Workshop organised by the Greek Tunnelling Society
Athens, 4 December 2008

European Approach to Road Tunnel Safety and Risk Assessment

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

Liberté • Égalité • Fraternité
RÉPUBLIQUE FRANÇAISE

CETU

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

Until 1999

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 M^{t}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

National

European

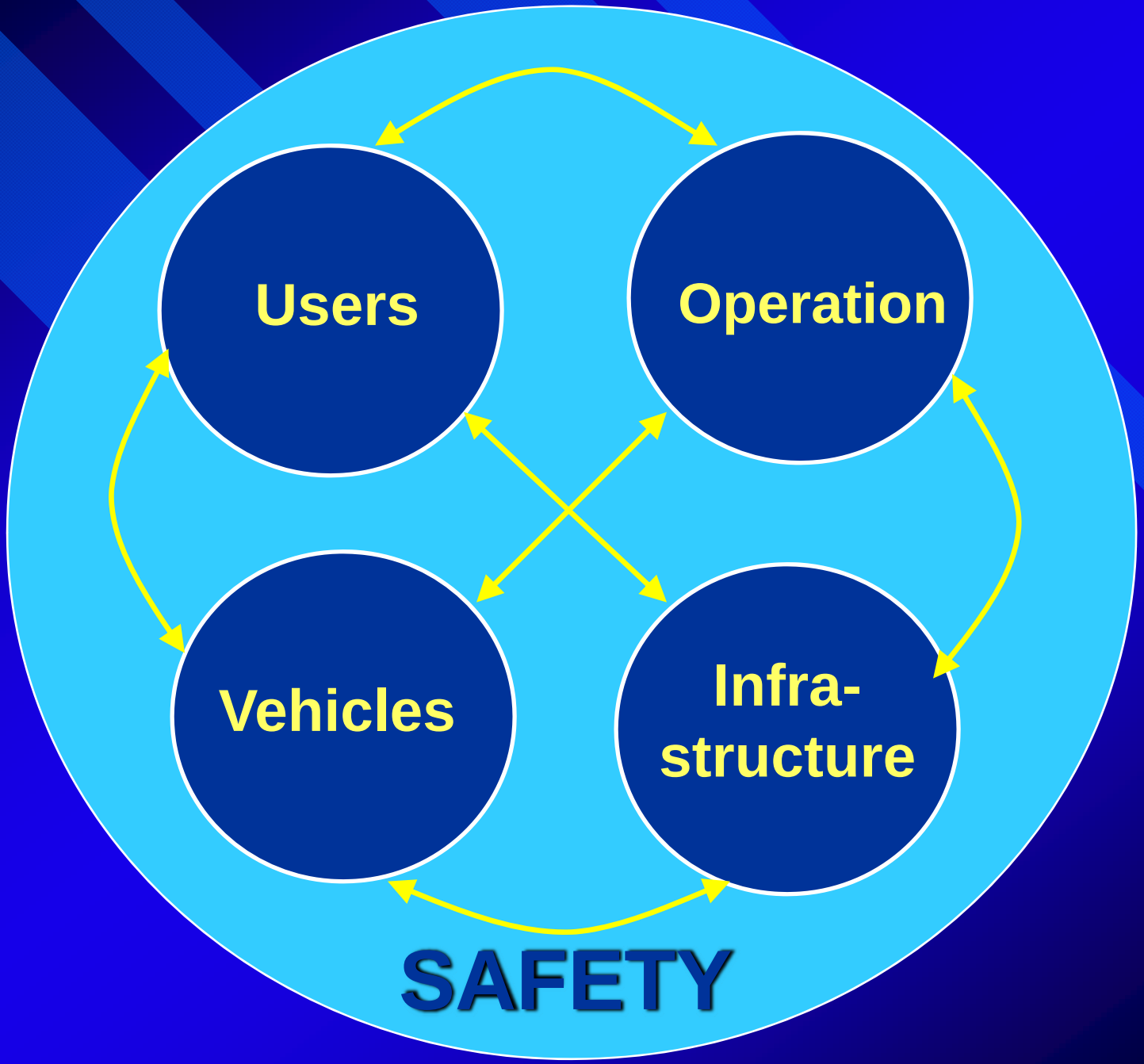
International

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.)


Users
Operation
Vehicles
Infra-
structure
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

D•A•R•T•S

UPTUN

SAFE TUNNEL

European Thematic Network Fire in Tunnels

SafeT

VIRTUAL FIRES

Sirtaki

European research projects / networks

6th Framework Programme

L-surF

Large Scale Underground Research Facility on Safety and Security

Sixth Framework Programme

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

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

At the international level

PIARC: World Road Association

113 member gouvernments

> 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 / deapen 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

