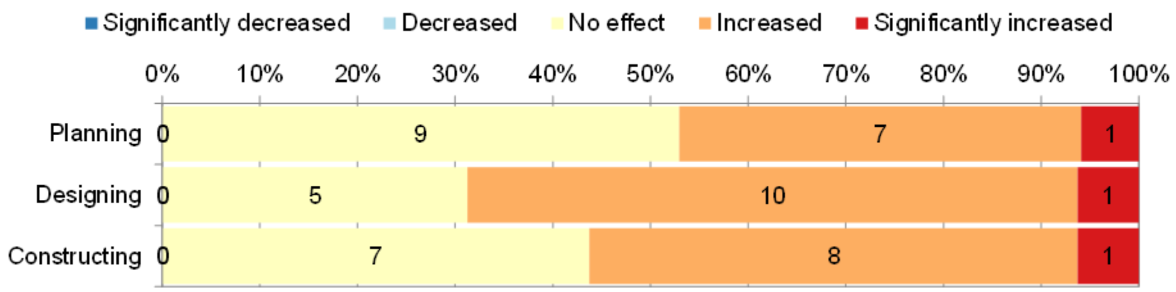
[48] http://ec.europa.eu/digital-agenda/ecall-time-saved-lives-saved

exits every 500 m). The Directive also contributed to: increases in tunnel construction costs[49], time delays before opening of tunnels and general increase of the equipment. Examples of impacts in specific countries include:

- the Netherlands: the Directive brought uniformity in planning, design and construction phases, which is a positive and widely acknowledged outcome. The Directive had a modest impact on the planning of new tunnels since the previous national safety standards were more strict. However, in few cases, like the requirement on the control centre[50] and the provision concerning the number of lanes before the entrance of the tunnel and inside it, a direct effect has been identified on the road design.
- Germany: all new tunnels are built according to the national guidelines (RABT 2006). These transposed the Directive but exceeding its requirements for structural measures and safety equipment. One changes brought by the Directive is the risk analysis to identify alternative measures where the provisions required are not feasible.
- Italy: the Directive's effect on planning and construction of new tunnels was analysed in an Italian study (ANAS, 2012). It concluded that some structural requirements, such as lay-bys, by-passes and, in particular, the emergency exits, pushed the designers to favour the "mechanized" excavation method with an increase of the cross-section of 45%-60%[51].

Figure 3.18 shows the perceived change in time spent on planning, designing and constructing new tunnels due to the requirements of the Directive. None of stakeholders consulted registered a decrease of the time, while the 69% reported an increase of the time spent on designing new tunnels, and 56% reported an increase in the time required for construction.

Figure 3.18 Impact on time spent on planning, designing and constructing new tunnels due to the Directive



Source: TRT analysis of the questionnaires (23 answers)

[49] For example, for adaptation to stricter requirements on geometry on the need of having egress ways every 500 m.

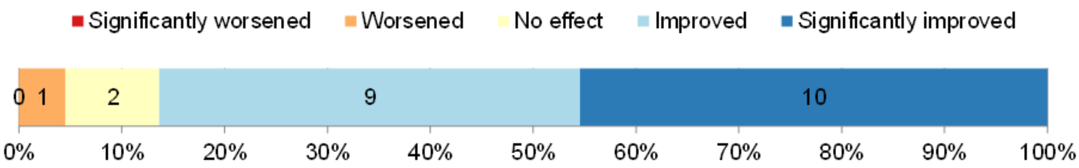
[50] The Roertunnel (2000 m in length) took a long time before equipment was able to communicate with each other without glitches in the system.

[51] In a new tunnel built with traditional excavation method lay-bys are provided by enlarging the transversal section of the tube during the excavation. Therefore, the construction costs and the working time are proportional to the increase of the excavation work of the enlarged section, in turn related to the volume occupied by the lay-bys. When a tunnel boring machine (TBM) is used for the excavation, the lay-bys are constructed in a second stage operation. The activities required to dig each lay-by are more costly, complex and time consuming. Hence, it is considered more convenient to build an emergency lane throughout the length of the tube such that the final transversal layout of tube's section directly incorporates the lay-by. Although this solution requires continuous excavation, the increase in construction costs is offset by the reduction of in construction time. A significant increase in the tunnel's safety, due to the presence of the emergency lane on its entire length, can be considered an additional advantage.

EQ12: To what extent has the Directive 2004/54/EC affected existing managing operations and practices in tunnels? Has this resulted in an improvement in terms of effectiveness of operations?

The Directive has changed managing operations and practices in tunnels. In particular, the safety documentation and periodic exercises have been extended and consolidated. In general terms, the 86% of the respondents (TMs and experts) feel that the Directive improved the effectiveness of the operations and the 53% of these ranked such improvement as significant (Figure 3.19).

Figure 3.19 Qualitative assessment of the Directive concerning the effects on operations in the management of the tunnels



Source: TRT elaborations of the questionnaires (23 answers)

Table 3.9 gives an overview of the entities defined by the Directive per country, showing figures before and after the introduction of the Directive. The Safety Officer requirement is the most significant change, this being a new role in most countries and involving the largest number of officer posts. The number of AAs and TMs has not changed significantly since the adoption of the Directive. In many countries inspection entities were introduced only after the implementation of the Directive.

Table 3.9 Entities in charge of managing safety issues in road tunnels before and after the introduction of the Directive

Entity		AT	CY	DK	EL	ES	FI	FR	HR	HU
Administrative Authority (Art. 4)	Pre-Directive	0	1	3	-	1	-	19	0	1
	Post-Directive	1	1	3	1	1	1	19	1	1
Tunnel Manager (Art. 5)	Pre-Directive	0	0	3	-	1	-	18	5	0
	Post-Directive	1	3	3	11	1	6	18	5	1
Safety Officer (Art. 6)	Pre-Directive	0	0	0	-	0	-	0	-	0
	Post-Directive	9	3	2	14	15	6	8	6	1
Inspection Entity (Art. 7)	Pre-Directive	0	1	0	-	0	-	10	2	1
	Post-Directive	1	1	1	1	3	1	19	2	1

Entity		IE	IT	LU	NL	RO	SE	SI	SK	UK
Administrative Authority (Art. 4)	Pre-Directive	2	0	1	2	1	-	1	2	-
	Post-Directive	1	1	1	2	1	1	1	2	1
Tunnel Manager (Art. 5)	Pre-Directive	3	16	1	1	5	1	1	1	-
	Post-Directive	3	18	1	1	5	1	1	1	1
Safety Officer (Art. 6)	Pre-Directive	0	0	0	0	1	-	0	0	-
	Post-Directive	2	35	1	1	1	6	1	1	1
Inspection Entity (Art. 7)	Pre-Directive	1	0	1	1	1	-	1	0	-
	Post-Directive	2	1	1	1	1	-	1	2	1

Entity		Total
Administrative Authority (Art. 4)	Pre-Directive	**34**
	Post-Directive	**40**
Tunnel Manager (Art. 5)	Pre-Directive	**56**
	Post-Directive	**81**
Safety Officer (Art. 6)	Pre-Directive	**1**
	Post-Directive	**113**
Inspection Entity (Art. 7)	Pre-Directive	**19**
	Post-Directive	**40**
Total	Pre-Directive	**110**
	Post-Directive	**274**
	Variation (%)	**149%**

Source: TRT elaborations of the questionnaires

Expert consultations suggest that the Directive has had a significant impact on the management of tunnel operations. For example:

- Austria: a new department of the Ministry (Tunnel Manager) was founded to fulfil the requirements of the Directive and obligatory exercises were required for all rescue forces, increasing costs and the intensity of monitoring.

- Germany: the Directive introduced new entities (Administrative Authority, Tunnel Manager and Safety Officer), with significant effects on the organisation.
- Spain: the newly created entity of the Safety Officer, coordinating all the preventive measures, had pushed forward the issue of improving tunnel safety.
- UK and Ireland: the Directive forced the industry to introduce a qualification for the staff of the control room, through training and assessment of competency (Diploma in Road Tunnel Operations). An appointed and responsible Manager and the Safety Officer are also widely appreciated.
- France: the Directive has led to the active involvement of all the relevant actors via the implementation of a safety policy based on safety documentation. This approach facilitates a joint and shared vision of safety measures, including good tunnel management and good operating practices. The positive role of the Safety Officer has been highlighted.

The research suggests an increased uniformity in tunnel management and operating over tunnels in different countries

There was no clear consensus among AAs on the changes to safety requirements, or practices adopted, at national level beyond its defined scope. France, Hungary, Ireland, Italy, Luxembourg, the Netherlands, Slovenia and Slovakia did not identify changes, whereas Austria, Cyprus, Greece, Spain, Finland, Croatia, Romania and Sweden did report changes.

The Directive did not trigger change beyond its scope where the national regulations were already stricter, as in France and in the Netherlands. The only exception in France was where the distance between emergency stations was reduced from the initial 200 m to 150 m.

In Italy the Directive has, in some cases, been considered as a reference for the design of new tunnels out of the TEN-T road network. In general terms, it helped enhance the safety knowledge of road designers, road managers and AAs. For example, the Italian road agency (ANAS) published new own guidelines on safety in tunnels (length > 500 m) valid also outside the TERN network.

In Finland, TM and Safety Officer and also tunnel Safety Documents[52] are required for all tunnels on the public road network. The AA regulates all the tunnels and approves the new tunnels before their opening to public traffic. The Directive had a significant role in the tunnel projects and the tunnel regulations are based on it.

The expert consultations and stakeholder consultations did not provide direct evidence of spill-over effects beyond the EU. The Directive has however:

- been applied by Norway and Switzerland;
- been part of the legislation that apply to new Member States, therefore, it extended its scope to countries that joined the EU in 2007 (Romania and Bulgaria) and in 2013 (Croatia);
- been adopted as a standard for projects to be funded by international financial institutions, in particular by the European Investment Bank (EIB).

EQ13: What effects has the need of refurbishing existing tunnels had on the environment, local population and on the traffic flows?

In general terms, the refurbishment works had little impact on the environment and on the local populations. The only significant effect is reported with respect to traffic flows. Figure

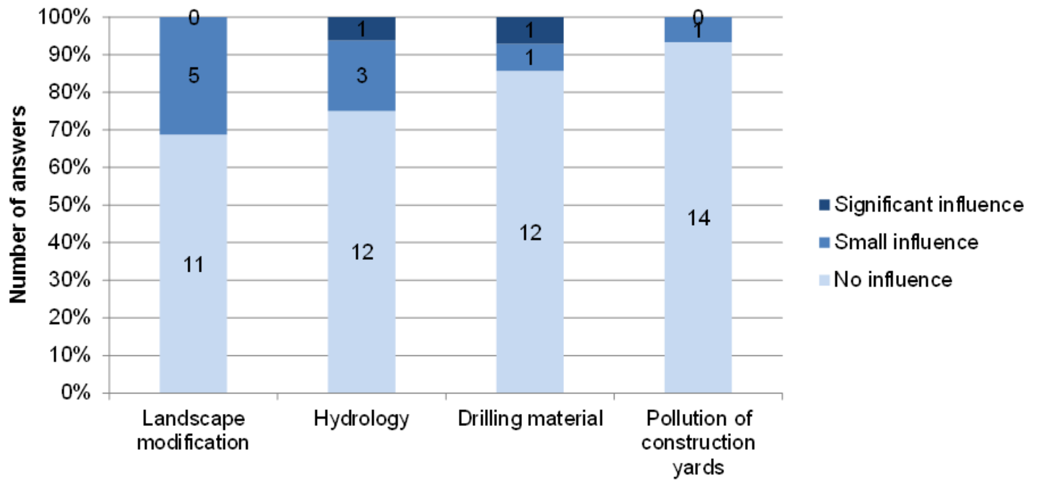
[52] Rescue Act, 2011

3.20 to Figure 3.22 show the perceived influence of the refurbishment works on the local environment, the local population and the traffic flows.

With regard to the environment, the mostly frequently quoted effects concern landscape modification. 31% of respondents reported an influence on the landscape and 25% an impact on hydrology. Nearly 25% of the respondents mentioned an impact on the local population, even if this is mainly linked to the construction of new infrastructure and the negotiation with local authorities. Illustrative is a case registered in Greece, where the local population refused to allow the transit of vehicles carrying dangerous goods, mindful of a previous devastating event of a fuel loading exploded truck.

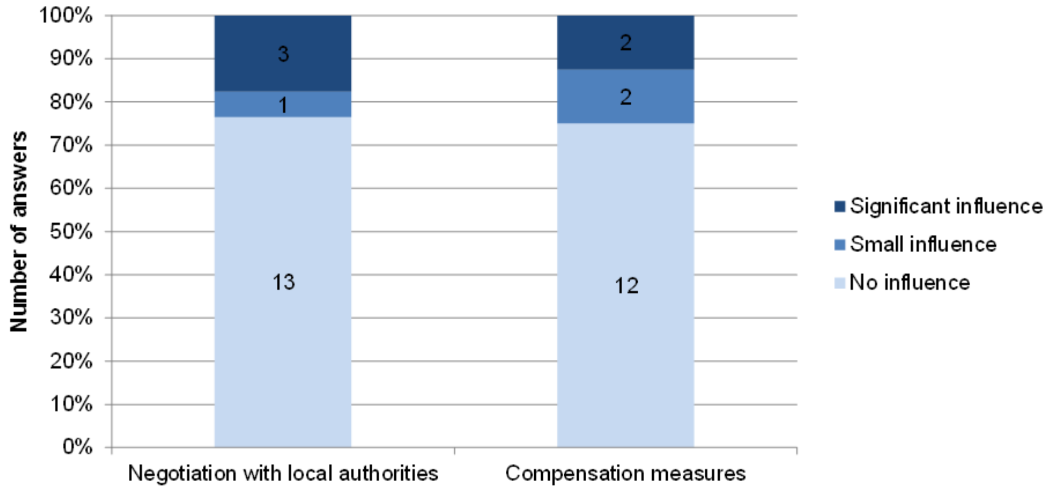
The effects of the refurbishment works are even more quoted with respect to the traffic flows. Such effects are considered as being significant where the density of tunnels along a trunk route is high, as in Italy. The need to find alternative routes while refurbishing tunnels is among the most constraining factors, especially on roads carrying high volumes of traffic.

Figure 3.20 Indirect effects of the Directive on the local environment



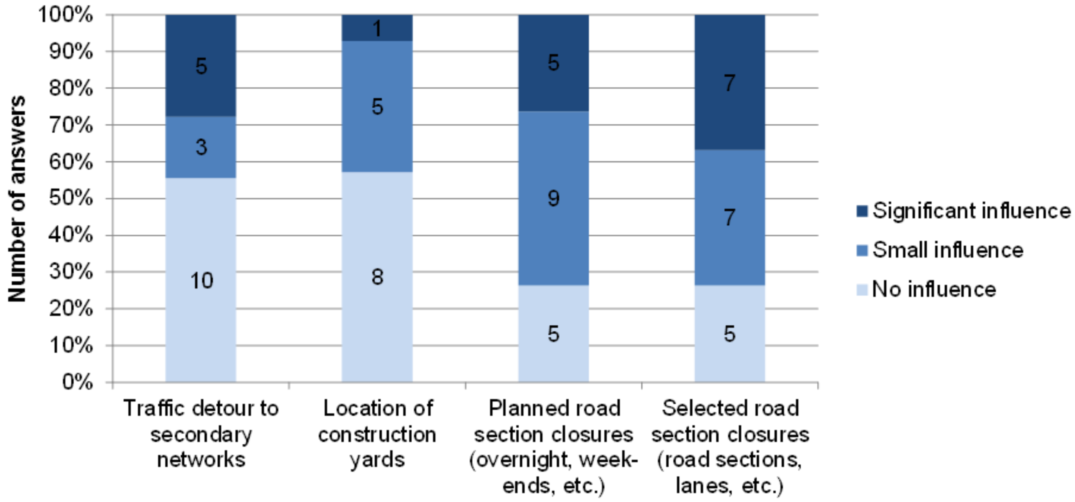
Source: TRT elaborations of the questionnaires (23 answers)

Figure 3.21 Indirect effects of the Directive on the local populations



Source: TRT elaborations of the questionnaires (23 answers)

Figure 3.22 Indirect effects of the Directive on the traffic flows



Source: TRT elaborations of the questionnaires (23 answers)

EQ14: Has Directive 2004/54/EC had other indirect or unexpected effects?

Other indirect effects generated by the Directive and mentioned by experts relate to costs.

A consultee identified extra costs brought by the need for risk analysis. In the case of tunnels with gradient higher than 3%, for example, the Directive assumes additional measures would be required: according to a number of stakeholders, it seems sufficient to determine initially whether an increased gradient leads to a safety problem and only in this case additional measures should be considered.

In Italy, the road manager is charged with the total cost of the implementation of the tunnel's safety measures. The investment costs are expected to be charged to the road users through increases in tolls.

As reported by a number of stakeholders, the Directive has enabled tunnel operators to lever extra funds from local and central governments, and sometimes from commercial sources that they probably would not otherwise have been able to reach.

No other specific indirect effects have been reported.

EQ15: To what extent did the Directive 2004/54/EC have an effect outside the trans-European network and outside the EU? Did it have an impact outside the EU? In particular, what are the positive experiences and spill-over generated outside the EU and beyond EEA and Switzerland?

Effects of the Directive outside the trans-European network are discussed in more detailed at EQ 9. The requirements of the Directive have been partially or in full applied to the tunnels of several countries (independently from length and network), such as Austria, Germany, Finland, Italy, Spain and the Netherlands.

In general, the Directive has been considered as a reference standard outside the trans-European network and outside the EU, and so helped to enhance the safety culture among designers, road managers and authorities. Furthermore, the European Investment Bank applies it as a condition for the financing of projects, irrespective of whether they are part of the TEN-T network or not.

EQ16: To what extent could the effects identified be increased by broadening the scope of the Directive 2004/54/EC to include non-TEN-T tunnels?

At least 537 tunnels would be affected by the extending the application of the Directive to tunnels beyond the TEN-T network. In some countries, like Austria, Germany, Finland, Italy, Spain and the Netherlands, the Directive is already applied to these assets, partially or in full.

The costs for the refurbishment of these additional tunnels is estimated at 1.6-2.4 billion Euro. This is based on:

- an assumed average cost of 2-3 million Euro per kilometre[53];
- an estimate of 806 km additional total tube length falling into the scope of the Directive[54].

The views of the AAs and experts on the extension of the scope of the Directive to non-TEN-T tunnels and to tunnels shorter than 500 m are discussed in EQ 9 and depicted in Figure 3.11. The respondents were divided: with regard to the first scenario (non-TEN-T tunnels), 48% were in favour, 48% against, while for the second scenario (tunnels shorter than 500 m) the 55% were against.

The principal benefit associated with any such extension would concern harmonisation of safety (perceived) and of regulations (see EQ 9). The minimum safety level would be extended to a greater number of tunnels, removing the difference between TEN-T and non-TEN-T tunnels. A more uniform level of safety would represent a further step towards the harmonisation of rules and of the characteristics of the road network. Anyway, safety requirements should be transferred to the other tunnels taking into account the real needs of the network, which is less uniform in term of geometry, traffic levels, number of tubes, and age of the tunnels.

The analysis of the different traffic intensity, the characteristics of the roads outside the TEN-T could suggest other solutions. The requirements to be applied need to be considered in the wider context of road safety policy across the whole road network and not just in relation to tunnels.

The additional costs that the implementation would require in terms of budget and human resource are an important consideration. Ordinary roads are often older than motorways included in the TEN-T road network. Costs for refurbishment of tunnels have been a strong constraint for those countries having high number of tunnels (in particular Italy) even within the existing scope. The extension of the scope of the Directive would seem to bring significant additional costs and the expected benefits would most be likely lower (the safety risks specific to tunnels are in general lower for shorter tunnels, while the lower traffic in some non-TEN-T tunnels may mean that the costs of implementation disproportionate to the benefits)..

3.6 Efficiency

This section presents the assessment of the relationship between financial inputs and identifiable outcomes, i.e. whether the effects have been achieved at a reasonable cost.

3.6.1 Summary findings

Refurbishment and operational costs are among the key information requested in the stakeholder consultation conducted for this study. The difficulties inherent in collecting this type of data are well documented, and are confirmed by the research results. The national programmes of refurbishment do not generally allow the operators to separate the costs

[53] The costs of the measures undertaken to implement the Directive are analysed in the response to EQ 17.

[54] This uses the average value of the classes of total tube length in Table 3.7 (750 m for the tunnels with total tube length in the range 500-1000 m, 2000 m for the range 1000-3000 m and 4000 m for the tunnels with total tube length greater than 3000 m).

generated by the Directive from their general investment costs. The number and age of the tunnels of each country is variable (EQ 17) so baseline expenditure varies widely. Cost categories are not standardised. The Directive brought in significant new requirements for some Member States but imposed few new requirements for others where national standards were already strict.

In general, the infrastructure measures are most cost-intensive where there are many tunnels that need to be refurbished, long and old, as in the case of Italy. Provisions concerning operational measures generated higher costs in countries where risk management was not used, or the Safety Officer was not foreseen, as in the case of Greece.

The measures undertaken to implement the Directive are estimated to have costs on average of 2-3 million Euro per kilometre of tube length for the refurbishment of tunnels, but the variability is very high, depending on the conditions of the tunnels.

The AAs and tunnel managers provided many data relevant to the estimation of the costs of compliance with the procedures and other administrative arrangements described in the Directive. As for the costs for the implementation of the other measures, the respondents highlighted the difficulty in identifying the expenditure triggered specifically by the Directive. The information provided includes, for example, the costs for the administrative arrangements, ranging from 10,000 Euro in Sweden to 320,000 Euro in Ireland. Expert consultations suggest alternative instruments would not have achieved the same results at lower cost (EQ 18).

No cost or benefit generated by the use of derogation have been quantified for the 16 derogations reported (EQ 19).

30% of the AAs and TMs considered the budget available to them for tunnel refurbishment allocated adequate. 57% did not express any opinion. The main source of financing for the investments in refurbishment and the maintenance of the tunnels was public funding. The concessionaires' equity and user tolls played a minor role, while the EU funds were used more in Greece compared to other countries (EQ 20).

3.6.2 Response to the evaluation questions

EQ17: What are the costs of measures undertaken to implement the Directive 2004/54/EC?

The available data on the costs of the measures undertaken to implement the Directive do not support an in-depth assessment the situation for all Member States but a partial analysis covering some Member States is possible. An average value for the refurbishment of existing tunnels, covering most of the measures provided by the Directive, is ranging between 2 and 3 million Euro per kilometre of tube. This value, which might vary a lot across Member States, depends on the measures that need to be implemented, the type of tunnel, the dimension etc. The weighted average value calculated is strongly influenced by the Italian data.

A number of pre-existing national regulations already required some of the measures specified in the Directive (even if applicable to "new" tunnels only). Therefore, the refurbishment works triggered by the Directive in any given Member State depended not only on the number of tunnels (varying from one in Ireland to more than 300 in Italy), but also on the number of the new requirements introduced by the Directive (varying from 25 in Ireland to one in France and Luxembourg) over and above those required by existing national law. Table A2.13 in Appendix 2 reports, for each country, the measures in the Directive that were already provided for under previous legislation.

The age of the tunnels in each country varies. For instance, the average year of opening to public traffic of the Italian tunnels is 1982, while in Slovenia the average year is 2000.Newer tunnels were built with different construction methods and supplied with different equipment, even before the implementation of the Directive. Countries with older tunnels would have faced maintenance and refurbishment costs even in the absence of the Directive.

Investments costs

Table 3.10 – Table 3.12 report the total costs for the refurbishment of the tunnels, in operation by the 30 April 2006 and new tunnels, as reported by the countries that provided such information. Details on the measures to which the cost refers are described later.

Table 3.10 Investment costs for the refurbishment of tunnels in operation by 30 April 2006

Country	Total costs (€)	Total tube length (km)	Total costs per km (€/km)
DENMARK	815,000	1.8	449,593
IRELAND	6,850,000	1.2	5,524,194
NETHERLANDS	10,000,000	15.2	657,895
SLOVENIA	16,927,832	23.9	707,183
SPAIN	39,200,000	11.0	3,563,636
SWEDEN	450,000	3.2	140,625

Source: TRT analysis of the questionnaires

Table 3.11 Investment costs for the refurbishment of new tunnels

Country	Total costs (€)	Total tube length (km)	Total costs per km (€/km)
NETHERLANDS	2,000,000	10.6	188,679
SWEDEN	1,100,000	16.0	68,750

Source: TRT analysis of the questionnaires

Table 3.12 Investment costs for the refurbishment of old and new tunnels in France and Italy

Country	Total costs (€)	Total tube length (km)	Total costs per km (€/km)
FRANCE	950,000,000	88.6	10,717,993
ITALY	2,200,000,000	747.0	2,945,114

Source: TRT analysis of the questionnaires

Details on the costs related to the Directive could not be clearly identified by the Member States where a national refurbishment programme was already ongoing, such as Germany and France. It is also difficult to associate, *ex post,* some improvements and their costs to the class of measures defined by the Directive. For example, expenditure on emergency stations can partially overlap with the excavation of niches), that could be better classified as structural works.

The costs provided for the refurbishment of tunnels in operation by the 30 April 2006 include:

- Italy: a partial estimation provided by the tunnel operators foresaw costs of 2.2 billion € for the refurbishment by 2019 of the existing tunnels, for a total tube length equal to 747 km. This corresponds to about 2.9 million €/km. This estimate will change, and probably increase, since the plan for adapting the tunnels to the provisions of the Directive is currently being revised.
- France: a budget amount of 950 M€ was allocated for the refurbishment of the TEN-T tunnels, of which 875 M€ have been spent so far, corresponding to approximately 10.7 million €/km; this cost is by far the highest among the available data, no clear explanation can be given for it but the contribution of civil works to the overall value is deemed to be very high (in particular emergency exits and emergency stations);

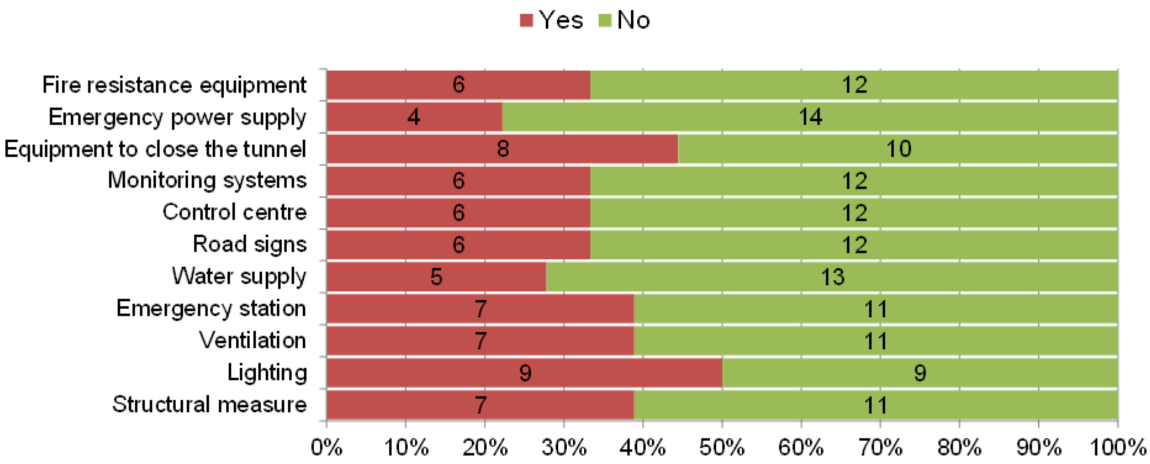
- Sweden: 141,000 €/km for lighting and equipment to close the tunnel for 3.2 km of total tube length;
- Ireland: 5.52 million €/km for control centre, monitoring systems and fire resistance equipment for a tunnel with total tube length equal to 1.2 km; this cost is high since all equipment (e.g. control centre, monitoring systems) has been installed for just one tunnel, thus lacking of economies of scale;
- Norway: in 2005[55] and 2007[56] it was decided that all tunnels longer than 500 meters on the national road network, all in all 237 tunnels, had to meet the requirements of the Directive. The costs of adding the required equipment (such as evacuation lighting, mechanical and longitudinal ventilation, radio network and video surveillance) in 22 tunnels were estimated at about 22 million Euro. The video surveillance equipment with incident detection functions accounted for more than half of the total cost. If all existing tunnels had to be rebuilt according to the provisions for new tunnels, the costs would have been nine times higher, at about 195 million Euro (2005 prices).

Data on the costs for the refurbishment of new tunnels were provided by the Netherlands and Sweden:

- the Netherlands: 2 million Euro for a total tube length of 10.6 km, corresponding to 189,000 €/km for the number of lanes inside and outside the tunnel;
- Sweden: about 1.1 million Euro for emergency stations and equipment to close the tunnel for a total tube length equal to 16 km, corresponding to 69,000 €/km.

Figure 3.23 shows the number of cases for each measure where the Directive required new investments, as reported by the AAs and TMs consulted. Lighting and equipment to close the tunnel are the measures for which the largest number of respondents identified that new investments had been triggered by the implementation of the Directive.

Figure 3.23 Measures for which the Directive requested new investments



Source: TRT analysis of the questionnaires (23 answers)

55 The Ministry of Transport and Communication asked in January 2005 the National Roads Administration to elaborate a regulation for road tunnel safety in cooperation with the Directorate for Civil Preparedness.

56 Forskrift om minimum sikkerhetskrav til visse vegtunneler (Tunnelsikkerhetsforskriften). According to ITA COSUF (2014) this legislation is still in force.

The analysis carried out on the Italian tunnels (described in more detail in section A1.5 of Appendix 1, Focus countries, Italy) identified the proportion of the overall costs of construction attributable to the various components (see Table A1.13 in Appendix 1). Comparison of costs for the construction of tunnels before and after the implementation of the Directive suggests that the fraction of total costs attributable to these systems has increased by around 2.5-2.7%. The share absorbed by lighting system costs has increased by 2.2% while that absorbed by ventilation fell 2.4%. New safety measures required by the Directive (e.g. connection to the control centre, communication, equipment to close the tunnel, etc.) have additional costs that are estimated to amount to 2-2.5% of the total.

The cost of civil works, generally ranging between 70-85% on the overall costs of construction, is closely related to the conditions of the tunnel (e.g. location of the tunnel, type of soil, length of the infrastructure, volume and type of traffic) and therefore not comparable.

Costs for each measure can be assessed on the basis of the refurbishment of sample tunnels. Table 3.13 shows the example of an Italian tunnel in operation by the 30 April 2006 and with a total tube length of 3240 m and 20 m distance between tubes, for which the refurbishment involved fourteen measures specified in the Directive. The total costs per kilometre, close to 2.8 million €/km are consistent with the average evaluation for Italy reported in Table 3.10. The weight of each measure on the total costs show the significance of mechanical ventilation costs, followed by the lighting system and the power supply and electrical circuits.

In Table 3.15 the Italian costs per kilometre of specific measures are compared with the costs for the refurbishment of tunnels in Slovenia (split by category in Table 3.14), where a similar number of measures needed implementation. The expenditures for emergency walkways, cross-connections and drainage for the Italian tunnel are placed in the “structural measure” class for comparison. The average total cost per kilometre in Slovenia is significantly lower, about one quarter of the cost per kilometre for the Italian tunnel. The main reason of this difference is to be found in the age of the tunnels, while the majority of Italian tunnels date from the 1970 and1980s, the Slovenian ones were mostly built in the early 2000s. The control centre represents the measure with the highest difference of cost per kilometre: in terms of absolute values, 700,000 Euro were on the control centre of the Italian tunnel, against about 76,000 Euro for at least two Slovenian tunnels. The cost for the ventilation is the second most cost-intensive measure: a new ventilation plant in the Italian tunnel cost about two times (in terms of absolute values) the cost of refurbishing the ventilation plants for a number of Slovenian tunnels. The breakdown by measures is consequently very different as well. The monitoring system is the most expensive component in Slovenia, followed by the water supply, while both are marginal contributors to cost in the Italian case.

These discrepancies demonstrate how difficult it is to evaluate the costs generated by the Directive. It is necessary to consider the local conditions, both in terms of existing infrastructure and classification of the costs.

Table 3.13 Investment costs for the refurbishment of an Italian tunnel in operation by 1970

Measure	Total costs (€)	Total tube length (km)	Total costs per km (€/km)	Weight of the measure over the total
Emergency Walkways - Existing tunnels (§2.3.2)	596,000	3.24	183,951	7%
Cross-connections in twin-tube tunnels (§2.4.1)	819,000	3.24	252,778	9%
Drainage (§2.6)	676,000	3.24	208,642	7%
Fire resistance of structures (§2.7)	321,000	3.24	99,074	4%
Normal lighting (§2.8.1)	1,258,000	3.24	388,272	14%
Mechanical ventilation (§2.9.2)	1,767,000	3.24	545,370	19%
Emergency stations (§2.10)	200,000	3.24	61,728	2%
Water supply (§2.11)	150,000	3.24	46,296	2%
Road signs (§2.12)	145,000	3.24	44,753	2%
Control centre (§2.13)	700,000	3.24	216,049	8%
Monitoring systems (§2.14)	200,000	3.24	61,728	2%
Traffic signals before the entrances (§2.15.1)	850,000	3.24	262,346	9%
Emergency radio messages for tunnel users (§2.16.2)	285,000	3.24	87,963	3%
Power supply and electrical circuits (§2.17)	1,200,000	3.24	370,370	13%
Total	**9,167,000**	**3.24**	**2,829,321**	**100%**

Source: TRT analysis

Table 3.14 Detail of the investment costs for the refurbishment of the tunnels in operation by the 30 April 2006 in Slovenia

Measure	Total costs (€)	Total tube length (km)	Total costs per km (€/km)	Weight of the measure over the total
Structural measure	2,046,041	13.6	150,533	21%
Lighting	2,181,020	22.7	95,996	14%
Ventilation	804,179	15.7	51,284	7%
Emergency station	2,140,560	22.7	94,215	13%
Water supply	1,665,334	10.9	153,317	22%
Road signs	768,258	14.9	51,714	7%
Control centre	76,417	7.8	9,793	1%
Monitoring systems	6,198,446	23.9	258,948	37%
Emergency power supply	180,462	7.8	23,127	3%
Fire resistance equipment	867,115	22.7	38,165	5%
Total	**16,927,832**	**23.9**	**707,183**	**100%**

Source: TRT analysis

Table 3.15 Comparison of the costs for the refurbishment of the Italian tunnel with the costs for the refurbishment of all Slovenian tunnels in operation by the 30 April 2006

Measure	Total costs per km (€/km)			Weight of the measure over the total		
	ITALY (A)	SLOVENIA (B)	Variation (A / B -1)	ITALY (C)	SLOVENIA (D)	Variation (C - D)
Structural measure	645,370.4	150,532.7	329%	23%	21%	2%
Lighting	388,271.6	95,995.6	304%	14%	14%	0%
Ventilation	545,370.4	51,283.7	963%	19%	7%	12%
Emergency station	61,728.4	94,214.8	-34%	2%	13%	-11%
Water supply	46,296.3	153,317.4	-70%	2%	22%	-20%
Road signs	44,753.1	51,713.7	-13%	2%	7%	-6%
Control centre	216,049.4	9,793.3	2106%	8%	1%	6%
Monitoring systems	61,728.4	258,948.3	-76%	2%	37%	-34%
Total	**2,829,321.0**	**707,182.7**	**300%**			

Source: TRT analysis

Maintenance costs

Table 3.16 and Table 3.17 report the maintenance costs for existing and new tunnels in a number of countries. The costs indicated for France refer to the maintenance of 84 State owned tunnels, 43 of which are longer than 300 m, and two emergency galleries for a total tube length of about 93 km. The values for Greece and Italy were provided, respectively, by the TMs Egnatia Odos and the ANAS. For the United Kingdom the value refers to the maintenance of the only tunnel in Kent. The costs indicated for Finland refer to a single tunnel long about 1 km.

