November 2005

Risk Analysis vesrsus Risk Acceptability in major European Tunnel Projects

Prof. Dr.-Ing. D. Diamantidis

Purpose of Presentation

- Scope and applicability of QRA in European tunnel projects
- Methodological aspects
- Case studies:
  - Subway in Denmark
  - Railway tunnel in Cental Europe
  - Road tunnel projects in Greece
- Summary and conclusions

Scope of QRA

- to provide evidence that an innovative engineering system can be operated with an acceptable level of safety for passengers, staff, third parties

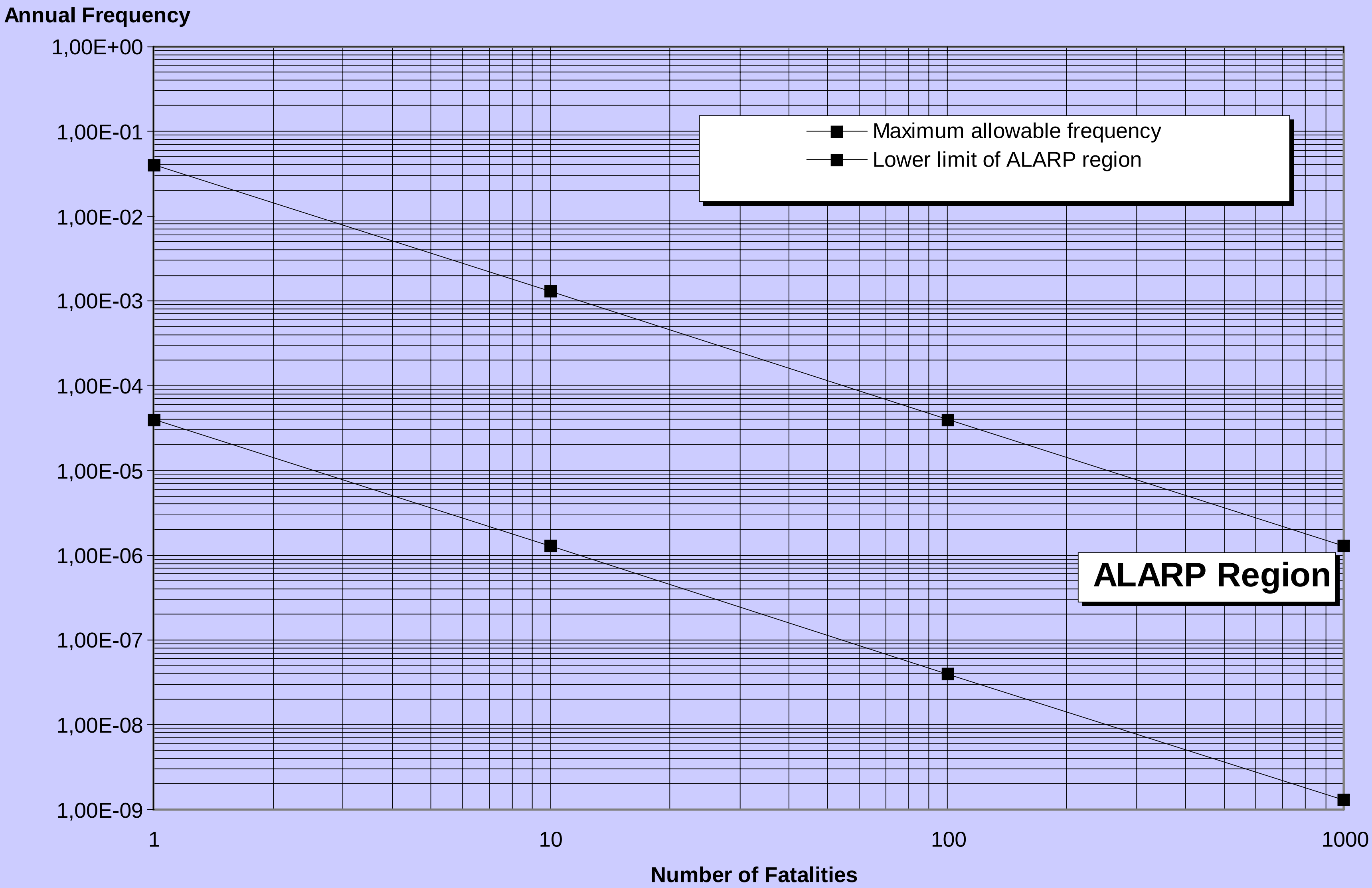
in other words

- to ensure that the occurrence of extreme or accidental events can be minimised or their consequences mitigated to an acceptable level

What is an “acceptable level of safety” ?

- **ALARP** - As Low As Reasonably Practicable
- **LQI** - Life Quality Index

Quantitative Risk Acceptance Criteria



Life Quality Index

$$L = g^{w}\, e^{(1-w)}$$

g: the gross domestic product per person per year

e: the life expectancy at birth

w: the proportion of life spent in economic activity.

ICAF – Implied cost of averting a fatality

□ Δg_{max} = g/2 (1-w)/(w)

ICAF = ge/4 (1-)/(w)