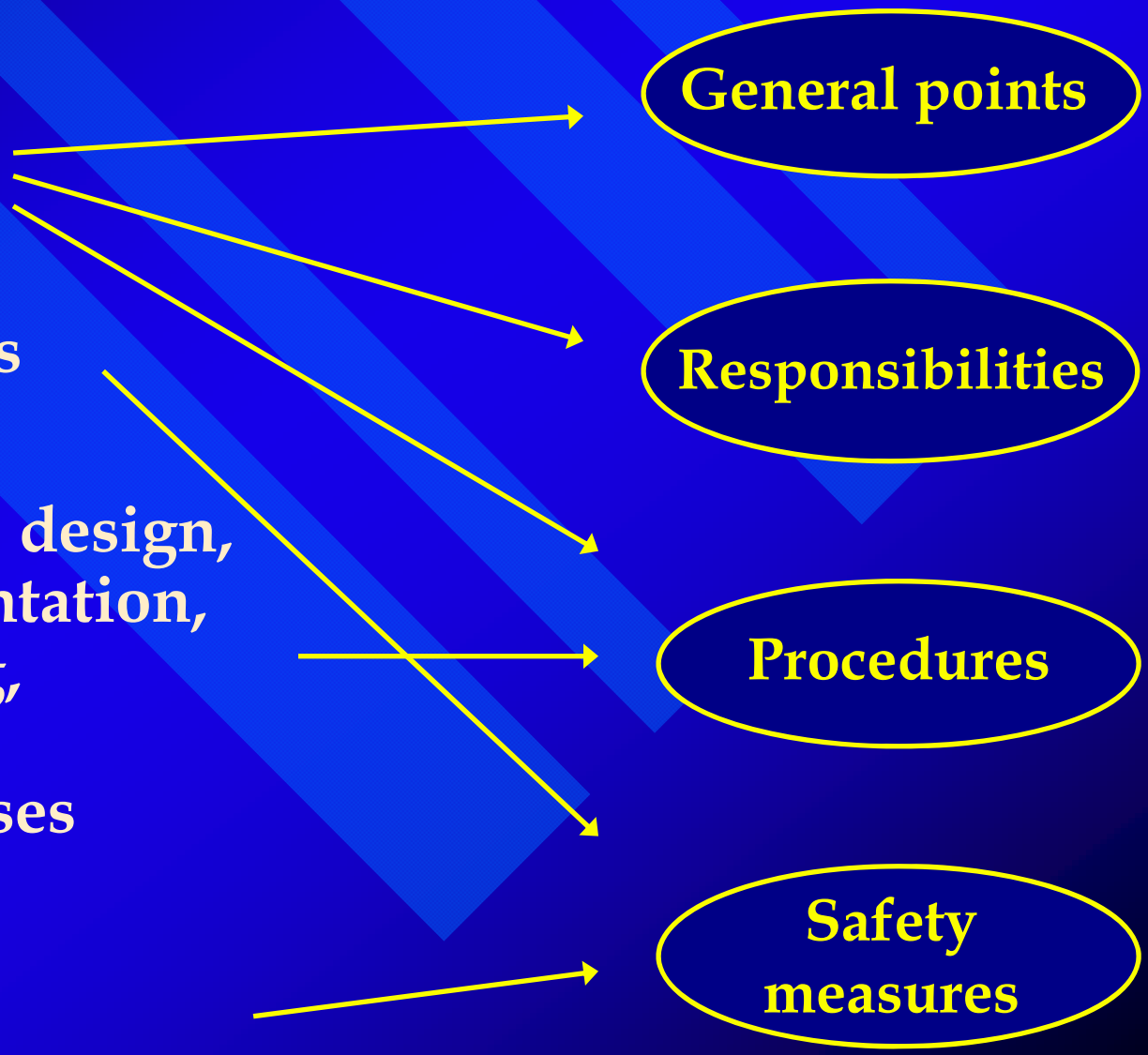
Directive 2004 / 54 / EC of 29 April 2004 on minimum safety requirements for tunnels in the trans-European road network

20 articles

Annex I:
safety measures

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

Annex III:
signing



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

Directive 2004/54/EC of 29/4/2004 on minimum safety requirements for tunnels in the trans-European road network

- ✓ 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*

Directive 2004/54/EC of 29/4/2004 on minimum safety requirements for tunnels in the trans-European road network

- ✓ 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

Administrative Authority (AA)

- ✓ 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

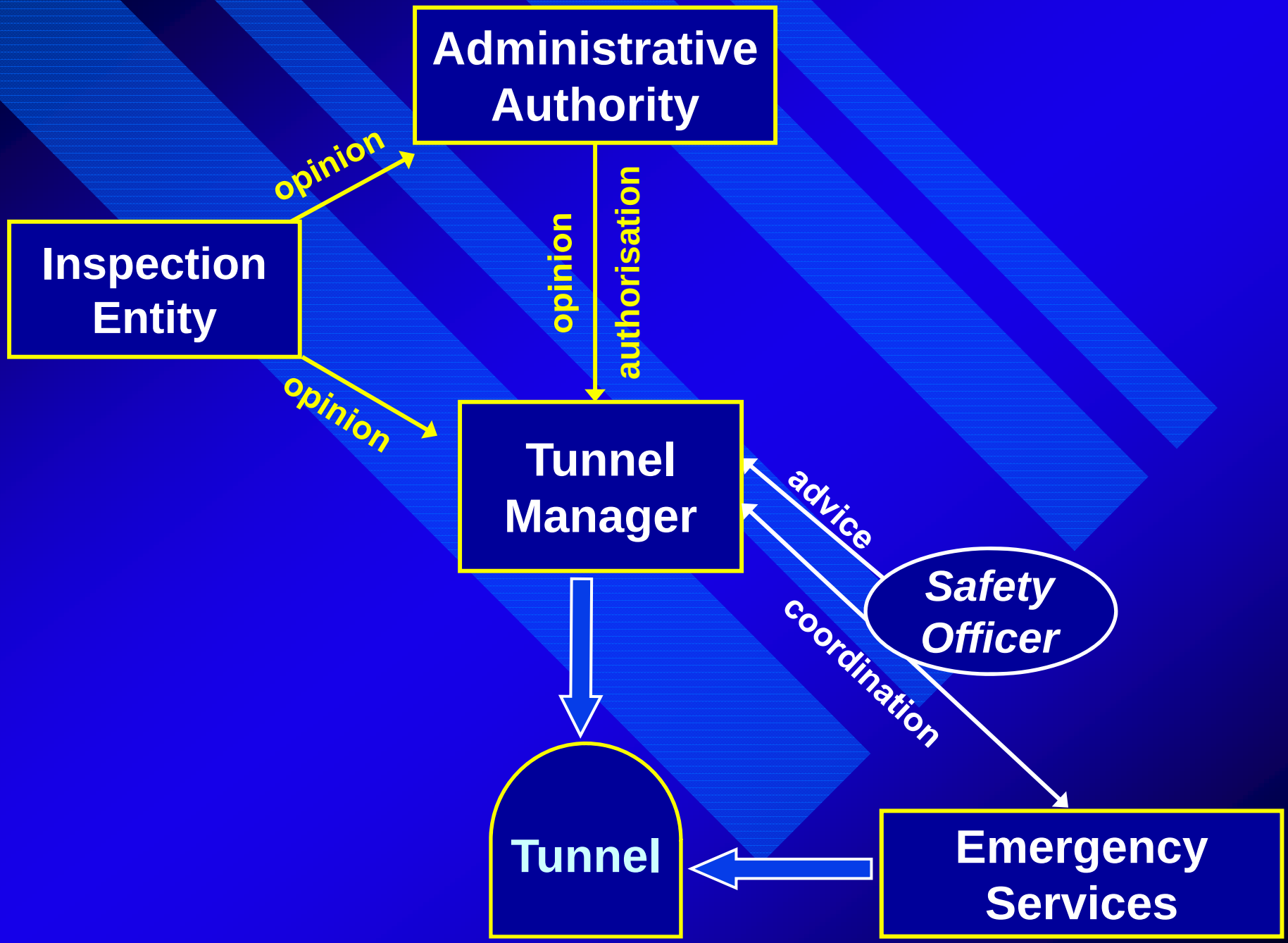
Safety Officer (SO)

