European Approach to Road Tunnel Safety and Risk Assessment

Didier Lacroix, Research Manager
Centre d’Etudes des Tunnels, France
European approach to road tunnel safety and risk assessment

1. Short history of European and international efforts
2. Road tunnel directive 2004/54/EC of 29 April 2004
3. Risk analysis
4. Experience gained in France
5. Conclusion
Road tunnel safety used to be mainly a matter of infrastructure. Regulations (if any) mainly dealt with:
- the infrastructure
- of new tunnels
In 1999

2 catastrophic road tunnel fires occurred:

- Mont Blanc (France - Italie) : 39 fatalities
In 1999

2 catastrophic road tunnel fires occurred:
- Mont Blanc (France - Italie) : 39 fatalities
- Tauern (Austria) : 12 fatalities

These fires dramatically showed that:
- other important safety factors are:
  - operation, intervention, users’ behaviour, etc.
- old tunnels are of concern
Safety Approach, Procedures, Actors

1. Short history of European and international efforts
2. Road tunnel directive 2004/54/EC of 29 April 2004
3. Experience gained in France
4. Conclusion
In / just after 1999

France / Italy
→ joint investigation into Mt Blanc fire

France
→ check of all tunnels > 1000 m
→ new regulation (August 2000)
→ new law (January 2002)

Switzerland
→ Tunnel Task Force

Austria, Norway, etc.
→ Need for consistency!
Safety Approach, Procedures, Actors

1. Short history of European and international efforts
2. Road tunnel directive 2004/54/EC of 29 April 2004
3. Experience gained in France
4. Conclusion
United Nations
Economic Commission for Europe
(located in Geneva; in charge of road traffic and road safety for 55 countries)

Ad hoc multidisciplinary group of experts

- Report on road tunnel safety (Dec. 2001)
- Amendments to European agreements (road traffic, road signing, dangerous goods, E-roads, vehicles, etc.)
SAFETY

Users

Operation

Vehicles

Infrastructure

SAFETY
European Union

Not competent (subsidiarity) but requested by the Heads of States

✓ Calls for research projects / networks
European research projects / networks
5th Framework Programme
European research projects / networks
6th Framework Programme

Large Scale Underground Research Facility
on Safety and Security

Structuring the European Research Area Specific Programme
European Union

Not competent (subsidiarity) but requested by the Heads of States

- Calls for research projects / networks
- Preparation of a policy on tunnel safety not an urgency...
In 2001

Another catastrophic fire:
- Gotthard tunnel (Switzerland): 11 fatalities

→ Reinforced the awareness

To prepare a directive became a priority
1. Short history of European and international efforts

2. Road tunnel directive 2004/54/EC of 29 April 2004

3. Experience gained in France

4. Conclusion
At the international level

PIARC: World Road Association

113 member governments
> 2000 members in 130 countries

PIARC Technical Committee on Road Tunnel Operation (since 1957)

30 countries
5 working groups
130 experts
Working Groups of the PIARC Committee on Road Tunnel Operation

WG 1 : Operation
WG 2 : Safety management
WG 3 : Human factors of tunnel safety
WG 4 : Ventilation and fire
WG 5 : Knowledge management

25 reports published in 15 years
freely available on www.piarc.org
PIARC Technical Committee on Road Tunnel Operation
Operation, Safety, Geometry Environment, Equipment

complementary activities / cooperation:

ITA (International Tunnelling and Underground Space Association)
Geotechnics, Construction, Materials, including non-road tunnels
ITA Committee on Operational Safety in Underground Facilities (COSUF)

✓ Proposed by European projects/networks to:
  - continue / deepen their activities
  - widen to international level

✓ Launched by ITA
  in cooperation with PIARC

✓ Deals with all kinds of underground facilities

✓ Main objectives:
  - create a worldwide network
  - develop research activities
  - promote safety underground
European approach to road tunnel safety and risk assessment

1. Short history of European and international efforts

2. Road tunnel directive 2004/54/EC of 29 April 2004

3. Risk analysis

4. Experience gained in France

5. Conclusion
Directive 2004/54/EC of 29 April 2004 on minimum safety requirements for tunnels in the trans-European road network

20 articles

Annex I: safety measures

Annex II: approval of the design, safety documentation, commissioning, modifications, periodic exercises