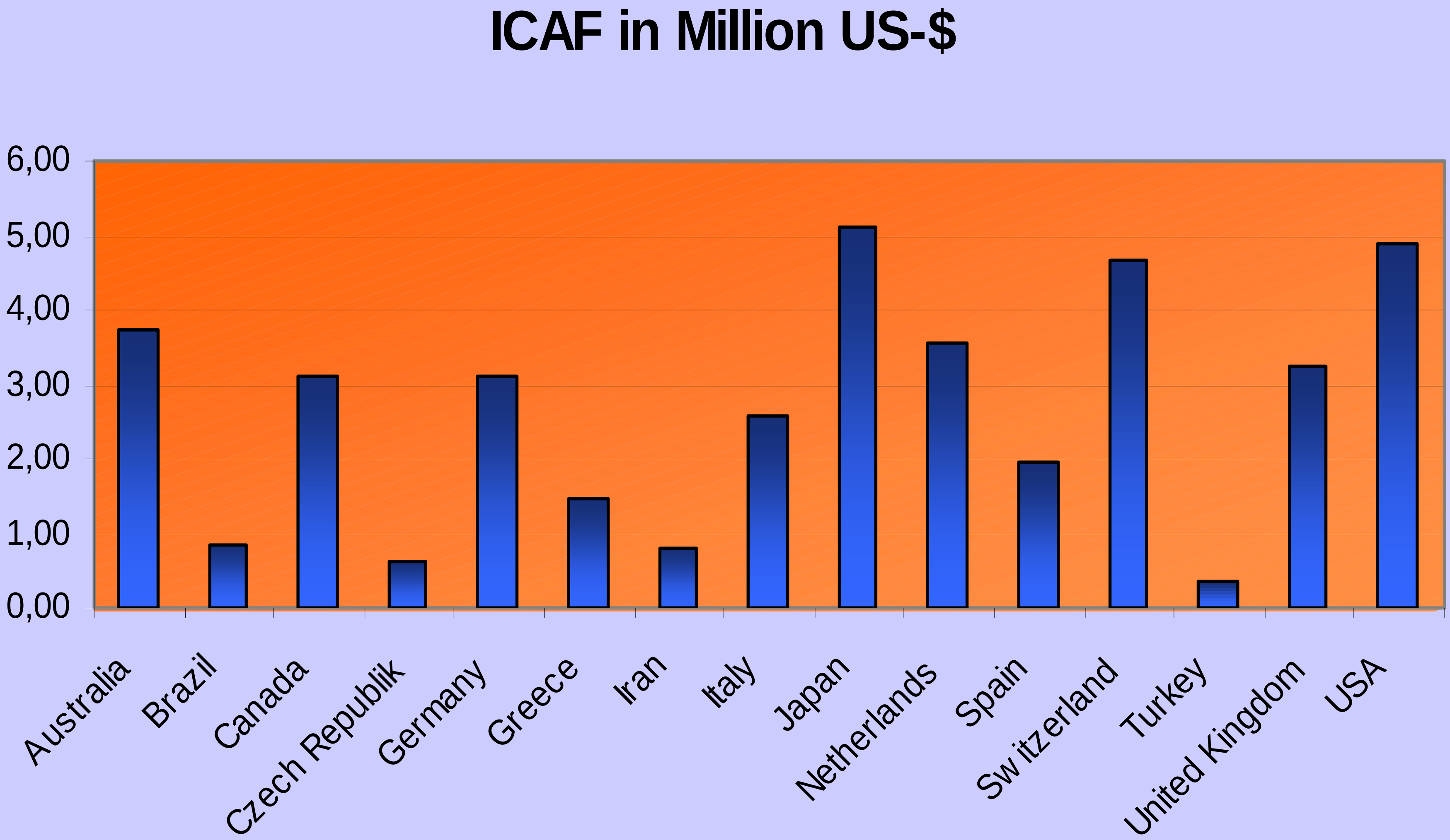
g = gross domestic product per year per person

e = life expectancy at birth

w =proportion of life spent in economic activity

ICAF = 2 – 3 Mio. $

Illustration of ICAF values for various countries



Optimization criterion

Costs:

- Annualised investment costs
- Annual maintenance/operation costs

Benefits:

- Human risk reduction
- Direct/Indirect financial loss reduction

QRA Approach

- Comprehensive hazard (events) identification
- Estimation of events' probability of occurrence
- Analysis of consequential events
- Quantification of the expected consequences
- Risk evaluation and risk summation
- Comparison to acceptability criteria
- Identification of additional safety measures
- Selection of additional safety measures, also by means of cost/benefit considerations


Copenhagen
Switzerland
Greece

Case Study 1: Automatic Metro System in Copenhagen

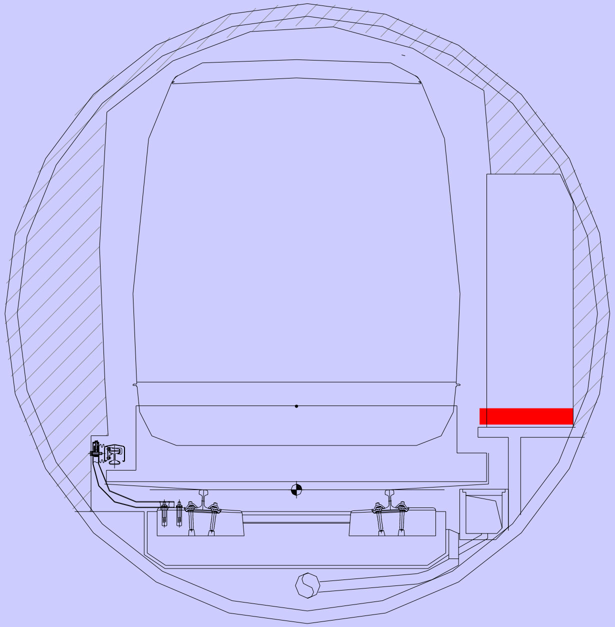
- Light Metro system
- Unmanned transportation system
- Underground for approximately 9 km
- Operational 24 hours / day
- Single compartment - three cars vehicles

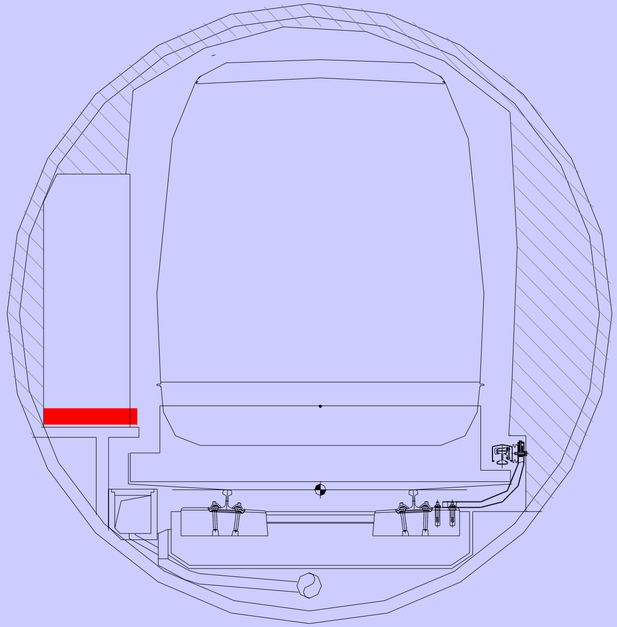
Main Safety Concerns

- Reliability of automatic signalling system
- Fire load of a “single compartment” vehicle
- Adequacy / sufficiency of escape routes
- Procedures to manage the ventilation system and the related escape scenarios
- Accessibility of the rescue teams
- Two bores tunnel configuration