- ✓ **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


Administrative Authority
opinion
Inspection Entity
opinion
authorisation
opinion
Tunnel Manager
advice
Safety Officer
coordination
Tunnel
Emergency Services

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

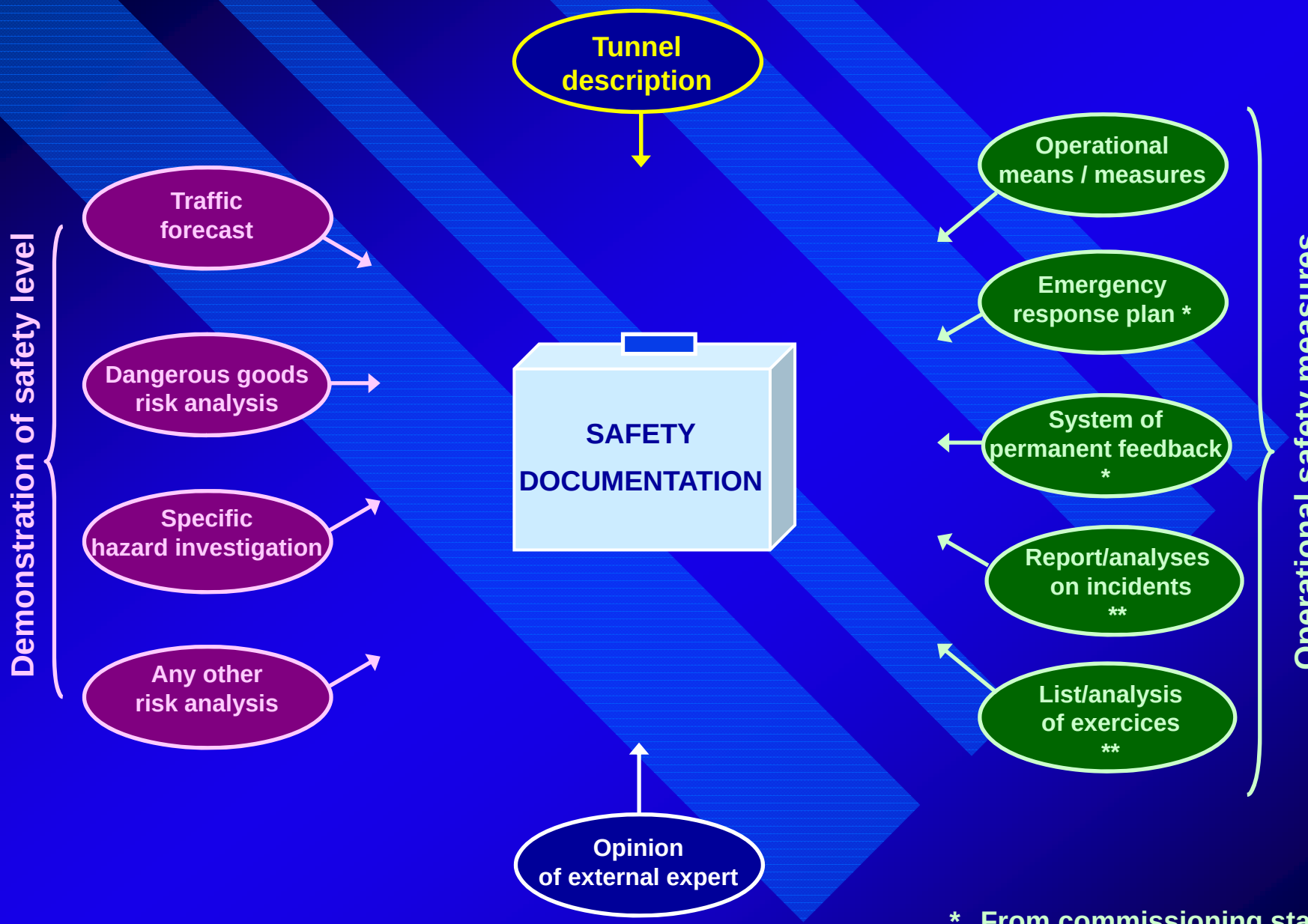
→ Procedures

→ Safety measures

Directive 2004 / 54 / EC of 29 April 2004

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



* 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

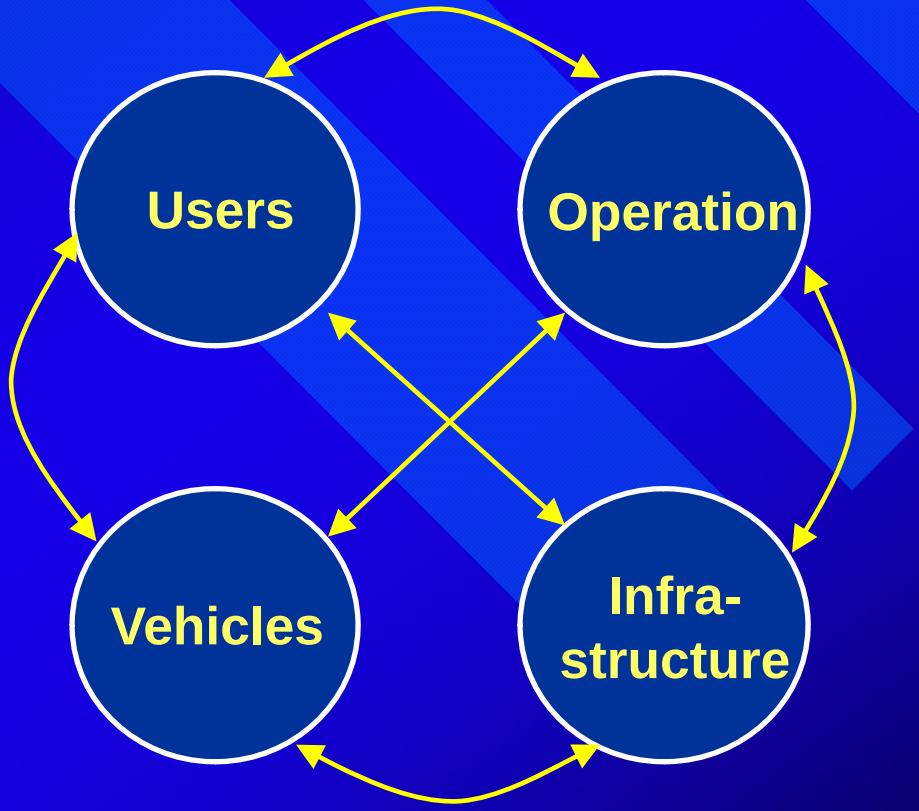
→ Responsibilities

→ Procedures