Annex III: signing

General points

Responsibilities

Procedures

Safety measures
European approach to road tunnel safety and risk assessment

1. Short history of European and international efforts

2. Road tunnel directive
   2004/54/EC of 29 April 2004

   ←→ General points

   ←→ Responsibilities

   ←→ Procedures

   ←→ Safety measures

- Applies to tunnels:
  - on the Trans-European Road Network
  - > 500 m

- Existing tunnels shall comply within 10/15 years
  - 400 existing tunnels

- New tunnels shall comply from preliminary design
  - 100 new tunnels by 2010

- Applicable only once transposed into national legislation / regulations
- All EU members States (+ Norway & Switzerland) have transposed (or are finalising transposition)
- Most States made provisions also applicable to:
  - tunnels > 500 m not on the TERN
  - and/or shorter tunnels
European approach to road tunnel safety and risk assessment

1. Short history of European and international efforts

2. Road tunnel directive
   2004/54/EC of 29 April 2004

   - General points
   - Responsibilities
   - Procedures
   - Safety measures
A single Administrative Authority for each tunnel (possibility of 2 for binational tunnels)

At national, regional or local level

Responsible for ensuring that all safety aspects are assured

Has power to suspend or restrict tunnel operation

Ensures that all necessary tasks are performed (inspections, schemes and plans, risk-reduction measures, etc.)
Tunnel Manager

✓ A single Tunnel Manager for each tunnel at each stage (design, construction, operation)

✓ Recognized by Administrative Authority (may be the AA itself)

✓ Not said as such in directive, but essential: the Tunnel Manager is responsible for the day-to-day operation and safety
Emergency Services

- Are imposed few requirements
- But mentioned 29 times in the directive! → very important role
- Provisions relate to their:
  - information
  - training
  - possibilities of action
  - coordination with Tunnel Manager
Safety Officer (SO)

✓ Nominated by Tunnel Manager and approved by Administrative Authority
✓ Independent
✓ Coordinates all preventive & safeguards measures
✓ Performs a number of tasks related to:
  1. General functions (coordination, advice)
  2. Official procedures to check safety (opinion on files submitted to AA, modifications...)
  3. Specific tasks: checks (training, maintenance) participation in exercises, analysis of incidents...
Technical expertise

✓ Inspection entities:
   → perform inspections, evaluations and tests

✓ Experts:
   → give opinion on safety
European approach to road tunnel safety and risk assessment

1. Short history of European and international efforts

2. Road tunnel directive 2004/54/EC of 29 April 2004
   - General points
   - Responsibilities
   - Procedures
   - Safety measures
A very important tool: the Safety Documentation

- To be compiled by Tunnel Manager
- Describes all preventive and safeguard measures
- Contents are adapted to each stage (design, commissioning, operation)
- Includes all information important for safety
  - Communication tool between all players
  - Basis of all safety procedures
SAFETY DOCUMENTATION

Tunnel description

Operational means / measures
- Operational safety measures
  - Emergency response plan *
  - System of permanent feedback *
  - Report/analyses on incidents **
  - List/analysis of exercises **

Demonstration of safety level
- Traffic forecast
- Dangerous goods risk analysis
- Specific hazard investigation
- Any other risk analysis
- Opinion of external expert

Operational safety measures
- * From commissioning stage
- ** Once tunnel in operation
1. Procedures for new construction and modifications

✔ Before construction starts:
  Safety documentation submitted to AA
  Then design approved by competent authority

✔ Before tunnel is opened to traffic:
  Authorisation of AA

✔ Substantial modifications of the tunnel:
  Authorisation by AA before reopening to traffic

✔ Other modifications of the tunnel:
  Opinion of Safety Officer
2. Procedures once tunnel in operation

- Safety documentation to be kept permanently up to date by Tunnel Manager

- Significant accidents and incidents to be reported within 1 month to AA and emergency services

- Exercises jointly organised by TM and emergency services with Safety Officer
  - full scale at least every 4 years
  - partial or simulation every year
  Joint evaluation by Safety Officer and Emergency Services

- Periodic inspections at least every 6 years → measures must be taken if not satisfactory
European approach to road tunnel safety and risk assessment