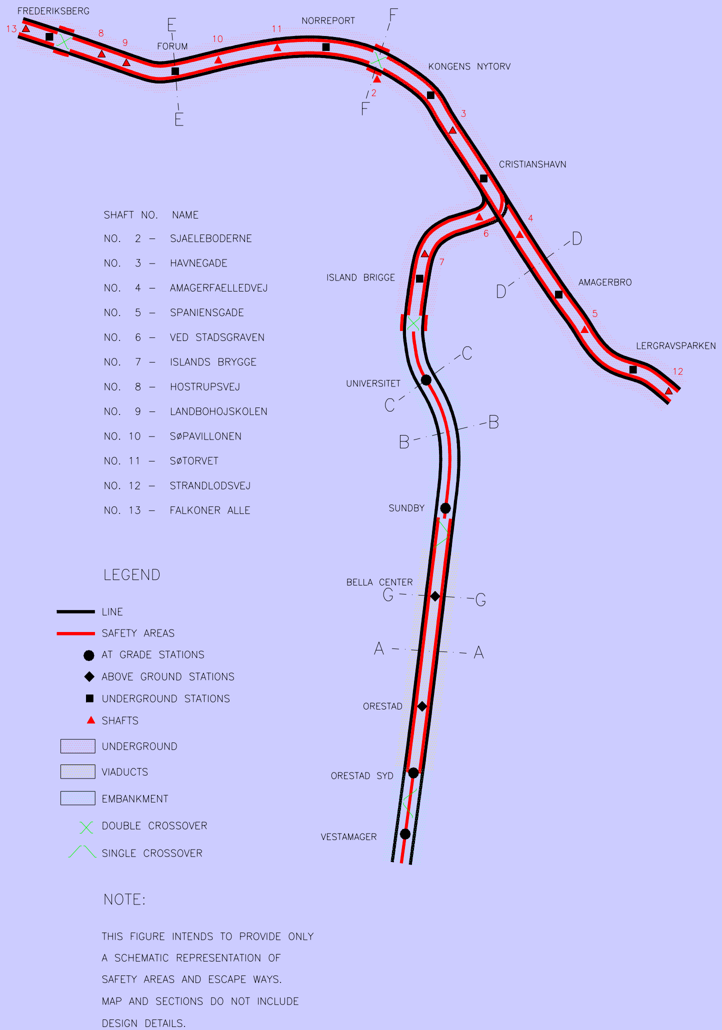
The Metro Vehicle

Tunnel Configuration





Metro Evacuation and Rescue Concept and Fire Protection Concept



- Safety areas of 700 mm along all tunnels
- Evacuation shafts every 600 meters maximum
- Water mains along tunnels
- Emergency lighting
- Various communication means with Control Centre