Table 3.16 Maintenance costs for the tunnels in operation by the 30 April 2006 per country

Country	Total costs (€)	Total tube length (km)	Total costs per km (€/km)
FRANCE	15,800,000	93.0	169,892
GREECE*	1,650,000	79.6	20,729
ITALY**	2,440,056	180.0	13,556
NETHERLANDS	1,000,000	15.2	65,789
SLOVENIA	1,235,458	16.1	76,632
UNITED KINGDOM***	396,264	0.8	495,330

* Egnatia Odos

** ANAS

*** Kent

Source: TRT analysis of questionnaires

Table 3.17 Maintenance costs for the new tunnels per country

Country	Total costs (€)	Total tube length (km)	Total costs per km (€/km)
FINLAND	515,000	1.0	515,000
NETHERLANDS	500,000	10.6	47,170
SLOVENIA	180,335	2.8	65,505

Source: TRT analysis of questionnaires

The details provided for the maintenance costs for the Kent and Finland, reported in Table 3.18 and Table 3.19, show that in both cases the control centre and the monitoring systems are the most costly measures.

Table 3.18 Detail of the maintenance costs for the tunnels in Kent (UK)

Measure	Total costs (€)	Total tube length (km)	Total costs per km (€/km)	Weight of the measure over the total
Lighting	10,701	0.8	13,376	3%
Ventilation	10,032	0.8	12,540	3%
Emergency station	8,694	0.8	10,868	2%
Road signs	18,726	0.8	23,408	5%
Control centre	155,162	0.8	193,952	39%
Monitoring systems	187,264	0.8	234,080	47%
Equipment to close the tunnel	4,682	0.8	5,852	1%
Emergency power supply	1,003	0.8	1,254	0%
Total	**396,264**	**0.8**	**495,330**	**100%**

Source: TRT analysis of questionnaires

Table 3.19 Detail of the maintenance costs for the tunnels in Finland

Measure	Total costs (€)	Total tube length (km)	Total costs per km (€/km)	Weight of the measure over the total
Rock structures	85,000	1.0	85,000	17%
Tunnel interior	103,000	1.0	103,000	20%
Road structures	44,000	1.0	44,000	8%
Power supply (includes emergency power supply)	80,000	1.0	80,000	15%
HVAC and automation and lightning	25,000	1.0	25,000	5%
Traffic management (includes road signs, control centre, monitoring systems, equipment to close the tunnel)	178,000	1.0	178,000	35%
Total	**515,000**	**1.0**	**515,000**	**100%**

Source: TRT analysis of questionnaires

As confirmed by the expert consulted, the Directive increased the costs of all measures implemented (operating, maintenance, investments, modifications), while decreasing costs associated with risk of harm, accidents and serious fires. Some causes of the increased costs include:

- continuous 24 hour control for tunnels longer than 3000 m (often extended also to shorter tunnels when included in the same road itinerary);
- maintenance for all the new equipment and system;
- modifications due to the installation of fire hydrants inside tunnels over 500 m;
- discussions and delays generated by the conflicts of responsibilities.

With respect to the maintenance costs, no cost savings associated with the measures provided by the Directive were reported by the respondents.

As noted in the discussion of the effectiveness of the Directive, the number and severity of accidents and fires has been decreasing over time in all the countries. There is a generalised trend across the highway network, not just in road tunnels. Thus, these positive developments cannot be directly attributed to the Directive. They also must be considered in the context of the following facts:

- the accident rates is decreasing even in countries where the (full) compliance rate is still very low (e.g. Italy), but where some provisions have improved the safety (e.g. lighting, signing, speed limits), demonstrating that also fewer measures, combined with other policies, can contribute to increase the safety levels[57];
- data on accidents before the entry into force of the Directive are not available (with the exception of Austria) therefore making it impossible to compare the trend with a "no Directive" scenario.
- the provisions of the Directive have raised awareness of the problem and the legislation is prompting investments that complement other road safety measures, such as safety campaigns, improvements in vehicle safety and introduction of speed control systems.

EQ18: At what costs were the procedures (commissioning, safety inspections, safety exercises, etc.) and other administrative arrangements described in the Directive established?

Costs included in this category strongly depend on how the procedures were implemented in the various countries. Furthermore, many respondents do not have an estimate of the various components identified and/or put these costs under different classifications.

Seven groups of expenditure, plus others suggested by the respondents (AAs and TMs), were identified and are reported in Table 3.20. These are:

- administrative arrangements;
- approval of design;
- commissioning;
- modifications;
- periodic exercises;
- safety documentation;
- safety inspections.

The information provided includes, for example, the costs for the administrative arrangements (ranging from 10,000 Euro in Sweden to 320,000 Euro in Ireland) and the costs for the periodic exercises (ranging from 10,000 Euro in Slovenia to 360.000 in Ireland[58]).

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[57] Attribution of benefits (in terms of accidents avoided etc.) to individual safety measures is not feasible.

[58] The 5 million Euro value referred to the Netherlands, indicated in the table, is very high and could not be verified with the AA.

The costs for the compliance with the procedural requirements of the Directive are not easy to define. For example, the roles defined by the Directive (AA, TM, SO, Inspection Entity) can be performed in conjunction with other roles, as reported by Finland. Discussions and delays generated by the conflicts of responsibilities, as described in EQ2 for the case of the Netherlands, led to substantial extra costs in the approval of design and the administrative arrangements that cannot be quantified.

It is a shared opinion of the consulted experts that no other instrument could have achieved the same results, in terms of administrative arrangements, at a lower cost.

Table 3.20 Cost of compliance with the procedural requirements of the Directive

Country	Total cost (€)	Number of tunnels	Total tube length (km)	Period	Notes
Administrative arrangements					
AUSTRIA	140,000			2006-2014	
IRELAND	320,000	3	11.7	2006-2014	
SWEDEN	10,000	3	20.0	2006-2014	TSO cost to be added
Approval of design					
AUSTRIA	930,000		81.0	2006-2014	
SWEDEN	400,000	2	16.0	2013-2014	
Commissioning					
AUSTRIA	470,000		98.0	2006-2014	
SWEDEN	20,000	3	20.0	2009-2014	
Modifications					
AUSTRIA	50,000			2006-2014	
SWEDEN	20,000	1	3.2	2012-2013	
Periodic exercises					
AUSTRIA	68,000			2006-2014	
FINLAND	50,000	1	3.0	2007-2014	
GREECE*	35,000		39.0	2006-2014	
IRELAND	360,000	3	11.7	2006-2014	
ITALY**	90,000		6.2	2008-2014	
LUXEMBOURG	30,000				
NETHERLANDS	5,000,000			2006-2013	
SLOVENIA	10,000	14	42.5	2007-2014	
SWEDEN	160,000	1	3.2	2006-2014	
UNITED KINGDOM***	13,400				every two years
Safety documentation					
AUSTRIA	110,000		248.0	2006-2014	
FINLAND	20,000				€/ document
GREECE*	160,000	32	80.0	2008-2014	provided as “in house” cost (2 engineers x 1 month per tunnel to prepare safety

Country	Total cost (€)	Number of tunnels	Total tube length (km)	Period	Notes
					documentation x 2.500€/month for 32 tunnels)
ITALY**	270,000		17.3	2011-2014	
NETHERLANDS	1,500,000			2006-2013	
SLOVENIA	500,000	14	42.5	2007-2014	
SWEDEN	200,000	3	20.0	2006-2014	
Safety inspections					
AUSTRIA	570,000	61	248.0	2006-2014	
FINLAND	80,000	1	3.0	2007-2014	
IRELAND	520,000	3	11.7	2013	
ITALY**	330,000		37.0	2012-2014	
SWEDEN	40,000	1	3.2	2013	
UNITED KINGDOM***	26,752	1	0.8		
Other					
FRANCE	20,000				€/year/tunnel for the Safety Officer
GREECE*	200,000	32	80.0	2012-2014	Risk Analyses

* Egnatia Odos

** Anas

*** Kent

Source: TRT analysis of the questionnaires

EQ19: To what extent did the use of derogations generate costs and/or benefits?

No cost or benefit generated by the use of derogation has been quantified. The derogations reported by the AAs are discussed in EQ 6. Table 3.6 reports the number of derogations and the provisions for which they were applied. Totally, 16 derogations were reported (collectively affecting 13 tunnels), 8 of which concern the point 2.11 of the Annex I of the Directive (Water supply), while 4 are related to point 2.10 (Emergency stations).

As a general qualitative remark, derogations are used for measures that are considered to have little impact on safety level for a given tunnel and that have disproportionate costs. In the case of Croatian tunnels the lack of a water supply would, in the absence of a derogation, have had a significant impact on total costs, for tunnels on roads with low traffic intensity.

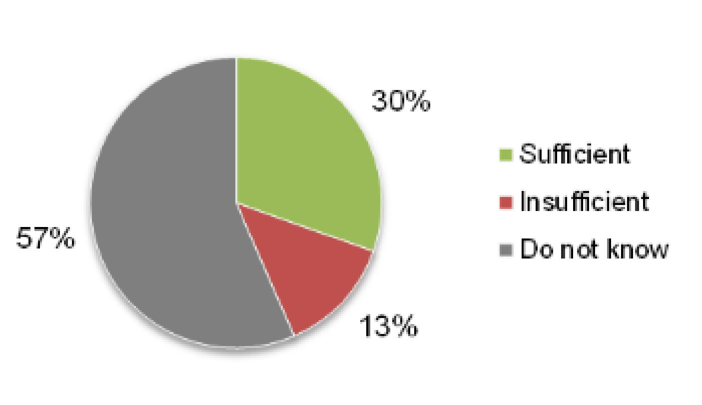
The small number of derogations recorded has to be put also in correlation with the deadline for compliance with the Directive. As cited above, it can be assumed that, for example in the case of Italy, more derogations will be asked while approaching the 2019 deadline

EQ20: Have measures related to budget planning been adequate for ensuring the minimum level of safety in tunnels?

The majority (57%) of the respondents (AAs and TMs) did not express an opinion about the adequacy of the allocation of financial resources to complete the refurbishment according to the Directive. 30% consider the measures related to the budget planning adequate, while according to the remaining 13% the measures are insufficient to complete the refurbishment and therefore for ensuring the minimum level of safety in tunnels (see Figure 3.24).

However, the fact that progress has been so limited in certain key countries (and behind original schedule), and the amount of money that will need to be spent before 2019 is still very large, suggests that budgetary planning has not been very good in those countries that benefit from the extended deadline. They have been deferring expenditure and there must be some risk that they cannot now achieve compliance by the 2019 deadline. For example in the case of Italy over 1,5 billion Euro has still to be spent for refurbishing tunnels; this raises suspects that there is too much to do (and not enough money) to achieve full compliance in the remaining time. Furthermore, in particular in the case of Italy, the overall budget required to achieve full compliance, is currently being revised, for various reasons, including the change of TEN-T network definition occurred in 2013.

Figure 3.24 Perceived level of adequacy of the allocation of financial resources to complete the refurbishment according to the Directive



Source: TRT analysis of the questionnaires (23 answers)

Few respondents provided detailed information on financing of investment plans, but general indications are available:

- Italy: the 2.2 billion Euro reported in Table 3.10 (EQ 17) for the refurbishment works in Italy are financed by a State budget (32%, equal to 700 million Euro) and user tolls (68%, equal to 1.5 billion Euro). This is a partial estimation provided by the tunnel operators, while the definition of a new plan of refurbishments is ongoing. Details are provided on the investment costs of the Italian State-owned operator ANAS, reported in Table 3.21.The EU fund[59] used covers only the 0.2% of the investments, 70% of the State budget is allocated for the new tunnels and the 30% is for the tunnels in operation by the 30 April 2006.

[59] "Programma di cofinanziamento della Commissione Europea a favore di progetti di interesse comune nel settore delle reti traseuropee dei trasporti (TEN-T)", EC Decision C(2010)4470 of 24/06/2010, as modified by Decision C(2011)592 of 28/01/2011, "Adeguamento delle gallerie S. Pellegrino (SS n. 675 Umbro-Laziale) e Colle Capretto (SS n. 3bis Tiberina) lungo l'itinerario europeo E45 alle prescrizioni di sicurezza per le gallerie nella rete stradale trans europea".

Table 3.21 Sources of financing used in implementing the provisions of the Directive by ANAS S.p.A.

Source of funding	Investment	%	Maintenance	Period
State budget	295 640 993	99.8%	19 520 451	2006-2014
EU funds	531 621	0.2%		2010-2011
Total	**296 172 615**	**100%**	**19 520 451**	

Source: TRT analysis of the questionnaires

- Austria: improvements are financed by user tolls. For the improvement of the tunnel safety of three tunnels (Klaus, Bosruck and Gleinalm) bridging finance in the form of a loan from the European Investment Bank is being used (Granted Volume: 390 million Euro, expected drawdown in 2014 - 2015).
- Greece: refurbishments on the motorway Attiki Odos were financed by user tolls, while the motorway Egnatia Odos was financed by a mix of State budget, EU funds during the period 2004-2013, and bank loans during the period 2006-2009[60].
- Cyprus, Netherlands Sweden: all investments were financed with State budget.
- Finland: a State budget allocation of about 2.5 billion Euro was used to construct new tunnels after year 2004 and about 3 million Euro for the refurbishment of the old tunnels.
- Denmark: improvements are financed by the concessionaire's equity.
- Hungary: the highways and the new tunnels were financed in different proportions through concessionaire's equity (64.2 million Euro) and concessionaire's loan (880.8 million Euro).
- Ireland: the three TERN tunnels were constructed in line with the Directive, financed by State budget and user tolls.
- France: no financing was necessary to implement the provisions of the Directive, because similar provisions were already required by the French regulation.

For Spain, Luxembourg, Slovenia and Slovakia no data are available, while in Croatia the planning process for the implementation of the Directive is ongoing.

3.7 Sustainability

This section presents the assessment of the extent to which positive changes attributable to the Directive are expected to last beyond the period of their implementation.

3.7.1 Summary findings

A review of the technologies applied to the provisions of the Directive suggests that communication and firefighting systems are the main areas where technologies influence safety measures, while the traffic management influences (albeit indirectly) the operational measures. A number of the examples reported indicate that some measures of the Directive could be obsolete. Developments in communication (GSM coverage and use of smartphones) reduce the need of the emergency stations. Additional suggestions on obsolete measures, not linked strictly to the technologies, are reported to better analyse the sustainability of the Directive.

[60] The funds accessed include European Funds for Cohesion policy (2nd and 3rd CSF); Operational Program (OP) "Accesses and Road Axes" of the 2nd CSF and by "Road Axes, Ports, Urban Development" of the 3rd CSF (Cohesion Strategy Fund); EIB (European Investment Bank) loan covering part of the national contribution; Bank Loans (through Greek Banks.

3.7.2 Response to the evaluation questions

EQ21: The evaluation should estimate the long and medium term effects of the Directive and in particular: how technological development might affect the application of the Directive 2004/54/EC, especially in terms of safety, operational and organisational measures.

In the medium term technological development will affect the implementation of the Directive through an improvement of the performance of the safety and operational measures (e.g. developments of devices of the monitoring systems and of the management software used in the control centres).

In the long term technological development will affect the implementation of the Directive through more cost-effective and/or better-performing measures that will make obsolete measures currently required by the Directive (e.g. developments in communication and in building methods).

The role and the effects of technologies were partially discussed in EQ 5, where some developments mentioned by the respondents (AAs, TMs and EXs) were presented. The technologies can involve different aspects of the tunnels, from the technologies used in the construction site (e.g., building methods) to the traffic management.

The technologies mentioned concern safety and operational measures. In the latter case the influence of the technological developments is largely indirect. Communication and fire-fighting systems are the main safety-related measures covered by the examples quoted. Traffic management systems and technologies influence the operational side. Table 3.22 lists the technological developments mentioned by stakeholders.

Table 3.22 Examples of technological developments affecting safety and operational measures

Safety measures	limitation of the traffic noise for the roadside telephones; GSM coverage in tunnels; emergency phones enriched with screen; loudspeaker systems used zonally to give different messages depending upon where one is inside the tunnel; LED lighting systems to reduce maintenance and operating costs; DAI (“détection automatique incident”, automatic detection of incident) devices; DAF (“détection automatique fumée”, automatic detection of smokes); visibility meters instead of fire detection cable; thermographic cameras; automatic sprinkler systems; scooter with extinguishing system; air compressor unit inside the control centre to refill quickly exhausted breathing apparatus of firemen (typical having 20 min autonomy) especially in rural motorways; portable Automatic External Defibrillator (AED) to enrich the equipment of the Control centres or other key safety points inside the tunnel; automated evacuation systems using flashing high intensity beacons, green chaser lights and directional white noise ‘exit here’ signage to guide sighted people in low smoke conditions or those with impaired vision to a cross tunnel Exit door or Safety Refuge;

	safety crash barriers in the lay-bys.
Operational measures	information technology system (ITS) to control and inform vehicles along their travel, far away from the tunnel; recorded safety related messages, via radio rebroadcast “leaky feed”, to inform every car entering a tunnel longer than 1 km on the procedures to follow in case of fires, on which facilities are available and how to use them; web site to enhance publicity campaigns to ensure drivers to understand that a tunnel poses different and more demanding challenges than the open road; MMI (man-machine-interface) in the Control centre; speed control in tunnels as in the rest of the network; automatic time interval at the toll barrier to allow vehicles to keep to the various required distances between vehicles; virtual reality in training operators (to mimic different incident scenarios); technology aids to extend the management of operations in case of emergency to senior officers that cannot be actually present in case of incidents (e.g., virtual “silver command” post).

As presented in Figure 3.7, 50% of the respondents (AAs and TMs) agreed that technological developments influenced the application of the Directive, in particular on the operational measures. An example of how technology influences the application of the Directive is reported by the Dutch AA: while the increased traffic flow requires a higher availability of safety equipment in tunnels, safety measures at higher technological content need more maintenance and therefore less availability of the infrastructure.

Figure 3.8 shows how many times the respondents indicated an influence of the technological developments on each safety requirement. Monitoring systems are the most affected, followed by the communication systems and the control centres.

About 60% of respondents (AAs, TMs and EXs) agreed that the requirements of the Directive are still relevant in the context of new developments in transport and technology, but several provided suggestions that mainly related to new technologies. The analysis of the main technological developments and their effects on the application of the Directive suggest some provisions that can be considered obsolete or which warrant discussion:

- the widespread use of mobile phones and the coverage of GSM in tunnels could overcome the need of emergency stations[61]. This is supported by studies carried out in Austria, the AA has suggested that the prescribed distance of 150 m between consecutive emergency stations should be discussed.
- smartphones and other multimedia devices (tablets, in-car entertainment systems, etc.), limit the effectiveness of radio re-broadcast systems, as many drivers do not listen to the radio. Variable Message Systems and loudspeakers would be far more effective.
- the requirements for structural integrity during fires may now be mitigated by the installation of passive fire protection (mist or deluge) which are intended to minimise damage and impact on the structure.

The removal of such provisions may lead to a corresponding reduction of compliance costs

From a wider point of view, the respondents are divided in three groups. Some recognize the balance of the Directive between generic and detailed requirements, and consider the implementation of concrete measures in the responsibility of the Member States. Others

[61] Closed niches equipped with telephone and 2 extinguishers at a maximum interval of 250 metres.

would like a revision of the Annex I of the Directive that includes new technologies, such as automated traffic management. The third group of respondents, are concerned that the specification of “safety measures” in Annex I has been taken as definitive and can hamper the introduction of new technology due to the protracted “derogation” process. According to the latter, the solution suggested should give more power to the Inspection Entity, for example to levy fines (or some other penalty) on case of failure complying with the measures required.

There is support for the EU having a role in assisting the Member States with the provision of relevant information on good practices and the latest developments in transport and technology issues.

Finally, to analyse in depth the sustainability of the Directive, stakeholders were asked for the identification of obsolete provisions, even if these were not strictly associated with changes in technology. The responses provided are that:

- the approach to tunnels with higher gradients should be revised. The Directive currently assumes that a tunnel with a gradient over 3% would require additional measures. Rather, it seems sufficient to determine initially whether an increased gradient leads to a safety problem and only in this case additional measures should be considered.
- the Directive should be revised taking into account a most likely scenario, not a worst (and rare) scenario in a context where small fires can evolve into larger fires, and it is not only large fires that have major consequences.
- in UK, the EU Emergency exit ‘man running’ signage conflicts with the national regulations and so do all road signs that must be shown in yards.

3.8 EU added value

This section presents the assessment of the extent to which interventions or activities supported at the EU level bring about changes that would not have occurred through Member States acting independently, or cooperating bilaterally.

3.8.1 Summary findings

The Directive has delivered EU added value. Operators and officers share the view that the Directive, transposed into the national regulations, has had much stronger effects than simple recommendations or guidelines, guaranteeing the same safety objective for all tunnels in the EU (see EQ 22).

With respect to the relevance of the measures, some revisions (changes/additions) are proposed by a number of stakeholders. For example, though not impacting only on tunnel safety, a targeted policy on driver training would be appreciated.

Finally, 62% of the AAs and EXs contacted are in favour of applying the conditions established by the Directive as a principle of conditionality for access to EU funds for financing (whether partially or totally) the refurbishment or construction of the new tunnels, including tunnels outside the TEN-T network and outside the EU (EQ 23). Many respondents (31%), however, did not express any opinion in this respect.

3.8.2 Response to the evaluation questions

EQ22: Due to accidents and fires in the Mont Blanc, Tauern and Gotthard tunnels, in 2004 the added value of EU action for ensuring a minimum level of safety was clear and practically self-explanatory. Is it still justified to maintain and possibly extend EU action for road tunnel safety?

Retention of the Directive, and EU action for road tunnel safety is justified. There is a consensus within the road tunnel safety community that it has had a positive impact on safety. Yet, despite the progress made in embedding better safety practices, the original objective of establishing a minimum safety standard in TEN-T tunnels with length greater than 500 m is not yet achieved (see EQ 1 and EQ 2). There is support for revising and improving the Directive, but there is not the same consensus on the merits of extending EU action by broadening its scope.

It is generally acknowledged that, in absence of the Directive, the same effects on organizational arrangements (Administrative Authority, tunnel Safety Officer) would have not be achieved at European level through other instruments.

Operators and officers agree that the Directive, transposed into the national regulations, has been a strong instrument in harmonising the approach of Member States towards the same objectives of tunnel safety, and this is still the main value of the Directive.

A similar general opinion was expressed about the effects of the safety measures. While standards comparable to those of the Directive were already introduced in some countries, it was right to harmonise best practice standards across Europe and coerce countries where safety standards were lower into improving them.

Some respondents were more doubtful on the effectiveness of the Directive (as also discussed in section 3.5). It is not yet demonstrated that the Directive has had a real impact on safety, the frequency of the events on which the Directive might have had an effect is so low that any evaluation about effectiveness is difficult.

Furthermore, a combination of a high level Directive, complemented by national standardisation, better adjusted to the national situation/budget could have achieved the same safety objectives in a better way.

With respect to the value of the Directive in comparison with other instruments concerning the prevention and mitigation effectiveness of accidents and fires, a mixed picture emerged. The German AA/EX stated that the national legislation or guidelines could better achieve such an objective. In Greece particular attention is paid to the spatial distribution of fire-fighting services. While the national regulations require the mobilization of firefighting teams in one minute, they do not guarantee the operational readiness *in situ*. Furthermore, it would be important to guarantee the ability and the authorization of tunnel operation staff (site patrols) to undertake fire-fighting operations (this implies additional issues like certification, training, equipment, clothing, hierarchy and procedures).

The Italian AA mentioned the behaviour of both users and safety operators. A national expert made the same point, noting that the training of drivers could be another possible instrument to focus on in the future. The compulsory driving education and psycho-physical readiness of the users, together with the technical characteristics of the vehicles, were cited by the AAs of Slovenia and Slovakia as well.

With respect to prevention and mitigation of fires, the Finnish AA stated that the minimum requirements have to be clear, but the risk analysis should have an important role and, where possible, it should allow to select cost efficient solutions.

Other respondents, namely the Italian and the Slovakian AAs, called for additional measures to fight fires. For example:

- measures addressing the behaviour of both safety operators and users, in particular the professional education of truck drivers;
- traffic management with subsequent closure of the tunnel;
- instant alert signals on vehicles;
- the implementation of temperature scanner;
- fixed fire-extinguisher.

The possibility to extend the EU action on road tunnel safety was analysed taking into account the difference between the Directive and the national regulations, in terms of measures provided and scope.

In 7 countries out of 17 national regulations are already stricter than the Directive, even if differences are small. The Directive fixes minimum requirements, which are internationally recognised as sufficient and reasonable, for both existing and new tunnels. In addition, Member States have the possibility to further raise the standard adopted in the respective national regulations. The application of stricter norms is linked either to the pre-existing regulation or to the request for more safety. The main differences concern the distance between emergency stations, between lay-bys and between the cross passageways for emergency services, in addition to the ventilation and water supply. The same considerations can apply to organisational measures: for example in Germany and Spain the safety inspections are carried out every 5 years, instead of 6.

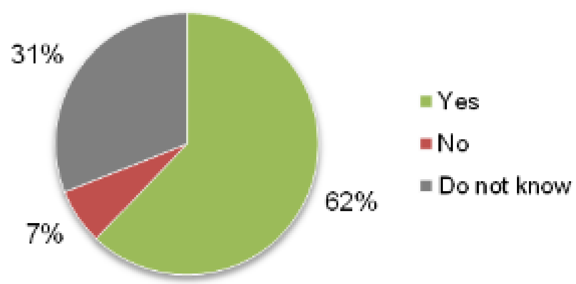
As shown in Figure 3.11 and discussed in EQ 9, 48% of the consulted AAs and experts consider it useful/viable to extend the scope of the Directive to include non-TEN-T tunnels and the same percentage disagree. The number and heterogeneity of tunnels caught by such an extension of scope would entail high refurbishment costs, assessed in the order of 1.6-2.4 billion Euro (see EQ 16). Quantification of the expected number of lives saved and damage avoided through such an extension was out of scope of this study. Significant benefits would be needed to justify the substantial costs.

EQ23: Would it be justified to apply the conditions established by Directive 2004/54/EC as principle of conditionality for acceding to EU funds for financing partially or totally, the works, refurbishment or construction of new tunnels, also outside the TEN-T network and outside the EU?

A majority (62%) of AAs and experts consulted support the application of the conditions established by the Directive as a principle of conditionality for access to EU funds for financing (partially or totally) tunnel refurbishment or construction of new tunnels, also outside the TEN-T network and outside the EU.

The Directive has become a widely recognised benchmark, used at international level to evaluate whether a tunnel meets basic safety standards. It is therefore recommended that it is used as reference also outside its current scope.

Figure 3.25 Support for applying the conditions of the Directive as a principle of conditionality for acceding to EU funds for new tunnels



Source: TRT analysis of the questionnaires (29 answers)

Additional notes were provided alongside some answers. If the minimum standard set by the Directive could be established also outside the TERN and outside the EU, several AAs and experts would not agree with such policy outside the EU.

One expert warned that there ought to be a clear line on which type of tunnels (traffic volume, risk level) the Directive would be valid, whilst another noted that it would be difficult to assess how to distribute those EU funds, as long as other aspects, such as economic and social issues should be taken into account.

4 Conclusions

This final section provides the evaluation's main findings and conclusions.

The objectives of Directive 2004/54/EC are not yet fully achieved, principally because many tunnels have not yet been upgraded to the point where they meet its requirements. The tunnel refurbishment programme in some countries is far from complete. The work required is greatest in the countries with a comparatively high number of tunnels. Achieving full compliance in the remaining time available will require a very significant effort, and investment.

Although the full effects of the Directive are yet to be realised the evaluation has found evidence of positive outcomes and impacts. Specifically:

- Directive 2004/54/EC is credited with focusing attention on the safety of road tunnels and concentrating the efforts of all stakeholders towards this as a common objective;
- The Directive is generally acknowledged to have had a positive effect in the awareness of the problem of tunnel safety. Though the case for regulating this specific aspect of road safety was built on a set of events that occurred in large tunnels between 1999 and 2002, the subject matter and scope of the Directive are still valid and widely shared;
- The Directive has contributed to the strengthening of safety-orientated systems and tunnel infrastructure. The benefits of these changes, in term of accidents and fires avoided, cannot be measured at this time due to a lack of the data that would facilitate a comparative analysis of accident rates pre/post refurbishment. Europe has seen a significant fall in the accident rate on the wider highway network and in road tunnels over the same period;
- The main outcome of the Directive is an improvement in capacity to manage dangerous events, and to prevent and mitigate the effects of accidents and fires. Overall compliance with the structural requirements of the Directive is still low but compliance with the operational and procedural requirements is much higher. This could be seen as the principal output of the investment and actions triggered by the Directive. A wider awareness of the problem and deeper understanding of the issues, together with clearer responsibilities assigned to the various entities defined (AA, TM, TSO, etc.) has provided benefits. These have extended beyond the TEN-T network.
- The Directive has become an internationally recognised standard for regulation in this field since it guarantees that minimum safety levels are met. Furthermore, the impact on costs for new tunnels has been manageable (in the order of 2-3% for a new tunnel) and new technologies might allow for reducing some safety measures and consequently reducing the additional cost burden.
- The analysis of the application of the Directive in selected focus countries has identified a number of good practices.

  In France, the effort deployed in the research for safety in tunnels and the international collaborations. In Germany, a number of detailed measures taken have proved to be very effective and cost efficient in achieving high safety levels (speed control, visibility meters, slot gutters and lay-bys layout). An extensive use of control centres has been identified in Greece and Slovakia, where all tunnels have CCTV systems with automatic accident detection and fire detection tools (usually linear thermal detection). Training of the tunnels operators jointly with the safety services (i.e., police, fire brigade and emergency medical service) is the best practice identified in Italy.
- The Directive has clearly supported progress in materials used in tunnels and construction techniques, and for operational systems and safety measures adopted to respond to the minimum requirements that it defines.

The table below summarises the answers to the evaluation questions.

Table 4.1 Summary of conclusions to each evaluation question

No	Evaluation questions	Conclusions
		Implementation
EQ 1	Has the refurbishment of tunnels in operation been completed? What is the state of implementation in countries where the work is not yet completed?	The refurbishment task is far from complete. 2014 was set as the default implementation deadline but seven Member States with a higher density of tunnels on the TEN-T network (Italy, Spain, Austria, Greece, Slovenia, Luxembourg and Croatia) were given a later implementation deadline of 2019. While 82% of the tunnels (measured by total tube length) that have a deadline of 2014 are compliant with the provisions of the Directive, only 17% of the tunnels subject to the extended deadline of 2019 are currently compliant. The EU28 compliance rate is therefore 29% on total tube length and 26% on number of tunnels according to the data made available till the end of 2014.
EQ 2	How many new tunnels were planned and constructed? Have the requirements of the Directive been applied to them?	According to the data collected, 30% of the tunnels in the scope of the Directive are 'new', i.e. have been or will be put into operation on or after 1 May 2006 (239 out of 787 tunnels in the EU28, or 282 out of 949 tunnels if Norway is also included). 154 new EU tunnels have become operational since 1 May 2006 (and further tunnels are planned or are being built). The provisions of the Directive have been fully applied in 87% of these new tunnels. Eleven tunnels are not fully compliant as their design was approved before the introduction of the Directive and they were opened after it entered into force.
EQ 3	How many tunnels were inspected? How were these inspections carried out?	Art. 12 of the Directive requires that the tunnels have to be inspected by the Inspection Entities at most every six years, to verify their compliance with the provisions of the Directive. According to the data collected, at least 251 of 705 tunnels (36%) in operation in the EU has been inspected. In most cases the most recent inspection was in the period 2012-2014. In general, the inspection criteria and frequency have been defined at national level. The AA acts as Inspection Entity in half of the countries.
EQ 4	Which factors might have hampered or slowed down the implementation of the Directive?	The 2014 deadline for the refurbishment works has been the most important driver for the implementation of Directive's provisions. The cost of refurbishing tunnels has been identified as the main factor hampering the implementation of the Directive.
EQ 5	How have technological developments affected the application of the Directive 2004/54/EC, especially in terms of safety, operational and organisational measures?	The existence of innovative technologies has not been a key driver for implementing the Directive, though technology development has affected the available solutions for some specific measures, namely communication systems, monitoring and control centres.
EQ 6	To what extent were the derogations, notably concerning structural requirements, innovative techniques and safety measures laid down by Directive 2004/54/EC applied in the different Member States?	Derogations have not been widely used. 16 derogations have been reported for 13 tunnels. Half of the derogations concern the water supply (point 2.11 of the Annex I of the Directive). Ten out of the 13 derogated tunnels are in Croatia. More derogations are expected to be applied as the 2019 deadline approaches.