1. Short history of European and international efforts
2. Road tunnel directive 2004/54/EC of 29 April 2004
   - General points
   - Responsibilities
   - Procedures
   - Safety measures
Holistic approach:
Systematic consideration of all aspects of the system composed of

- Users
- Operation
- Vehicles
- Infrastructure
Basis for deciding on safety measures

✓ Holistic approach:
  Systematic consideration of all aspects of the system

✓ Minimum requirements
  with some derogation possibilities for:
  - structural measures (only for tunnels in operation or in construction)
  - limited differences with minimum requirements

✓ Risk analysis
Minimum requirements

Minimum safety measures are required for:

- **Infrastructure**
  - including signing (annex III)
  - requirements for existing tunnels \( \leq \) new tunnels

- **Operation**
  - requirements for existing tunnels \( \equiv \) new tunnels

- **Information campaigns**

Additional measures should be included in other directives (vehicles, driving education, etc.)
European approach to road tunnel safety and risk assessment

1. Short history of European and international efforts

2. Road tunnel directive 2004/54/EC of 29 April 2004

3. Risk analysis

4. Experience gained in France

5. Conclusion
A partial move from prescriptive to risk-based approaches

Traditionally: prescriptive standards

« A tunnel is safe if it is designed in line with valid regulations »

Advantages:

- Easy to use / to check
- Uniformity in tunnels

Drawbacks:

- Choices are not optimal
- May be difficult to apply in existing tunnels
- Owners/designers/operators may forget to think about safety
A partial move from prescriptive to risk-based approaches

Definition of a risk-based approach:

« A tunnel is safe if it meets predefined risk criteria »

Why no purely risk-based standard today?

✓ Quantitative objectives
  - are difficult to establish
  - raise objections

✓ QRA tools are not reliable

✓ Authorities do not trust QRA

✓ It may lead to very different facilities according to cases and experts...
A partial move from prescriptive to risk-based approaches

Several current standards (incl. EU directive):
Risk analysis is a complement to prescriptive provisions

- To choose between alternatives
- To check general consistency
- To demonstrate safety in case of deviations from prescriptions or cases not dealt with by prescriptions
Risk analysis is requested:
✓ To justify alternative measures (derogations)
✓ When a tunnel has special characteristics
✓ To substantiate some measures
✓ Before regulations on DGs are set / modified

Additionnally, for all tunnels,
the safety documentation must include:
✓ Specific Hazard Investigation
  - describing possible accidents & consequences
  - substantiating risk reducing measures
  ➔ a risk analysis in itself
Methodology to be defined at national level

By 30 April 2009,
the European Commission:
- shall publish a report on national practices
- where necessary, shall make proposals for a common harmonised methodology

Commission is assisted by a Committee, which examined previous work by PIARC

Work by EC will take place in 2009, on the basis of the methodologies reported by Member States
**New PIARC report on Risk Analysis for Road Tunnels (2008)**

Based on:

- Experience from PIARC members countries
- Results of major European research activities, mainly Safe-T

Freely available at: [www.piarc.org](http://www.piarc.org)
What is risk analysis?

✓ A big family of
  - different approaches, methods, models
  - combining various components
  - for specific tasks

✓ A systematic analysis of sequences & interactions in potential accidents

✓ Thereby identifying weak points and recognising possible improvements

✓ Risk analysis can attempt to quantify the risk
What is the purpose of risk analysis?

✓ To check general consistency of safety planning
✓ To choose between alternatives
✓ To demonstrate safety in case of deviations from prescriptions
✓ To optimise safety planning in terms of cost-effectiveness
✓ To assess safety in the framework of a performance-based approach
Two types of risk-based approaches

1. Scenario-based approach

- Select relevant scenarios
- Analyse development of scenarios
- Investigate consequences of scenarios

- scenario 1
- scenario 2
- scenario 3
- ...

eg. evacuation
Types of risk-based approaches

1. Scenario-based approach
   ✓ Optimisation of design
   ✓ Detailed investigation of specific problems
   ✓ Planning of emergency response measures
Types of risk-based approaches

1. Scenario-based approach
2. System-based approach

Input: Influencing factors
Tunnel length  Traffic volume  Portion of heavy vehicles

Modelling of Consequences

Results
Expected risk value (fatalities/year)

Risk distribution (F-N-Curve)
Types of risk-based approaches

1. Scenario-based approach

2. System-based approach
   - Risk indicators for an overall system:
     - Evaluation of different safety measures
     - Comparison with other cases (or acceptance criteria)
Methodological components used at each step

Qualitative

Intuitive approach
- Expert judgment
- Brainstorming
- What-if-method
- Delphi-method
- etc.