Key Hazards Considered

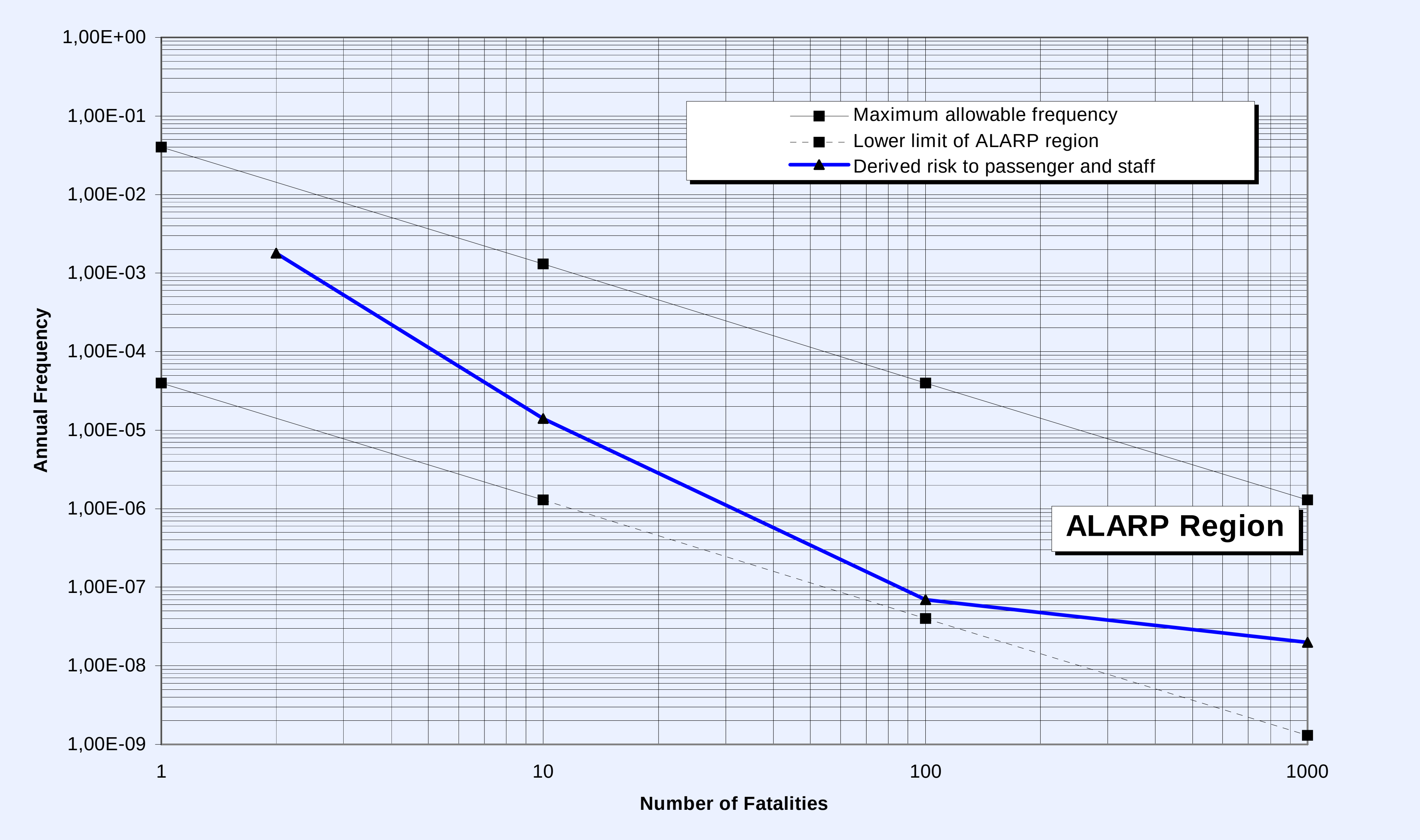
INTERNAL

- Collision with persons
- Derailment
- Collision between vehicles
- Fire in rolling stock
- Fire in tunnel or station
- Electrocution hazards

EXTERNAL

- Street traffic collision with bridges
- Flooding of tunnels or stations
- Geological hazards
- Spillage of hazardous substances in the system
- Sabotage