→ Safety measures

Basis for deciding on safety measures

- ✓ **Holistic approach:**
  Systematic consideration of all aspects of the system composed of



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 ≤ new tunnels
- ✓ **Operation**
  - requirements for existing tunnels ≡ 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

Provisions of Directive 2004/54/EC

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*

Additional provisions of EU Directive

- ✓ 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

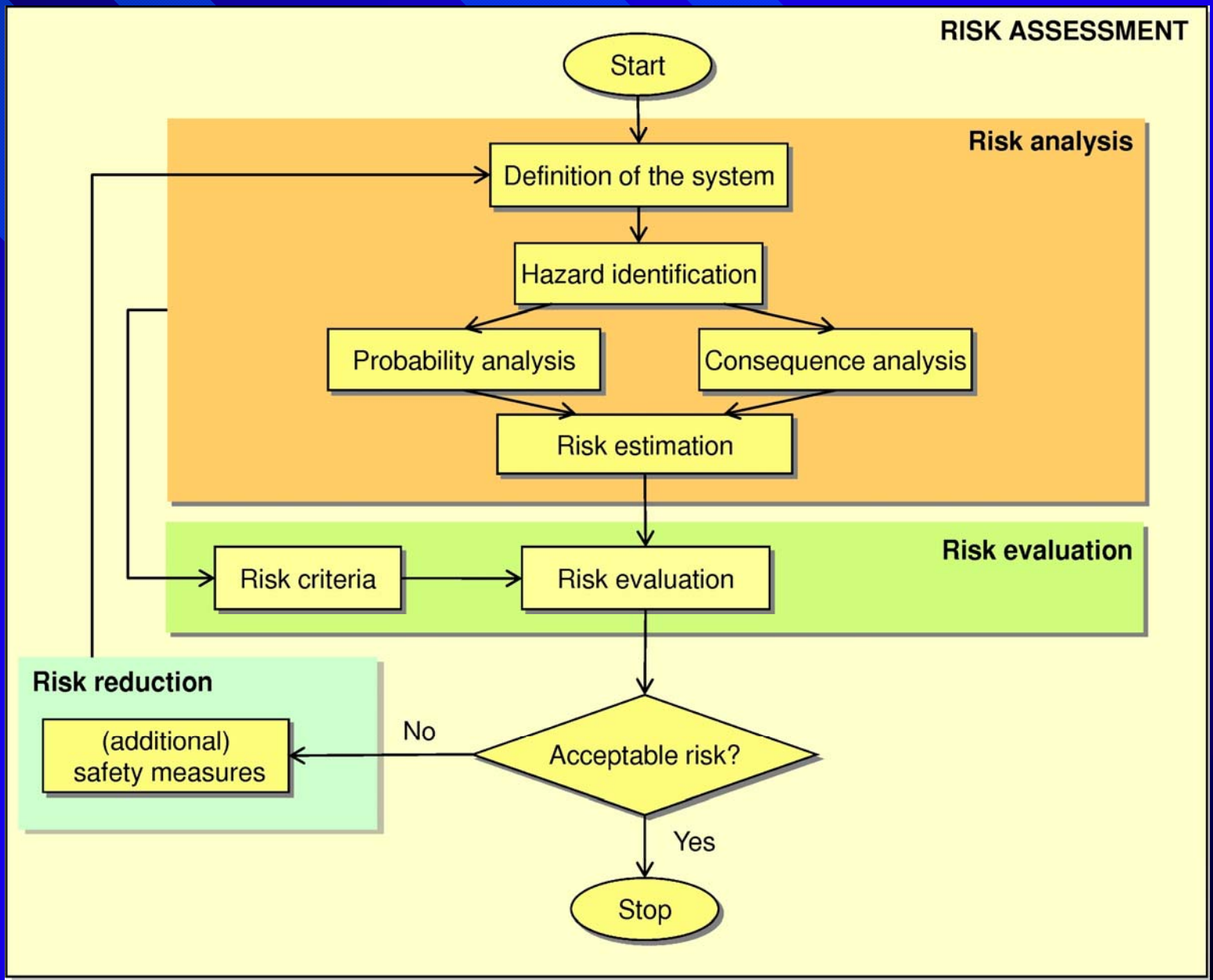
What is risk analysis?