Standardised approach
- Checklist
- Preliminary hazard analysis (PHA)
- Hazard and operability study (HAZOP)
- Management Oversight and Risk Tree (MORT)
- Safety Review Audit

Statistical approach
- Data appraisal
- Data analysis

Factor analysis
- $F, N$

Analytical approach
- Logical trees

Spread and effect models
- $N$

Simulations
- $F$

Quantitative

Risk analysis

Risk evaluation

Risk reduction

General approach

Intuitive approach
- Expert judgment

General principles
- Best practice, Standards
- Guidelines, Recommendations

Scenario-based approach

Frequency (Comparison, limits)
- $F_{max} \leq F_{ref}$

Consequence (Comparison, limits)
- $N_{max} \leq N_{ref}$

FN matrix
- with acceptability line
- With acceptability areas (cost-effectiveness-ratio)

Risk value (Comparison, limits)
- $R_{max} \leq R_{ref}$
- Individual risk
- $f_{max} \leq f_{ref}$
- Perceived risk
- $R_{pmax} \leq R_{p ref}$

FN curve
- with acceptability line
- With acceptability areas (cost-effectiveness-ratio)

Cost-effectiveness
- Marginal cost
- Risk-cost-diagram

Cost-effectiveness-analysis
- $R_0$
- $R_p$
- $\Delta Cost$
- $\Delta Risk$

F: Frequency
N: Consequence
Investigation of example methods

✓ State-of-the-art in selected PIARC countries
   (15 countries – of which 12 in Europe)

✓ Description of 6 methods
   - Austrian model TuRisMo
   - Dutch scenario analysis
   - Dutch TUNPRIM model
   - French specific hazard investigation
   - Italian risk analysis for road tunnels
   - OECD/PIARC DG-QRA model

✓ Case studies
Lessons drawn on risk analysis

1. As they provide a structured & transparent assessment of risks, **Risk-based approaches are a valuable complement to prescriptive requirements**

2. No method is today the most suitable in all cases: **Possibilities for harmonisation are limited**

3. **General guidelines could be developed** to ensure appropriate use of risk analysis
4. Uncertainties are high due to the limited data and modelling techniques
   - results of quantitative risk analysis must be interpreted as orders of magnitude
   - risk evaluation by relative comparison may improve robustness of conclusions

5. To go further, strategies for risk evaluation should be investigated deeper
European approach to road tunnel safety and risk assessment

1. Short history of European and international efforts
2. Road tunnel directive 2004/54/EC of 29 April 2004
3. Risk analysis
4. Experience gained in France
5. Conclusion
Transposition of the Directive in France

- Directive 2004/54/ EC was strongly inspired from the French regulations (the only pre-existing modern regulations)

  \( \Rightarrow \) Not so many changes for France!

- The French regulations apply to all tunnels > 300 m (\( \approx \) 200 existing tunnels)
200 French road tunnels > 300 m
Transposition of the Directive in France

✓ Directive 2004/54/EC was strongly inspired from the French regulations (the only pre-existing modern regulations)

→ Not so many changes for France!

✓ The French regulations applied to all tunnels > 300 m (≈ 200 existing tunnels)

✓ The Directive applies to tunnels > 500 m on TERN (≈ 30 existing tunnels)

→ What had to be done for the 170 other ones?
Transposition of the Directive in France

Principle:

- **Same safety level for all tunnels**
- **Same procedures** as far as possible  
  (main exception: reports to Brussels)
- **Possibly a few different safety measures**

An exception: tunnels shared with Italy or Spain  
→ specific approaches
Actors of the Directive in France

Administrative Authority: Prefect
(local representative of the Government in each of the 100 « départements »)

assisted by 2 commissions:
- national commission (CNESOR)
- local commission (CCDSA)

Tunnel Manager: Tunnel Owner
(Governmental or local authority, concessionnaire)