Results of the Analysis

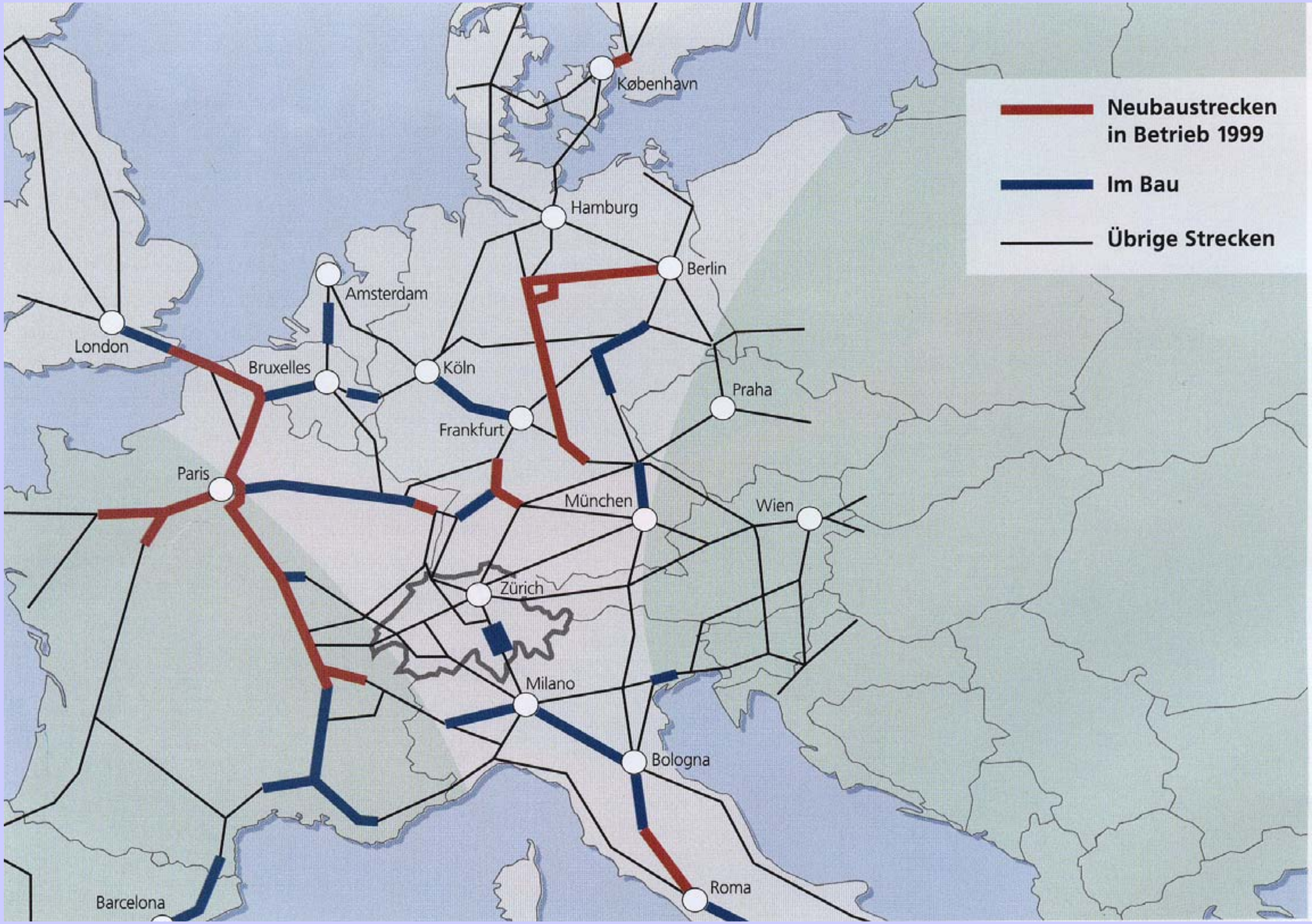


Case Study 2:
Long Railway Tunnel in Central Europe

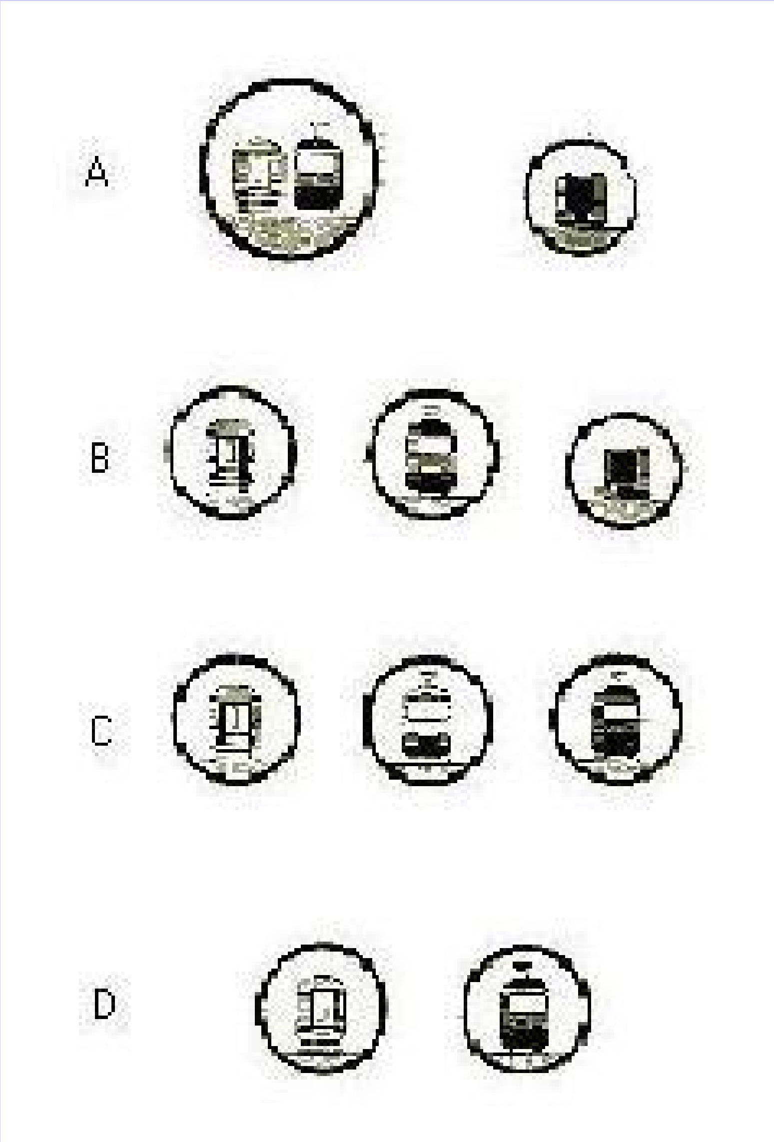
Example: Gotthard-Tunnel

- 8 billions $
- 57 km long

European Rail Network



Aspects of Tunnel Configuration