- ✓ 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?

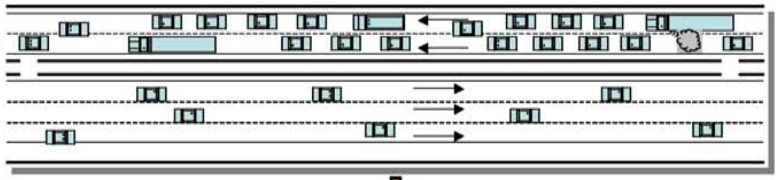
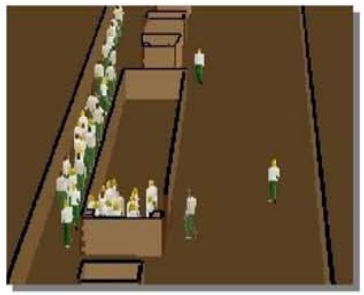
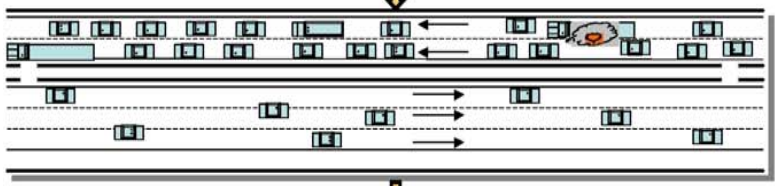
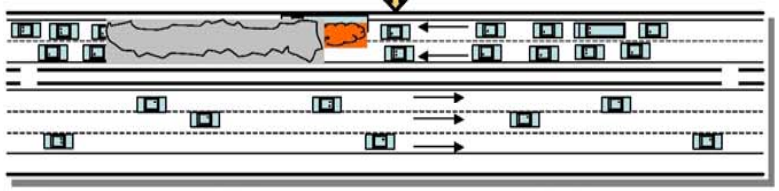
- ✓ To check general consistency of safety planning
- ✓ To choose between alternatives
- ✓ To demonstrate safety in case of deviations from prescriptions
- ✓ To optimise safety planning in terms of cost-effectiveness
- ✓ To assess safety in the framework of a performance-based approach

Risk Assessment Process



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

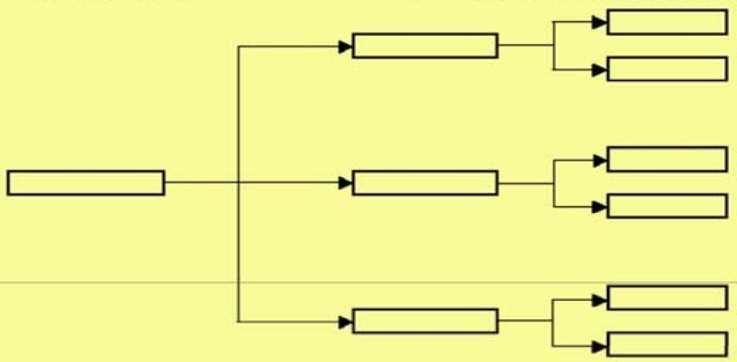
1. Scenario-based approach
2. System-based approach

Input: Influencing factors

Tunnel length Traffic volume Portion of heavy vehicles . . .

Logical tree

initial event → accident scenarios



X

Modelling of Consequences

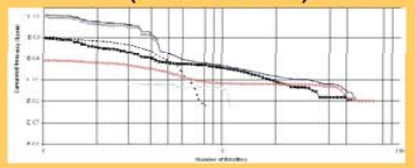
RISK

Results

Expected risk value
(fatalities/year)

R

Risk distribution
(F-N-Curve)



Types of risk-based approaches

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

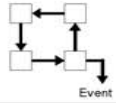
→ Risk indicators for an overall system:

- ✓ Evaluation of different safety measures
- ✓ Comparison with other cases *(or acceptance criteria)*

Methodological components used at each step

Qualitative ⟶ **Qantitative**

Risk analysis

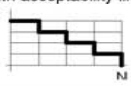
Intuitive approach	Standardised approach (Danger)	Statistical approach (F, N)	Factor analysis (F, N)	Analytical approach (F, (N))	Spread and effect models (N)	Simulations (F)
Expert judgment Brainstorming What-If-method Delphi-method etc.	Checklist Preliminary hazard analysis (PHA) Hazard and operability study (HAZOP) Management Oversight and Risk Tree (MORT) Safety Review Audit etc.	Data appraisal Data analaysis	$R = X \cdot x_1 \cdot x_2 \cdot x_3$	Logical trees 		

Risk evaluation

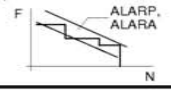
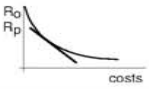
General approach

Intuitive approach	General Prinziples
Expert judgment	Pest practice, Standards Guidelines, Recommendations

Scenario-based approach

Frequency (Comparison, limits)	Consequence (Comparison, limits)	FN matrix
$F_{new} \leq F_{ref}$	$N_{new} \leq N_{ref}$	with acceptability line  With acceptability areas (cost-effectiveness-ratio) 

System-based approach

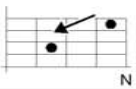
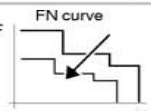
Risk value (Comparison, limits)	FN curve	Cost-effectiveness
Societal risk $Ro_{new} \leq Ro_{ref}$ Individual risk $r_{new} \leq r_{ref}$ Perceived risk $Rp_{new} \leq Rp_{ref}$	with acceptability line  With acceptability areas (cost-effectiveness-ratio) 	Marginal cost Risk-cost-diagram 