No	Evaluation questions	Conclusions
EQ 7	To what extent were the technical measures implemented?	The data on the implementation of each measure specified by the Directive are less complete than those describing the overall compliance of the tunnels, and are derived from stakeholder responses rather than MS reports submitted to the Commission. The available data suggest that for the 705 tunnels in operation, there is compliance across all tunnels for only three of the measures prescribed by the Directive. The measure least respected relates to point 2.10 of Annex I ("Emergency stations"): 40% of the tunnels in operation are non-compliant. The analysis for only the Member States that had a 2014 refurbishment deadline shows that the maximum rate of non-compliance is equal to 4%. This condition regards the provisions on emergency exits and fire resistance of equipment that have been identified in 5 cases out of 118.
Relevance		
EQ 8	To what extent is the Directive 2004/54/EC addressing the causes of accidents and fires in tunnels? Are other possible safety issues in tunnels sufficiently addressed?	The human error and mechanical failures are the two most significant causes of accidents in road tunnels. Examples of human error include inappropriate driver behaviour (e.g. not maintaining a safe distance from the vehicle in front), misinterpretation of the traffic situation or driving conditions, lack of vigilance (with distractions, fatigue, alcohol, etc. as contributory factors) and excessive speed. The Directive does not address all these causal factors directly but overall the implementation of its requirements is effective at improving the level of safety in tunnels and containing the consequences when a problem occurs. If the Directive is reviewed a number of other possible safety issues in tunnels could be considered, specifically: flooding, communication inside the tunnel to enhance the self-rescue of the users, definition of "special" tunnels, and detection of high temperature on heavy vehicles before entering the tunnel.
EQ 9	Is the scope of the Directive, i.e. tunnels of over 500m on the TEN-T network in all EU Member States and EEA plus Switzerland, adequate?	The current scope of the Directive is regarded as adequate. Two possible extensions of the scope were considered: (i) the inclusion of tunnels longer than 500 m outside the TEN-T; and (ii) the inclusion of tunnels shorter than 500 m. With respect to non-TEN-T tunnels, an extension of the scope to seems practicable, considering that in some countries similar provisions are already required for these tunnels. An extension to include the tunnels shorter than 500 m is considered less feasible and likely to have limited impact.
Coherence		
EQ 10	The analysis on the coherence should evaluate the links of Directive 2004/54/EC with other objectives of the EU transport policy. In particular, the contractor should assess whether Directive 2004/54/EC is coherent with the objectives of transport externalities and road safety	In general, the provisions of the Directive fit well into the overall regulatory framework on road safety, but improvements are possible. At the European level, the consolidation of Directive 2004/54/EC and Directive 2008/96/EC would be important as it could reduce the differences in the approach to safety issues in tunnels shorter than and over 500 m. In particular "the principles set out in Directive 2008/96 should be preserved and carefully adapted to the specific context of road tunnels"

Effectiveness		
EQ 11	To what extent has Directive 2004/54/EC contributed to prevention of accidents and mitigations of the consequences of accidents? What have been the effects of the Directive on the planning and construction of new tunnels?	The Directive increased the level of safety in the tunnels of the trans-European road network and, in a number of countries, outside the TEN-T network. A qualitative analysis was carried out in which the impact of eleven measures of the Directive on the prevention of accidents and fires and on the mitigation of their effects was assessed. The control centre and the monitoring systems are perceived to be the most effective measures for the prevention of accidents and the mitigation of their effects. With regard to prevention, the contributions of the lighting and the road signs are highly ranked, while the equipment to close the tunnel plays an important role in mitigating the accidents' effects. Monitoring systems are effective in the prevention of fires, together with the control centre. Important measures for mitigating the effects of fires are ventilation, the control centre, the monitoring systems, the equipment to close the tunnel and the fire resistance equipment. The available evidence suggests that the Directive has led to an increase in the time required for design of new tunnels. In those Member States where the Directive has introduced additional infrastructure and equipment requirements there has also been an impact on construct costs.
EQ 12	To what extent has the Directive 2004/54/EC affected existing managing operations and practices in tunnels? Has this resulted in an improvement in terms of effectiveness of operations?	The Directive has changed management and operational practices in tunnels, introducing new roles and responsibilities. In particular, the compilation of safety documentation and the organisation of periodic exercises have been made mandatory. Such changes are considered to have improved the effectiveness of the operations.
EQ 13	What effects has the need of refurbishing existing tunnels had on the environment, local population and on the traffic flows?	The effects of the refurbishment works on the environment, the local populations and the traffic flows are, in general, considered to be minor. Data on this issue are scarce. Traffic detours and tunnel closures are a constraint on the tunnel refurbishment programme in some cases.
EQ 14	Has Directive 2004/54/EC had other indirect or unexpected effects?	An indirect effect generated by the Directive concerns the costs to carry out the risk analysis that could not be always necessary. Another indirect effect concerns, the impact on users as tolls rise to support the investments of the road concessionaries.
EQ 15	To what extent did the Directive 2004/54/EC have an effect outside the trans-European network and outside the EU? Did it have an impact outside the EU? In particular, what are the positive experiences and spill-over generated outside the EU and beyond EEA and Switzerland?	The requirements of the Directive have been partially or in full applied to the tunnels of several countries (independently from length and network). Examples are Austria, Germany, Finland, Italy, Spain and the Netherlands. In general, the Directive has been considered as a reference standard outside the trans-European network and outside the EU, and so helped to enhance the safety culture among designers, road managers and authorities. Furthermore, the European Investment Bank requires compliance with the requirements of the Directive as a condition for the financing of projects, irrespective of whether they are part of the TEN-T network or not.
EQ 16	To what extent could the effects identified be increased by broadening the scope of the Directive 2004/54/EC to include non-TEN-T tunnels?	The broadening of the scope of the Directive to include non-TEN-T tunnels would harmonise tunnel safety requirements and the regulations at national level and then at European level. There would be a significant cost to this extension (provisionally estimated at 1.6-2.4 billion Euro).

Efficiency		
EQ 17	What are the costs of measures undertaken to implement the Directive 2004/54/EC?	For some Member States the requirements of the Directive are similar to pre-existing national legislation so the cost of compliance has been very small. Some Member States have few tunnels and so have seen only modest expenditure. Other Member States have spent and programmed very significant sums for tunnel refurbishment but the investment data do not distinguish between general refurbishment costs and those triggered by the Directive. The variation in age, type and number of tunnels, across Member States makes generalisations difficult, as does the variations in cost accounting practice.
EQ 18	At what costs were the procedures (commissioning, safety inspections, safety exercises, etc.) and other administrative arrangements described in the Directive established?	As for the costs for the implementation of the other measures, it can be reported a difficulty in identifying the specific expenditure. The information provided includes, for example, the costs for the administrative arrangements, ranging from 10,000 Euro in Sweden to 320,000 Euro in Ireland, and the costs for the periodic exercises, ranging from 10,000 Euro in Slovenia to 360.000 in Ireland.
EQ 19	To what extent did the use of derogations generate costs and/or benefits?	No cost or benefit data generated by the use of derogation were available for the 16 derogations reported.
EQ 20	Have measures related to budget planning been adequate for ensuring the minimum level of safety in tunnels?	The progress so limited in certain key countries (and behind original schedule), and the amount of money that will need to be spent before 2019 (still very large), suggest that budgetary planning has not been very good in those countries that benefit from the extended deadline The State budget represents the main source of financing for the investments costs for the refurbishment and the maintenance of the tunnels. Concessionaire equity and the user tolls play a minor role, while the EU funds were used more in Greece compared to other countries.
Sustainability		
EQ 21	The evaluation should estimate the long and medium term effects of the Directive and in particular: How technological development might affect the application of the Directive 2004/54/EC, especially in terms of safety, operational and organisational measures.	In the medium term technological development will affect the implementation of the Directive through an improvement of the performance of the safety and operational measures (e.g. developments of devices of the monitoring systems and of the management software used in the control centres).
EU added value		
EQ 22	Due to accidents and fires in the Mont Blanc, Tauern and Gotthard tunnels, in 2004 the added value of EU action for ensuring a minimum level of safety was clear and practically self-explanatory. Is it still justified to maintain and possibly extend EU action for road tunnel safety?	The Directive, hence the EU action for road tunnel safety, is still valid, since the objective of establishing a minimum safety standard in TEN-T tunnels with length greater than 500 m is not yet achieved. The Directive is still needed, not only as an instrument to harmonise the characteristics of tunnels in Europe but specifically to increase the awareness of the tunnel safety issue. The Directive is credited with raising awareness of the safety and to have led to greater cooperation among different actors (mainly AA, TM, but also fire-fighters, safety officers and construction companies)) The potential broadening of the scope of the Directive, however seems not feasible, mainly due to the costs it would generate. Rather, a revision of some measures should be proposed, for example, better defined policy on the education of the drivers..

EQ 23	Would it be justified to apply the conditions established by Directive 2004/54/EC as principle of conditionality for acceding to EU funds for financing partially or totally, the works, refurbishment or construction of new tunnels, also outside the TEN-T network and outside the EU?	The Directive has become a widely recognised benchmark, used at international level to evaluate whether a tunnel meets basic safety standards. It is therefore recommended that it is used as reference standard for project finance. Eventually, it seems justified to apply the conditions established by the Directive as a principle of conditionality for acceding to EU funds for financing partially or totally refurbishment or construction of the new tunnels, also outside the TEN-T network and outside the EU.

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ANNEXES

Annex 1 Focus countries

A1.1 Introduction

This section describes the implementation of the Directive in the following five Member States: France, Germany, Greece, Italy and Slovakia. The implementation profile for each country has the following structure:

- a description of the trans-European road network (TERN) and the tunnels in the scope of the Directive;
- a summary of the state of implementation of the Directive;
- details of accidents and fires recorded;
- an estimate of the costs of implementation of the Directive;
- notes on other findings and best practices.

For each country, a number of direct interviews involving key stakeholders and experts complemented the consultation to provide an in-depth examination of topics of particular interest to the study (e.g. clarify particular aspects on the implementation of the Directive, identify best practices). The following interviews were carried out:

- France:
  - representative of the AAs and Centre D'Etudes Des Tunnels (CETU) expert;
- Germany:
  - representative of the AAs and Bundesanstalt für Straßenwesen (BASt) expert;
  - expert from University of Darmstadt;
- Greece:
  - AA in charge of all Greek TERN tunnels (Dioikitikí Archí Sirangon - D.A.S). AA;
  - the biggest TM, Egnatia Odos S.A.;
- Italy:
  - AA in charge of all Italian TERN tunnels (Commissione permanente per le gallerie);
  - the State-owned TM (ANAS S.p.A.);
  - expert from ASTM-SIAS Group including eight TMs having tunnels within the scope of the Directive;
  - expert from University of Florence;
- Slovakia:
  - expert from the Industry.

A1.2 France

A1.2.1 TERN and tunnels in scope

In France the trans-European road network extends to about 9,350 km of highways. There are 30 tunnels within scope of the Directive. These have a total tube length of 71.5 km (see Table 3.1). In addition to these, three tunnels are shared with Italy (Mont-Blanc and Fréjus) and Spain (Somport). Figure A1.1 shows the location of the tunnels.

The 30 national tunnels are controlled by 16 regional governments (départements) (see Table A1.1). Half of the tunnels managed by the regional governments are under the responsibility of three authorities (Savoie, Ain and Alpes Maritimes). Thirteen other authorities manage one or two tunnels each. Table A1.2 lists the French tunnel managers of the national tunnels.

Data from 2011[62] show that at the end of 2010 France had 940 road tunnels in use, of which 201 were longer than 300 m. 86 were State-owned and 115 belonged to regional governments, municipalities or partnerships of local public authorities (Établissement public de Coopération intercommunale, EPCI).

All technical aspects of tunnels fall under the responsibility of the Ministry of Ecology, Sustainable Development, Transport and Housing, assisted by the CETU (the Tunnel Studies Centre) which acts as a central technical service.

Table A1.1 Administrative Authorities in France

Administrative Authority	Number of tunnels	Total tube length (km)
Le préfet du département de la Haute-Savoie	2	3.9
Le préfet du département de la Loire	1	1.1
Le préfet du département de la Lozère	1	1.2
Le préfet du département de la Savoie	6	19.1
Le préfet du département de la Seine-Maritime	1	3.1
Le préfet du département de l'Ain	3	10.4
Le préfet du département de l'Ariege	1	2.2
Le préfet du département de l'Hérault	1	1.7
Le préfet du département de l'Isère	2	2.0
Le préfet du département de Maine-et-Loire	1	3.4
Le préfet du département des Alpes de Haute-Provence	1	1.0
Le préfet du département des Alpes Maritimes	6	9.4
Le préfet du département des Pyrénées Orientales	1	4.8
Le préfet du département du Pas de Calais	1	1.6
Le préfet du département du Rhône	1	3.7
Le préfet du département du Var	1	3.0
Total France	**30**	**71.5**

Source: TRT analysis of the questionnaire and reports of France

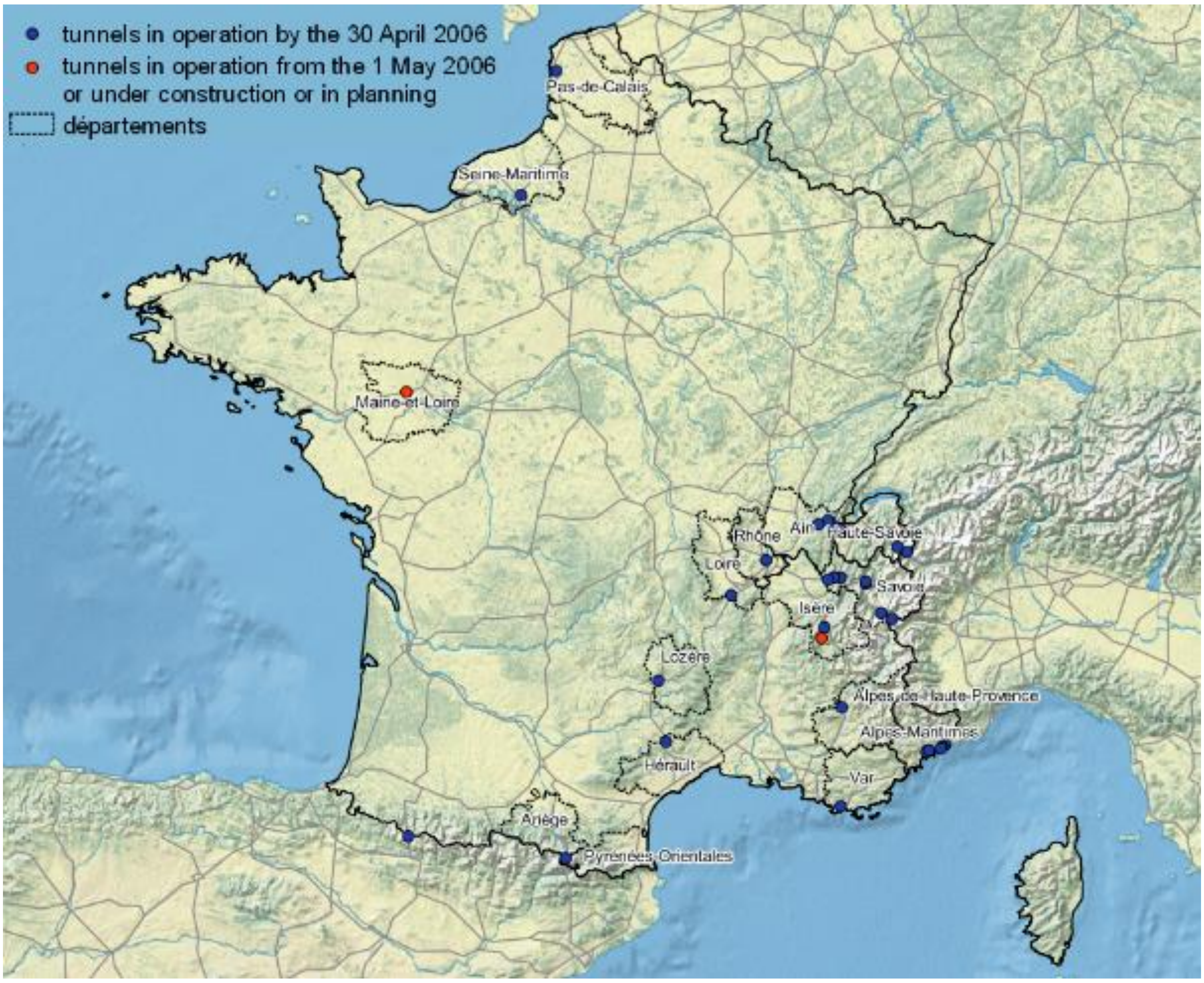
[62] Deffayet M., Tesson M. (2011). L'amélioration de la sécurité dans les tunnels routiers, TEC Transports/Environnement/Circulation n° 210.

Table A1.2 Tunnel Managers in France

Tunnel Manager	Number of tunnels	Total tube length (km)
Autoroutes et tunnel du Mont-Blanc (ATMB)	1	2.9
Autoroutes du Sud de la France (ASF)	1	4.8
Autoroutes Paris-Rhin-Rhone (APRR)	3	10.4
Cofiroute	1	3.4
Direction Interdépartementale des Routes Centre Est	3	3.9
Direction Interdépartementale des Routes Massif Central	1	1.2
Direction Interdépartementale des Routes Méditerranée	1	3.0
Direction Interdépartementale des Routes Nord Ouest	1	3.1
Direction Interdépartementale des Routes Sud-Ouest	2	3.9
Grand Lyon	1	3.7
SANEF	1	1.6
Société des Autoroutes Estérel, Cote d'Azur, Provence, Alpes (ESCOTA)	7	10.4
Société des Autoroutes Rhone-Alpes (AREA)	4	11.5
Société Francaise du Tunnel Routier du Fréjus (SFTRF)	3	7.9
Total France	**30**	**71.5**

Source: TRT analysis of the questionnaire and reports of France

Figure A1.1 Tunnels in the scope of the Directive in France[63]



Source: TRT analysis

A1.2.2 State of implementation of the Directive

According to France's submission to the Commission on the state of implementation (dated September 2014), three out of 28 tunnels that were operational as of 30 April 2006 still need refurbishment work. According to the plans, one of these is expected to be compliant at the beginning of 2015, while the other two will be made compliant within 2017/2018. Work is needed on fire resistance of equipment, safety lighting, emergency stations, monitoring systems, emergency power supply and ventilation to bring them into line with safety requirements.

Two new tunnels have been opened since May 2006. In one case the state of compliance was not reported.

Table 3.2 and Table 3.4 list the French tunnels in the scope of the Directive and their state of compliance. No information on the last year of inspection was provided for the tunnels in France.

A1.2.3 Accidents and fires

In France, the TMs in charge of tunnels longer than 300 m are required to set up a permanent system for recording and analysing significant incidents and accidents. These are defined as:

- all events that result in personal injury;

[63] See footnote 17 for the credits.

- all the fires inside the tunnel;
- other events which required unscheduled closure of the tunnel, except those related to the management of traffic outside of the structure.

For each tunnel, the reported events include the number of accidents that caused fires, with and without injury to road users, and the number of fires not due to an accident. For the accidents causing injury to road users, the number of injured, slight or severe, is provided. An analysis of the events is also carried out.

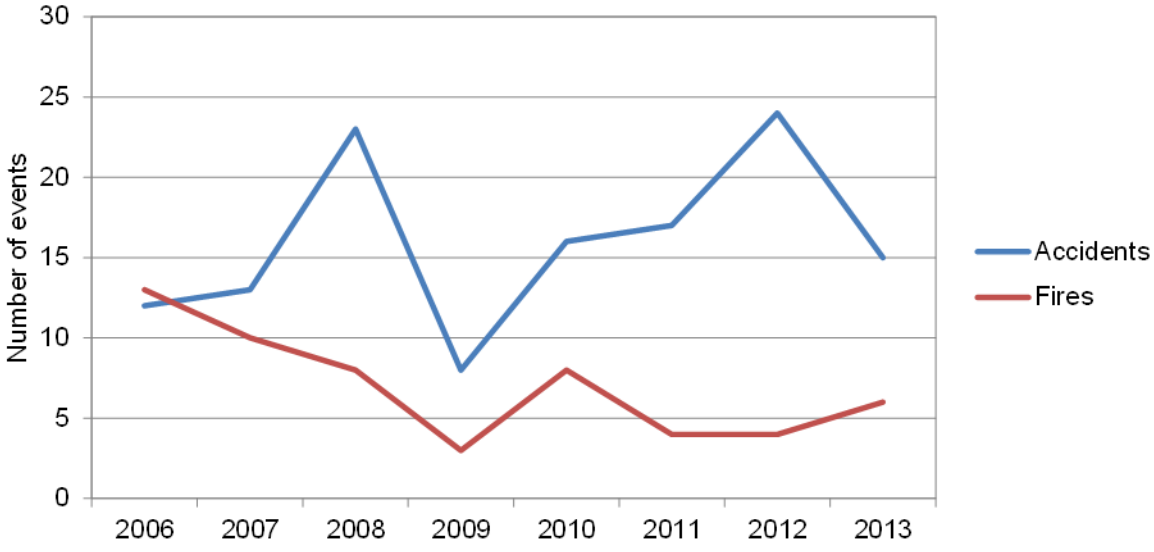
Table A1.3 reports the number of accidents, fires, fatalities and injuries occurred in the French TERN tunnels over the period 2006-2013. Figure A1.2 depicts the trends of accidents and fires for the same period.

Table A1.3 Accidents, fatalities, injuries and fires in French road tunnels

Events	2006	2007	2008	2009	2010	2011	2012	2013
Accidents	12	13	23	8	16	17	24	15
Fires	13	10	8	3	8	4	4	6
Fatalities	1	0	0	0	1	1	0	2
Severe injuries	1	1	1	0	3	0	5	3
Slight injuries	12	13	28	10	18	17	28	24

Source: TRT analysis of the questionnaire of France

Figure A1.2 Trends of accidents and fires in road tunnels in France



Source: TRT analysis of the reports on accidents and fires of France

A1.2.4 Costs for the implementation of the Directive

It is difficult to assess the costs of implementation of the Directive because: (i) there was a national programme for the refurbishment of tunnels longer than 300 m that predated the Directive; and (ii) responsibilities are distributed among different national, regional and local authorities.

At the end of 2010 about 2 billion Euro were allocated for refurbishment of the tunnels on the national network. The budgeted funds were estimated to meet 75% of the total resources required. As shown in Table 3.13 (EQ 17), 950 million Euro were allocated to refurbish the tunnels in the scope of the Directive. Another 210 million Euro were earmarked for the construction of a new emergency gallery in the transnational tunnel Fréjus.

19.8 million Euro was allocated to maintenance of the 84 State-owned tunnels (of which 43 are longer than 300 m) and two emergency galleries[64] in 2014.

A1.2.5 Other findings and best practices

France provides examples of best practice in relation to:

- The effort deployed in the research for safety in tunnels;
- International collaborations.

Such efforts are channelled through the Centre D'Etudes Des Tunnels (CETU).

The CETU is the central technical service of the French Ministry of Ecology, Sustainable Development, Transport and Housing. It is responsible for all technical aspects of tunnels. Created in 1970, it is attached to the Directorate General for Infrastructure, Transport and the Sea and it is involved in all stages of tunnel engineering works, from design to asset management, including issues related to facilities and civil engineering.

The work conducted by CETU for State-owned tunnels also directly benefits local authorities which are responsible for numerous other tunnels. CETU is frequently requested to supply its expertise and assistance to engineering projects as well as to counselling and training.

The French Speaking Working Group of Road Tunnel Operators

The French Speaking Working Group of Road Tunnel Operators (GTFE) was created in 1973 at the CETU with, as main objective, the collaboration between all the actors for management and operation of tunnels in service, under construction or under project.

The GTFE is composed to a very large extent of the operators of French tunnels but it has also been enriched, in the course of its existence, by the French speaking operators of the tunnels of other countries (Spain, Italy, Switzerland, Belgium, Canada, etc.). The group today consists of about 130 members managing more than 200 tunnels, of which 20% are located outside France or are cross-border tunnels. The operators come from a variety of background (ministries of Transport, local authorities, motorway companies, etc.).

Meetings are held twice a year. At each meeting the Tunnel Managers share experience on problems or difficulties encountered, compare management practices with that of similar tunnels and benefit from the common experience to find solutions and improve practices. The information exchange concerns traffic data, incidents and accidents, energy demand, maintenance of equipment and structures and the operating costs of each of the tunnels.

Regulatory or legal aspects, questions of training, technical issues on equipment and its use in tunnels or on new technologies available in this field are also discussed, as is the behaviour of users and that of the tunnel operators in case of incidents.

External links have been established with the UK Road Tunnel Operators Forum, the British equivalent of the GTFE, with the purpose of sharing and comparing practices at the international dimension. A representative of the UK Forum is thus invited to each meeting of the GTFE and vice versa, a member of the GTFE represents the working group at each six-monthly meeting of the UK Forum.

[64] Corresponding to a total tube length of about 93 km.

A1.3 Germany

A1.3.1 TERN and tunnels in scope

The trans-European road network (TERN) in German territory is 10,066 km long.

The geographic distribution of Germany's tunnels reflects its geomorphology. Mountains cover large parts of the country, from the Alps in the very south to the "Mittelgebirge" in the centre, while the northern parts are mainly flat. Therefore, most of the tunnels are located in the southern and central parts of the country. In the north, tunnels essentially serve to cross rivers or other water bodies (e.g. the Elbtunnel in Hamburg or the Emstunnel in the northwest of Lower Saxony).

Figure A1.3 shows the location of the 29 tunnels in Germany that fall within the scope of the Directive. Of these 25 were in operation by 30 April 2006, and 4 are new tunnels (see Table 3.1). The total tube length is 91.2 km (84.7 km of old tunnels and 6.5 km new). Tunnel lengths vary between 540 m and 7.91 km. Of the 29 tunnels, only two have a single tube.

The 29 tunnels fall under the responsibility of 11 Administrative Authorities (see Table A1.4), mainly at the level of the German States; in the case of Bavaria and Baden-Württemberg in the south of Germany, two separate authorities, each with geographically separated competences, are responsible. Each Administrative Authority is responsible for between one and seven TERN tunnels.

Tunnel Managers are specific departments of the responsible Administrative Authorities (see Table A1.5). The German Federal Highway Research Institute (BASt) is the practice-oriented, technical-scientific research institute of the German Government in the field of road engineering, including tunnels. BASt provides the German Federal Ministry of Transport and Digital Infrastructure (BMVI) with scientific-based decision support in transport policy issues. In the framework of the Directive, BASt compiles the relevant information on accidents and fires in tunnels as a basis for the reporting of the German Government to the European Commission.

Figure A1.3 Tunnels in the scope of the Directive in Germany[65]

Source: TRT analysis of the questionnaires and reports of Germany

65 See footnote 17 for the credits.

Table A1.4 Administrative Authorities in Germany

Administrative Authority	Number of tunnels	Total tube length (km)
Autobahndirektion Nordbayern, Bayern	2	5.32
Autobahndirektion Südbayern, Bayern	5	10.16
Behörde für Stadtentwicklung, Hamburg	1	11.05
Hessen Mobil – Straßen- und Verkehrsmanagement, Hessen	1	1.08
Landesamt für Straßenbau und Verkehr, Sachsen	3	13.42
Landesbetrieb für Straßenbau, Saarland	1	1.20
Landesbetrieb Straßenbau Nordrhein-Westfalen, Nordrhein-Westfalen	1	3.00
Niedersächsische Landesbehörde für Straßenbau und Verkehr, Niedersachsen	2	5.33
Regierungspräsidium Freiburg, Baden-Württemberg	1	1.63
Regierungspräsidium Stuttgart, Baden-Württemberg	5	8.76
Thüringer Landesamt für Bau und Verkehr, Thüringen	7	30.22
Total Germany	**29**	**91.17**

Source: TRT analysis of the questionnaires and reports of Germany

Table A1.5 Tunnel Managers in Germany

Tunnel Manager	Number of tunnels	Total tube length (km)
Autobahndirektion Nordbayern, Bayern	2	5.3
Autobahndirektion Südbayern, Bayern	5	10.2
Behörde für Stadtentwicklung, Landesbetrieb Straßen, Brücken und Gewässer (LSBG), Hamburg	1	11.1
Hessen Mobil – Straßen- und Verkehrsmanagement; Tunnelleitzentrale Eschwege, Hessen	1	1.1
Landesamt für Straßenbau und Verkehr, Tunnelbetriebsstelle Dresden, Sachsen	3	13.0
Landesbetrieb für Straßenbau, Neunkirchen, Saarland	1	1.2
Landesbetrieb Straßenbau Nordrhein-Westfalen, Niederlassung Krefeld, Nordrhein-Westfalen	1	3.0
Niedersächsische Landesbehörde für Straßenbau und Verkehr – Geschäftsbereich Gandersheim, Niedersachsen	2	5.3
Regierungspräsidium Freiburg, Referat 45, Baden-Württemberg	1	1.6
Regierungspräsidium Stuttgart, Referat 45, Baden-Württemberg	5	8.8
Thüringer Landesamt für Bau und Verkehr, Thüringen	7	30.2
Total Germany	**29**	**91.2**

Source: TRT analysis of the questionnaires and reports of Germany

The requirements of the Directive are reflected at national level in the “Richtlinie für die Ausstattung und den Betrieb von Straßentunneln (RABT)”[66] of 2006. This guideline is an evolution of the 2003 version and implements the requirements of the Directive, notably with respect to:

- bodies (Administrative Authority, Tunnel Manger, Safety Officer, Inspection Entity);
- road signs, informative signs, etc.;
- reporting;
- safety documentation;
- risk analysis;
- infrastructure and operational measures.

In certain aspects, the previous guideline (RABT 2003) provided for stricter safety requirements, e.g. as to the distance of emergency exits, requirements for and distance of lay-bys, distance of cross passages for emergency services, ventilation. The greatest change brought by the Directive is represented by the use of risk-based considerations providing flexibility in complying with the provisions required. Examples of the use of innovative safety equipment, or innovative safety procedures that provide an equivalent, or higher, level of protection than the technologies prescribed in the Directive are:

- speed control in tunnels;
- visibility meters instead of fire detection cable;
- slot gutter instead of gullies;
- lay-bys without walls perpendicular to the driving direction.

RABT 2006 exceeds the requirements of the Directive in terms of requirements for structural measures and safety equipment in the tunnel. RATB 2006 goes beyond the scope of the Directive in that it is applicable to all tunnels in Germany, not only TERN tunnels.

Improvements in the safety level of German tunnels achieved by the Directive have been limited, as most of the safety measures (structural and operational) required by the Directive were already mandatory in Germany before 2004.

A1.3.2 State of implementation of the Directive

According to Germany’s October 2014 report to the Commission on the state of implementation, eight out of 29 tunnels need refurbishment before they will comply with RABT 2006. For all eight tunnels, conversion has begun; the expected dates for the finalisation of the refurbishment works vary between 2014 and 2018, with completion scheduled for the end of 2015 for four tunnels, and for the end of 2016 for another three. The standard reporting of the administrative authorities in Germany is based on RABT 2006, which has more stringent requirements than the Directive. A dedicated analysis of the compliance with the Directive carried out by BASt in consultation with the ministry (BMVI) revealed that only three tunnels are not yet compliant with the Directive. On current plans they will be compliant by 2015 (“Prüfening”), 2016 (“Schönbuch”), and 2018 (“Königshainer Berge”). Table 3.2 presents the state of compliance with the Directive of the German tunnels in operation on 30 April 2006.

There are four new tunnels, all in operation, with a total tube length of 6.5 km. All four are compliant with the Directive (see Table 3.4).

Information on the last year of inspection has been made available for only one tunnel (inspected in 2014), while no information was provided for the remaining 28 tunnels in Germany.

[66] Guideline for the equipment and operation of road tunnels.

Only two tunnels have one tube; however, these tunnels are compliant nonetheless as they are unidirectional (with the other direction of traffic being either outside a tunnel or having an entirely different road trajectory). Non-compliance in German road tunnels is recorded for

- Evacuation lighting (1 tunnel);
- Water supply (1 tunnel);
- Monitoring systems (1 tunnel);

Each non-compliant tunnel does not comply with only one provision of the Directive.

A1.3.3 Accidents and fires

The available information for Germany about accidents and fires in tunnels in the scope of the Directive covers the period 2006-2013. The accidents reported from 2006 to 2011 include events with and without personal injury, while in the last report only accidents with personal damage are taken into account. All kinds of fire are considered, not only vehicle compartment fires, but also engine, tire and small smouldering fires. Table A1.6 reports the data collected.

Table A1.6 Accidents and fires in German road tunnels

Events	2006-2007	2008-2009	2010-2011	2012-2013
Accidents	501	654	710	96*
Fires	26	41	36	26
Total events with personal damage	100	98	104	122

* Number of accidents with personal damage

Source: TRT analysis of the questionnaires and reports of Germany

According to the 2014 report, 80% of the incidents were caused by human error; only 12% of the incidents were caused by technical failures of the vehicles, while 1% was caused by tunnel technology. Security installations and measures were used in 57% of the incidents.

A1.3.4 Costs for the implementation of the Directive

Tunnels in Germany, including TEN-T and non-TEN-T tunnels, are retrofitted by the ongoing national retrofitting programme. This programme started before the Directive and was then adjusted to meet the 2014 deadline for compliance of all TEN-T tunnels with the requirements of the Directive. Certain delays in implementing this 960 million Euro programme, which had a duration of 12 years[67], meant that not all TERN tunnels are yet fully compliant with the requirements of the Directive (see above). The retrofitting programme applies all requirements of RABT 2006 to all tunnels in Germany without making use of any derogations foreseen in the Directive.

Information on the additional costs associated with the requirements of the Directive is not available but they are thought to be very low since the Directive is not more stringent than the pre-existing German standards. Cost aspects thus have not influenced the speed of implementation of the Directive in Germany.

A1.3.5 Other findings and best practices

Germany decided at an early stage to apply all requirements of the Directive, and those requirements of RABT 2006 that were more stringent, to all tunnels (both TEN-T and non-TENT-T tunnels) in Germany without making use of possible derogations. This has obviously involved significantly higher expenditure than compliance with the minimum requirements.