Inspection entity: Approved expert
(Ministerial list of approved experts/bodies)
Risk analysis in France

1 - To decide on autorisation/banning of dangerous goods (DG)

Methodology based on the OECD/PIARC model:

Step 1: "Intrinsic risk" (IR: indicator of absolute value of risk if all DG allowed in the tunnel)
- IR < 10^{-3}: risk low in tunnel, not a problem
- IR \geq 10^{-3}: perform step 2

Step 2: Comparison with alternative routes
- If significant differences: route with lowest risk
- If not: use other criteria
Risk analysis in France

1 - To decide on autorisation/banning of dangerous goods (DG)

2 - Other cases

Specific Risk Investigation:
1. Overview of tunnel and environment
2. Functional description
3. Identification of hazards; choice of scenarios
4. Examination of the scenarios
5. Summary
Guide to road tunnel safety documentation

Objectives

1. Practical method of compiling
2. In-service tunnels: from existing to reference condition
3. Risk analyses related to dangerous goods transport
4. Specific hazard investigation
5. Emergency response plans

Results of 7 years’ application

✓ 140 tunnels assessed since 2000
Results of 7 years’ application

✓ 140 tunnels assessed since 2000

✓ A very important programme of works
  - 2 000 millions euros from 2001 to 2014

✓ Other very important safety improvements:
  - better organisation of operation
  - training of operators and rescuers
  - exercises
  - actions towards tunnel users
Results of 7 years’ application: Feedback from incidents and accidents

✓ Principle:
  - incident report within 1 month
  - sent to Administrative Authority, emergency services and CETU (internet)
RÉFÉRENCES DE LA FICHE : Numéro 4845, année 2004
TUNNEL : BLANC  SOUMIS À LA CIRCULAIRE 2000-63 : Oui

Type d'incident
- Type d'incident : Accident corporel (suivi d'un incendie)
- Suivi d'un incendie : Oui
- Incident enregistré en vidéo : 

Localisation
- Date : 25/02/2004 (format : 25/06/2000)
- Heure : 15:00 (format : 24:00)
- PR + abs : 

Circulation pendant l'incident
- Type de circulation habituelle : Bidirectionnelle
- Circulation pendant l'incident : fermeture totale d'un sens
Dans le cas de restriction de circulation, indiquer le temps :

Entre la 1ère alarme et la mise en œuvre de la 1ère mesure d'exploitation du trafic:

La durée totale jusqu'à rétablissement du trafic:

Nombre de véhicules immobilisés en tunnel:

**Désenfumage**

Déclenchement du désenfumage:

Délai:

**Si incendie...**

Maîtrise de l'incendie:

Durée du feu:

Équipements utilisés:

Utilisation

Extinguishers tunnel

Réservoir incendie tunnel

Enregistrer la fiche
Results of 7 years’ application: Feedback from incidents and accidents

✓ 95 tunnels concerned since 2001

✓ Every year: 150 to 300 incidents
  - 20 to 70 accidents (0-5 fatalities, 20-80 injured)
  - 10 to 25 fires (nearly all of them minor)

✓ Report and summary published every year
  (www.cetu.developpement-durable.gouv.fr)
Fires in the 95 tunnels covered since 2001

- Number of fires per year
- Self-ignition
- After accident
European approach to road tunnel safety and risk assessment

1. Short history of European and international efforts
2. Road tunnel directive 2004/54/EC of 29 April 2004
3. Risk analysis
4. Experience gained in France
5. Conclusion
EU directive provides all elements for a true risk/safety management system

- **Safety objectives:**
  1. Prevention
  2. Reduction of consequences

- **Holistic approach:**
  users, operation, infrastructure, vehicles

- **Risk analysis**
  to complement prescriptive provisions
  to check global consistency

- **Feedback from experience**
  to improve safety
6-YEAR VIRTUOUS CIRCLE

- Technical reference system
- Risk analysis
- Safety measures
- Safety documentation
- Analysis of incidents
- Feedback from operation
- Exercise every year
- Inspection and external point of view every 6 years

EVERYDAY VIRTUOUS CIRCLE
Thank you for your attention!

Didier Lacroix, Research Manager
Centre d’Etudes des Tunnels, France