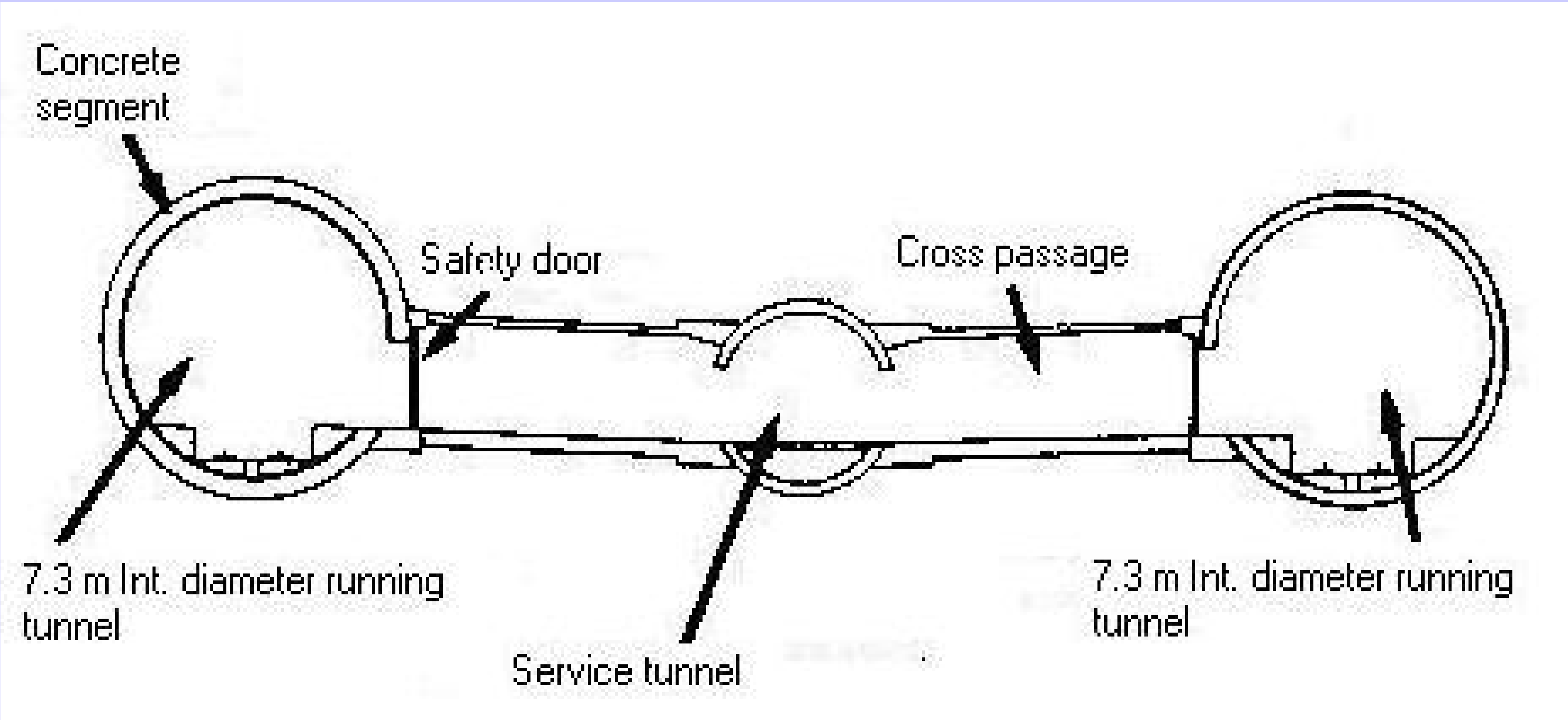


- **Key configuration aspects:**
  - Number of bores
  - Cross Passages between bores
  - Size of the bores
  - Ventilation shafts
- **Related to:**
  - Construction time and method
  - Operational capacity
  - Maintenance
  - Safety for the passengers and the personnel