[67] Status end of 2011. Further refurbishment work will require an additional budget of several hundred million Euro in the coming years.

A number of detailed measures taken in Germany have proved to be very effective and cost efficient in achieving high safety levels. These include:

- speed controls in tunnels are very effective as exceeding speed limits is an important cause of accidents;
- use of visibility meters instead of fire detection cables allows for more rapid fire detection and thus provides an important time advantage in case of a fire;
- slot gutters instead of gullies provide for a much faster drainage of flammable and toxic liquids, and thus reduces negative impacts considerably;
- lay-bys without walls perpendicular to the driving direction reduce the impact of vehicles entering the lay-by at excessive speed.

The implementation of the Directive in Germany is linked to the update of the European Agreement Concerning the International Carriage of Dangerous Goods by Road (ADR) of 2007, wherein tunnel restriction codes for hazardous goods have been established. With respect to the Directive and to RABT 2006, a procedure for Germany was developed under the leadership of BASt that evaluates standardised hazardous goods risks for all road tunnels based on a multistage risk assessment process[68]. This process has led to the identification of restrictions for hazardous goods transport by defined ADR tunnel categories. The process includes the following steps:

- step 1a: simplified analysis of risk relevant tunnel characteristics; initial selection of tunnels to be analysed in more detail.
- step 1b: analysis of intrinsic tunnel risks applying the quantitative risk assessment model DG-QRAM.
- step 2a: detailed risk analysis for individual tunnels using specific consequence models, e.g. computational fluid dynamics models (CFD).
- step 2b: detailed risk analyses for alternative transport routes applying specific consequence models for open routes.

To give an example of the practical application and benefits of this procedure, the consequences of these restrictions have been analysed[69] in the context of the introduction of a safe supply infrastructure for hydrogen, which is an alternative transport fuel. This analysis provides a solid basis for the development of alternative fuels infrastructure in Europe, as stipulated by the Alternative Fuels Infrastructure Directive of October 2014 in its minimum requirements for recharging points for electric vehicles and refuelling points for natural gas (liquefied and compressed natural gas: LNG and CNG) and hydrogen[70].

[68] World Road Association (PIARC): Current Practice for Risk Evaluation for Road Tunnels. Paris, 2013. 2012R23EN

BUNG et al.: Verfahren zur Kategorisierung von Straßentunneln nach ADR 2007. OKT 2009

[69] Ludwig-Bölkow-Systemtechnik et al.: Sichere Wasserstoffinfrastruktur (Safe Hydrogen Infrastructure). DEC 2011

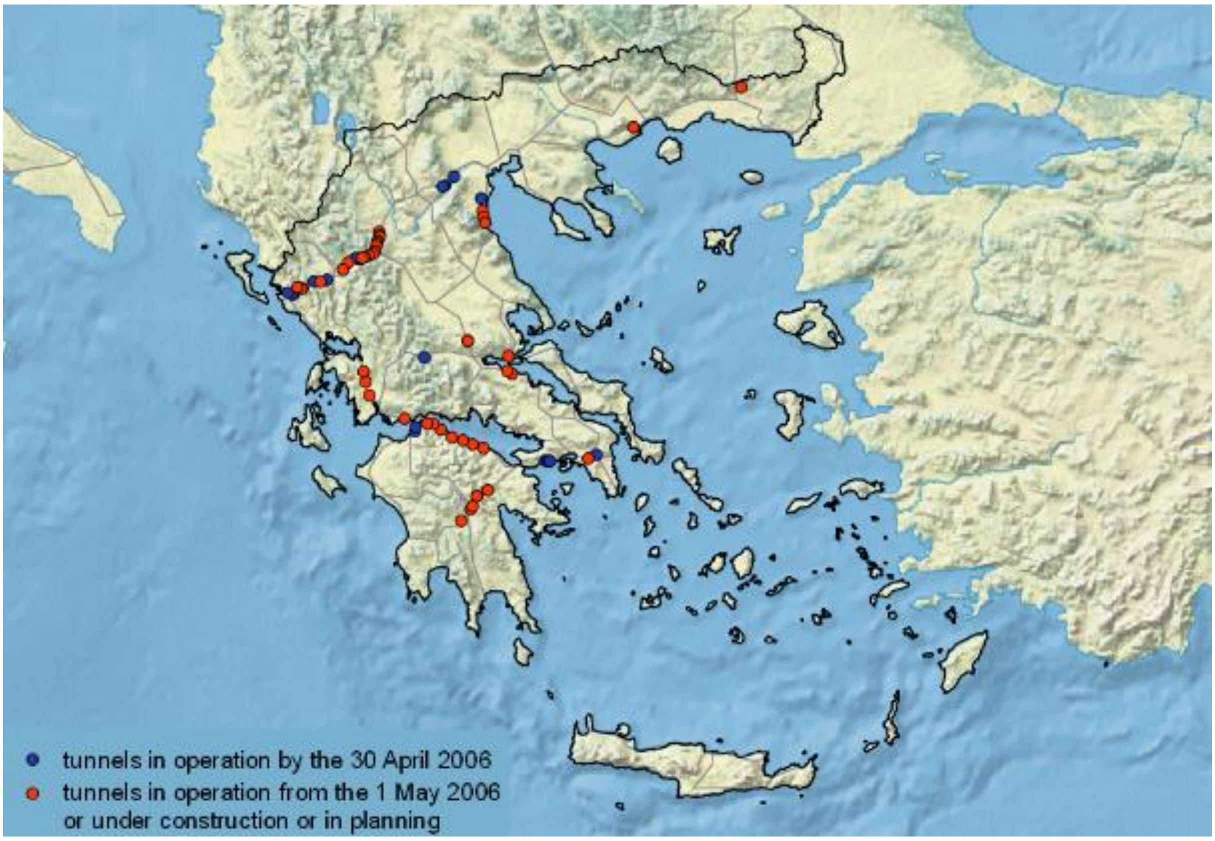
[70] Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure. OJ L 307, 28.10.2014, p. 1

A1.4 Greece

A1.4.1 TERN and tunnels in scope

The trans-European road network (TERN) in the territory of Greece is about 900 km long. There are 68 tunnels in the scope of the Directive. These have a total tube length of 173 km. Table 3.1 reports the number of "old" (i.e. opened by the 30 April 2006) and "new" tunnels and their total tube length. Figure A1.4 shows the location of the tunnels.

Figure A1.4 Tunnels in the scope of the Directive in Greece[71]



Source: TRT analysis

The Directive was transposed in Greece by the Presidential Decree 230/2007. This created a single Administrative Authority D.A.S. (Dioikitikí Archí Sirangon, Administrative Authority for Road Tunnels).

Table A1.7 lists the Tunnel Managers operating in Greece. About 46% of the tunnels in the scope of the Directive (in terms of total tube length) are managed by Egnatia Odos and located on the motorway A2 in northern Greece.

[71] See footnote 17 for the credits.

Table A1.7 Tunnel Managers in Greece

Tunnel Manager	Number of tunnels	Total tube length (km)
Aegean Motorway	4	24.7
Attiki Odos	1	1.7
Dmeo	1	4.8
Egnatia Odos	32	80.2
Eyde Pathe	2	2.4
Kentriki Odos	1	6.0
Moreas	6	11.9
Nea Odos	6	17.3
Olympia Odos	14	22.7
Sterea Ellada Perfecture	1	1.4
Total Greece	**68**	**173.0**

Source: TRT analysis of the questionnaires and reports of Greece

A1.4.2 State of implementation of the Directive

The ratio between total tube length and length of the TERN allows Greece to postpone the deadline for the refurbishments until 2019, according to paragraph 7 of Art. 11 of the Directive. Currently, 10 out of 24 tunnels in operation by the 30 April 2006 still need refurbishment, while all the 26 new tunnels in operation are fully compliant with the Directive (see Table 3.2 and Table 3.4). The main measures to be addressed are: drainage, fire resistance of the equipment, emergency exits and crossing of the central reserve outside each portal.

The last year of inspection was provided for 35 out of the 50 tunnels in operation: 57% of these tunnels were inspected in the period 2008-2009.

The implementation of the Directive in Greece was analysed in depth through an interview with the Administrative Authority and the main Tunnel Manager, Egnatia Odos. Three main issues emerged:

- the costs generated by the introduction of the Safety Officer;
- the costs generated by a widespread use of risk analysis;
- the difficulties related to the measures on the drainage of flammable and toxic liquids when the transport of dangerous goods is permitted.

As for many countries (see EQ 12), the role of Safety Officer (SO) had not existed in Greece prior to the adoption of the Directive. Initially, the functions of the SO were committed to external services, generating additional costs for the Tunnel Managers.

The Directive enhanced also the use of risk analysis to identify alternative measures, when the provisions required are not feasible or feasible only at a disproportionate cost. Such approaches were not so frequently adopted in Greece, thus their introduction generated additional costs. Hence, the lack of a risk methodology to properly assess the consequences of not implementation of Directive provisions may have led to an not optimal identification of alternative measures.

A significant number of “old” tunnels (i.e. those in operation by 30 April 2006) cannot meet the provision of the Directive relating to the drainage of flammable and toxic liquids, or can do so only at disproportionate cost. The Directive[72] establishes that the transport of dangerous goods shall be allowed on the basis of an analysis of relevant risks. On the motorway A2, most of the tunnels have a well-designed drainage system but lack a special provision to prevent fire and flammable and toxic liquids from spreading inside the tubes. Therefore, such tunnels are closed to the dangerous goods vehicles (DGVs), pending the identification of alternative measures. The prohibition of DGVs inside the

[72] Point 2.6.2 of Annex I.

tunnels generated problems with the local communities (as described in EQ 13) where alternative routes were lacking. A large number of violations of the prohibition were also registered.

A1.4.3 Accidents and fires

The reports on accidents and fires submitted by Greece to the Commission present data per road axis during a two-year period, providing a description of the accidents with casualties. Table A1.8 presents the data for 2010-2011 and 2012-2013.

Table A1.8 Summary of events reported by Greece

Event	2010-2011	2012-2013
Accidents with affected persons	15	n. a.
Accidents with casualties	6	7
- Casualties	6	8
Accidents with injured persons	9	11
- Injured persons	11	17
Fires in the vehicles	6	2
Fires in the facilities of the tunnels	2	0

Source: TRT analysis of the questionnaires and reports of Greece

A1.4.4 Costs for the implementation of the Directive

Few data on the costs of the implementation of the Directive were provided. Most of what was available concerned the 32 tunnels on the motorway A2.

Table A1.9 Investments required by the Directive for Greece

Measure	Total cost
Safety lighting	10,400 – 40,000 €/tunnel km
Ventilation	20,000 €/ cross connection
Control centre	50,000 €/ Control Centre
Monitoring systems	100,000 – 200,000 €/ Control Centre
Equipment to close the tunnel	16,000 €/tunnel

Source: TRT analysis of the questionnaires of Greece

A1.4.5 Other findings and best practices

The motorway A2 is a four-lane motorway route of 658 km, located in northern Greece. It starts at Igoumenitsa Port and runs to Greece's border with Turkey. 59% of the 31 tunnels inside the scope of the Directive were put in operation from 2008; the oldest opened to public traffic in 2002. Hence, the tunnels were built according to (most of) the provisions of the Directive and equipped with the newest technologies.

A system of six control centres monitor 225 km (34% of the motorway) 24 hours a day and 7 days a week, assisted by intelligent traffic management systems (TMS). The main objectives of the control centres are to:

- maximize the available capacity of the motorway;
- prevent accidents and/or minimize their effects;
- regulate the traffic volume;
- coordinate the emergency patrol units (EPUs) and assist the rescue services;
- provide timely information to road users.

Each control centre manages a section ranging from 30 km to 70 km in length. The system includes 1,000 CCTV cameras, 700 SOS phones in tunnels, 100 variable message system devices, several hundred lane control signals, variable speed limits signs, 30 road weather information systems, etc. All sections of the motorway are daily patrolled by 14 EPUs.

TMS software allow the operators of the control centres to control all traffic management electronic signs and devices installed along the motorway and to communicate with the EPUs and the rescue services in case of accident. Predefined traffic management scenarios have been developed. When an accident occurs, the operator of the control centre verifies the state of the road section and identifies the best response with the assistance of the proposed scenarios and a forecast of the possible consequences. After the clearance of the accident, automatic reports provided by the TMS help in the analysis of the event.

The contribution of the TMS to the improvement of the operations of the Tunnel Manager is highly valued. The benefits are shared by other stakeholders. For example, the quick response in case of accident enhances the intervention of the emergency services. The automatic collection of data and their reporting, furthermore, improves the analysis of the events and the identification of solutions.

A1.5 Italy

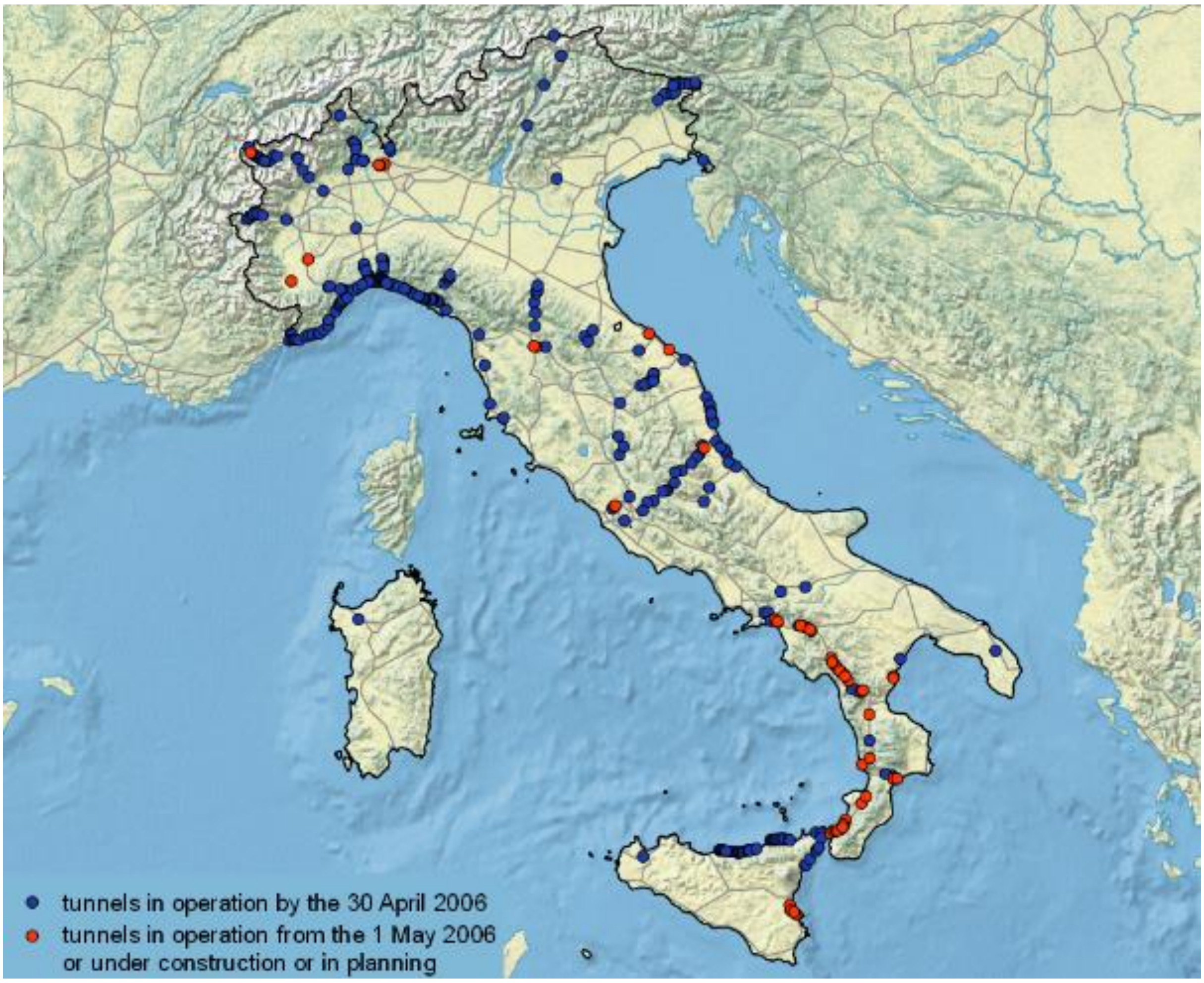
A1.5.1 TERN and tunnels in scope

The trans-European road network in the territory of Italy is about 5,800 km long. There are 349 tunnels in the scope of the Directive. These have a total tube length of 760.4 km. Figure A1.5 shows the location of the tunnels in the scope of the Directive in Italy. Due to its ratio between total tube length and length of TERN, Italy is allowed to postpone the deadline for the refurbishment of its tunnels to 2019, according to Art. 11.7 of the Directive.

The Directive was transposed in Italy by the Law Decree n. 264 of 5 October 2006. This defined the "Commissione permanente per le gallerie" as Administrative Authority for all tunnels on the national territory. The Administrative Authority act also as Inspection Entity.

The Tunnel Managers are the road operators of the motorways or national roads which the tunnels belong to (see Table A1.10). The Safety Officer is a new role defined by the Directive: 35 Safety Officers have been nominated.

Figure A1.5 Italian tunnels in the scope of the Directive[73]



Source: TRT analysis of the questionnaires and reports of Italy

[73] See footnote 17 for the credits.

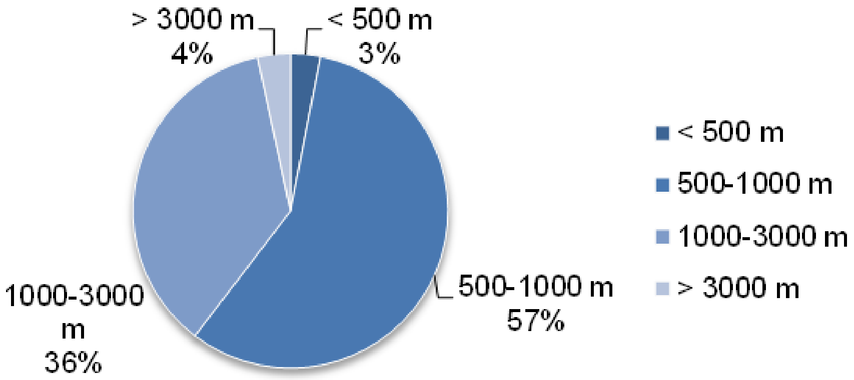
Table A1.10 Tunnel Managers in Italy

Tunnel Manager	Number of tunnels	Total tube length (km)
Autostrade per l'Italia	114	211.6
ANAS	98	179.6
Consorzio Autostrade Siciliane	40	105.4
Strada dei Parchi	16	64.4
Raccordo Autostradale Valle d'Aosta	10	49.3
Autostrada dei Fiori	19	40.8
Società Italiana Traforo Autostradale del Frejus	7	34.1
Società Autostrada Ligure Toscana	14	24.8
Società Autostrade Valdostane	5	11.7
Autocamionale della Cisa	4	10.3
Autostrada Torino-Savona	7	7.2
Auto Brennero	4	6.5
Autostrada Pedemontana Lombarda	3	6.1
Autostrada Asti-Cuneo	2	2.8
Autostrada Torino Ivrea Valle d'Aosta	2	2.3
Società Autostrada Tirrenica	1	1.8
Autostrada BS-VR-VI-PD	1	1.1
Autostrade Meridionali	1	1.0
Total Italy	**349**	**760.4**

Source: TRT analysis of the questionnaires and reports of Italy

The report on the state of implementation submitted by Italy presents an in depth analysis of the tunnels in the scope of the Directive. Figure A1.6 shows the share of tubes grouped by four classes of length. 60% of the tubes have a length shorter than 1000 m and 40% of the tubes are longer than 1000 m.

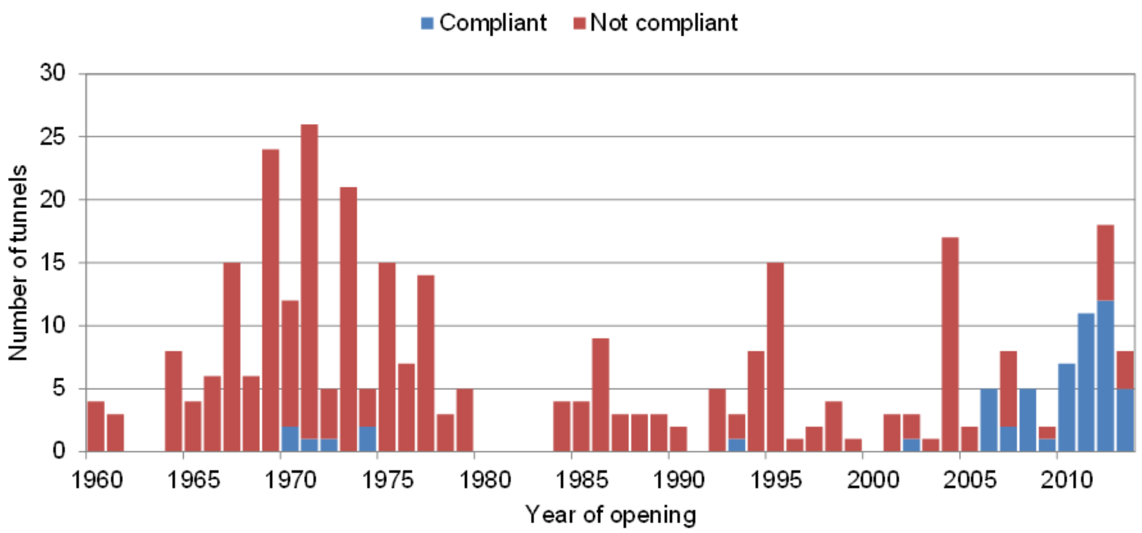
Figure A1.6 Share of Italian TERN tubes grouped by class of length



Source: TRT analysis of the report 2014 on the state of implementation of Italy

The number of tunnels grouped by year of opening is charted in Figure A1.7. As discussed in EQ 17, the age of the tunnels can be considered an index of their safety level, since the more recent tunnels were designed and constructed according to higher standards of safety and better characteristics of the cross section than older tunnels. A large number of tunnels were built in the 1970s. Half of all tunnels are more than 30 years old. This influenced the refurbishment works required by the Directive and their costs. A further analysis of the opening years related to the classes of tube length shows that the average length of the tubes has risen in the last years. Such trend is explained by a greater impact of the environmental restrictions on the development of the road network.

Figure A1.7 Number of Italian TERN tunnels grouped by year of opening



Source: TRT analysis of the questionnaires of Italy

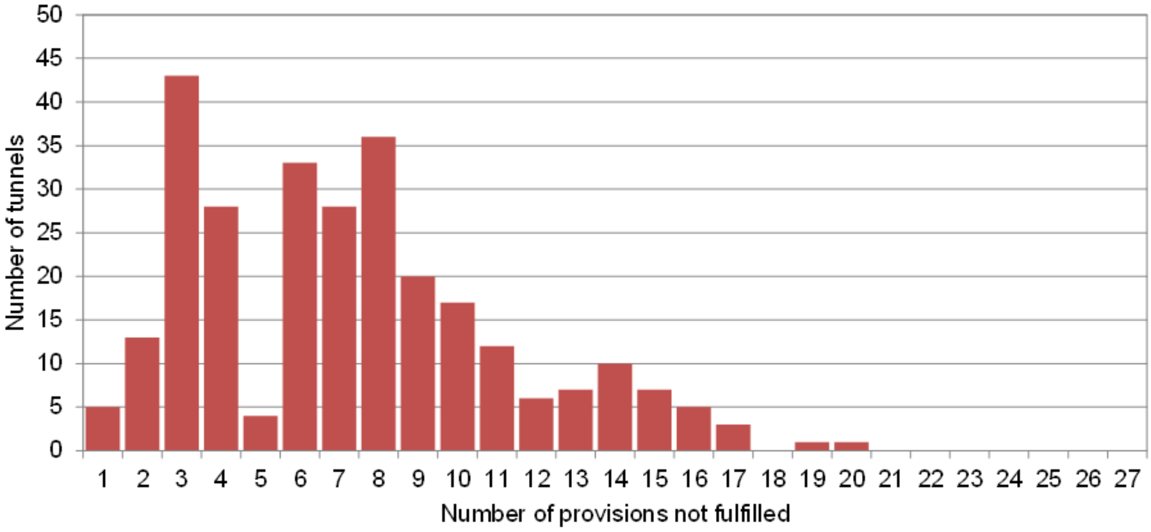
The morphology of the territory determines the distribution of the tunnels. About the 60% of the tubes in operation are concentrated in four regions: Liguria (north-west), Sicilia, Calabria (south) and Abruzzo (centre), along the Apennine Mountains. The Liguria region has the highest density of tunnels in the scope of the Directive. The orography and morphology of the region mean that there is a lack of alternative routes able to absorb traffic in case of the closure of a tunnel for refurbishment.

A1.5.2 State of implementation of the Directive

Table 3.2 and Table 3.4 report the state of compliance of the “old” tunnels (i.e. those in operation by the 30 April 2006) and of the “new” tunnels: 4% of the old tunnels and 85% of the new tunnels are fully compliant with the provisions of the Directive. Table A1.11 charts the share of tunnels in operation (344 in total) by the number of measures with which they are not compliant. Half of the tunnels need up to seven measures addressed to be compliant with the Directive.

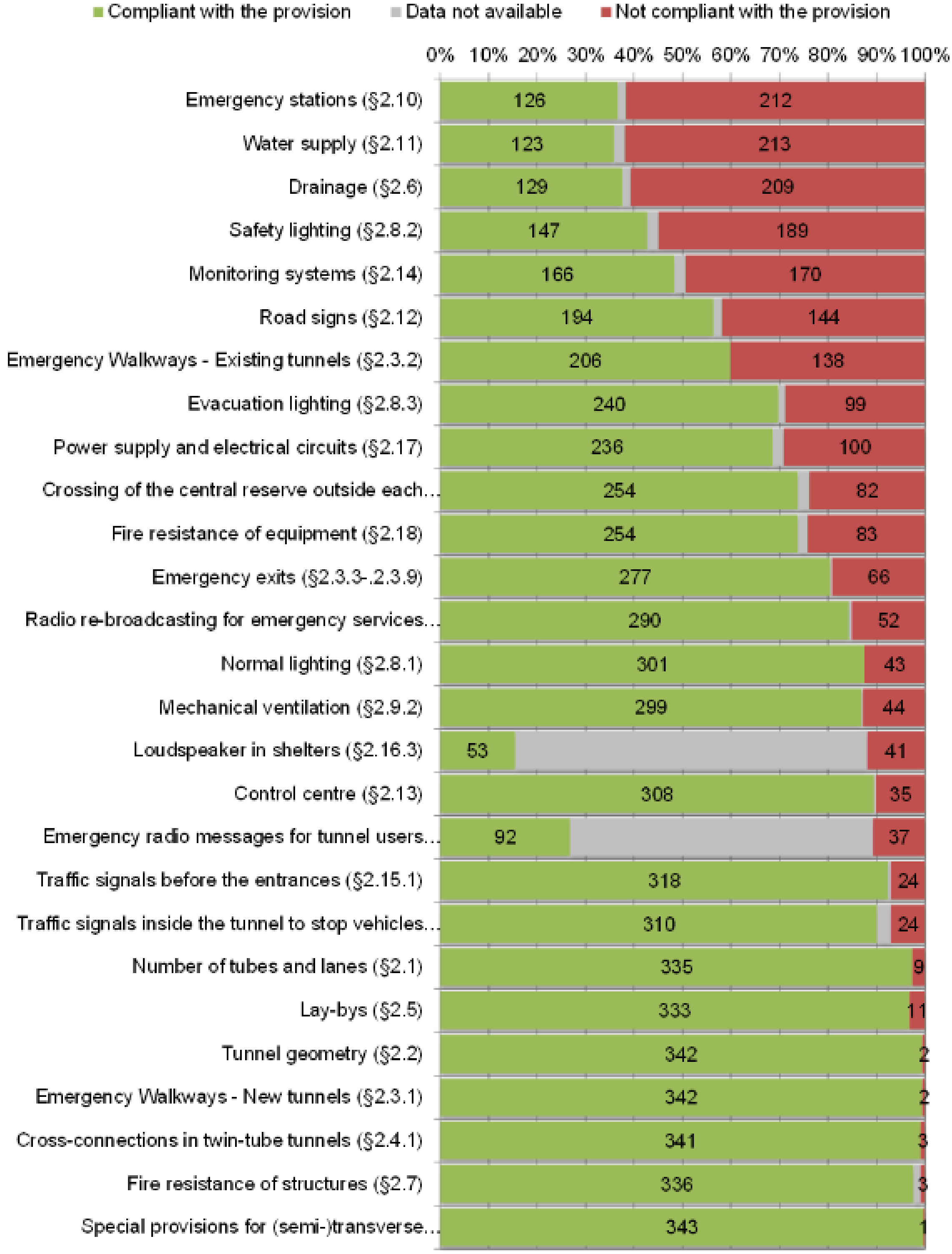
Figure A1.8 shows, for specific measures, the number of tunnels fully compliant and not compliant. The measures are ordered by percentage of non-compliance. For five measures (emergency stations, water supply, drainage, safety lighting and monitoring systems) over half the tunnels are non-compliant.

Table A1.11 Share of the tunnels according to the number of specific measures not fulfilled, Italy



Source: TRT analysis of the questionnaires and reports of Italy

Figure A1.8 Compliance with specific provisions of the Directive, Italy



Source: TRT analysis of the questionnaires and reports of Italy

A1.5.3 Accidents and fires

The data on accidents and fires occurred reported by Italy are presented in EQ 8.

The rate of accidents in tunnels is well below the rate measured on the whole network. Over the period 2006-2013 traffic on the highway network dropped by 8% (in terms of millions of vehicles-km) and accidents/km fell by 37%. The reduction of the accidents/km in tunnels over the same period is more significant at 76%.

A1.5.4 Costs for the implementation of the Directive

A study on the implementation and the effects of the Directive for Italian tunnels was carried out in 2014 by Project Management & Engineering s.r.l. (P.M.&E.). The study considered a number of tunnels on different classes of roads to assess the costs for each measure provided by the Directive.

According to P.M.&E., it is necessary to divide the safety requirements introduced by Directive into two main categories:

- Structural interventions
- Plant interventions

The first group of interventions includes requirements that are highly dependent on the boundary conditions (type of soil, position of the tunnel, need of related infrastructure as road access to the new tube, etc.). It is therefore not possible to effectively parameterize the construction costs.

The construction of a second tube is needed where 15 year traffic forecasts indicate a future traffic volume exceeding 10,000 vehicles per day. Upgrading existing tunnels can be achieved by:

- the construction of a new tube and a by-pass connection;
- the construction of a new tube, upgrading of the existing tube according to the size required by the Directive, and a by-pass connection;
- the construction of a new twin tube tunnel, leaving the existing one (that can possibly be transformed into a safety tunnel).

It is therefore not possible to effectively parameterize the construction costs of a new tube, because the construction costs of a new tunnel are closely linked to the specific situation.

The works needed to get a gradient lower than 5% could require the complete closure of the tunnel to traffic.

The construction of pedestrian walkways requires the cross section to be sufficiently large to provide the necessary space. For new tunnels the construction of pedestrian walkways can require excavations equivalent to 28% to 44% of that required for the road itself.

As mentioned in EQ 11, in case of mechanized excavation, it could be more efficient to increase the excavation section to have a safety lane instead of lay-bys and to include the escape route instead of creating a separate safety tunnel.

The electrical plant changes required by the Directive may be less expensive than structural interventions, with the exception of the measures necessary for the implementation of special cross-ventilation. In general, however, the increase of the equipment in the tunnel, determined by the requirements imposed by the Directive and the evolution industry norms, has proportionally increased the operating costs of the tunnels (e.g. the energy consumption and maintenance activities).

In addition to the costs of construction / installation, the minimum requirements of ventilation and lighting imposed by the Directive require continuing maintenance and a considerable consumption of electrical energy. ANAS indicated its expenditure on energy increased by 150% between 2005 and 2012. In 2012, 87% of total energy costs was attributed to the systems present in the tunnel.

ANAS estimates that its energy costs are distributed as follows:

- 80% lighting (46% reinforcement, 25% permanent, 9% external);
- 16% ventilation;
- 4% power supply and lighting for technical rooms.

From the analysis of a number of projects listed at tender, it is possible to identify energy and maintenance costs. The costs for a recently constructed 600 m tunnel are shown in Table A1.12.

Table A1.12 Example of costs for energy for a new Italian tunnel

	Estimated annual cost (€/km)
Electricity consumption	42,000
Planned maintenance	22,000
Unplanned maintenance	16,000

Source: P.M.&E.

Table A1.13 reports the contribution of plants interventions to overall construction costs.

Table A1.13 Incidence of the plants interventions on the overall construction costs

Plant interventions	Incidence on the overall construction costs
Lighting (reinforcement, permanent and emergency)	3.5-5.5%
Power supply (transformer stations, electricity supply lines, switchboards and distribution, etc.)	0.5-4.5%
Ventilation (longitudinal)	2.0-4.5%
Emergency stations (including excavation of the volume occupied, supply and installation)	1.0-3.0%
Monitoring systems (video surveillance, installation of traffic control, sensors for fire prevention)	1.5-3.5%
Road signs	0.1-0.3%
Equipment to close the tunnels (variable message signs, traffic lights lane, etc.)	<1.0%
Control Centre (connection to the control centre)	<1.0%

Source: P.M.&E.

A1.5.5 Other findings and best practices

The implementation and the effects of the Directive were discussed with five Italian stakeholders: the Administrative Authority, two Tunnel Managers and one expert.

The **Commissione permanente per le gallerie**, the only Administrative Authority in Italy (excluding the AAs of the transnational tunnels) and therefore the central regulator for the several Italian TMs, was asked for suggestions on best practices. Three examples of innovative techniques relating to fire protection were provided:

- extinguishing plant through remote-controlled monitors ("iTunnel" system): the iTunnel system, developed by the Italian G.S.A. and co-funded by the European Regional Development Fund, consists of hydro-foam remote controlled monitors installed on a remote controlled car. Remote controlled monitors are the most adopted fire-fighting devices in industrial complexes with high risk and in facilities such as ports and airports. The great power of its hydro-foam jet, its high operational reliability and the absence of toxicity of their use for people, makes this kind of monitor the best solution for fire-fighting. The remote controlled car, which has a cruising speed of more than 40km/h, can reach the event area in one minute, while the monitors activate in a few seconds. Additional functions can be assigned to the system by equipping the car with an amplified sound system, variable messages and detectors of hazardous substances, combustible, flammable, toxic or corrosive substances. The iTunnel system is being tested in the twin tube tunnel Gran Sasso (long 10.2 km).