Risk reduction

General approach

Intuitive approach	General prinziples
Expert judgment	Best practice, Standards Guidelines, Recommendations

Effectiveness

Frequency	Consequence	Frequency and Consequence	Risk value
ΔF	ΔN	FN matrix  FN curve 	Individual risk Δr Societal risk ΔRo Perceived risk ΔRp

Cost-effectiveness-analysis

Cost-effectiveness-ratio	Cost-effectiveness-diagram
$\frac{\Delta \text{ Cost}}{\Delta \text{ Risk}}$	

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

Lessons drawn on 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

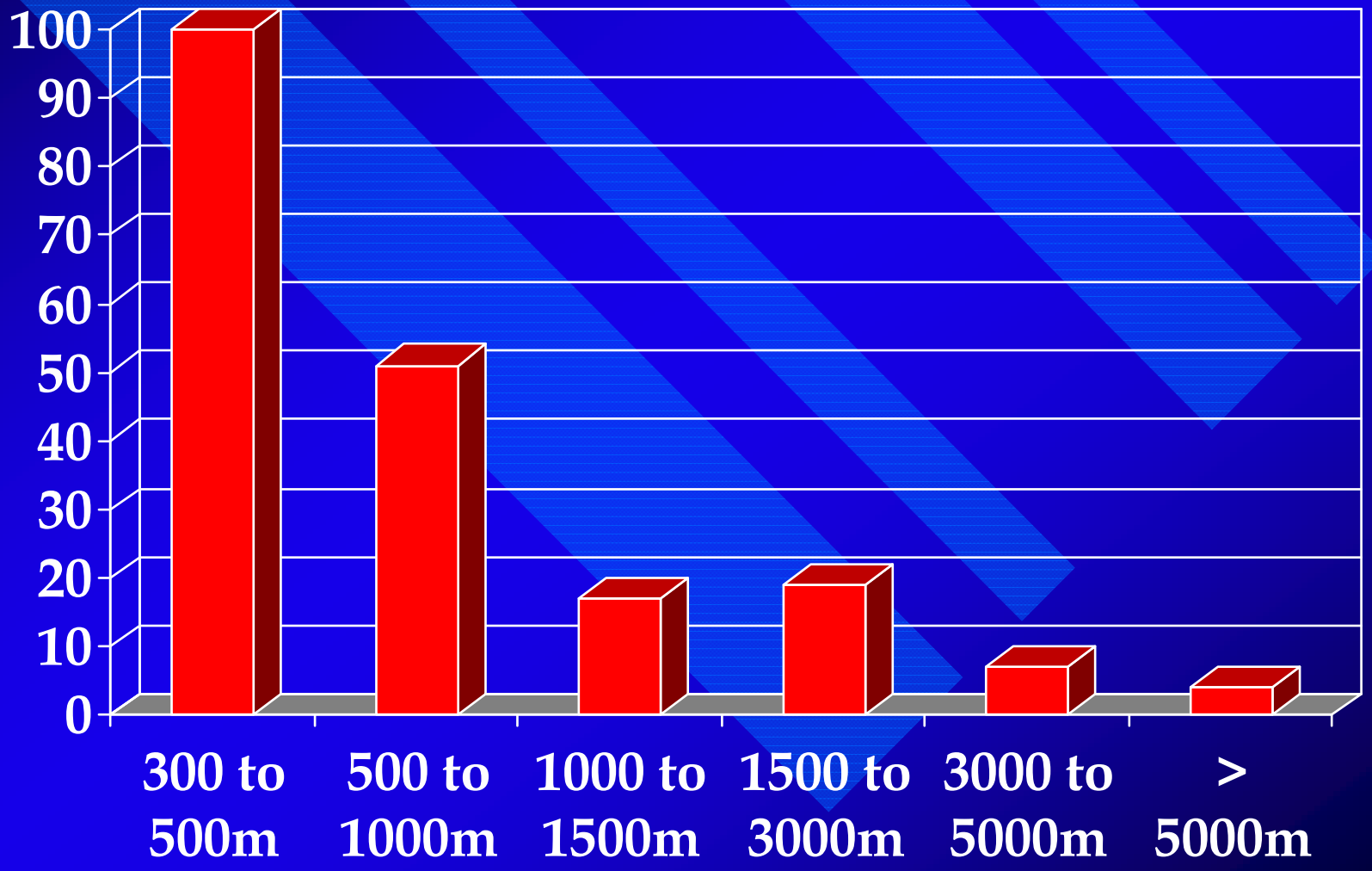
Transposition of the Directive in France

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

  → **Not so many changes for France!**

- ✓ **The French regulations apply to all tunnels > 300 m (≈ 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, concessionaire)

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 ≥ 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