Major Rail Tunnel Accidents

Date	Location	Fatalities	Initiating Event
22-7-1971	Simplon (CH)	5	Derailment
16-6-1972	Soissons (F)	108	Hit against obstacle
22-8-1973	S. Sasso (I)	4	Collision
23-7-1976	Simplon (CH)	6	Derailment
....-4-1980	Sebadell (E)	5	Fire
21-1-1981	Calabria (I)	5	Hit against obstacle
9-1-1984	El Pais (E)	2	Collision
18-4-1984	Spiez (CH)	1	Collision
23-12-1984	Bologna (I)	15	Sabotage
26-7-1988	Castiglione (I)	1	Fire
14-9-1990	Gurtnellen (CH)	1	Derailment
31-7-1993	Domodossola (I)	1	Collision

Railway - the Channel Tunnel (1994)



Risk - Expected fatalities (per 10^6 train km)

Initiating Event	ODTT	TSTT
Derailment	0.012 (23%)	0.005 (16%)
Collision	0.025 (46%)	0.017 (55%)
Hit Against Obstacle	0.011 (20%)	0.003 (10%)
Fire	0.006 (11%)	0.006 (19%)
Total	0.054 (100%)	0.031 (100%)

Notes:

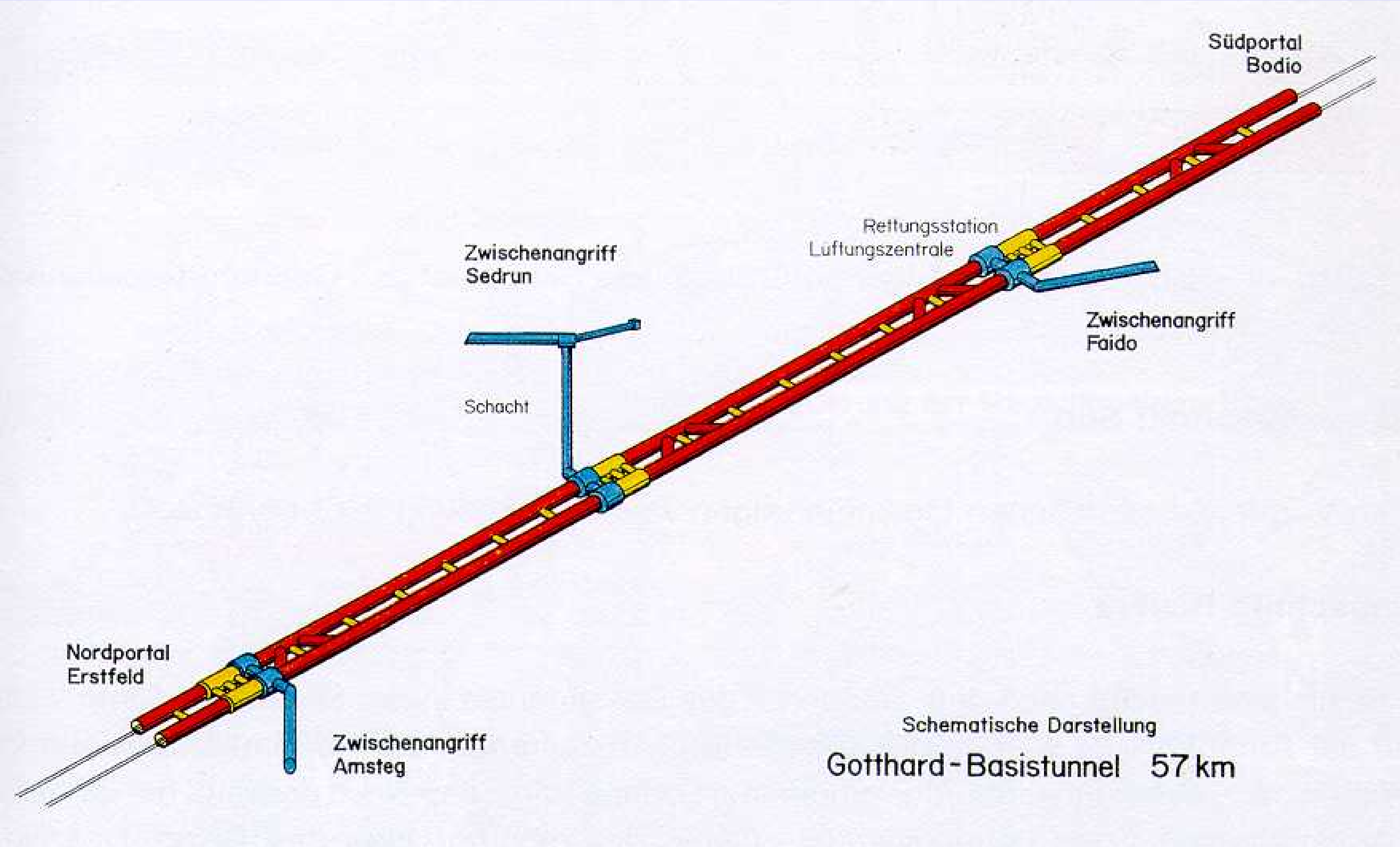
ODTT: One Double Track Tunnel

TSTT: Two Single Track Tunnel

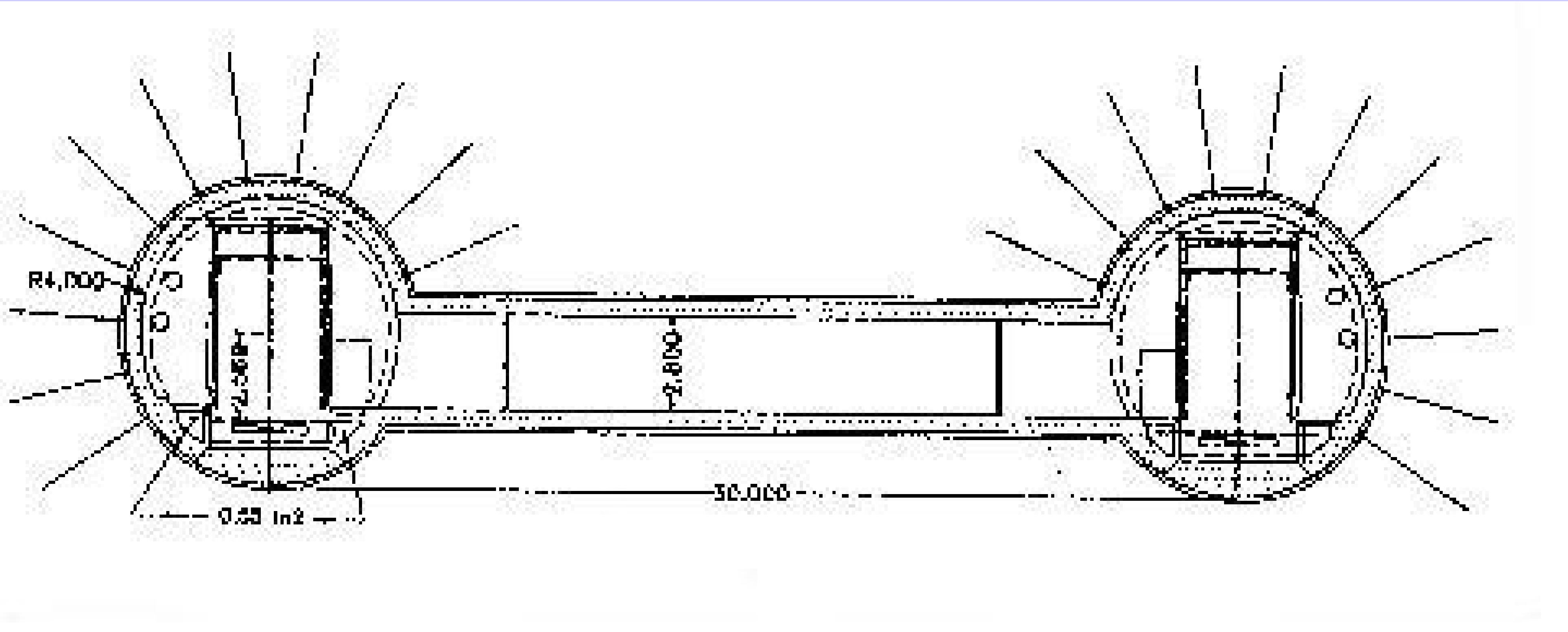
Service Tunnel Discussion

- Improves self rescue
- Improves rescue by third
- Reduces risk (20%-30%)
- Serves for maintenance purposes
- Cost of the order of 10 Mill. $ per km associated to 20 Mill. $ per saved human life