- automated plan for the mitigation and extinguishing of fires through deluge: the system is installed in the 2.5 km Murtineddu tunnel which opened in 2013 (outside the TEN-T) and is managed by the State-owned road operator ANAS. The system consists of nozzles installed at a height of 2.5 m every 3 m. It can deal with fires of class B (pool fires with fire loads up to 100 MW) and A (representing vehicles on fire with fire load up to 40 MW). The plan is activated when at least three systems detect the alarm (e.g. a heat detector and a CCTV with smoke detector).
- mobile fire brigade: the service consists of a fire service mobile team furnished with special vehicles. The service has been active since 2003 in the 10 km Gran Sasso tunnel which provides the only access to the National Institute of Nuclear Physics. Given the considerable length of the tunnel and the presence of the laboratories, the service has been set up to provide first aid in any emergency situation through the use of two and four-wheel vehicles specifically adapted and equipped with extinguishers that can be worn by the operators. The system is based on the principle that micro particles of water are fired from a compressed air gun. It allows operators to make safe a car that is on fire in about 30 seconds and to guarantee the complete extinction of the fire in further 30 seconds. The technology was developed with the concept of fighting fires using only one per cent of the amount of water used by traditional systems. The use of such equipment allows operators to reach any type of fire centre in different traffic conditions.

ANAS S.p.A. is a State-owned company that operates expressways and highways of national interest that extend to 25,400 km. It manage 1,235 tunnels that have a total tube length of 754 km (census 2011), 98 of which are tunnels in the scope of the Directive (with a total tube length of 180 km). Ranked by the number of TERN tunnels managed it is the second largest Italian Tunnel Manager, but its main role relates to tunnels outside the scope of the Directive. Guidelines that it issued in 2006, 2009 and 2012, provide recommendations on the requirements of new and existing tunnels (for example, the model of risk analysis is described in the 2009 guidelines). The company has divided its network into 19 sections.

Its control centres are connected to each other so that the monitoring is provided 24 hours a day and 7 days a week across the whole network. As discussed in EQ 8, the control centre, together with the monitoring systems, represents the most effective measure for the prevention of accidents and fires and for the mitigation of their effects. The system of control centres, also operating for tunnels outside the scope of the Directive, provides a highly valued contribution to their safety.

ASTM-SIAS is a group of highway operators that manages a total of 60 tunnels (with a total tube length of 134 km) in the scope of the Directive, corresponding to the 17% of the Italian TERN tunnels (see Table A1.14). It created a work group focussed on road safety and a web site (www.autostradafacendo.it), where the group publishes its work. The work is carried out in collaboration with national and local authorities, the State Police, universities and international entities like the transport division of UN-ECE and the World Road Association.

The collaboration among the several concessionaires of the group allows them to share experience and concentrate efforts on safety. With regards to the safety in tunnels, the two main paths followed by the work group are:

- the training of the tunnels operators together with the safety services;
- an information campaign for road users.

The joint training, involving tunnel operators (in particular the staff of the control centres) together with all emergency services (police, fire brigade and emergency medical service), allows the evaluation of the necessity of each group of operators and thus to possibly combine their efforts.

The effectiveness of the operations carried out by the different services is based on the information available about the event and the speed with which it is gathered. This is the case, for example, of information on the people involved in the accident required by the emergency medical service. When the road users call the road operator to notify it of an accident, the staff of the control centre should ask for the phone number of the caller, so that the medical emergency service can get through him/her and obtain the necessary information. Thus, the tunnel operators can focus on the other necessary operations while the operations of the medical service have been supported.

Another example concerns the fire brigade which used to arrange its vehicles in order to protect the operators from possible spreading of the flames but in so doing caused an obstacle for other services. The mutual knowledge of their respective necessities helps in the identification of the best solution for all services.

Such achievements are an objective of the periodic exercises required by the Directive (point 5 of the Annex II) but joint training and continuous engagement among the various parties are considered to be more effective.

Information campaigns are also provided for by the Directive (point 4 of Annex I), although the legislation does not clearly define who is responsible for their implementation. At national level, the information campaign for the safety in tunnels is included in the wider topic of the road safety, through messages transmitted by radio, television, internet and posters. The safety work group of the ASTM-SIAS Group promoted such campaigns through its web site “autostradafacendo.it” and its monthly newsletter. In addition, the safety work group developed its own campaigns, taking advantage of the distribution of the ASTM-SIAS Group. For example, the safety messages were printed on the back of the tickets that the users receive when they enter the tolled motorways.

Table A1.14 Tunnel Managers of the ASTM-SIAS Group

Tunnel Manager	Number of tunnels	Total tube length (km)
Autostrada dei Fiori	19	40.8
Società Italiana Traforo Autostradale del Frejus	7	34.1
Società Autostrada Ligure Toscana	14	24.8
Società Autostrade Valdostane	5	11.7
Autocamionale della Cisa	4	10.3
Autostrada Torino-Savona	7	7.2
Autostrada Asti-Cuneo	2	2.8
Autostrada Torino Ivrea Valle d'Aosta	2	2.3
Total ASTM-SIAS Group	**60**	**134.0**

Source: TRT analysis of the questionnaires

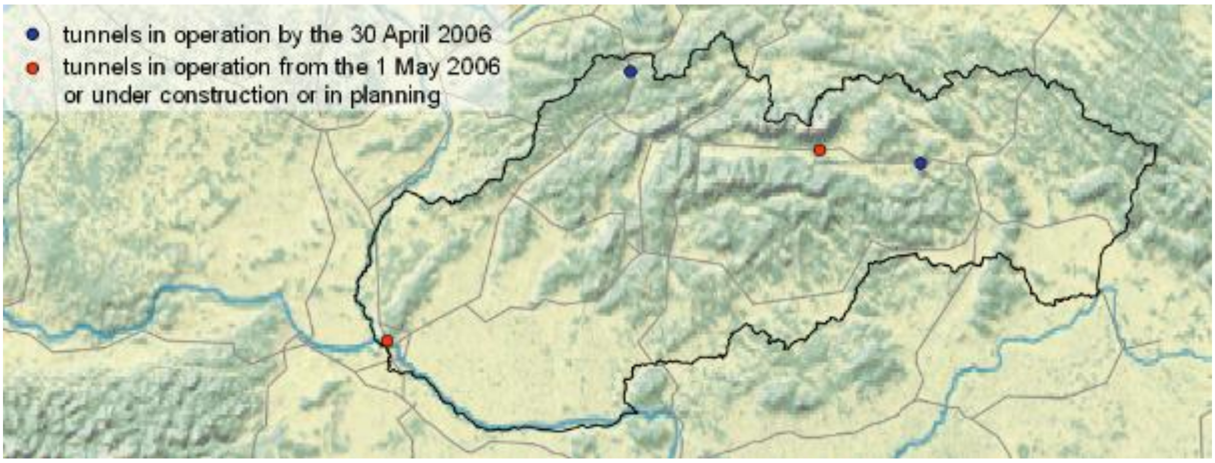
A1.6 Slovakia

A1.6.1 TERN and tunnels in scope

The trans-European road network in the territory of Slovakia is about 659 km long. Four tunnels fall under the scope of the Directive, of which two were in operation by the 30 April 2006 and two opened after the 1 May 2006.

Three tunnels are under the responsibility of the Ministry of Transport, Construction and Regional Development, while the Administrative Authority of the fourth tunnel is the District office in Žilina. The National Motorway Company is the only Tunnel Manager.

Figure A1.9 Tunnels in the scope of the Directive74



Source: TRT analysis of the questionnaires

A1.6.2 State of implementation of the Directive

The Directive was transposed in Slovakia by the government act No 344/2006 which came into force from 2006. The previous legislation[75] required most of the provisions of the Directive (see Table 3.20) and as such it is difficult to quantify the incremental effects of the application of the Directive. Some of the previous national requirements were slightly different to those of Directive, for example:

- minimum distance between emergency stations: 250 m (lower than required by the Directive but acceptable for existing tunnels);
- maximum distance between emergency exits: 300 m (higher than is required by the Directive).

On the other hand, the number of tunnel tubes (bidirectional versus unidirectional tunnel system) was not ruled as in the Directive.

Both existing tunnels (Branisko and Horelica) opened while the Directive was in preparation (2003 - 2004), the focus on safety was present during their construction and some design modifications were implemented. The same is true for the third TERN tunnel Sitina (built in the period 2003 - 2007).

There are no other road tunnels in Slovakia outside the TEN-T network except for one short tunnel on a local road. As the national guidelines apply also on tunnels shorter than 500 m, there is in fact no relevant difference with tunnels designed according to the Directive.

With respect to the entities defined by the Directive, the changes from the previous legislation concerned the Safety Officer and the Inspection Entity. Only one Safety Officer has been nominated, while the two Administrative Authorities act as Inspection Entities as well. The last year of inspection for all tunnels is 2014.

A1.6.3 Accidents and fires

The methodology for registering events that have occurred in tunnels has changed in the last report on accidents and fires (2014). While in the previous report (2012) all events were registered and grouped by four categories (accidents with death, fires, other and combined) in the last report only major incidents were considered. The definition of a major incident derives from a free translation of the definition given by PIARC. Table A1.15 lists the events that occurred in the period 2006 – 2013: the events classified as “other” occurred in 2012 and 2013 are incidents when injury occurred. Figure A1.10 charts the accident rate per kilometre of tube over the 2006 – 2013 period.

[74] See footnote 17 for the credits.

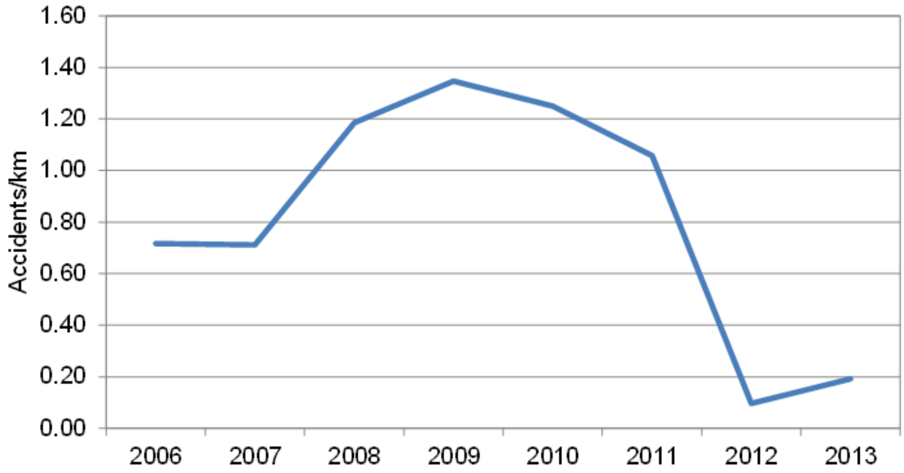
[75] Standards, STN 737507 Design of road tunnels (2001), Fire protection guideline for road tunnels (2001)

Table A1.15 Accidents and fires in TERN tunnels in Slovakia

Event	2006	2007	2008	2009	2010	2011	2012	2013
Accidents with death	0	0	0	1	1	0	0	0
Fires	0	0	0	0	0	1	0	0
Other	4	6	10	13	12	10	1	2
Combined	4	6	10	14	13	11	1	2

Source: TRT analysis of the reports of Slovakia

Figure A1.10 Trend of the accidents/km in Slovakian tunnels in the scope of the Directive



Source: TRT analysis of the reports of Slovakia

A1.6.4 Costs for the implementation of the Directive

No information about the costs for the implementation of the Directive is available. Since the two existing tunnels were already compliant with the provision of the Directive in 2006, no refurbishment works were needed.

A1.6.5 Other findings and best practices

All existing tunnels and new tunnels under construction are or will be operated by the National Motorway Company, which is owned by the government. This means that requirements on safety are consistent for all tunnels in question. All the tunnels have a control centre with permanent service; all the tunnels have CCTV systems with automatic accident detection and fire detection tools (usually linear thermal detection).

The requirements of national guidelines are, in several respects, more strict than those of the Directive. For example, the pavement of motorway tunnels has to be constructed from concrete according to the TP 11/2011 Fire protection of road tunnels.

During 2010 - 2014 several national guidelines relating to tunnel safety were developed. These are:

- TP 02/2011 Risk analysis for road tunnels;
- TP 11/2011 Fire protection of road tunnels;
- TP 12/2011 Ventilation of road tunnels;
- TP 04/2014 Safety documentation of road tunnels.

The risk model for evaluation of risks of road tunnels in Slovakia is adapted from the Austrian tunnel safety model TuRisMo (RVS 09.03.11). This tunnel risk model gives the methodological basis for a quantitative determination of damage values for road tunnels with a length of more than 500 m in the higher Slovakian road network (motorways and highways). Such risk values are then considered as reference for the other road tunnels.

The risk analysis is supplemented by a specific hazard analysis in which specific factors related to overall safety of the project are analysed and the influence on safety is outlined in qualitative terms. This has been done independently from the quantitative risk analysis. The results from the specific hazard analysis can then be used to deduce quantitative influence factors for the risk analysis.

The Risk Model is a system based quantitative risk model allowing a systematic and quantitative risk evaluation by including all essential accident scenarios in road tunnels.

The tunnel risk model provides the tool to cover and integrate almost all substantial factors influencing tunnel safety in a quantitative manner if the required input data are available.

The risk model covers the following accident scenarios:

- Breakdown with fire
- Breakdown with rear end collision (with/without secondary fire)
- Single accident (with/without secondary fire)
- Rear end collision (with/without secondary fire)
- Heads-on collision (with/without secondary collision)

All accident scenarios are further distinguished by the type of involved vehicles (car, HGV, bus) and a possible participation of dangerous goods.

During 2013 and 2014 a risk analysis have been executed for all 4 existing motorway tunnels as a part of safety documentation of these tunnels.

Currently eight motorway tunnels are under construction. Their design fully complies with the requirements of the Directive. This means that safety documentation including risk analysis is part of the design stage (building permit design).

Annex 2 Tables and figures

This section provides tables and figures that support the main part of the report.

Table A2.1 Summary of minimum safety requirements set by Directive 2004/54/EC

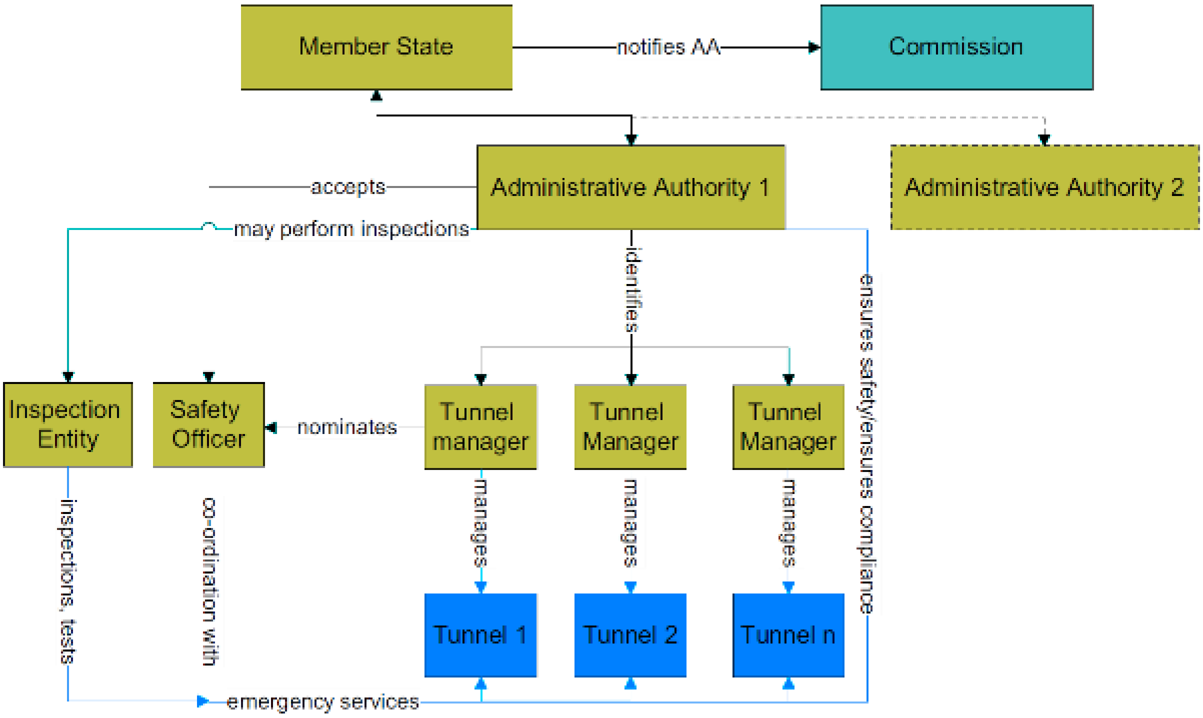
Measure		Reference to Annex I of the Directive	Traffic ≤ 2,000 vehicle/lane		Traffic > 2,000 vehicle/lane		
			Tunnel length				
			500-1,000 m	>1,000 m	500-1,000 m	1,000-3,000 m	>3,000 m
Structural	2 tubes or more[76]	2.1					
	Gradient ≤ 5%	2.2	◙	◙	◙	◙	◙
	Emergency walkways	2.3.1 2.3.2	◙	◙	◙	◙	◙
	Emergency exits at least every 500 m	2.3.3 2.3.9	○	○	◙	◙	◙
	Cross-connections for emergency services at least every 1,500 m	2.4.1	○	○ / ●	○	○ / ●	●
	Crossing of the central reserve outside each portal	2.4.2	●	●	●	●	●
	Lay-bys at least every 1,000 m	2.5	○	○	○	○ / ●	○ / ●
	Drainage for flammable and toxic liquids	2.6	◙	◙	◙	◙	◙
	Fire resistance of structures	2.7	●	●	●	●	●
Lighting	Normal lighting	2.8.1	●	●	●	●	●
	Safety lighting	2.8.2	●	●	●	●	●
	Evacuation lighting	2.8.3	●	●	●	●	●
Ventilation	Mechanical ventilation	2.9	○	○	○	●	●
	Special provisions for (semi-) transverse ventilation	2.9.5	○	○	○	○	●
Emergency stations	At least every 150 m	2.10	◙	◙	◙	◙	◙
Water supply	At least every 250 m	2.11	●	●	●	●	●
Road signs		2.12	●	●	●	●	●
Control centre		2.13	○	○	○	○	●
Monitoring systems	Video	2.14	○	○	○	○	●
	Automatic incident detection and/or fire detection	2.14	●	●	●	●	●
Equipment to close the tunnel	Traffic signals before the entrance	2.15.1	○	●	○	●	●
	Traffic signals inside the tunnels at least every 1,000 m	2.15.2	○	○	○	○	◘
Communication systems	Radio re-broadcasting for emergency services	2.16.1	○	○	○	●	●
	Emergency radio messages for tunnel users	2.16.2	●	●	●	●	●
	Loudspeakers in shelters and exists	2.16.3	●	●	●	●	●
Emergency power supply		2.17	●	●	●	●	●
Fire resistance equipment		2.18	●	●	●	●	●

- ●→Mandatory for all tunnels; ○ → Not mandatory; ◙→Mandatory with exceptions; ◘→Recommended.

Source: Directive 2004/54/EC

[76] Mandatory where a 15-year forecast shows traffic > 10,000 vehicles/lane.

Figure A2.1 Organisation defined by the Directive



Source: Krieger J. (2006)

Table A2.2 Evaluation framework

Evaluation criteria	Evaluation question		Methodology for answering the evaluation question
Implementation	1	Has the refurbishment of tunnels in operation been completed? What is the state of implementation in countries where the work is not yet completed?	The state of implementation of the refurbishments works will be obtained through the database assembled from the spreadsheets returned by stakeholders. The contents of the database will be verified and updated (where necessary) with details of the tunnels to be refurbished under the Directive and their main features. Results will be consolidated into one table for each Member State. Possible values for the fields of the spreadsheet are: 0 - Measure not compliant 1 - Measure compliant 2 - Derogation applied 3 - Measure not applicable
	2	How many new tunnels were planned and constructed? Have the requirements of the Directive been applied to them?	As there is no obligation to communicate the state of implementation of the new tunnels, the situation to date will be obtained through the database assembled from the spreadsheets provided by stakeholders. This will allow preparation of a database verified and updated (where necessary) with details of new tunnels and their main features. Results will be consolidated in a table for each Member State. Possible values for the fields of the spreadsheet are: 0 - Measure not compliant 1 - Measure compliant 2 - Derogation applied 3 - Measure not applicable
	3	How many tunnels were inspected? How were these inspections carried out?	For each tunnel a field for the year of the last inspection is provided in the spreadsheet enclosed with the questionnaire (questions B1 and B2). If the field is populated, the tunnel will be counted as having been inspected. The answers to the questionnaire will be collected and compared to summarise the existing methodologies of the inspections. The comparison between methodologies is expected to allow the identification of best practices and to outline common guidelines. Area tested: - Highway infrastructure; - Mechanical and electrical infrastructures; - Tunnel structures; - Geotechnical infrastructures; - Others.
	4	Which factors might have hampered or slowed down the implementation of the Directive?	The answers to the questionnaire will be scrutinised to analyse the obstacles and drivers and provide a ranking of factors. In parallel, other factors will be mentioned where possible, according to the findings of the desk research. The answer will be substantiated providing specific case analysis in order to demonstrate the extent of the various factors. Possible factors are: - additional costs; - technical aspects; - limited resources; - impact on traffic flows. - others (to be specified by respondents).
	5	How have technological developments affected the application of the Directive 2004/54/EC, especially in terms of safety, operational and organisational measures?	The contribution of the experts will be essential to get an overview of the innovative techniques that may have affected the application of the Directive. The answers to the questionnaire will be collected and analysed to get a list of provisions affected by the technological developments, highlighting the most involved. Importantly, specific cases will be checked in order to demonstrate the relevance of technology development.
	6	To what extent were the derogations, notably concerning structural requirements, innovative techniques and safety measures laid down by Directive 2004/54/EC applied in the different Member States?	Analysis of the frequency with which the derogations have occurred in the spreadsheet enclosed to the questionnaire. The occurrence will be determined as resulting from the answers "compliant with derogation" reported. Summary of the most relevant findings obtained from the answers provided by the experts.
	7	To what extent were the technical measures implemented?	The information updated by tunnel in the spreadsheet enclosed to the questionnaire is used in the analysis of the fulfilled requirements concerning technical measures. The summary will be returned by Member State.
Relevance	8	To what extent is the Directive 2004/54/EC addressing the causes of accidents and fires in tunnels? Are other possible safety issues in tunnels sufficiently addressed?	Analysis of the frequency with which the causes of accidents and fires occurred and considerations on whether and to what extent the Directive addresses these issues (in terms of mitigation and prevention). The analysis will take into account the possibility of a limited record of data, due to the restricted scope of the Directive and number of events. In this case risk analysis will be used.

Evaluation criteria	Evaluation question		Methodology for answering the evaluation question
	9	Is the scope of the Directive, i.e. tunnels of over 500m on the TEN-T network in all EU Member States and EEA plus Switzerland, adequate?	Analysis of the content of the answers and assembling of the information regarding the number of tunnels outside the scope of the Directive.
Coherence	10	The analysis on the coherence should evaluate the links of Directive 2004/54/EC with other objectives of the EU transport policy. In particular, the contractor should assess whether Directive 2004/54/EC is coherent with the objectives of transport externalities and road safety	The Tunnel Managers are requested to report the number of accidents and fires in tunnels before and after the refurbishment works (1999-2013). The trends will be compared with the status of the refurbishment works to identify the contribution of the Directive to the reduction of the transport externalities. Externalities will be calculated as described in the evaluation framework The analysis will take into account the possibility of a limited record of data, due to the restricted scope of the Directive and number of events. In this case risk analysis will be used. Possible contradictions, duplications or inconsistencies between the provisions of the Directive and the overall regulatory framework on road safety will be examined. Trend of the events recorded in the field of road tunnel safety against the overall trend of road safety.
Effectiveness	11	To what extent has Directive 2004/54/EC contributed to prevention of accidents and mitigations of the consequences of accidents? What have been the effects of the Directive on the planning and construction of new tunnels?	The tunnel managers and experts are required to provide a list of measures and the degree of contribution to prevention and mitigation of the consequences of accidents. The frequency of the occurrence of measures mentioned and degree of importance will be summarised. Quantifiable indicators will be assessed though the questionnaire and through interviews with experts. The contribution of the specialists will be essential to identify possible changes in the design choices and construction methods due to the provisions of the Directive. Some examples or specific cases to demonstrate these changes will be highlighted by the experience in the 5 focus countries.
	12	To what extent has the Directive 2004/54/EC affected existing managing operations and practices in tunnels? Has this resulted in an improvement in terms of effectiveness of operations?	The answers to the questionnaire will be collected and compared to extract a review of the main changes in the managing operations and practises due to the implementation of the Directive. The Tunnel Managers and Experts are expected to indicate whether the changes have resulted in an improvement in terms of effectiveness of operations.Specific analysis will be derived by the 5 focus countries.
	13	What effects has the need of refurbishing existing tunnels had on the environment, local population and on the traffic flows?	Analysis and summary of the answers obtained from the questionnaire. Review and report of other best practices, where available.
	14	Has Directive 2004/54/EC had other indirect or unexpected effects?	Analysis and summary of the answers obtained from the questionnaire. Review and report of other best practices, where available.
	15	To what extent did the Directive 2004/54/EC have an effect outside the trans-European network and outside the EU? Did it have an impact outside the EU? In particular, what are the positive experiences and spill-over generated outside the EU and beyond EEA and Switzerland?	Research on the national policy frameworks of the EU countries and of neighbouring countries will be integrated with the answers to the questionnaire about the adoption of the provisions of the Directive outside the TERN.
	16	To what extent could the effects identified be increased by broadening the scope of the Directive 2004/54/EC to include non-TEN-T tunnels?	Analysis and summary of the answers to the questionnaire. Where possible, these will be integrated with the results obtained from the evaluation performed on the efficiency of the measures provided in the Directive.
Efficiency	17	What are the costs of measures undertaken to implement the Directive 2004/54/EC?	The questions require a thorough scrutiny of the answers obtained from the stakeholders addressed. The costs will be differentiated between type of requirement, considering the refurbishment works of tunnels in operation and the compliance costs of new tunnels. The distinction by requirements considers the different lifecycle between structural and other measures. The application of new technologies will be taken into account. The most cost-effective and the most cost-intensive measures will be identified. Where possible the implementation plans deployed by the Member States will be provided and analysed to highlight the level of reaction to the provisions of the Directive. The categories of costs considered will refer to Annex I(2) of the Directive.
	18	At what costs were the procedures (commissioning, safety inspections, safety exercises, etc.) and other administrative arrangements described in the Directive established?	The stakeholders will be asked for data that will facilitate comparison between the costs per type of procedures and administrative arrangement. Any difference of the costs will be reported through a comparison of the measures reported in the questionnaire with the measures in Annex I(3) of the Directive.
	19	To what extent did the use of derogations generate costs and/or benefits?	The answers to the questionnaire will be collected and compared to extract a review of the costs and benefits generated by the granted derogations.
	20	Have measures related to budget planning been adequate for ensuring the minimum level of safety in tunnels?	Identification of sources of funding and trends over the periods reported by the stakeholders addressed.
Sustainability	21	The evaluation should estimate the long and medium term effects of the Directive and in particular: How technological development might affect the application of the Directive 2004/54/EC, especially in terms of safety, operational and organisational measures.	The reported technological developments will be described and the affected requirements will be highlighted. The future trends of the technological development will be investigated to identify possible impacts on the application of the provisions. Requirements of the Directive still relevant will be identified in the context of the new developments in transport and technology (increasing traffic flows, other safety rules, etc.).

Evaluation criteria	Evaluation question		Methodology for answering the evaluation question
EU added value	22	Due to accidents and fires in the Mont Blanc, Taurern and Gothard tunnels, in 2004 the added value of EU action for ensuring a minimum level of safety was clear and practically self-explanatory. Is it still justified to maintain and possibly extend EU action for road tunnel safety?	Analysis of the costs generated by the Directive, against the benefits generated (e.g., in terms of reduction of transport externalities). Level of appropriateness of the provisions of the Directive against the technological developments available and able to generate the same level of road safety, but at a lower cost. Level of appropriateness of the Directive against other instruments (standards, guidelines, etc.) able to achieve the same effects. The assessment will give outline appraisal of how the repeal of the Directive would impact the approach on tunnel safety in Member States. According to the results obtained the repeal would be downsized to a partial review of the provision of the Directive, in which some minimum requirements might be held unchanged.
	23	Would it be justified to apply the conditions established by Directive 2004/54/EC as principle of conditionality for acceding to EU funds for financing partially or totally, the works, refurbishment or construction of new tunnels, also outside the TEN-T network and outside the EU?	

Source: TRT analysis

Table A2.3 Date of the last forms and reports available in the CIRCABC repository

Country	Form on the state of implementation of the plan (Art. 15, par.2)	Form for "new" tunnels (i.e. tunnels whose design has been approved by the responsible authority as of 1 May 2006 - Art. 9)	Report on fires and on accidents in tunnels (Art. 15, par.1)	
	date of the last form	date of the last form	date of the last report	period covered
AUSTRIA	28/10/2014	28/10/2014	26/09/2014	1999-2013
BELGIUM	06/02/2013	not available		2006-2011
BULGARIA	07/11/2012	not available		2006-2011
CROATIA	not available	not available		not available
CYPRUS	-	not available		not available
CZECH REPUBLIC	24/10/2012	30/11/2012		2009-2011
DENMARK	25/09/2014	not available	30/09/2014	2006-2013 (partially from 1998)
ESTONIA	-	not available		not available
FINLAND	-	31/08/2010	31/07/2014	2009, 2012-2013
FRANCE	25/09/2014	not available	25/08/2014	2006-2013
GERMANY	23/10/2014	27/09/2012	20/10/2014	2006-2013
GREECE	31/10/2012	31/10/2012	09/2014	2010-2013
HUNGARY	-	10/08/2010	12/09/2014	2010-2013
IRELAND	12/09/2006	04/03/2010	29/07/2014	2007-2014
ITALY	30/09/2014	01/10/2012	30/09/2014	2006-2013
LATVIA	-	not available		not available
LITHUANIA	-	not available		not available
LUXEMBOURG	14/06/2013	not available		2007-2010
MALTA	-	not available		not available
NETHERLANDS	06/02/2015	not available		2006-2012
POLAND	-	14/10/2010		not available
PORTUGAL	09/03/2010	24/10/2012		2006-2013
ROMANIA	-	07/12/2012		not available
SLOVAKIA	not available	not available	20/10/2014	2003-2013
SLOVENIA	28/11/2014	16/08/2010	28/11/2014	2007-2014
SPAIN	01/11/2013	10/10/2012	30/09/2014	2007-2013
SWEDEN	27/11/2014	01/12/2011		2006-2011
UNITED KINGDOM	01/10/2012	not available		2006-2012
NORWAY	09/2014	not available	13/04/2014	2001-2013
SWITZERLAND	not available	not available		not available

Source: TRT analysis on reports from CIRCABC repository

Table A2.4 Number of Administrative Authorities and Tunnel Managers per country[77]

Country	Administrative Authorities	Tunnel Managers
AUSTRIA	1	1
BELGIUM	2	2
BULGARIA	1	1
CROATIA[78]	1	not available
CZECH REPUBLIC	3	1
DENMARK	3	3
FINLAND	1	1
FRANCE	19	17
GERMANY	10	11
GREECE	1	10
HUNGARY	1	1
IRELAND	1	3
ITALY	3	19
LUXEMBOURG	1	1
NETHERLANDS	7	3
POLAND	4	1
PORTUGAL	1	4
ROMANIA	1	5
SLOVAKIA	1	1
SLOVENIA	1	1
SPAIN	1	2
SWEDEN	1	1
UNITED KINGDOM	3	3
NORWAY	1	5
SWITZERLAND	not available	not available
Total	**69**	**97**

Source: TRT analysis on reports from CIRCABC repository

[77] Estonia, Latvia, Lithuania, Malta do not have TERN tunnels in the scope of the Directive.

[78] Reports are not available as Member State since 1st July 2013.