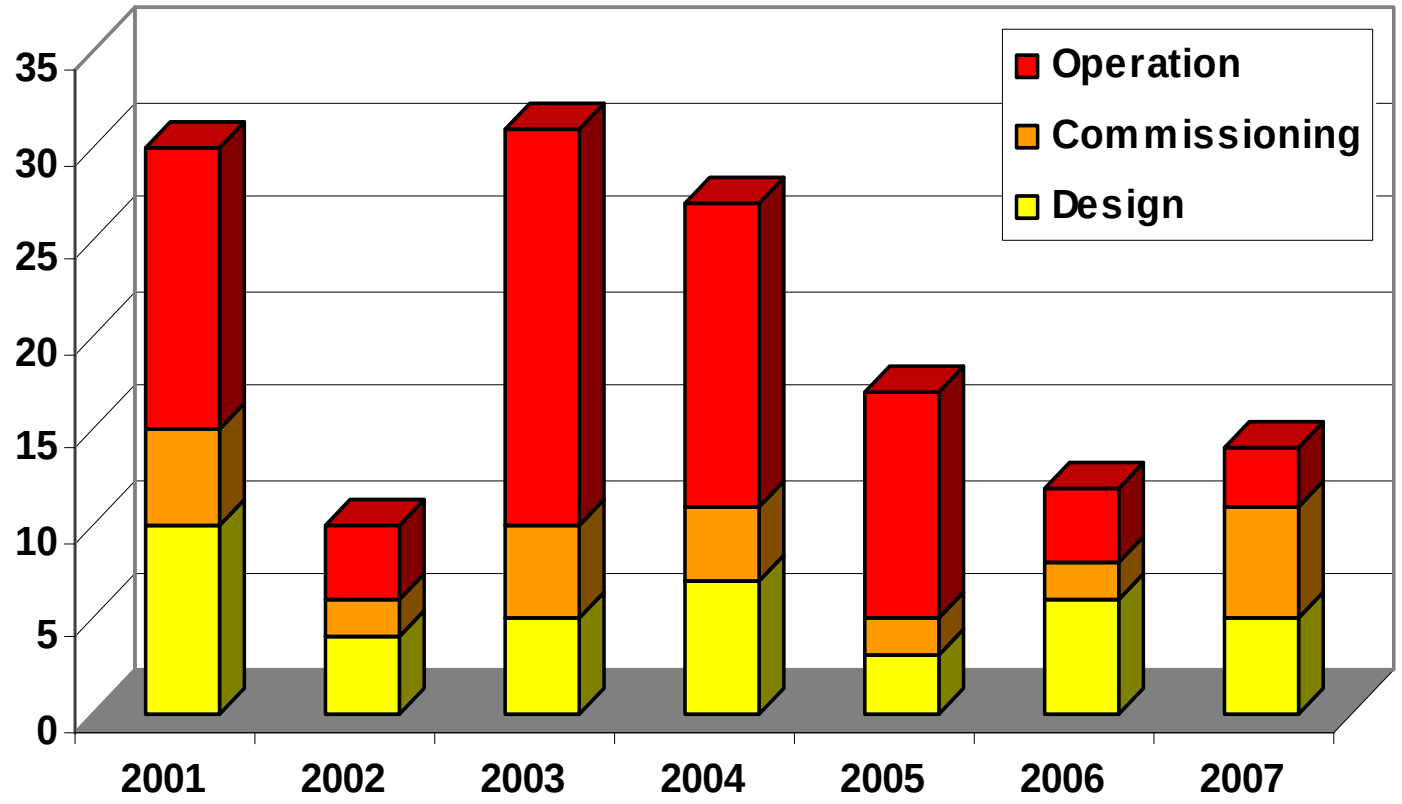
1. Practical method of compiling
2. In-service tunnels: from existing to reference condition
3. Risk analyses related to dangerous goods transport
4. Specific hazard investigation
5. Emergency response plans

Available in French and English at

www.cetu.developpement-durable.gouv.fr

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)**

Fiche Descriptive d'Incident - Page 1

Imprimer la fiche - Imprimer les paramètres - Exporter la fiche

Page 1 | Page 2 | Page 3 | Page 4

RÉFÉRENCES DE LA FICHE : Numéro 4645, 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 : 21/08/2000)

Heure : 15:00 (format : 00:15)

Tube :

PR + abs : (Repérage sur l'itinéraire par le PR+Abscisse)

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 oeuvre de la 1ère mesure d'exploitation du trafic (mn)

La durée totale jusquà rétablissement du trafic) (mn)

Nombre de véhicules immobilisés en tunnel :

Désenfumage

Déclenchement du désenfumage :

Délai : (mn)

Si incendie...

Maîtrise de l'incendie :

Durée du feu : (mn)

Equipements utilisés :

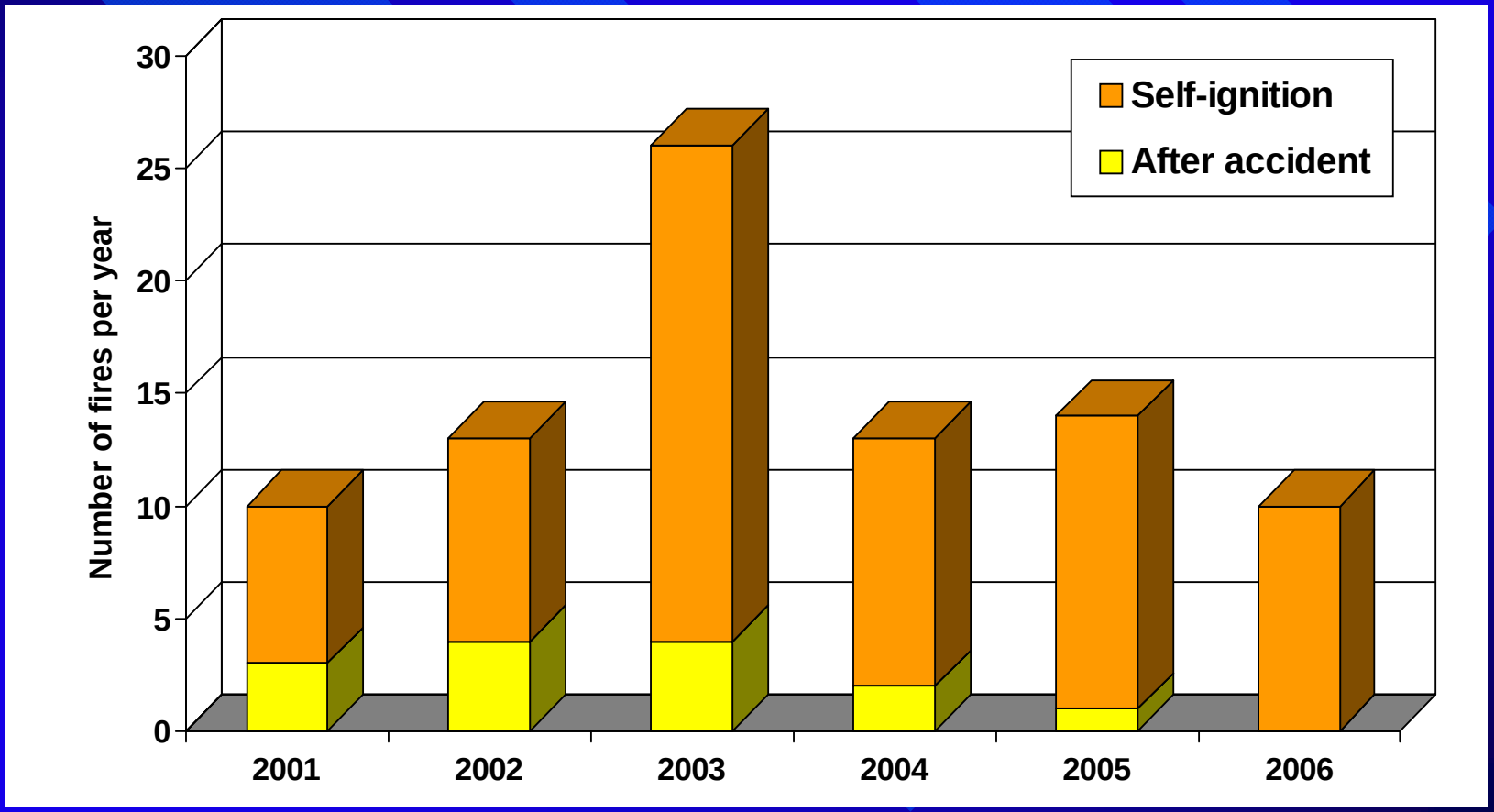
	Utilisation
Extincteurs tunnel	
Réseau incendie tunnel	