Gotthard Tunnel



Selected Tunnel System



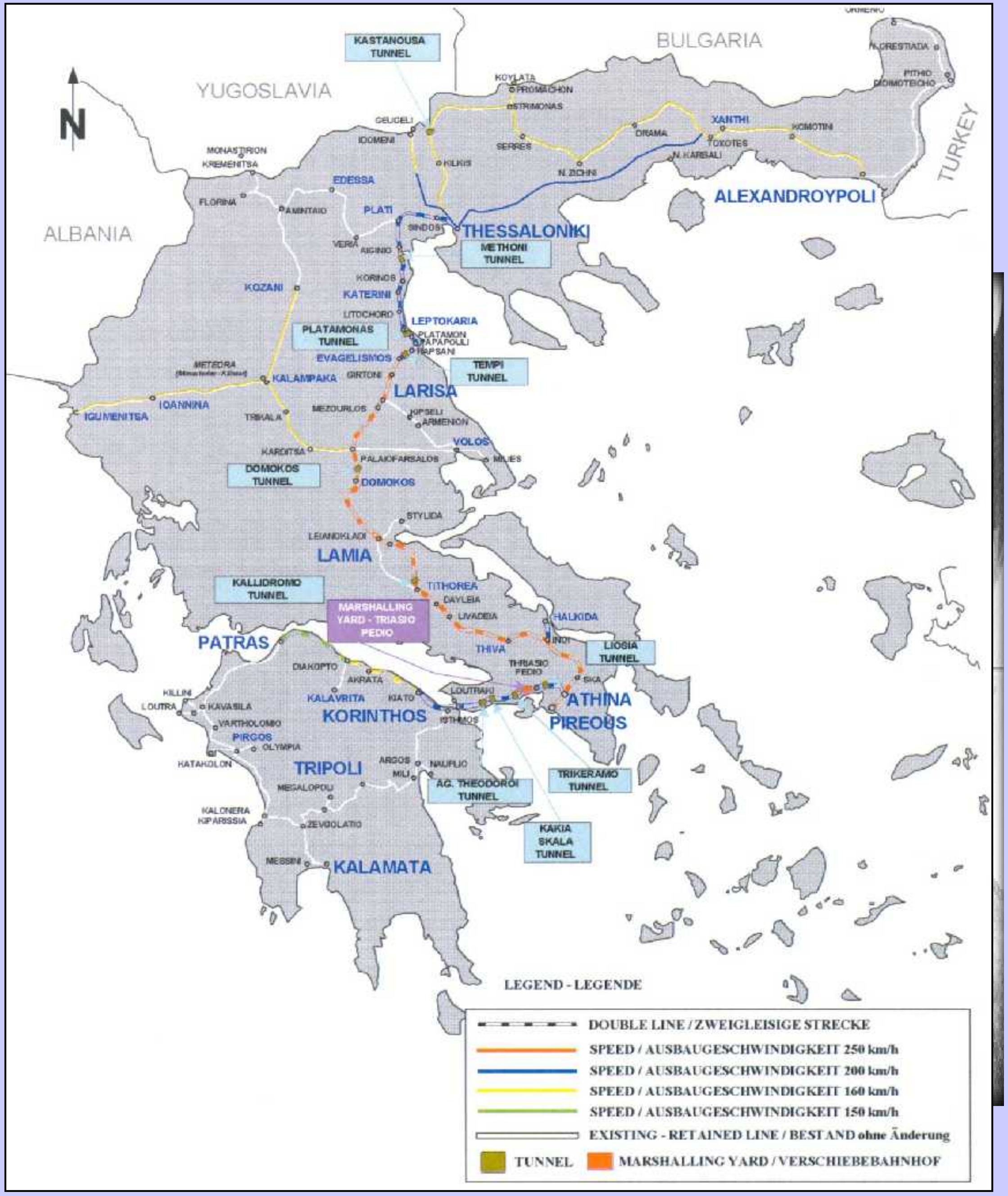
Comparison of Current Projects

TUNNEL	System	Length [km]	Distance Interconnect. [m]	Width of Escape-way [m]	Traffic [train/day]	Freight Trains [%]	Velocity [km/h]
Mont Cénis	TSTT	54	250	$\geq$ 1.20	160 – 180	44 – 50*)	220
Great Belt	TSTT	8.0	250	1.20	240	40	100
Eurotunnel	TSTT	50	375	1.10	110	45	160
Seikan	ODTT	53.9	600-1000	0-0.6	40	50	240
Gotthard	TSTT	57	325	0.75	300	80	200
Brenner	TSTT	55	250	1.60	340	80	250

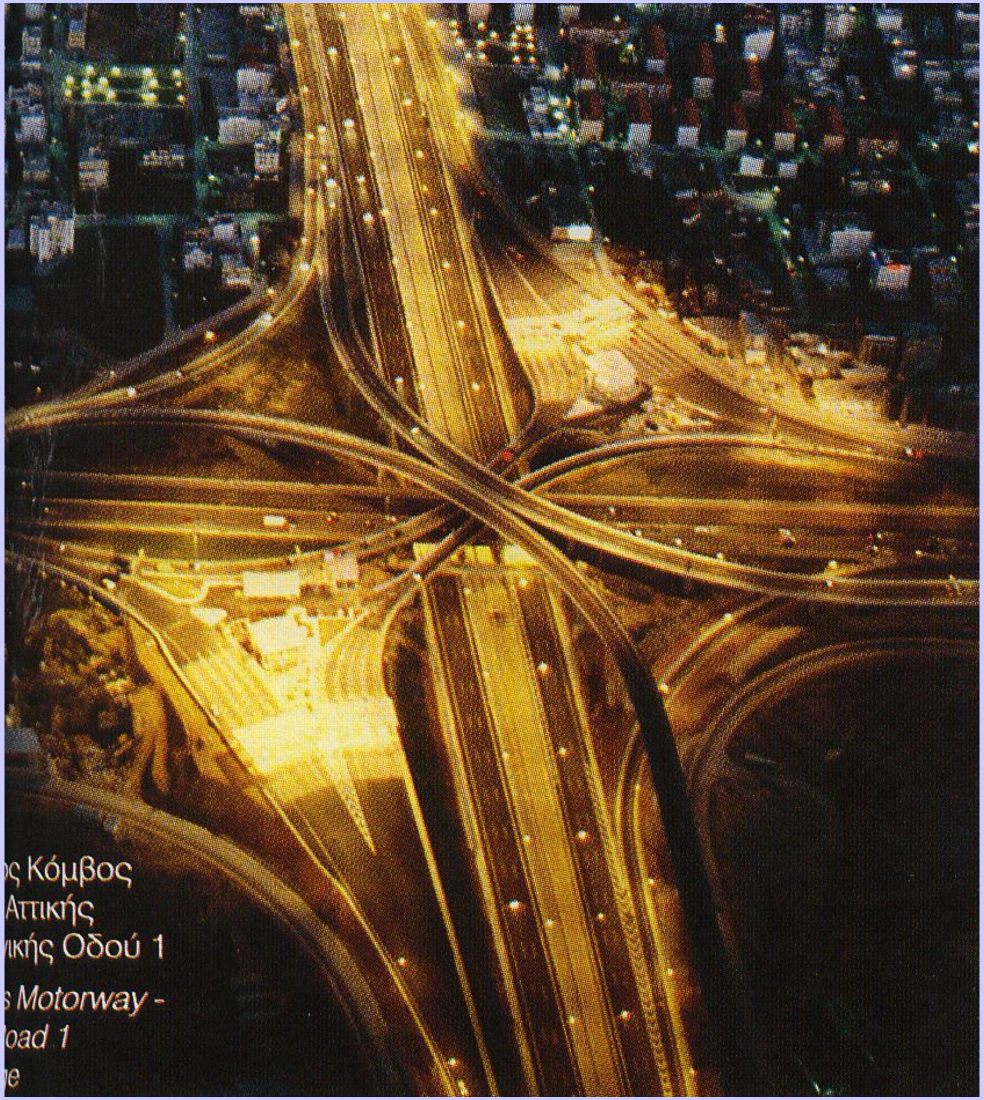
Notes: TSTT: Two Single Track Tunnel

ODTT: One Double Track Tunnel

Case Study 3: Road Tunnel in Greece



Olympic Road Network in Athens (Olympic Games 2004)



Tunnel in the South-North Highway

- 6 Kilometers long
- Two tubes
- 30000 vehicles per day
- 25% heavy traffic
- 200 Mill. Euros

Alternative solutions (emmergency lane)

Solution A

Emmergency lane 0.5m and lay-bys every 1000m

Solution B

Emmergency lane 2.5m

35% more expensive

25% less risk

Study results

- Both solutions are acceptable according to ALARP criterion
- Additional Cost of solution B > Benefit

=> Solution A was selected!

Conclusions (QRA for tunnels)

- Risk analysis is a powerful decision tool
- Risk analysis leads to cost-optimal solutions
- Risk analysis techniques are available
- Risk perception criteria need broader acceptability (and compatibility with standards)