Table A2.5 Number of answered questionnaires per country and version of the questionnaire

Country	AA	TM	EX	AA+TM	AA+TM+EX	Total
AUSTRIA	0	0	2	0	1	3
BELGIUM	0	0	0	0	0	0
BULGARIA	0	0	0	0	0	0
CROATIA	1	0	0	0	0	1
CYPRUS	1	0	0	0	0	1
CZECH REPUBLIC	0	0	0	0	0	0
DENMARK	0	0	0	1	0	1
ESTONIA	no tunnels in the scope of the Directive					
FINLAND	1	0	0	0	0	1
FRANCE	0	0	0	0	1	1
GERMANY	0	0	2	0	0	2
GREECE	1	2	0	0	0	3
HUNGARY	1	0	0	0	0	1
IRELAND	1	0	0	0	0	1
ITALY	1	2	1	0	0	4
LATVIA	no tunnels in the scope of the Directive					
LITHUANIA	no tunnels in the scope of the Directive					
LUXEMBOURG	0	0	0	1	0	1
MALTA	no tunnels in the scope of the Directive					
NETHERLANDS	0	0	2	0	1	3
POLAND	0	0	0	0	0	0
PORTUGAL	0	0	0	0	0	0
ROMANIA	1	0	0	0	0	1
SLOVAKIA	1	0	0	0	0	1
SLOVENIA	0	0	0	1	0	1
SPAIN	0	0	1	1	0	2
SWEDEN	1	1	0	0	0	2
UNITED KINGDOM	1	0	0	0	0	1
Total EU	**11**	**5**	**8**	**4**	**3**	**31**
Total MS 2014	**9**	**1**	**4**	**1**	**2**	**17**
Total MS 2019	**2**	**4**	**4**	**3**	**1**	**14**

Source: TRT analysis

Table A2.6 National laws that transpose the Directive in each country

Country	Transposition of the Directive
AUSTRIA	Straßentunnel-Sicherheitsgesetz – STSG, BGBl. I Nr. 54/2006, 8.5.2006
BELGIUM	not available
BULGARIA	not available
CROATIA	Roads Act (Official Gazette 084/2011) Ordinance on minimum safety requirements for tunnels (Official Gazette 096/2013)
CYPRUS	Law106(I)/2006, 21 July 2006
CZECH REPUBLIC	not available
DENMARK	BEK nr 726 af 03/07/2008 - Bekendtgørelse om minimumssikkerhedskrav for tunneler i det transeuropæiske vejnet BEK nr 142 af 20/02/2012 - Bekendtgørelse om ændring af bekendtgørelse om minimumssikkerhedskrav for tunneler i det transeuropæiske vejnet
ESTONIA	not available
FINLAND	Highways Act and the regulations of Road Administrations (Road tunnels Adminstrative and safety regulations firs version 2007 and newer version 2014)
FRANCE	Art 10 law 2006-10 - 05/01/2006 Decree n° 2006-1354 - 8/11/2006 Order of 8/11/2006 modified on 9/11/2007 Order of 18/04/2007
GERMANY	Richtlinie für die Ausstattung und den Betrieb von Straßentunneln RABT 2006 (ARS No.10/2006)
GREECE	Presidential Decree 230/2007
HUNGARY	Gov. Regulation 18/2007. (II.20.) of Minimum safety requirements for the Trans-European road network of tunnels in the territory of the Republic of Hungary
IRELAND	Statutory Instrument 213 of 2006
ITALY	Decreto legislativo n. 264 - 5 October 2006
LATVIA	not available
LITHUANIA	not available
LUXEMBOURG	Law of the 21 November 2007 concernant les exigences de sécurité minimales applicables à certains tunnels routiers Règlement grand-ducal du 20 décembre 2007
MALTA	Safety Requirements For Tunnels In The Trans-European Road Network Regulations (Subsidiary Legislation 499.60)

Country	Transposition of the Directive
NETHERLANDS	Wet aanvullende regels veiligheid wegtunnels 2006 (Road Tunnel Safety Act); Besluit aanvullende regels veiligheid wegtunnels 2006 (Road Tunnel Safety Decree); Regeling aanvullende regels veiligheid wegtunnels 2006 (Road Tunnel Safety Regulation); Bouwbesluit 2006 (Building Decree, under the Building Act). updated by: Wet aanvullende regels veiligheid wegtunnels 2013 (Road Tunnel Safety Act); Regeling aanvullende regels veiligheid wegtunnels 2013 (Road Tunnel Safety Regulation); Bouwbesluit 2012 (Building Decree, under the Building Act).
POLAND	Ustawa z dnia 12 marca 2008 r. o zmianie ustawy o drogach publicznych (Dz. U. z dnia 31 marca 2008 r., Nr 54, Poz. 326) Rozporządzenie Ministrów Infrastruktury Oraz Spraw Wewnętrznych i Administracji z dnia 23 września 2008 r. zmieniające rozporządzenie w sprawie znaków i sygnałów drogowych (Dz. U. z dnia 9 października 2008 r., Nr 179, Poz. 1104) Rozporządzenie Ministra Infrastruktury z dnia 14 października 2008 r. w sprawie dokumentacji bezpieczeństwa tunelu (Dz. U. z dnia 30 października 2008 r., Nr 193, Poz. 1192) Rozporządzenie Ministra Transportu, Budownictwa i Gospodarki Morskiej z dnia 16 maja 2012 r. zmieniające rozporządzenie w sprawie warunków technicznych, jakim powinny odpowiadać drogi publiczne i ich usytuowanie (Dz. U. z dnia 21 maja 2012 r., Poz. 560) Rozporządzenie Ministra Transportu, Budownictwa i Gospodarki Morskiej z dnia 16 maja 2012r. zmieniające rozporządzenie w sprawie warunków technicznych, jakim powinny odpowiadać drogowe obiekty inżynierskie i ich usytuowanie (Dz. U. z dnia 29 maja 2012 r., Poz. 608)
PORTUGAL	Decree Law of 27/03/2006
ROMANIA	Law. 277 / 10.10.2007 on minimum safety requirements for tunnels located on the national sections of the trans-European network.
SLOVAKIA	Decree of the Government No. 344/2006 from 24th May 2006 on minimum safety requirements for road tunnels in road network
SLOVENIA	Public Roads Act (Zakon o javnih cestah (Uradni list RS, št. 33/06 - uradno prečiščeno besedilo, 45/08, 57/08 - ZLDUVCP, 69/08 - ZCestV, 42/09, 109/09 in 109/10 - ZCes-1)) Decree on technical standards and requirements for road tunnel designing in the Republic of Slovenia (Uredba o tehničnih normativih in pogojih za projektiranje cestnih predorov v Republiki Sloveniji (Uradni list RS, št. 48/06, 54/09 in 109/10 - ZCes-1))
SPAIN	Royal Decree 635/2006 (for tunnels of the Spanish State Road Network)
SWEDEN	Law (2006:418) Safety in road tunnels Decree (2006:421) Safety in road tunnels BFS (2007:11) Regulations and general advice on safety in road tunnels
UNITED KINGDOM	The Road Tunnel Safety Regulations 2007 (Statutory Instrument No. 1520)
NORWAY	Forskrift om minimum sikkerhetskrav til visse vegtunneler (Tunnelsikkerhetsforskriften, 2007)
SWITZERLAND	Agreement between the Swiss Confederation and the European Community on the carriage of goods and passengers by rail and road (SR 0.740.72)

Table A2.7 State of implementation of the Directive per Tunnel Manager for the tunnels in operation by the 30 April 2006[79]

Country	Tunnel Manager	Number of tunnels					Total tube length (km)				
		Total (A)	Compliant with the Directive (B)	Not compliant with the Directive (C)	State of compliance unknown (D)	Ratio (B)/(A)	Total (E)	Compliant with the Directive (F)	Not compliant with the Directive (G)	State of compliance unknown (H)	Ratio (F)/(E)
AT	ASFINAG	58	8	50	0	14%	236.9	50.7	186.3	0.0	21%
BE	SOFICO	2	2	0	0	100 %	4.7	4.7	0.0	0.0	100 %
BE	Vlaamse overheid - Agentschap Wegen en Verkeer	3	0	3	0	0%	5.7	0.0	5.7	0.0	0%
BG	Executive Director of National Road Infrastructure Agency	5	0	0	5	0%	8.8	0.0	0.0	8.8	0%
CY	Lemesos District Engineer, Public Works Department	1	1	0	0	100 %	1.8	1.8	0.0	0.0	100 %
CZ	Ředitelství silnic a dálnic ČR	1	1	0	0	100 %	1.0	1.0	0.0	0.0	100 %
DE	Autobahndirektion Nordbayern	2	2	0	0	100 %	5.3	5.3	0.0	0.0	100 %
DE	Autobahndirektion Südbayern	5	4	1	0	80%	10.2	8.8	1.3	0.0	87%
DE	Hessen Mobil – Straßen- und Verkehrsmanagement; Tunnelleitzentrale Eschwege	1	1	0	0	100 %	1.1	1.1	0.0	0.0	100 %
DE	Landesamt für Straßenbau und Verkehr, Tunnelbetriebsstelle Dresden	3	2	1	0	67%	13.4	6.8	6.6	0.0	51%
DE	Landesbetrieb für Straßenbau, Neunkirchen	1	1	0	0	100 %	1.2	1.2	0.0	0.0	100 %
DE	Landesbetrieb Straßen, Brücken und Gewässer (LSBG)	1	1	0	0	100 %	11.1	11.1	0.0	0.0	100 %
DE	Niedersächsische Landesbehörde für Straßenbau und Verkehr - Geschäftsbereich Gandersheim	1	1	0	0	100 %	1.9	1.9	0.0	0.0	100 %
DE	NLStBV - rGB Gandersheim	1	1	0	0	100 %	3.4	3.4	0.0	0.0	100 %

[79] Estonia, Finland, Hungary, Latvia, Lithuania, Malta, Poland and Romania do not have TEN-T road tunnels open by 30 April 2006. The Norwegian TM Statens vegvesen includes tunnels that could not be associated to a specific region (nord, øst, sør, vest and midt).

Country	Tunnel Manager	Number of tunnels					Total tube length (km)				
		Total (A)	Compliant with the Directive (B)	Not compliant with the Directive (C)	State of compliance unknown (D)	Ratio (B)/(A)	Total (E)	Compliant with the Directive (F)	Not compliant with the Directive (G)	State of compliance unknown (H)	Ratio (F)/(E)
DE	Regierungspräsidium Freiburg - Referat 45	1	1	0	0	100 %	1.6	1.6	0.0	0.0	100 %
DE	Regierungspräsidium Stuttgart - Referat 45	4	3	1	0	75%	8.2	7.0	1.2	0.0	85%
DE	Thüringer Landesamt für Bau und Verkehr	5	5	0	0	100 %	27.3	27.3	0.0	0.0	100 %
DK	A/S Øresund	1	0	1	0	0%	1.4	0.0	1.4	0.0	0%
DK	Øresundsbro Konsortiet	1	1	0	0	100 %	8.1	8.1	0.0	0.0	100 %
DK	The Danish Road Directorate	1	1	0	0	100 %	1.2	1.2	0.0	0.0	100 %
EL	AEGEAN MOTORWAY	1	0	1	0	0%	2.2	0.0	2.2	0.0	0%
EL	ATTIKI ODOS	1	1	0	0	100 %	1.7	1.7	0.0	0.0	100 %
EL	EGNATIA ODOS	13	13	0	0	100 %	27.2	27.2	0.0	0.0	100 %
EL	MOREAS	1	0	1	0	0%	1.4	0.0	1.4	0.0	0%
EL	OLYMPIA ODOS	7	0	7	0	0%	7.4	0.0	7.4	0.0	0%
EL	STEREA ELLADA PERFECTURE	1	0	1	0	0%	1.4	0.0	1.4	0.0	0%
ES	BIDEGI	1	0	1	0	0%	1.0	0.0	1.0	0.0	0%
ES	Diputación Foral de Gipuzkoa	4	0	4	0	0%	7.5	0.0	7.5	0.0	0%
ES	Dirección General de Carreteras	56	12	44	0	21%	119.3	26.1	93.2	0.0	22%
ES	Dirección General de Infraestructuras Viarias	1	1	0	0	100 %	2.7	2.7	0.0	0.0	100 %
ES	INTERBIAK S.A.	6	5	1	0	83%	16.9	15.7	1.2	0.0	93%
FR	Autoroute et tunnel du Mont-Blanc (ATMB)	1	1	0	0	100 %	2.9	2.9	0.0	0.0	100 %
FR	Autoroutes du Sud de la France (ASF)	1	1	0	0	100 %	4.8	4.8	0.0	0.0	100 %

Country	Tunnel Manager	Number of tunnels					Total tube length (km)				
		Total (A)	Compliant with the Directive (B)	Not compliant with the Directive (C)	State of compliance unknown (D)	Ratio (B)/(A)	Total (E)	Compliant with the Directive (F)	Not compliant with the Directive (G)	State of compliance unknown (H)	Ratio (F)/(E)
FR	Autoroutes Paris-Rhin-Rhone (APRR)	3	3	0	0	100 %	10.4	10.4	0.0	0.0	100 %
FR	Direction Interdépartementale des Routes Centre Est	3	2	1	0	67%	3.9	2.8	1.1	0.0	72%
FR	Direction Interdépartementale des Routes Massif Central	1	1	0	0	100 %	1.2	1.2	0.0	0.0	100 %
FR	Direction Interdépartementale des Routes Méditerranée	1	1	0	0	100 %	3.0	3.0	0.0	0.0	100 %
FR	Direction Interdépartementale des Routes Nord Ouest	1	0	1	0	0%	3.1	0.0	3.1	0.0	0%
FR	Direction Interdépartementale des Routes Sud-Ouest	2	2	0	0	100 %	3.9	3.9	0.0	0.0	100 %
FR	Grand Lyon	1	0	1	0	0%	3.7	0.0	3.7	0.0	0%
FR	SANEF	1	1	0	0	100 %	1.6	1.6	0.0	0.0	100 %
FR	Société des Autoroutes Estérel, Cote d'Azur, Provence, Alpes (ESCOTA)	7	7	0	0	100 %	10.4	10.4	0.0	0.0	100 %
FR	Société des Autoroutes Rhone-Alpes (AREA)	3	3	0	0	100 %	10.5	10.5	0.0	0.0	100 %
FR	Société Francaise du Tunnel Routier du Fréjus (SFTRF)	3	3	0	0	100 %	7.9	7.9	0.0	0.0	100 %
HR	Bina Istra upravljanje i održavanje d.o.o.	1	0	1	0	0%	5.1	0.0	5.1	0.0	0%
HR	Hrvatske autoceste d.o.o.	9	9	0	0	100 %	19.4	19.4	0.0	0.0	100 %
HR	Rijeka-Zagreb Motorway	1	0	0	1	0%	1.1	0.0	0.0	1.1	0%
IE	Cork City Council	1	1	0	0	100 %	1.2	1.2	0.0	0.0	100 %
IT	ANAS	43	2	41	0	5%	70.4	4.5	65.9	0.0	6%
IT	Auto Brennero	4	3	1	0	75%	6.5	5.2	1.3	0.0	80%
IT	Autocamionale della Cisa	4	0	4	0	0%	10.3	0.0	10.3	0.0	0%
IT	Autostrada BS-VR-VI-PD	1	0	1	0	0%	1.1	0.0	1.1	0.0	0%

Country	Tunnel Manager	Number of tunnels					Total tube length (km)				
		Total (A)	Compliant with the Directive (B)	Not compliant with the Directive (C)	State of compliance unknown (D)	Ratio (B)/(A)	Total (E)	Compliant with the Directive (F)	Not compliant with the Directive (G)	State of compliance unknown (H)	Ratio (F)/(E)
IT	Autostrada dei Fiori	19	1	18	0	5%	40.8	2.0	38.8	0.0	5%
IT	Autostrada Torino Ivrea Valle d'Aosta	2	0	2	0	0%	2.3	0.0	2.3	0.0	0%
IT	Autostrada Torino-Savona	7	0	7	0	0%	7.2	0.0	7.2	0.0	0%
IT	Autostrade Meridionali	1	0	1	0	0%	1.0	0.0	1.0	0.0	0%
IT	Autostrade per l'Italia	110	4	106	0	4%	204.8	11.8	193.0	0.0	6%
IT	Consorzio Autostrade Siciliane	40	0	40	0	0%	105.4	0.0	105.4	0.0	0%
IT	Raccordo Autostradale Valle d'Aosta	9	0	9	0	0%	42.6	0.0	42.6	0.0	0%
IT	Società Autostrada Ligure Toscana	14	0	14	0	0%	24.8	0.0	24.8	0.0	0%
IT	Società Autostrada Tirrenica	1	1	0	0	100%	1.8	1.8	0.0	0.0	100%
IT	Società Autostrade Valdostane	5	0	5	0	0%	11.7	0.0	11.7	0.0	0%
IT	Società Italiana Traforo Autostradale del Frejus	7	0	7	0	0%	34.1	0.0	34.1	0.0	0%
IT	Strada dei Parchi	15	0	15	0	0%	62.8	0.0	62.8	0.0	0%
LU	Ministère du Développement durable et des Infrastructures Administration des ponts et chaussées	2	1	1	0	50%	4.4	3.2	1.2	0.0	73%
NL	Rijkswaterstaat West-Nederland Noord	2	2	0	0	100%	4.0	4.0	0.0	0.0	100%
NL	Rijkswaterstaat West-Nederland Zuid	6	6	0	0	100%	11.3	11.3	0.0	0.0	100%
NO	Statens vegvesen	5	2	3	0	40%	0.0	0.0	0.0	0.0	
NO	Statens vegvesen Region midt	12	5	7	0	42%	20.8	10.0	10.8	0.0	48%
NO	Statens vegvesen Region nord	25	0	25	0	0%	42.0	0.0	42.0	0.0	0%
NO	Statens vegvesen Region øst	3	0	3	0	0%	10.4	0.0	10.4	0.0	0%
NO	Statens vegvesen Region sør	24	6	18	0	25%	35.1	9.0	26.1	0.0	26%
NO	Statens vegvesen Region vest	50	7	43	0	14%	127.6	16.2	111.4	0.0	13%
PT	Euroscut Norte - Sociedade Concessionária da Scut do Norte Litoral, S. A.	1	1	0	0	100%	1.6	1.6	0.0	0.0	100%

Country	Tunnel Manager	Number of tunnels					Total tube length (km)				
		Total (A)	Compliant with the Directive (B)	Not compliant with the Directive (C)	State of compliance unknown (D)	Ratio (B)/(A)	Total (E)	Compliant with the Directive (F)	Not compliant with the Directive (G)	State of compliance unknown (H)	Ratio (F)/(E)
PT	Norscut - Concessionária de Auto-Estradas, S. A.	1	1	0	0	100 %	1.6	1.6	0.0	0.0	100 %
PT	Scutvias Auto-Estradas da Beira Interior, S. A.	1	1	0	0	100 %	3.2	3.2	0.0	0.0	100 %
SE	Swedish Transport Administration	1	1	0	0	100 %	3.2	3.2	0.0	0.0	100 %
SI	DARS d.d.	9	6	3	0	67%	24.9	17.6	7.3	0.0	71%
SK	Národná diaľničná spoločnosť	2	2	0	0	100 %	5.6	5.6	0.0	0.0	100 %
UK	Connect Plus	3	1	2	0	33%	6.6	1.5	5.1	0.0	23%
UK	North & Mid Wales Trunk Road Agent - North Wales Traffic Management Centre	3	0	3	0	0%	3.7	0.0	3.7	0.0	0%
UK	Tony Ambrose	1	1	0	0	100 %	0.8	0.8	0.0	0.0	100 %
FR/IT	Groupement Européen d'Intéret Economique Tunnel du Fréjus	1	1	0	0	100 %	6.6	6.6	0.0	0.0	100 %
AT/SI	ASFINAG + DARS d.d.	1	0	1	0	0%	7.9	0.0	7.9	0.0	0%
FR/IT	Groupement Européen d'Intéret Economique Tunnel du Mont-Blanc	1	1	0	0	100 %	11.6	11.6	0.0	0.0	100 %
ES/FR	Union Temporaire d'Entreprises Tunnel de Somport	1	1	0	0	100 %	8.6	8.6	0.0	0.0	100 %
Total EU		**548**	**140**	**402**	**6**	**26%**	**1,370.0**	**401.9**	**958.2**	**9.8**	**29%**
Total EU + Norway		**667**	**160**	**501**	**6**	**24%**	**1,605.9**	**437.1**	**1,159.0**	**9.8**	**27%**

Source: TRT analysis of the questionnaires

Table A2.8 New tunnels per Tunnel Manager

Country	Tunnel Manager	Number of tunnels				Total tube length (km)			
		Total	in operation	under construction	planned	Total	in operation	under construction	planned
AT	ASFINAG	10	2	6	2	31.1	3.4	20.0	7.7
CY	Public Works Department	4	0	0	4	9.8	0.0	0.0	9.8
CZ	Ředitelství silnic a dálnic ČR	17	2	1	14	44.8	6.4	1.2	37.2
DE	Landesbetrieb Straßenbau Nordrhein-Westfalen, Niederlassung Krefeld	1	1	0	0	3.0	3.0	0.0	0.0
DE	Regierungspräsidium Stuttgart - Referat 45	1	1	0	0	0.5	0.5	0.0	0.0
DE	Thüringer Landesamt für Bau und Verkehr	2	2	0	0	2.9	2.9	0.0	0.0
EL	AEGEAN MOTORWAY	3	0	3	0	22.4	0.0	22.4	0.0
EL	DMEO	1	0	0	1	4.8	0.0	0.0	4.8
EL	EGNATIA ODOS	19	19	0	0	53.0	53.0	0.0	0.0
EL	EYDE PATHE	2	0	2	0	2.4	0.0	2.4	0.0
EL	KENTRIKI ODOS	1	0	1	0	6.0	0.0	6.0	0.0
EL	MOREAS	5	5	0	0	10.5	10.5	0.0	0.0
EL	NEA ODOS	6	2	3	1	17.3	6.3	5.3	5.8
EL	OLYMPIA ODOS	7	0	7	0	15.3	0.0	15.3	0.0
ES	Dirección General de Carreteras	21	17	4	0	48.1	41.8	6.3	0.0
FI	Tieyhtiö Seiskatie Oy	1	0	1	0	1.0	0.0	1.0	0.0
FI	Tieyhtiö Ykköstie Oy	4	4	0	0	8.4	8.4	0.0	0.0
FI	Uusimaa ELY Center	1	1	0	0	3.0	3.0	0.0	0.0
FR	Cofiroute	1	1	0	0	3.4	3.4	0.0	0.0
FR	Société des Autoroutes Rhone-Alpes (AREA)	1	1	0	0	1.0	1.0	0.0	0.0
HR	EGIS ROAD OPERATION CROATIA D.O.O./Autocesta Zagreb-Macelj d.o.o.	2	2	0	0	2.3	2.3	0.0	0.0
HR	Hrvatske autoceste d.o.o.	7	7	0	0	30.9	30.9	0.0	0.0
HR	Hrvatske ceste d.o.o.	3	3	0	0	3.6	3.6	0.0	0.0
HR	Rijeka-Zagreb Motorway	11	11	0	0	20.8	20.8	0.0	0.0
HU	MAK Mecsek AutópályaKoncessziós Zrt.	2	2	0	0	4.4	4.4	0.0	0.0
HU	MK Magyar Közút NPZrt.	2	0	0	2	10.4	0.0	0.0	10.4
IE	DirectRoute Ireland	1	1	0	0	1.4	1.4	0.0	0.0
IE	Egis Road and Tunnel Operations	1	1	0	0	9.1	9.1	0.0	0.0
IT	ANAS	56	54	2	0	108.8	102.7	6.1	0.0

Country	Tunnel Manager	Number of tunnels				Total tube length (km)			
		Total	in operation	under constructio n	planned	Total	in operation	under constructio n	planned
IT	Autostrada Asti-Cuneo	2	2	0	0	2.8	2.8	0.0	0.0
IT	Autostrada Pedemontana Lombarda	3	0	3	0	6.1	0.0	6.1	0.0
IT	Autostrade per l'Italia	4	4	0	0	6.9	6.9	0.0	0.0
IT	Raccordo Autostradale Valle d'Aosta	1	1	0	0	6.6	6.6	0.0	0.0
IT	Strada dei Parchi	1	1	0	0	1.6	1.6	0.0	0.0
NL	Rijkswaterstaat Midden-Nederland	1	1	0	0	6.6	6.6	0.0	0.0
NL	Rijkswaterstaat West-Nederland Noord	1	0	1	0	13.9	0.0	13.9	0.0
NL	Rijkswaterstaat West-Nederland Zuid	1	0	0	1	0.0	0.0	0.0	0.0
NL	Rijkswaterstaat Zuid-Nederland	2	1	1	0	12.3	4.0	8.3	0.0
NO	Statens vegvesen	40	24	16	0	0.0	0.0	0.0	0.0
NO	Statens vegvesen Region øst	2	2	0	0	2.0	2.0	0.0	0.0
NO	Statens vegvesen Region sør	1	1	0	0	0.6	0.6	0.0	0.0
PL	GDDKiA	12	1	0	11	32.0	0.7	0.0	31.3
PT	AE do Marão	1	0	1	0	11.3	0.0	11.3	0.0
RO	D.R.D.P. Brasov	1	0	0	1	2.1	0.0	0.0	2.1
RO	D.R.D.P. Bucuresti	1	0	0	1	2.7	0.0	0.0	2.7
RO	D.R.D.P. Cluj	1	0	0	1	3.0	0.0	0.0	3.0
RO	D.R.D.P. Craiova	4	0	0	4	8.1	0.0	0.0	8.1
RO	D.R.D.P. Timisoara	1	0	0	1	0.8	0.0	0.0	0.8
SE	Swedish Transport Administration	2	1	0	1	63.0	13.0	0.0	50.0
SI	DARS d.d.	4	3	1	0	9.6	5.4	4.2	0.0
SK	Národná diaľničná spoločnosť	2	2	0	0	4.8	4.8	0.0	0.0
UK	Connect Plus	1	1	0	0	1.0	1.0	0.0	0.0
Total EU		**239**	**157**	**37**	**45**	**675.5**	**372.0**	**129.8**	**173.8**
Total EU + Norway		**282**	**184**	**53**	**45**	**678.1**	**374.6**	**129.8**	**173.8**

Source: TRT analysis of the questionnaires

Table A2.9 State of compliance of the new tunnels per Tunnel Manager[80]

Country	Tunnel Manager	Number of new tunnels					Total tube length of the new tunnels (km)				
		Total in operation (A)	Compliant with the Directive (B)	Not compliant with the Directive (C)	State of compliance unknown (D)	Ratio (B)/(A)	Total in operation (E)	Compliant with the Directive (F)	Not compliant with the Directive (G)	State of compliance unknown (H)	Ratio (F)/(E)
AT	ASFINAG	2	2	0	0	100%	3.4	3.4	0.0	0.0	100%
CZ	Ředitelství silnic a dálnic ČR	2	0	0	2	0%	6.4	0.0	0.0	6.4	0%
DE	Landesbetrieb Straßenbau Nordrhein-Westfalen, Niederlassung Krefeld	1	1	0	0	100%	3.0	3.0	0.0	0.0	100%
DE	Regierungspräsidium Stuttgart - Referat 45	1	1	0	0	100%	0.5	0.5	0.0	0.0	100%
DE	Thüringer Landesamt für Bau und Verkehr	2	2	0	0	100%	2.9	2.9	0.0	0.0	100%
EL	EGNATIA ODOS	19	19	0	0	100%	53.0	53.0	0.0	0.0	100%
EL	MOREAS	5	5	0	0	100%	10.5	10.5	0.0	0.0	100%
EL	NEA ODOS	2	2	0	0	100%	6.3	6.3	0.0	0.0	100%
ES	Dirección General de Carreteras	17	16	1	0	94%	41.8	40.3	1.4	0.0	97%
FI	Tieyhtiö Ykköstie Oy	4	4	0	0	100%	8.4	8.4	0.0	0.0	100%
FI	Uusimaa ELY Center	1	1	0	0	100%	3.0	3.0	0.0	0.0	100%
FR	Cofiroute	1	0	0	1	0%	3.4	0.0	0.0	3.4	0%
FR	Société des Autoroutes Rhone-Alpes (AREA)	1	1	0	0	100%	1.0	1.0	0.0	0.0	100%
HR	EGIS ROAD OPERATION CROATIA D.O.O./Autocesta Zagreb-Macelj d.o.o.	2	0	0	2	0%	2.3	0.0	0.0	2.3	0%
HR	Hrvatske autoceste d.o.o.	7	7	0	0	100%	30.9	30.9	0.0	0.0	100%
HR	Hrvatske ceste d.o.o.	3	0	0	3	0%	3.6	0.0	0.0	3.6	0%
HR	Rijeka-Zagreb Motorway	11	11	0	0	100%	20.8	20.8	0.0	0.0	100%
HU	MAK Mecsek AutópályaKoncessziós Zrt.	2	2	0	0	100%	4.4	4.4	0.0	0.0	100%
IE	DirectRoute Ireland	1	1	0	0	100%	1.4	1.4	0.0	0.0	100%
IE	Egis Road and Tunnel Operations	1	1	0	0	100%	9.1	9.1	0.0	0.0	100%
IT	ANAS	54	47	7	0	87%	102.7	92.3	10.3	0.0	90%
IT	Autostrada Asti-Cuneo	2	1	1	0	50%	2.8	1.2	1.6	0.0	44%

[80] Belgium, Bulgaria, Denmark, Estonia, Latvia, Lithuania, Luxembourg and Malta do not have new TEN-T road tunnels. Cyprus, Portugal and Romania do not have new tunnels in operation.

Country	Tunnel Manager	Number of new tunnels					Total tube length of the new tunnels (km)				
		Total in operation (A)	Compliant with the Directive (B)	Not compliant with the Directive (C)	State of compliance unknown (D)	Ratio (B)/(A)	Total in operation (E)	Compliant with the Directive (F)	Not compliant with the Directive (G)	State of compliance unknown (H)	Ratio (F)/(E)
IT	Autostrade per l'Italia	4	3	1	0	75%	6.9	4.6	2.3	0.0	67%
IT	Raccordo Autostradale Valle d'Aosta	1	1	0	0	100%	6.6	6.6	0.0	0.0	100%
IT	Strada dei Parchi	1	1	0	0	100%	1.6	1.6	0.0	0.0	100%
NL	Rijkswaterstaat Midden-Nederland	1	1	0	0	100%	6.6	6.6	0.0	0.0	100%
NL	Rijkswaterstaat Zuid-Nederland	1	1	0	0	100%	4.0	4.0	0.0	0.0	100%
NO	Statens vegvesen	24	23	1	0	96%	0.0	0.0	0.0	0.0	
NO	Statens vegvesen Region øst	2	2	0	0	100%	2.0	2.0	0.0	0.0	100%
NO	Statens vegvesen Region sør	1	1	0	0	100%	0.6	0.6	0.0	0.0	100%
PL	GDDKiA	1	0	0	1	0%	0.7	0.0	0.0	0.7	0%
SE	Swedish Transport Administration	1	1	0	0	100%	13.0	13.0	0.0	0.0	100%
SI	DARS d.d.	3	3	0	0	100%	5.4	5.4	0.0	0.0	100%
SK	Národná diaľničná spoločnosť	2	2	0	0	100%	4.8	4.8	0.0	0.0	100%
UK	Connect Plus	1	0	1	0	0%	1.0	0.0	1.0	0.0	0%
Total EU		**157**	**137**	**11**	**9**	**87%**	**372.0**	**339.1**	**16.6**	**16.3**	**91%**
Total EU + Norway		**184**	**163**	**12**	**9**	**89%**	**374.6**	**341.7**	**16.6**	**16.3**	**91%**

Source: TRT analysis of the questionnaires

Table A2.10 Inspection Entities per country

Country	Number of entities	Entity	National methodology
AT	1	Administrative Authority (bmvit)	Yes
CY	1	Lemesos District Engineer, Public Works Department, Ministry of Communications and Works	Yes
DK	1	The Safety Officers from the three tunnels supplemented with independent institutes/authorities	No
EL	1	Administrative Authority (D.A.S.)	Yes
ES	3	Geocontrol Euroestudios & Auding (Joint-Venture) Idom & Geocontrol (Joint-Venture)	Yes
FI	1	-	No
FR	19	Engineering offices Expert consultants CETU	Yes
HR	2	Road inspection Fire inspection	-
HU	1	Administrative Authority (Nemzeti Közlekedési Hatóság - National Transport Authority)	No
IE	2	Administrative Authority (National Roads Authority)	No
IT	1	Administrative Authority (Commissione permanente per le gallerie - Ministero delle Infrastrutture e dei Trasporti)	Yes
LU	1	Administrative Authority (Inspection des Travaux et des Mines - ITM)	Yes
NL	1	Administrative Authorities (Municipalities)	No
RO	1	I.S.C.	Yes
SE	-	Administrative Authority (Swedish Transport Agency)	No
SI	1	Inspectorate for transport, energy and special planning of Republic Slovenia	Yes
SK	2	Administrative Authority (Ministry of Transport, Construction and Regional Development) District Office in Žilina	No
UK (Kent)	1	Amey Consulting	Yes

Source: TRT analysis of the questionnaires

Table A2.11 Measures applied by each country in tunnels outside the TEN-T

Measure	AT	CY	DK	EL	ES	FI	FR	HR	HU	IE	IT	LU	NL	RO	SE	SI	SK	UK	Total number of countries where the measure is applied (over 18)
2 tubes or more	N	N	-	Y	-	Y	N	-	Y	N	Y	Y	Y	N	N	N	N	Y	7
Gradients ≤ 5 %	Y	N	-	Y	-	Y	N	-	Y	N	N	Y	Y	N	N	N	N	Y	7
Emergency walkways	Y	N	-	Y	-	Y	N	-	Y	N	Y	Y	Y	N	N	N	N	Y	8
Emergency exists at least every 500 m	Y	N	-	Y	-	Y	N	-	Y	N	Y	Y	Y	N	N	N	N	Y	8
Cross-connections for emergency services at least every 1 500m	Y	N	-	Y	-	Y	N	-	Y	N	Y	Y	Y	N	N	N	N	N	7
Lay-bys at least every 1 000 m	Y	N	-	Y	-	Y	N	-	Y	N	Y	Y	N	N	N	N	N	N	6
Drainage for flammable and toxic liquids	Y	N	-	Y	-	Y	N	-	Y	N	N	Y	Y	N	N	N	N	Y	7
Fire resistance of structures	Y	N	-	N	-	Y	N	-	Y	N	N	Y	Y	N	N	N	N	Y	6
Lighting - Normal lighting	Y	N	-	Y	-	Y	N	-	Y	N	Y	Y	Y	N	N	N	N	Y	8
Lighting - Safety lighting	Y	N	-	Y	-	Y	N	-	Y	N	Y	Y	Y	N	N	N	N	Y	8
Lighting - Evacuation lighting	Y	N	-	Y	-	Y	N	-	Y	N	N	Y	Y	N	N	N	N	N	6
Ventilation - Mechanical ventilation	Y	N	-	Y	-	Y	N	-	Y	N	N	Y	Y	N	N	N	N	Y	7
Ventilation - Special provisions for (semi-) transverse ventilation	Y	N	-	N	-	N	N	-	Y	N	N	Y	N	N	N	N	N	N	3
Emergency stations	Y	N	-	Y	-	Y	N	-	Y	N	N	Y	Y	N	N	N	N	Y	7
Water supply	Y	N	-	Y	-	Y	N	-	Y	N	N	Y	Y	N	N	N	N	Y	7
Road signs	Y	N	-	Y	-	Y	N	-	Y	N	Y	Y	Y	N	N	N	N	Y	8
Control centre	Y	N	-	N	-	Y	N	-	Y	N	N	Y	Y	N	N	N	N	Y	6
Monitoring systems - Video	Y	N	-	Y	-	Y	N	-	Y	N	N	Y	Y	N	N	N	N	Y	7
Monitoring systems - Automatic incident detection and/or fire detection	Y	N	-	Y	-	Y	N	-	Y	N	N	Y	Y	N	N	N	N	N	6
Equipment to close the tunnel	Y	N	-	N	-	Y	N	-	Y	N	N	Y	N	N	N	N	N	N	4
Communication systems - Radio re-broadcasting for emergency services	Y	N	-	Y	-	Y	N	-	Y	N	N	Y	Y	N	N	N	N	N	6
Communication systems - Emergency radio messages for tunnel users	Y	N	-	Y	-	Y	N	-	Y	N	N	Y	Y	N	N	N	N	N	6
Communication systems - Loudspeakers in shelters and exists	Y	N	-	N	-	Y	N	-	Y	N	N	Y	Y	N	N	N	N	N	5
Emergency power supply	Y	N	-	Y	-	Y	N	-	Y	N	N	Y	Y	N	N	N	N	N	6
Fire resistance of equipment	Y	N	-	Y	-	Y	N	-	Y	N	N	Y	Y	N	N	N	N	Y	7
Total number of measures applied (over 25)	**24**	**0**	**0**	**20**	**0**	**24**	**0**	**0**	**25**	**0**	**8**	**25**	**22**	**0**	**0**	**0**	**0**	**15**	**163**