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

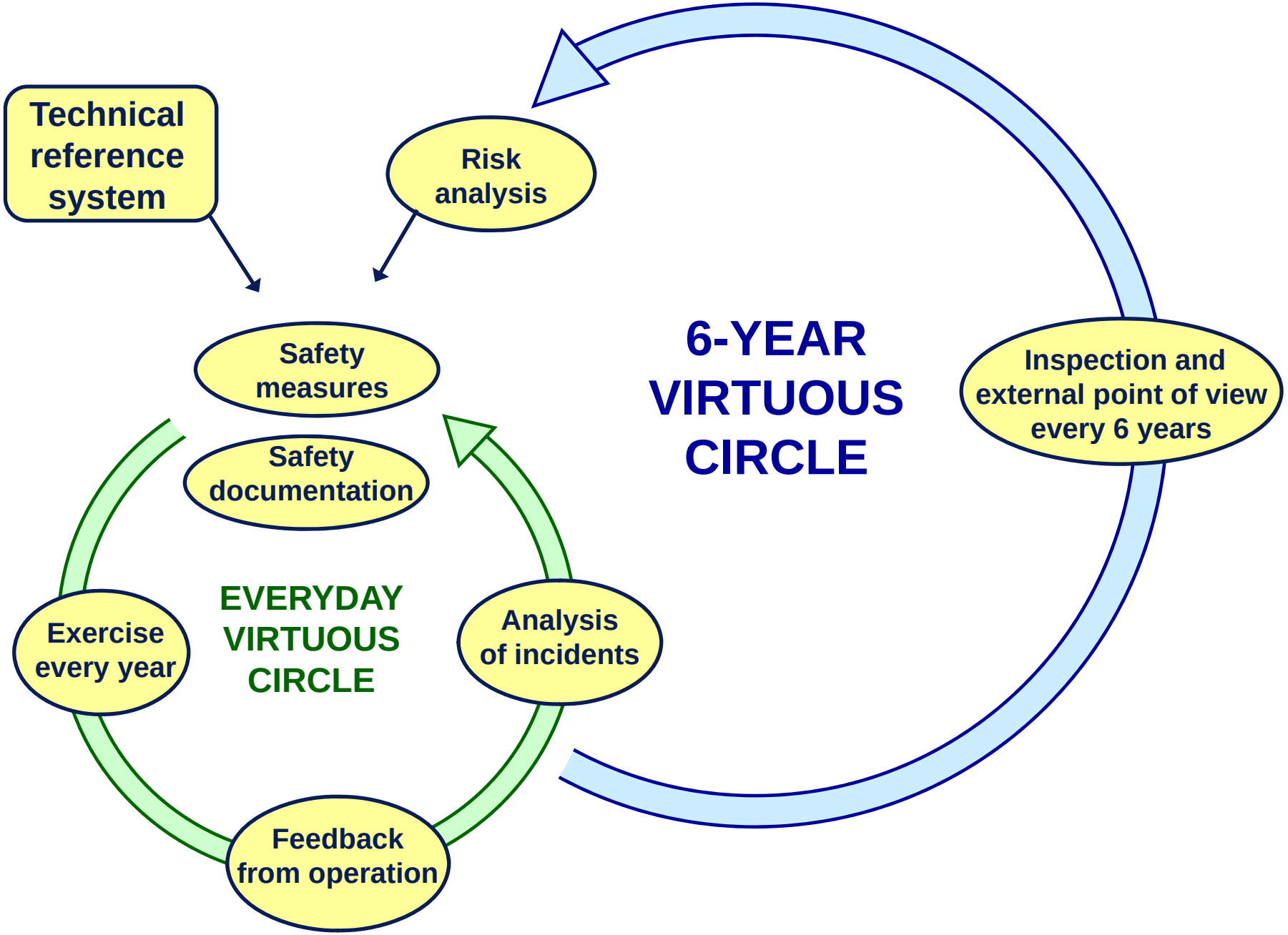


European approach to road tunnel safety and risk assessment

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


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

Thank you
for your attention!

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

Liberté • Égalité • Fraternité
RÉPUBLIQUE FRANÇAISE

CETU