Source: TRT analysis of questionnaires

Table A2.12 Measures applied by each country in TEN-T tunnels shorter than 500 m

Measure	AT	CY	DK	EL	ES	FI	FR	HR	HU	IE	IT	LU	NL	RO	SE	SI	SK	UK	Total number of countries where the measure is applied (over 18)
2 tubes or more	N	Y	-	Y	-	Y	Y	-	Y	N	Y	Y	Y	N	N	N	N	-	8
Gradients ≤ 5 %	Y	Y	-	Y	-	Y	N	-	Y	N	N	Y	Y	N	N	N	N	-	7
Emergency walkways	Y	Y	-	Y	-	Y	Y	-	Y	N	Y	Y	Y	N	N	N	N	-	9
Emergency exists at least every 500 m	N	Y	-	N	-	Y	Y	-	Y	N	Y	Y	Y	N	N	N	N	-	7
Cross-connections for emergency services at least every 1 500m	N	Y	-	N	-	Y	Y	-	Y	N	Y	Y	Y	N	N	N	N	-	7
Lay-bys at least every 1 000 m	N	Y	-	N	-	Y	Y	-	Y	N	Y	Y	N	N	N	N	N	-	6
Drainage for flammable and toxic liquids	Y	Y	-	Y	-	Y	Y	-	Y	N	N	Y	Y	N	N	N	N	-	8
Fire resistance of structures	Y	Y	-	N	-	Y	Y	-	Y	N	N	Y	Y	N	N	N	N	-	7
Lighting - Normal lighting	Y	Y	-	Y	-	Y	Y	-	Y	N	Y	Y	Y	N	N	N	N	-	9
Lighting - Safety lighting	Y	Y	-	Y	-	Y	Y	-	Y	N	Y	Y	Y	N	N	N	N	-	9
Lighting - Evacuation lighting	Y	Y	-	Y	-	Y	Y	-	Y	N	N	Y	Y	N	N	N	N	-	8
Ventilation - Mechanical ventilation	N	Y	-	N	-	N	Y	-	Y	N	N	Y	Y	N	N	N	N	-	5
Ventilation - Special provisions for (semi-) transverse ventilation	N	Y	-	N	-	N	Y	-	Y	N	N	Y	N	N	N	N	N	-	4
Emergency stations	N	Y	-	Y	-	Y	Y	-	Y	N	N	Y	Y	N	N	N	N	-	7
Water supply	N	Y	-	Y	-	Y	Y	-	Y	N	N	Y	Y	N	N	N	N	-	7
Road signs	Y	Y	-	Y	-	Y	Y	-	Y	N	Y	Y	Y	N	N	N	N	-	9
Control centre	N	Y	-	N	-	Y	Y	-	Y	N	N	Y	Y	N	N	N	N	-	6
Monitoring systems - Video	N	Y	-	Y	-	Y	Y	-	Y	N	N	Y	Y	N	N	N	N	-	7
Monitoring systems - Automatic incident detection and/or fire detection	N	Y	-	Y	-	Y	Y	-	Y	N	N	Y	Y	N	N	N	N	-	7
Equipment to close the tunnel	N	Y	-	N	-	N	Y	-	Y	N	N	Y	N	N	N	N	N	-	4
Communication systems - Radio re-broadcasting for emergency services	N	Y	-	Y	-	Y	Y	-	Y	N	N	Y	Y	N	N	N	N	-	7
Communication systems - Emergency radio messages for tunnel users	N	Y	-	Y	-	Y	Y	-	Y	N	N	Y	Y	N	N	N	N	-	7
Communication systems - Loudspeakers in shelters and exists	N	Y	-	N	-	N	Y	-	Y	N	N	Y	Y	N	N	N	N	-	5
Emergency power supply	Y	Y	-	Y	-	Y	Y	-	Y	N	N	Y	Y	N	N	N	N	-	8
Fire resistance of equipment	Y	Y	-	Y	-	Y	Y	-	Y	N	N	Y	Y	N	N	N	N	-	8
Total number of measures applied (over 25)	**10**	**25**	**0**	**16**	**0**	**21**	**24**	**0**	**25**	**0**	**8**	**25**	**22**	**0**	**0**	**0**	**0**	**0**	**176**

Source: TRT analysis of questionnaires

Table A2.13 Requirements of the Directive that were already provided for under the previous legislation

Measure	AT	CY	DK	EL	ES	FI	FR	HR	HU	IE	IT	LU	NL	RO	SE	SI	SK	UK	Total number of countries where the measure is applied (over 18)
2 tubes or more	N	N	-	Y	N	Y	Y	-	-	N	Y	Y	Y	N	N	N	Y	N	7
Gradients ≤ 5 %	N	N	-	Y	Y	Y	N	-	-	N	N	Y	Y	N	Y	Y	Y	N	8
Emergency walkways	Y	N	-	Y	Y	Y	Y	-	-	N	Y	Y	Y	N	Y	Y	Y	Y	12
Emergency exists at least every 500 m	Y	N	-	Y	N	Y	Y	-	-	N	Y	Y	Y	N	Y	Y	Y	N	10
Cross-connections for emergency services at least every 1 500m	Y	N	-	Y	N	N	Y	-	-	N	Y	Y	Y	N	N	N	Y	N	7
Lay-bys at least every 1 000 m	Y	N	-	Y	N	N	Y	-	-	N	Y	N	N	N	N	Y	Y	N	6
Drainage for flammable and toxic liquids	Y	N	-	Y	N	Y	Y	-	-	N	N	Y	Y	N	Y	N	Y	Y	9
Fire resistance of structures	N	N	-	N	N	N	Y	-	-	N	N	Y	Y	N	Y	Y	Y	Y	7
Lighting - Normal lighting	Y	N	-	Y	Y	Y	Y	-	-	N	Y	Y	Y	N	Y	Y	Y	Y	12
Lighting - Safety lighting	Y	N	-	Y	N	N	Y	-	-	N	Y	Y	Y	N	Y	N	N	Y	8
Lighting - Evacuation lighting	Y	N	-	Y	N	N	Y	-	-	N	N	Y	Y	N	Y	N	N	Y	7
Ventilation - Mechanical ventilation	Y	N	-	Y	N	N	Y	-	-	N	N	Y	Y	N	Y	Y	Y	Y	9
Ventilation - Special provisions for (semi-) transverse ventilation	Y	N	-	N	N	N	Y	-	-	N	N	Y	N	N	N	Y	Y	N	5
Emergency stations	N	N	-	Y	N	N	Y	-	-	N	N	Y	Y	N	Y	N	Y	Y	7
Water supply	Y	N	-	Y	N	N	Y	-	-	N	N	Y	Y	N	Y	N	N	Y	7
Road signs	Y	N	-	Y	Y	Y	Y	-	-	N	Y	Y	N	N	Y	Y	Y	Y	11
Control centre	N	N	-	N	N	Y	Y	-	-	N	N	Y	Y	N	Y	Y	Y	Y	8
Monitoring systems - Video	Y	N	-	Y	N	Y	Y	-	-	N	N	Y	Y	N	Y	N	Y	Y	9
Monitoring systems - Automatic incident detection and/or fire detection	N	N	-	Y	N	Y	Y	-	-	N	N	Y	Y	N	Y	N	Y	N	7
Equipment to close the tunnel	Y	N	-	N	N	Y	Y	-	-	N	N	Y	N	N	Y	N	Y	N	6
Communication systems - Radio re-broadcasting for emergency services	Y	N	-	Y	N	Y	Y	-	-	N	N	Y	Y	N	Y	N	N	Y	8
Communication systems - Emergency radio messages for tunnel users	Y	N	-	N	N	N	Y	-	-	N	N	Y	Y	N	Y	N	Y	N	6
Communication systems - Loudspeakers in shelters and exists	N	N	-	N	N	N	Y	-	-	N	N	Y	N	N	N	N	N	N	2
Emergency power supply	Y	N	-	Y	N	N	Y	-	-	N	N	Y	Y	N	Y	N	N	Y	7
Fire resistance of equipment	Y	N	-	Y	N	N	Y	-	-	N	N	Y	Y	N	Y	Y	Y	Y	9
Total number of measures applied (over 25)	**18**	**0**	**0**	**19**	**4**	**12**	**24**	**0**	**0**	**0**	**8**	**24**	**20**	**0**	**20**	**11**	**19**	**15**	**194**

Source: TRT analysis of the questionnaires

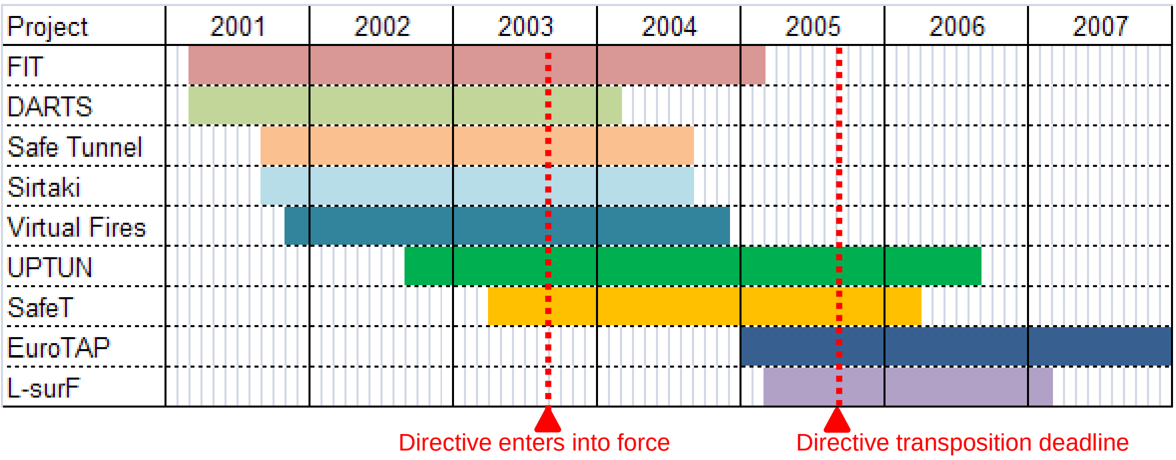
Annex 3 Literature review

This section presents the main features of the nine studies undertaken in tunnel safety and funded by the EC over a period 2001-2007.

A3.1 Previous EU studies

A major objective of the FP funded projects was a review of road tunnel safety with a perspective of supporting actions for competitive and sustainable growth of European industry (see the timeline in Figure A3.1).The actions undertaken in these nine projects were important for achieving progress through innovation in technology and holistic evaluations of safety levels.

Figure A3.1 Timeline of EU funded projects in tunnel safety under 5th and 6th Framework Programmes81



Source: Elaborations from Katalagarianakis (2004)[82], EuroTAP project in summary[83] and L-surF project in summary[84].

In the appendix the main features of the nine studies undertaken in tunnel safety and funded by the EC over a period of seven years are presented. The main topics analysed throughout the programmes are outlined below and summarised in Table A3.1.

- Pro-action: structural and operational safety measures during the planning phase (before construction, or refurbishment);
- Prevention: traffic management measures to avoid incidents and accidents;
- Preparation: emergency preparedness; measures to deal with incidents and accidents adequately;
- Repression: actual emergency repression after the incident or accident to reduce the consequences of the incident or the accident;
- Evaluation: evaluation of (near) accidents (lessons learned).

81 See footnote 102 on the entities funding the project. EuroTAP was outside the 5th and 6th Framework Programmes.

82 For the projects: FIT, DARTS, Safe Tunnel, Sirtaki, Virtual Fires, UPTUN and SafeT.

83 Document available on the webpage http://ec.europa.eu/transport/road_safety/pdf/projects/eurotap.pdf.

84 See EU (2005). L-SURF:Design Study for a Large-ScaleUnderground Research Facility on Safetyand Security.

Table A3.1 Synopsis EU studies by topic

Project	Pro-action	Prevention	Preparation	Repression	Evaluation
FIT					√
DARTS	√				
Safe Tunnel		√			
Sirtaki	√	√	√	√	√
Virtual Fires			√		
UPTUN	√				√
SafeT			√		
EuroTAP	√	√	√		
L-surF		√	√		

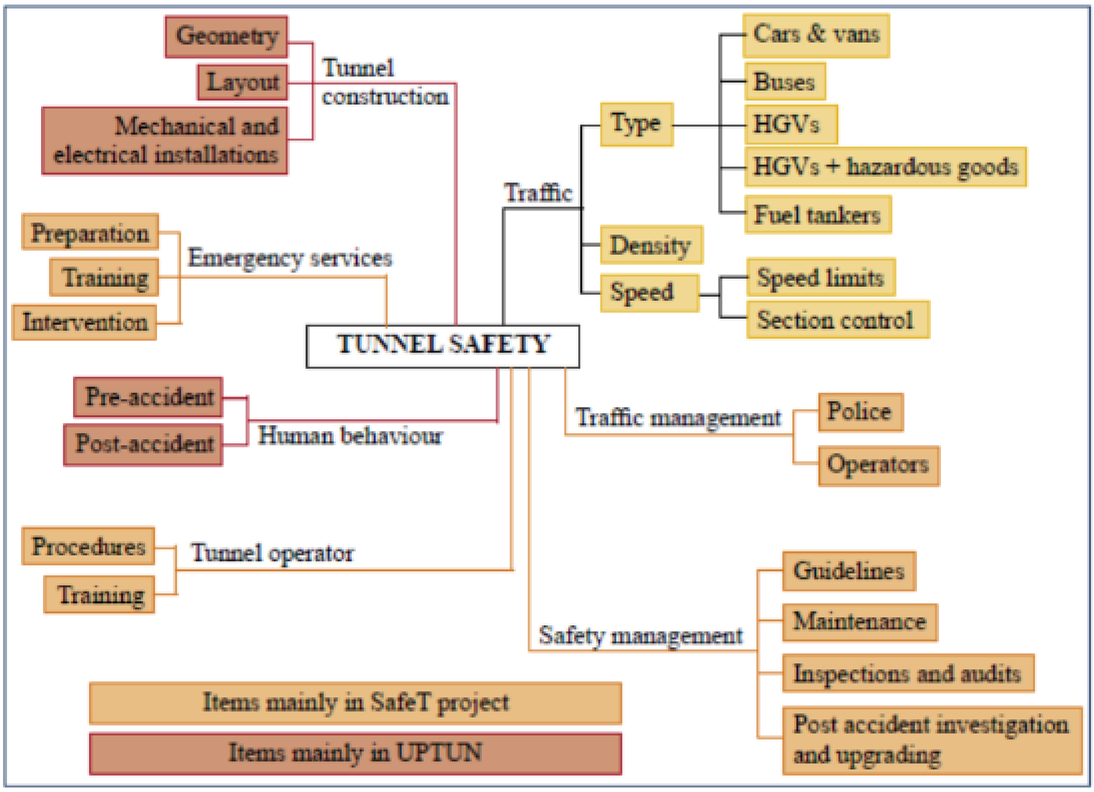
Source: Elaborations from SafeTD6.1 Report (2005), EuroTAP (2010) and L-surF webpage.

The Directive aims at ensuring that minimum safety standards of the institutional, organisational, and operational aspects of tunnel safety management systems (TSMS) are adopted across EU Member States.

After the examination of the results obtained under the EU funded projects on road tunnel safety and related thematic networks, it was concluded that there was a need for an integrated "holistic" approach to achieve adequate safety levels.

In this view, SafeT provided recommendations and prescriptive guidelines for enhancing safety in tunnels through TSMS and involving (i) the major tunnel safety management processes and their interrelationships, (ii) the major legal, institutional, organisational, and operational aspects of the system, and (iii) the technological tools for accommodating the tunnel safety management processes. The outcome of this analysis was a set of comprehensive guidelines for organising, planning, and implementing a TSMS based on the existing technological tools and the associated legal and institutional framework.

Figure A3.2 Focus on road tunnel safety in UPTUN and SafeT



Source: Integrated approach to road tunnel safety, PIARC (2007).

The SafeT project can be used as a reference source for guidelines on tunnel safety management[85] and for risk assessment (see section 3.2.3).

For the purpose of this study the EU research projects cannot be considered as having influenced the legislation entered into force in 2004. Their timelines span the date (30 April 2006) by when the Directive had to be transposed by the Member States (see Figure A3.1).

In general, the EU studies have been considered in all cases where they have brought an added value to EU legislation. However the research studies presented do not provide direct information to contribute to the evaluation of the Directive.

The following subsections present the main features of the nine studies undertaken in tunnel safety and funded by the EC over a period of seven years. The main topics analysed throughout the programmes are outlined below and summarised in Table A3.1.

A3.1.2 FIT

Full name: Fire in Tunnels
Framework Programme: 5th
Period: 03/2001-02/2005
Total funding:€ 1,478,550 (EU funding € 1,451,400)
Coordinator: BBRI (Belgium)
Number of partners: 33
Countries involved: 12 (Austria, Belgium, Denmark, Finland, France, Germany, Spain, Sweden, Switzerland, The Netherlands, United Kingdom)

[85] See SafeT. (2005). D6.1 Report, (Section 3).

Description

The European Thematic Network FIT was launched the 1st of March 2001 for a period of four years. A wide range of information was accessible through the project's webpages[86], including six databases[87] containing essential knowledge about fire in tunnels.

This initiative resulted from an increasing interest of the public and among professionals in the topics concerning fire in tunnels. This interest was certainly influenced by records on casualties which reported 221 lives lost in four major fire events over a period of two years.

FIT established and developed a European platform to optimise efforts on fire safety in tunnels. The Network's ambition was to develop a European consensus on fire safety for road, rail and metro tunnel infrastructures and enhance the exchange of up-to-date knowledge gained from current practice and ongoing European and national research projects. To deliver this ambition, the project had the following objectives:

- Disseminate European and national research results in optimising synergy, reaching critical mass and enhancing impact at European level;
- Establish a set of consultable databases with essential knowledge on fire in tunnels;
- Develop recommendations on design fires for tunnels;
- Develop European consensus for fire safe design on the basis of existing national regulations, guidelines, codes of practice and safety requirements;
- Identify best practices for tunnel authorities and fire emergency services on prevention and training, accident management and fire emergency operations.

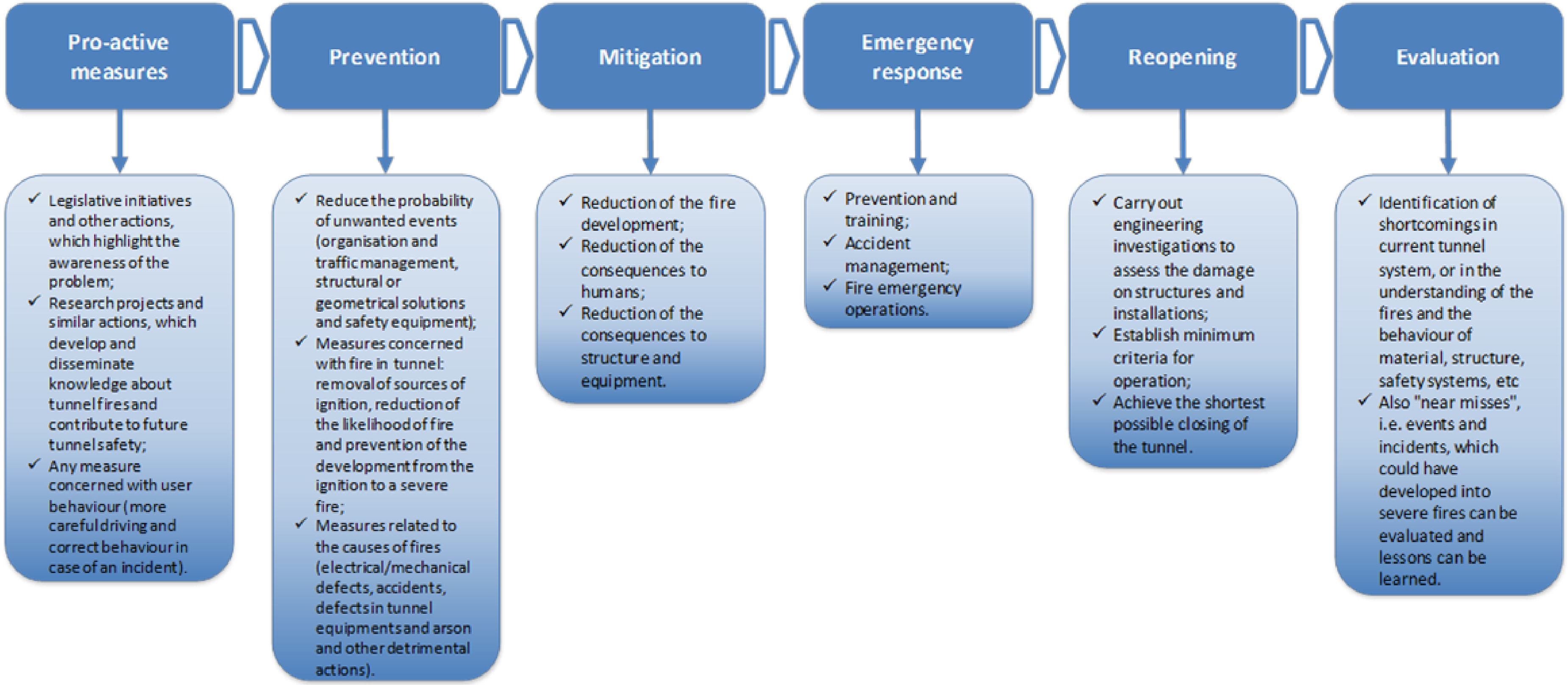
In analysing the basic aspects of causes of fire in road tunnels the project concluded that up to about 95% of these events were caused by electrical and mechanical defects (e.g., overheating of engine and brakes). The remaining causes of fires were identified as collisions, technical defects of tunnel equipment and maintenance works in tunnels. Moreover, findings highlighted that the probability of fires due to heavy goods vehicles (HGV) was larger than for passenger cars, and when HGVs are involved in the fire, there exists a higher risk that the fire develops into a serious event. As regards the consequences generated, according to the conclusions of FIT (2006) Final Report "*heat is the cause of damage to structure and installations, whereas it is rarely the original cause of death. The threat to humans is primarily loss of visibility due to smoke (which impedes evacuation), then toxicity. A secondary risk is that fires may potentially also represent a hazard to the environment caused by the toxicity of the smoke and substances in the drainage*".

Having identified drivers and consequences, the project elaborated an integrated approach emphasising "consecutive safety aspects", from pro-active measures to evaluations (see Figure A3.3).

[86] The web address http://www.etnfit.net is no longer active.

[87] Database 1: RTD on fire safety in tunnels, Database 2: A mapping of tunnel test site facilities, Database 3: Overview of numerical computer codes for tunnel fires, Database 4: Data on safety equipment in tunnels, Database 5: Assessment reports on fire accidents in tunnels and Database 6: A mapping and overview of upgrade activities on tunnels.

Figure A3.3 Consecutive safety aspects of FIT project



Source: Elaborations of the authors from FIT General Report[88].

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88 See FIT General Report, section 2.2.

The FIT research project included a detailed comparison describing the requirements of the national guidelines of Germany, France, UK, Norway, Austria, Switzerland and Netherlands, to which were added the requirements of the Directive. The substantial ideas that can be deducted from the comparison were:

- Traffic and underground length are used in the definition of the requirements for safety measures; this allowed several countries to define tunnel categories (UK, Austria, Norway, France). The presence of lorries transporting dangerous materials led to complementary specifications.
- The emergency passenger exits to safety and the emergency access for rescue staff generally dealt with national regulations, precise but not homogeneous between the various countries. It was found that inter-distances can vary from 100 m to 400 m between the escape routes, while the Directive defines a maximum at 500 m, if any89. Although the requirement for shelters was not always mentioned, where needed the access way was connected to the outside (France and the Directive).
- The drainage of flammable liquid was a safety element well defined by certain countries, with civil engineering and geometry arrangements specially adapted.
- Among the safety equipment ventilation and smoke control in case of fire were considered as fundamental and led in most countries to detailed guidelines. The following were introduced as compulsory: artificial ventilation, the mechanical ventilation system, the required air volumes and velocities, or simply the objectives that must be met according to the selected design fire (performance base approach). Requirements were stated to prevent smoke penetrating into the emergency exits and rescue access.
- The lighting of the tunnel and emergency exits and rescue access was – except special cases – defined with a minimum illumination level.
- The requirements for traffic signage, both outside and within the tunnel, and signage for pedestrian exit and rescue generally were well stated in the guidelines, but criteria remained heterogeneous.
- Regarding communication and alarm systems, the emergency telephones and the alarm push-buttons were imposed as minimal basic elements; the required intervals however varied from 50 to 250 m; the value of 150 m as stated by the Directive therefore was a compromise90. Requirements also existed on automatic alarms on equipment, automatic incident detection, fire or smoke detection and on radio rebroadcast. The installation of loudspeakers within the tunnel itself was not frequent, but requested in the evacuation facilities, or shelters for the users.
- For traffic regulation and monitoring equipment the measures were adapted to the surveillance level of the tunnel. Mainly guidelines described the quick detection of the traffic incidents, through speed and density measurement or video control, and the means for rapid closure of the tunnel. Thermographic portal detectors to detect abnormally hot lorries before entering tunnels were not prescribed.
- The requirements for emergency power supply of the safety equipment were generally well described.
- Regarding fire fighting, the distribution within the tunnel of extinguishers and the presence of a water network and fire hydrants of sufficient capacity were compulsory, but with varying characteristics and intervals. Several countries defined a hydrant interval between 150 and 250 m, in line with the maximum value of 250 m stated for all tunnels by the Directive91. The installation of a fixed fire suppression system was not imposed in any regulation.
- The structure and equipment in response to fire dealt within a rather large range of requirements, however without consistency. Regarding the resistance of structures, the formulation varied from

89 See Annex I, on page 65, section 2.3.8.

90 See Annex I, on page 69, section 2.10.3. For new tunnels the distance shall not exceed 150 m and in existing tunnels 250 m.

91 See Annex I, on page 69, section 2.11.

very prescriptive requirements (Germany) to more or less performance based criteria (France, Austria, Norway). The criteria were given in terms of duration and specified fire curves or heat release rate. Calculated documentation was required in all guidelines. Concerning the equipment the notion of continuity of service for the safety elements is often emphasised and connected to most varying criteria of heat reaction or resistance. The Directive defines these requirements less precisely than certain national guidelines[92].

Main achievements:

Six databases available to registered members on research projects, test sites, numerical models, equipment, fire accidents and tunnel upgrade activities;
Optimised measures for evacuation, assisted rescue and fire fighting;
Evaluation of guidelines and recommendations for the tunnel design.

A3.1.3 DARTS

Full name: Durable and Reliable Tunnel Structures
Framework Programme: 5th
Period: 03/2001-02/2004
Total funding: € 3,313,269(EU funding € 1,656,624)
Coordinator: COWI (Denmark)
Number of partners:7
Countries involved:5 (Denmark, France, Germany, Sweden, The Netherlands)

Description

Durable and Reliable Tunnel Structures (DARTS)[93] was a three year project, launched in March 2001, undertaken by eight European partners coordinated by COWI (Denmark),through six technical workpackages. DARTS aimed at developing, for each individual case, operational methods and supporting tools for the choice of cost optimal tunnel type and construction procedures regarding environmental conditions, technical qualities, safety precautions and long service life.

Notably, DARTS developed an integrated decision framework transforming the traditional fragmented design approach into a total economic life cycle evaluation, namely a so-called “cradle-to-grave” approach, including social costs and benefits arising during the process.

The total economic evaluation means that not only financial costs were considered (construction, operation and maintenance), but also environmental and traffic related impacts. In order to assess the total life cycle cost and make them comparable, all inputs were assumed in monetary terms. Thus, the core of the integrated design took into account a number of impacts on the society and over the entire lifetime of the project.

In this regard, such integrated design included:

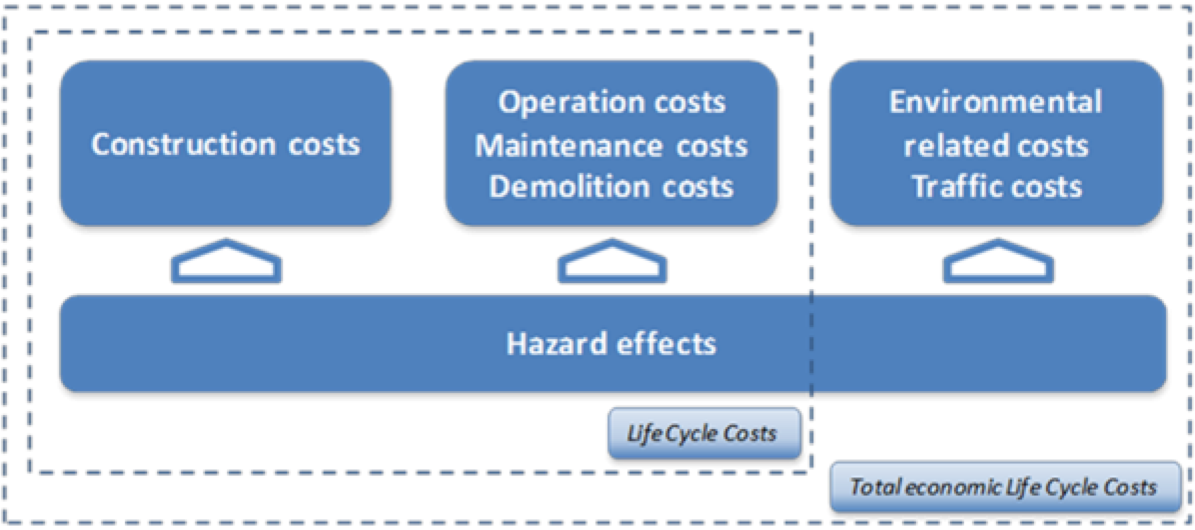
- Environmental impacts on nature and health, namely:
  - Pollution of air, soil, ground and surface water;
  - Ecotoxicological effects;
  - Noise and vibrations;
  - Consumption of resources (land, energy, water, materials, etc.);
  - Health and psychological impacts.
- Traffic related costs, in terms of change in travel time and distance.

[92] See Annex I, on page 72, section 2.18.

[93] The web address www.dartsproject.net is no longer active.

The integrated design also encompassed hazard effects potentially affecting any of the aforementioned costs (see Figure A3.4). The studies on hazard occurrence during construction and operation of tunnels focussed on fire, explosion, leakage of aggressive materials, toxic release, water inundation and earthquakes.

Figure A3.4 Life cycle costs and total economic life cycle costs



Source: Elaborations of the authors from Rostman and Høj (2004).

Main achievements: Cost optimisation decision model based on life cycle approach, combining interactions between structure, environment, durability, consequences of fire and possible effects on human beings.

A3.1.4 Safe Tunnel

Full name: Innovative systems and frameworks for enhancing of traffic safety in road tunnels Framework Programme: 5th **Period:** 09/2001-08/2004 **Total funding:** € 4,942,959(EU funding € 2,223,048) **Coordinator:** Centro Ricerche FIAT (Italy) Number of partners: 10 **Countries involved:** 5 (France, Germany, Italy, Israel, Switzerland)

Description

Innovative systems and frameworks for enhancing traffic safety in road tunnels[94] (SafeTunnel) was a three year project of nine partners initiated in September 2001 and coordinated by Centro Ricerche FIAT[95] (Italy).

Safe Tunnel's main objective was to contribute to reduce the number of accidents inside road tunnels by preventive safety measures. Its main focus was to achieve a dramatic decrease of "fire accidents" particularly in mono-tube tunnels.

Secondly, the project aimed to avoid the entry in to tunnels of those vehicles with detected or imminent on-board anomalies and introduce measures to achieve the control of the speed and the distance between the vehicles.

94 The web address www.crfproject-eu.org is no longer active.

95 FIAT Researches Centre.

The project was based on observations on the average frequency of fires for a specific group of tunnels (e.g., Fréjus, Mont Blanc and St. Gotthard). In these cases, the frequency was found to be much higher, especially for HGVs.

In measurable terms, the project introduced measures enabling a reduction of the number of HGV incidents of 40% within 10 years and a cut by 50% of the frequency of fires in tunnels within 6 years.

To achieve this objective, Safe Tunnel introduced a set of preventive safety measures made possible by the integration of on board vehicle devices and ITS infrastructures.

The vehicle-infrastructure integration was designed with respect to the following three activities:

- Adapt existing on-board vehicle sensors to monitor its main functions in order to forecast and detect anomalies to on-board devices.
- Develop a control centre to receive and to process the information transmitted by equipped HGVs and by infrastructure-based electronic systems (when the vehicles were not equipped).
- Develop the “tele-control” of the equipped vehicle by the automatic actuation of the recommended speed by the control centre. The study analysed the possibility to install inside the tunnel a system showing a light beam which drivers of not equipped vehicles must follow (i.e., the moving spot light concept).

Two HGVs were arranged as demonstrators and fitted with diagnostic systems for checking main mechanical and electronic components (engine, brakes, power train, transmission, tyres, adaptive cruise control (ACC), automatic differential brake (ADB), electronic stability program (ESP) and communication system). A second system was installed to automatically control the speed of the vehicle, acting on brakes and throttle. A monitoring centre was set up in the control rooms of Fréjus tunnel managers (SITAF and SFTRF).

Main achievements:

Provision of the recommended speed for the tele-control application;
Activation of access control measures to stop the potentially dangerous vehicle;
Detection of potential danger and alert the emergency services;
Issue warning messages to the drivers on-board vehicles.

A3.1.5 SIRTAKI

Full name: Safety Improvement in Road and Rail Tunnels Using Advanced Information Technologies and Knowledge Intensive decision support model
Framework Programme: 5th
Period: 09/2001-08/2004
Total funding: € 3,003,585(EU funding € 1,453,256)
Coordinator: ETRA Investigacion y desarrollo SA (Spain)
Number of partners: 10
Countries involved: 7 (Denmark, France, Greece, Italy, Norway, Spain, Switzerland)

Description

SIRTAKI[96] was a three year project, initiated in September 2001, undertaken by a consortium of 10 European partners. It aimed at developing an advanced tunnel management system specifically tackling safety issues and emergencies and was fully integrated in the overall network management. The proposed system was evaluated in several road and rail tunnel sites. SIRTAKI developed innovations in four main aspects of tunnel management and emergencies: the prevention of conflictive situations and emergencies; supporting tunnel managers; integrated management within the transport network; improvements to sensors and surveillance.

The Decision Support System (DSS) was one of the main components of SIRTAKI. Basically, the DSS provided a smart aid between, on the one hand, the crisis manager and the real time information

[96] The web address www.sirtakiproject.com is no longer active.

needed to analyse the situation and, on the other, between the crisis manager and the emergency response means.

Main achievements:

Tunnel Control Model (helpful for an easier customisation to any tunnel characteristics);
Inference Module (a real time decision support system by identifying potentially dangers);
Knowledge Basis (a learning tool for training and decision taking by applying previous experiences).

A3.1.6 Virtual Fires

Full name: Virtual Real Time Emergency Simulator
Framework Programme: 5th
Period: 11/2001-11/2004
Total funding: € 1,786,200 (EU funding €1,509,76)
Coordinator: Technische Universität Graz (Austria)
Number of partners: 7
Countries involved: 5 (Austria, France, Germany, Spain, Sweden)

Description

Virtual Fires[97] was a three year project with seven partners from five European countries, initiated in November 2001 and coordinated by the Institute for Structural Analysis (Austria). The aim of the project was to develop a simulator allowing for the training of fire fighters in the efficient mitigation of fires in a tunnel, using a computer generated virtual environment.

This was a low-cost and environmentally friendly alternative to real fire fighting exercises involving burning fuel in a disused tunnel. The simulator used techniques of virtual reality and was used to test the fire safety of a tunnel and the influence of mitigating measures (e.g., ventilation, fire suppression etc.) on its fire safety level.

In the simulator the observer was able to visualise the fire and smoke development and the transport of heat and toxic combustion of products inside a tunnel and walk, or run through the virtual structure in the same way as through a real tunnel. Final users included tunnel managers, designers and government regulatory authorities.

For demonstration purposes some historic fire accidents were calculated with the simulator. The Mont Blanc (see Figure A3.5) and Glenalm (Austria) tunnels were examined comparing the former ventilation systems with the improved ones after the reopening.

97 The web address www.virtualfires.org is no longer active.

Figure A3.5 Fire simulation in the Mont Blanc tunnel

Source: Beer G, Reichl Th. and Lenz G. (2004).

Main achievements:

Simulator consisting of a software and specialised hardware components (CAVE and HMD technology implementation) which allowed the three-dimensional visualisation of results of combustion simulations (in computational fluid dynamics[98]).

A3.1.7 UPTUN

Full name: Cost-effective sustainable and innovative upgrading methods for fire safety in existing tunnels
Framework Programme: 5th
Period: 09/2002-08/2006
Total funding: € 11,925,764 (EU funding € 6,200,477)
Coordinator: TNO (the Netherlands)
Number of partners: 35
Countries involved:16 (Austria, Belgium, Czech Republic, Denmark, France, Germany, Greece, Italy, Lithuania, Norway, Poland, Portugal, Slovenia, Spain, the Netherland, United Kingdom)

Description

In the UPTUN[99] project 35 partners from EU member states participated and worked closely together in a joint effort to overcome fire safety issues emerging from the tragic Alpine tunnel accidents in the years 1990-2000.

UPTUN's objectives were:

- Development of innovative methodologies and technologies where appropriate and, where relevant, comparison to and assessment of existing methodologies and technologies for tunnel application. New technologies were developed: water mist, water curtains, smoke compartimentation, CCTV detection techniques, training tools and programs, repair mortars and software assessment tools, including local and regional cost effect models.

[98] This is one of the branches of fluid mechanics that uses numerical methods and algorithms to solve and analyse problems that involve fluid flows. Computers are used to perform calculations required to simulate the interaction of fluids and gases with the complex surfaces used in engineering.

[99] The web address www.uptun.net is no longer active.

- Development, demonstration and promotion of procedures for rational safety level evaluation, including decision support models and knowledge transfer. Safety level assessment criteria were drawn up and integrated in manual and automatic upgrade procedures/models. Knowledge was transferred through dissemination on various levels: papers and presentations, international symposia (Prague and Lausanne), dedicated workshops throughout Europe and beyond (Australia, China and USA) and the establishment of a manual for good practice and an UPTUN summer course.

The desired spin-off was the restoration of faith in tunnels as safe components of the transportation systems, the levelling out of trade barriers imposed by supposedly unsafe tunnels, and an increased awareness of stakeholders of the necessity to develop initiatives to link all relevant research.

Main achievements:

Design fire curves data;
Validation of fire mitigation sets with respect to heat, toxicity and smoke stresses in large fires;
Human behaviour and escape guidance (tunnel users information, rescue teams/tunnel operators selection and training);
Development of innovative methods for tunnel damage detection and repair (assessment of real fire damage in Great Belt and Channel Railway Tunnel, Mont Blanc Road Tunnel);
Test on functional equipment operability (cables, doors and signs) and on structural component (suspended ceiling).

A3.1.8 SafeT

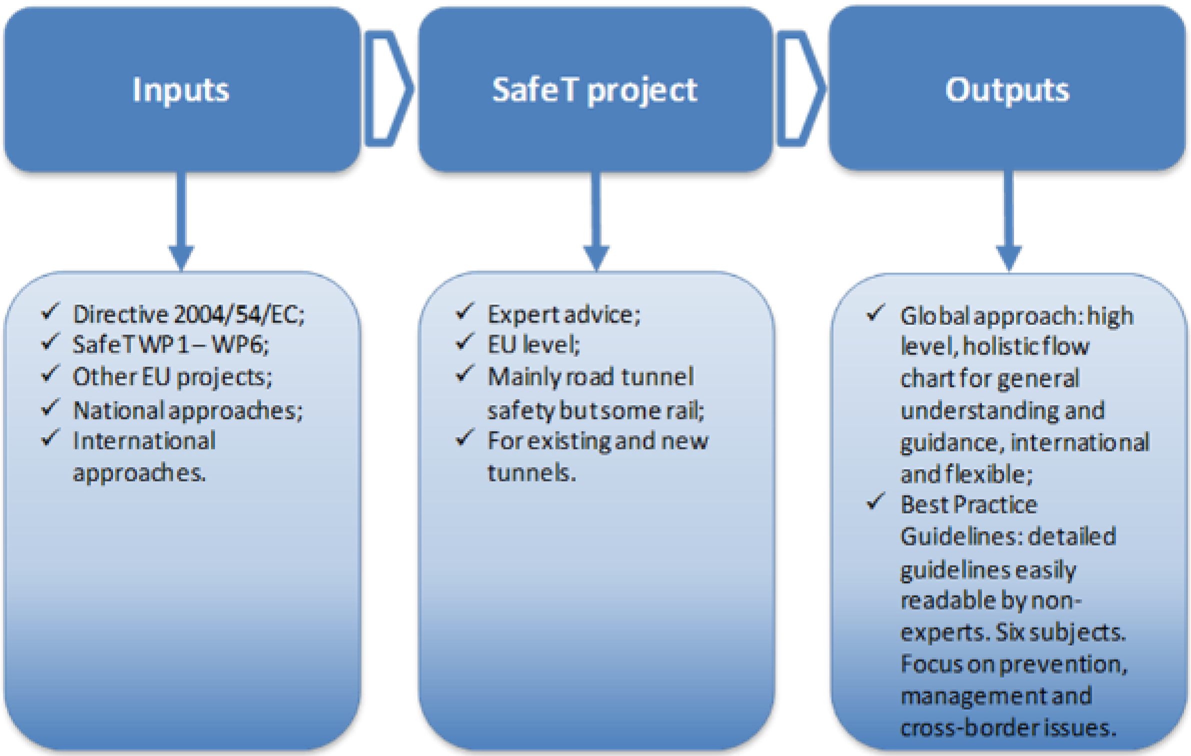
Full name: Safe Tunnels
Framework Programme: 5th
Period: 04/2003-03/2006
Total funding: € 999,450 (EU funding €999,450)
Coordinator: TNO (the Netherlands)
Number of partners: 21
Countries involved: 8 (Austria, Belgium, Germany, Greece, Italy, Norway, Spain, the Netherlands)

Description

SafeT was the culmination of seven projects funded by the European Union to address the problem of tunnel design and safety. It consisted of a “Thematic Network” and as such did not involve research and development, but rather the judicial collection and analysis of data and led to recommendations in order to gather the best practice of European guidelines.

SafeT was developed in view of a global approach to tunnel safety, at encompassing both specific and general approaches from different specific areas of the topic. It was also conceived to identify wider approaches from different countries and organisations. The subjects embodied within the thematic network started with data collection and were followed by their analysis in order to carry out recommendations for the harmonised European guidelines (see Figure A3.6).

Figure A3.6 Outline of the SafeT approach



Source: Elaborations of the authors from WP 7.0 SafeT Project Outline (2006).

Differently from other global approaches, SafeT was focussed on issues regarding preventive measures and cross-border infrastructures. Its main objectives can be summarised as follows:

- Development of a global holistic approach to tunnel safety accommodating both accident prevention and mitigation[100].
- Production of best practice guidelines focussing on specific issues101:
  - Accident/incident detection and traffic management;
  - Evacuation intervention management;
  - Post-accident investigation/evaluation;
  - Harmonised risk assessment;
  - Integrated tunnel safety management system.

The objectives above were set to:

- Help in the deployment of EU Directive, notably for data collection and risk assessment;
- Provide guidance towards any potential future development of the Directive;

[100] Generalised global approach, albeit flexible, developed both from knowledge gained in SafeT project and from tunnel safety approaches worldwide, including the previous 6 projects on tunnel safety and design. The analysis pointed out that there were few "global" approaches in the world and mostly partial and incomplete. The majority of the countries surveyed did not have a global approach to tunnel safety, only detailed manuals (see Report 7.1).

[101] Recommendations were distilled from the first five Work Packages of the project to form the Best Practices European Guidelines to tunnel safety. The EU Directive was assumed as a starting point of the exercise leading to the guidelines. The subject areas of the guidelines can be view as part of the wider picture through the Global approach designed (see Report 7.2).

- Provide guidance to decision makers and operators;
- Provide contact details of tunnel operators who were employing certain risk assessment methods;
- Help in general improvement of tunnel safety.

The target audience included: EU, tunnel mangers, safety officers, consultants, industry, research organisations and local, national and international authorities.

Main achievements:

Guidelines for tunnel safety management system
Tools for probabilistic risk assessment.

A3.1.9 EuroTAP

Full name: European Tunnels Assessment Programme
Framework Programme:-
Period: 01/2005-12/2007[102]
Total funding: € 4,500,000
Coordinator: ADAC - Allgemeiner Deutscher Automobil-Club (Germany)
Number of partners:16
Countries involved: Austria, Belgium, Croatia, Denmark, France, Finland, Italy, Luxembourg, Norway, Portugal, Slovenia, Spain, Switzerland, the Netherlands, United Kingdom

Description

Aside from systematic testing of Europe's most important road tunnels, EuroTAP produced user friendly information and educational campaigns. The aim was to boost awareness of tunnel safety among those in authority, to achieve transparent tunnel standards and to thus improve these standards along with motorists' behaviour in tunnels.

The programme's aims were to:

- Improve European safety standards through systematic benchmarking;
- Track tunnels' safety performance over the years;
- Inform the public about the safety of road tunnels;
- Make tunnel users aware of correct behaviour in road tunnels.

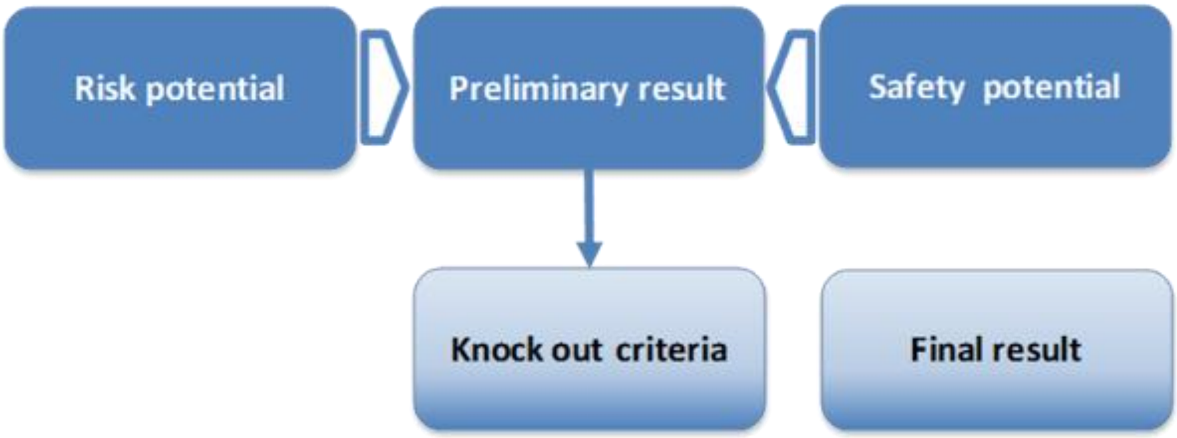
The EuroTAP methodology comprised more than 200 criteria grouped in eight categories[103]. They examined the preventative, mitigating and remedial features of a tunnel as well as its risk and safety potentials. A so-called "knock-out criteria" (see Figure A3.7) led to any tunnel, with a single serious defect, automatically having its score downgraded. The criteria used to test the tunnels were based on:

- Updates of methodology and application since 2006;
- Quantitative elements in a mostly qualitative approach;
- Allowance for the fact that some deficiencies cannot be compensated by safety precautions in other categories;
- Allowance for the interdependencies of different safety precautions in the assessment;
- Presentation of and commenting on these dependencies in the detailed reviews.

[102] Supported by the European Commission from 2005-2007 and by the FIA Foundation in 2008 and 2010.

[103] Four with respect to prevention (traffic control, tunnel system, lighting and energy supply and emergency management) and other four based on incident management (fire protection, escape and rescue routes, communication and ventilation).

Figure A3.7 Tunnel Test Methodology – Assessment System



Source: Elaborations of the authors from EuroTAP, Nordic Tunnel Conference (2010).

Over the period 1999-2010 EuroTAP programme inspected 316 tunnels (in 21 countries) that were characterised by significant European transit traffic, a minimum length of 1,000 metres, high traffic volume and preferably part of the Trans-European Road Network.

The most common deficiencies were identified in:

- Escape and rescue:
  - No additional escape routes in single-tube tunnels;
  - Emergency exits insufficiently marked and too far apart.
- Ventilation:
  - Smoke extraction not controlled by tunnel control centre;
  - Functionality of ventilation system not tested.
- Traffic:
  - No, or insufficient, video surveillance and recording;
  - No barriers, or information, displays in front of portals.
- Fire protection:
  - Fire brigade based too far from tunnel, no “hot” training;
  - Insufficient respiratory protection;
  - No automatic fire detection.
- Tunnel system;
  - One in five tunnels has one tube only;
  - No lay-bys, emergency lanes or emergency walkways.
- Communication:
  - Emergency phones not soundproof;
  - No traffic radio reception, no P/A announcements possible.

According to EuroTAP (2007), the need to refurbish existing tunnels was recognised in the majority of countries, concepts were developed and funds earmarked. The successful implementation of these concepts was confirmed when tunnels were re-tested.

Main achievements:

Implementation of national upgrading programmes;
Renovation of "problem tunnels";
EU monitoring, tracking and sanctioning of delays or non-compliance in Member States;
Promotion of national and European R&D projects;
Use of state-of-the-art safety technologies;
Awareness campaigns and training for safe behaviour in road tunnels.

A3.1.10 L-surF

Full name: Design Study for a Large-Scale Underground Research Facility on Safety and Security
Framework Programme: 6th
Period:03/2005-02/2007
Total funding: € 1,678,040 (EU funding €1,678,040)
Coordinator: Hagerbach Test Gallery Ltd (Switzerland)
Number of partners: 6
Countries involved: France, Germany, Norway, Sweden, Switzerland, the Netherlands

Description

L-surF[104] was an EU funded feasibility study on safety and security of enclosed underground spaces. It was a joint initiative of European leading institutions of safety and security of underground spaces. The consortium gathered more than 40 organisations providing a range of services, including full scale testing, training and education.

The study performed a survey on operating and planned facilities and research projects, and encouraged integration between research centres and organisations involved. This contributed to the objectives of European research by putting resources to better use, avoiding duplication of efforts and using research funding in this area in a more efficient way.

L-SurF identified and prioritised research needs related to safety and security considerations, on the basis of the users and clients of a future research infrastructure. This work led to an evaluation of the technology requirements and construction constraints, which were used to create the required study spaces for specified contours, shapes and sizes of enclosed underground areas. It also evaluated other aspects, such as installations of fire-related measuring and protective equipment – gas and heat flux sensors, infrared cameras, wind velocity readers – and effects on the environment. All equipment and measuring installations were based on the latest technologies available.

An integral part of the study drafted a proposal for the creation of a European entity, with a business plan based on public-private partnership funding and proper evaluation of the legal status. The plan made reference to existing models, like CERN, and identified possible sources of funding for the different stages in the setting up of the facility.

Main achievements:

Large scale tests:

Real tunnel test in situ;

Large and model scale testing;

Fire detection tests;

Fire protection of underground facilities;

Safety and security of underground constructions.

Technical support to authorities and emergency services:

[104]See http://www.l-surf.se.

Protecting environment against noise, vibration and exhaust gases created by road and rail transport;

Environmental Impact Assessment;

Investigation after accidents;

Research activities;

Second opinion and critical review of safety concepts.

Technical support to tunnel operators:

Design of tunnels and underground facilities;

Expertise to design and perform test (including the test required by the Directive 2004/54/EC);
Research work related to safety during the construction and operation of tunnels.

A3.2 Risk analysis

Directive 2004/54/EC acknowledges the need for a harmonised risk analysis method with a view to meeting the requirements of technical progress.

Within the EU legislation in force, Article 13 introduces risk analysis as the methodology to refer to when dealing with specific features of road tunnels[105] and recommends Member States to use a well-defined methodology, in view of proposals of the Commission for the adoption of a harmonised approach.

Generally, risk analysis is an instrument used to trade-off amongst measures. In the context of road tunnels, it should be applied when comparing options to technical solutions that cannot be implemented, or that are feasible only at disproportionate costs (e.g., variation of longitudinal gradient, or the construction of additional emergency exits).

The results of a risk analysis can also be considered as a starting point for additional applications, such as cost-effectiveness analyses. A broader scope of the methodology could better support plans devised for safety purposes to reduce risks and enhance social welfare.

Several methodologies were developed on risk assessment, mainly focusing on: hazard identification, deterministic risk assessment and probabilistic risk assessment. On the basis of the scrutiny of several methods and models, the EU funded SafeT project[106] concluded that none "*gives the perfect solution for every risk assessment problem*". Combining methods can be appropriate, depending on the situation.

Similar conclusions are provided by PIARC (2008). In this occasion, it was argued that each approach to risk assessment has advantages and disadvantages. Again it was demonstrated that combinations were used in practice (e.g. expert judgements, qualitative and quantitative approaches) and depending on the context. The case studies presented provided quantification of the effectiveness of the measures implemented.

The evaluation of the documents developed by Member States supports, with additional details, the conclusions above. The list below summarises the information gathered by country[107].

Austria[108]: the risk analysis is done by comparing different safety measures with the risk model TuRisMo. In that model, the risk of the tunnel being appraised is compared to the risk of a reference

[105] See Annex I of the Directive at points: 1.1.3, 1.2.1, 1.3.2, 2.2.3, 2.2.4, 2.3.5, 2.6.2, 2.9.3, 3.4, 3.7 and 3.8.

[106] See SafeT (2004).

[107] Reports are available for 15 countries, namely: Austria, Bulgaria, Czech Republic, Germany, Denmark, Finland, France, Hungary, Italy, Latvia, Slovakia, Slovenia, Spain, Sweden and the Netherlands.

[108] Slovakia and Slovenia adopted the Austrian model.

tunnel. Within this framework, alternative measures are evaluated and assessed following a cost-effectiveness analysis covering all the fields of application of the Directive. The model was tested to support the decision for the selection of safety measures (for new tunnels), for upgrading measures (for existing tunnels) and in prioritising the implementation of the measures.

The model consists of two main quantitative phases. It is considered to be flexible and applicable to every configuration of tunnel and traffic condition and it allows for a clear comparability of results. However, it cannot investigate events with low probability and high consequences (e.g. accidents involving the transport of dangerous goods).

Czech Republic: a qualitative risk assessment method was introduced (SAFMEA[109]) basically exploiting expert's judgment. The scenario analysis is carried out with a standardised deterministic and quantitative tool (CAPITA). This takes into account a number of equipment and systems and evaluates their impact on safety levels. Practically, it determines weaknesses in the tunnel system design concentrating on events involving fires.

Denmark: the implementation of the risk analysis combines qualitative and quantitative phases. The former one involves the identification of critical incidents and the latter one focuses on injury/loss of human lives, repair costs, accessibility to the tunnel and environment. Acceptance criteria were defined for each critical incident to rank preventive measures, also taking into account the implementation costs. In the few road tunnels in operation, the manager decides with a consultant on the most appropriate method.

Finland: the instructions for conducting a risk analysis are included in the Road Tunnel Design Guidelines[110]. Safety arrangements and the quality and scale of technical systems are specified case by case, on the basis of a functional description.

As there are only few tunnels in operation, the experience in estimating the probability of occurrence of different types of accidents is limited. For this reason, foreign assessment models and experience-based knowledge are used as comparison to estimate risks and occurrence of incidents.

France: a scenario-based analysis method (not a model) is in use for every tunnel longer than 300 metres. The method integrates different tools with quantitative and semi-quantitative approaches and is applied to tunnels for which the safety level after refurbishment needs to be assessed.

The advantage of this methodology is its adaptability to specific situations and the implementation of different level of investigation. It takes into account complex interactions of quantitative elements, like smoke development and user behaviour in a situation of fire.

Germany: the minimum safety requirements and the operation procedures of road tunnels are specified in the "Directives for equipping and operating road tunnels" (RABT, 2006).

In this case, if a tunnel has special characteristics, a risk analysis shall be carried out to identify additional safety measures and/or supplementary equipment to cover deviations occurring. The quantitative methodology developed allows for a standardised comparison of accident scenarios. They are evaluated according to their probability of occurrence and the expected damage.

Italy: the national legislation in force[111] required the adoption of a quantitative method for risk assessment, based on risk acceptability levels. An integrated and quantitative methodology was developed in terms of comparison of design alternatives and to measure the increase of risk due to deviations from the reference standard.

Spain: a risk analysis is carried out when the tunnels have specific characteristics with respect to design, equipment, or operating conditions.

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[109] Statistically Adjusted Failure Mode and Effect Analysis.

[110] Issued by the Finnish Road Administration in 2005.

[111] Legislative Decree 264/06.

Sweden: risk analysis is used to identify and adopt measures to reduce the risk to acceptable levels. The choice of the method depends on the stage of the planning process and is linked to the safety objectives.

The Netherlands: the method is deterministic and used to identify weaknesses regarding infrastructure and organisational measures. The scope of application is limited to the optimisation of procedures before and after the occurrence of an accident[112] and focuses on self-rescue and emergency response. Effectiveness is measured in terms of control of the development of events and the consequence analysis is carried out qualitatively. Cost-effectiveness measure is not possible as the frequency of the events is not determined.

In summary, all countries with large numbers of tunnels (Italy, Spain, France, Austria, Germany) in operations developed their own methodologies. Countries with few tunnels under the scope of the Directive adopted methodologies already in use in other Member States.

Importantly, the review suggests little scope for harmonisation of the methodology across Member States. The problems to be investigated, national characteristics, regulations and laws are different and do not allow for the introduction of one method to cover all the existing issues. Standardisation seems achievable only for some specific elements of risk analysis. Another problem influencing the reliability of the risk assessment is the relatively small numbers of incidents in road tunnels. Statistics published on a regular basis (e.g., yearly) are available only for a few countries and the information on fires is scarce.

Therefore, the demonstration of the effectiveness of the measures implemented on minimum safety requirements could be based on a catalogue of best practices in risk analysis, as the adoption of a common harmonised methodology seems unrealistic. With respect to the transport of dangerous goods, the methods and modes mentioned above cannot be applied. For this matter the use of the OECD/PIARC Quantitative Risk assessment (QRA) has become a common practice across Member States. It involves comparison of the risk level of transport of dangerous goods inside a tunnel with the same risk occurring on alternative external routes. The results obtained determine the decision on allowing, or forbidding (even partially), their transit in the tunnel analysed.

A3.3 Additional literature sources

A3.3.1 Case studies

The literature review conducted on the measures introduced to improve the safety levels of road tunnels identified a number of best practices deployed since the introduction of the Directive. In particular, many case studies were presented at the conference organised by ASECAP in 2010[113] focussed on the theme of road safety. Four of these case studies, covering Austria, Croatia, France and Italy, are worthy of mention.

In Austria, the motorway concessionaire ASFINAG developed a database in 2006 to record accidents, fires and material damages inside tunnels.

The Croatian concessionaire ARZ[114] introduced the safety requirements of the Directive before the accession of Croatia[115] to the EU. In 2010, 18 tunnels were operating on the Croatian motorway network, with a total length of 13 km. As the structures were opened in recent years, the requirements were designed and constructed according to advanced qualitative standards. Consequently, AZR reached almost all the safety requirements according to the article 3 of the Directive.

The French concessionaire ESCOTA was a forerunner in the introduction and application of good practices in the field of road tunnel safety. Further to the introduction of the Directive and according to the French Regulation 63 issued in 2000, ESCOTA planned the improvement of the ventilation system

112 Breakdowns, collisions, fire, explosions, spill of dangerous goods.

113 See Arditi (2010).

114 Autocesta Rijeka – Zagreb (Zagreb-Rijeka motorway).

115 Croatia became the 28th member of the EU on 1 July 2013.

and smokes removal of the tunnel in Monaco (motorway A500). At the time when the upgrade was carried out, pressurised shelters were constructed[116].

And finally, four Italian best practices:

- The Gran San Bernardo tunnel is a cross-border structure joining Italy and Switzerland. The refurbishment of the ventilation system was carried out following new procedures for the activation of this safety measure, and with appropriate smokes extraction. Moreover, in 2010 the design procedures were followed for a safety tunnel provided with 23 lay-bys (every 240 metres) and including an intermediate safety compartment.
- The Fréjus tunnel concessionaires SITAF and SFTRF developed and introduced a simulator to create different fire scenarios. The innovative system, covering an area of more than 600 square metres, is used to test safety equipment and for staff training.
- The Sorreley-Meysattaz tunnel is managed by the concessionaire SAV, which introduced a permanent structure for joint exercises in managing emergencies, equipment and materials.
- Further to the introduction of the Directive, the motorway concessionaires of the group ASTM-SIAS[117] implemented a training programme for the staff and promoted periodic joint exercises to manage emergency situations.

A3.3.2 Other references

This section includes other documents considered useful for the evaluation of the Directive.

Leitner (2001) emphasises the additional safety equipment introduced after the fire occurred in the Tauern tunnel. The paper explains how Austria revised the national guidelines to improve safety levels, three years before the entry into force of the Directive.

Secondly, the case of Norway (OECD, 2006) can be taken as an example for activity outside the EU. To some extent the conclusions presented could anticipate the results of the evaluation of the Directive. A cost-benefit analysis on social cost of accidents in road tunnels is mentioned as methodological example.

In Austria, the fire in the Tauern tunnel highlighted the importance of additional safety equipment in the tunnel. Leitner analysed the experience drawing conclusions for the Austrian guidelines.

Further to the course of the events, additional safety measures were identified as necessary and installed in the Tauern tunnel:

- 136 exhaust air blinds to bring full ventilation power in the area of fire;
- A compressed air system to keep the emergency niches smoke-free in case of fire.

Other works were necessary and consisted of a renewing of 600 metres of the drainage system located in the middle of the road. All remedial works were completed in 3 months, requiring financial resources for 6.5 million USD[118].

After intensive discussion, the Austrian guidelines for tunnel design were revised. The main improvements are listed in the Table A3.2 and compared with the previous situation.

[116] Three shelters of 50 square metres each, with space to safely host 100 persons. The shelters were provided with fire extinguishers, a closet equipped with safety tools (water, blankets and first aid kit), a phone line in direct communication with the control centre and an internal video surveillance system. Structurally, the service tunnels were terminally protected. Additionally, the tube designed for supplying fresh air was modified into an escape route.

[117] Grouping the concessionaires: AutocamionaledellaCisa, SALT, SAV and ATIVA.

[118] Lost toll fees were estimated at $19.5m.

Table A3.2 Improvements in the Austrian guidelines for tunnel design

Requirement	Previous situation	New situation
Clearance for pedestrian cross-passage and escape tunnels	W/H 2.0m/2.5m	W/H 3.6m/3.5m accessible for fire engines
Pavement	Asphalt or concrete	> 1,000 m, only concrete
Caps for cable conduct	No requirement	Max length 1 m
Support for ceiling	Console	Reinforced console
Vehicle cross passages	Every 2nd lay-by niche	Every lay-by niche
Water supply	In single-tube tunnels, operation from one portal possible. In twin-tube tunnels, ring required.	In single-tube tunnels, operation from both portals. In twin-tube tunnels, ring required.
Distance of first emergency niche from portal	Max 500 m	Max 250 m
Signalisation and escape direction	At cross passages	Every 150 m with lighting at 1 m height

Source: Leitner (2001).

Though it is not a Member State Norway is a country of particular interest for the purposes of this study[119] because of the number of tunnels and the legislation aligned with the EC Directive. The OECD (2006) report on tunnel safety analysed the evolution in its safety management doctrine, arguing that Norwegian transport and tunnel safety policy have been influenced by large-scale national initiatives in traffic safety, preparedness and fire safety.

The importance of risk management and preparedness was recognised at the government level in the second half of the nineties with a White Paper issued in 1998[120]. A second document was the investigation report ordered by the Ministry of Justice and the Police, which undertook the first large-scale vulnerability analysis of critical infrastructures at the national level. The report identified tunnels and the transport of dangerous goods as areas with considerable accident potential and called for better preparedness levels.

Another important development in relation to transport safety was the introduction of the “Vision Zero” for all transport modes. This programme for road safety was launched in 2001 and based on the principles of integrating the fallibility of the road user into the traffic system and of spreading accident responsibility among several actors. “Vision Zero” acknowledged that tunnel structures are safer (in terms of road accident fatalities) than most open roads and therefore tunnel safety was not assumed as a first priority area within the programme[121].

In the Norwegian case, measures of particular relevance for tunnel fire safety include those directed towards heavy goods transport (increased frequency of police control of competence certificates for drivers of dangerous goods, increased frequency of controls of heavy goods vehicles (brakes, driving and resting regulations). Furthermore, the tunnel handbook which is the main reference for all road tunnel construction in Norway, was changed in 2002, involving a reinforcement of requirements to safety equipment and introducing the requirement to use twin-bored tunnels at a lower level of traffic

[119] Norwegian tubes belonging to the trans European road network measure 257 km in total, namely the second highest length in the ranking including all EU Member States, Switzerland and Norway.

[120] No. 25. Main guidelines for the activities and development of civil preparedness for the time period 1999-2002 (St.meld. 25 (1997-1998)).

[121] Nevertheless, the Ministry of Transport and Communication in the transport plan for 2006-2015 (Stortingsmelding nr. 24 (2003-2004): Nasjonaltransportplan 2006-2015) underlined the importance of improving tunnel safety because of the consequences of a potential accident.

concentration than before. Advances in digital technology will also enable the increased use of automatic traffic control (video surveillance) in tunnels.

Finally, a remark about the efficiency of the implementation of the safety requirements, according to the Norwegian assessment. Quoting from the OECD (2006) report: "*The question of tunnel safety in Norway reflects this problem. Many tunnels were not constructed with the current transport situation in mind, and supplementary safety measures come at a very high price, if they are at all possible. At the same time, accident rates are low in tunnels, and it is difficult to justify the extra costs with traditional cost-benefit analysis methods. Transport authorities are making sincere efforts to improve risk management policies, both through new safety and risk routines and institutional reorganisation, but it may be questioned whether the efforts are counterproductive or give a false sense of safety.*

As regards the quantification of the effects determined by the provisions of the Directive, Caliendo and De Guglielmo (2012) have estimated for the case of Italy (on Italian motorways tunnels), through an exemplified cost-benefit analysis, the reduction of social costs associated to a potential 50% reduction in deaths and injuries estimated at 2020, compared to 2010, without indicating whether analyses were targeting refurbished or not yet refurbished tunnels.

The case analysed considered on the benefit side a reduction to 50% in deaths and injuries by 2020, when compared to that of 2010. The benefit over cost ratio (B/C) was found to be within the large range 7.75-0.0035, with a mean value of 0.61. The paper concludes that only in the 18% of cases the B/C ratio is higher than 1. However the methodology proposed might represent a tentative point in prioritising the assignment of funds in order to improve tunnel safety in compliance with the Directive.