# Safety and the use of Underground Space

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**Chair of Underground Space Technology**

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**Delft University of Technology**

# Objective of lecture

- Awareness of safety issues
- Interaction between technique and society
- Relations with the use of Underground Space



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# Content

1. Introduction
2. Safety & Risk
3. Risk models
4. Tunnel Safety in the Netherlands
5. Cases:
   - Delft Spoorzone
   - HSLzuid
   - RandstadRail
   - Utrechtse Baan
   - Rotterdam CS



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# Introduction

Safety in various fields:

- Aviation
- Industries
- Dikes
- Health care
- Food



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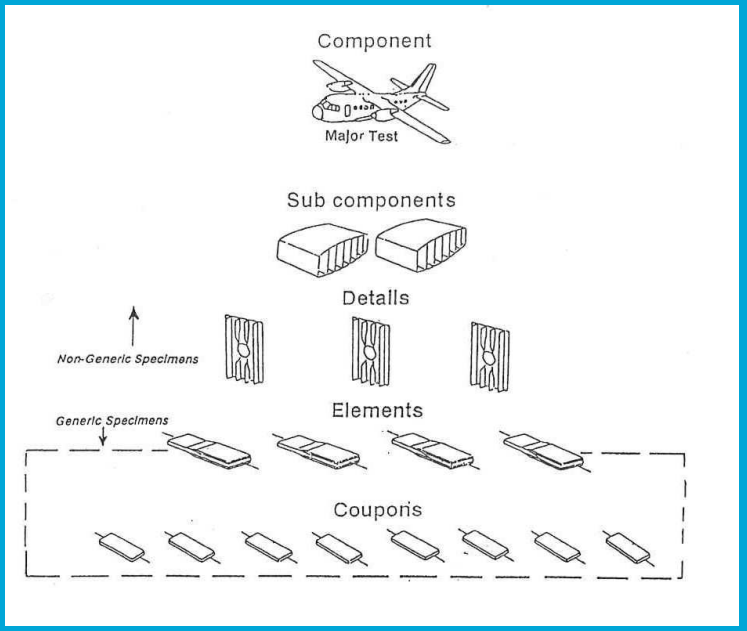
# Aviation



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# Industries

- External / Internal safety


Fire work disaster Enschede



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# Inundation risk



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Unfortunately…



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# Tunnels

- Derailment of Metro in Valencia June 2006

(app. 37 lethal victims)

- Mont Blanc tunnel

(1999, flour and margarine - 39 lethal victims)

- Channel tunnel (1996)
- Gotthard tunnel

(head-on collision 2 lorries)

*Mont Blanc tunnel*



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# Layered use of Space


Transport of Hazardous materials



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# Thinking of safety

- Lots of social attention
- Lack of (legally) specified safety standards
- Various involved stakeholders: attention for process
- Safety is expensive!



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# Safety & Risk

- Safety does not exist!
- **Risk = probability of failure * consequences**



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# Safety characteristics (1)

- Risk:
  - Probabilistic approach:

Risk = probability of failure * consequence

*All type of incidents*.

  - Deterministic approach (fire brigades)

*Scenario thinking of several incidents*



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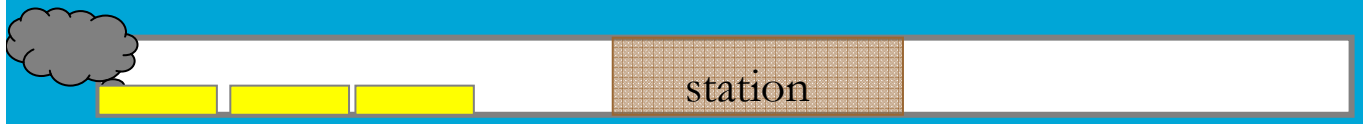
# Safety characteristics (2)

- Integral approach:

  - **Internal safety**
    (using airplane, train, working in factory – objective)
  - **External safety** (near industry/rail track - objective)
  - **Social safety** (subjective)



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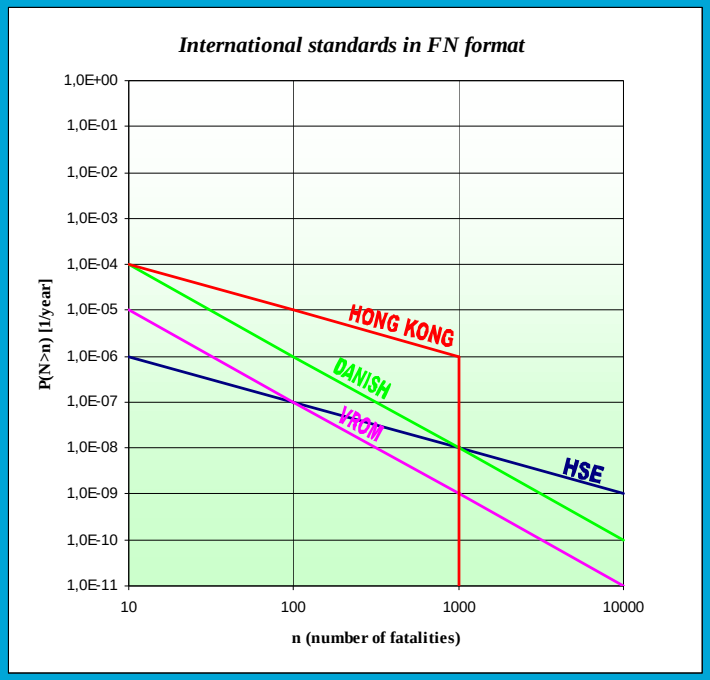
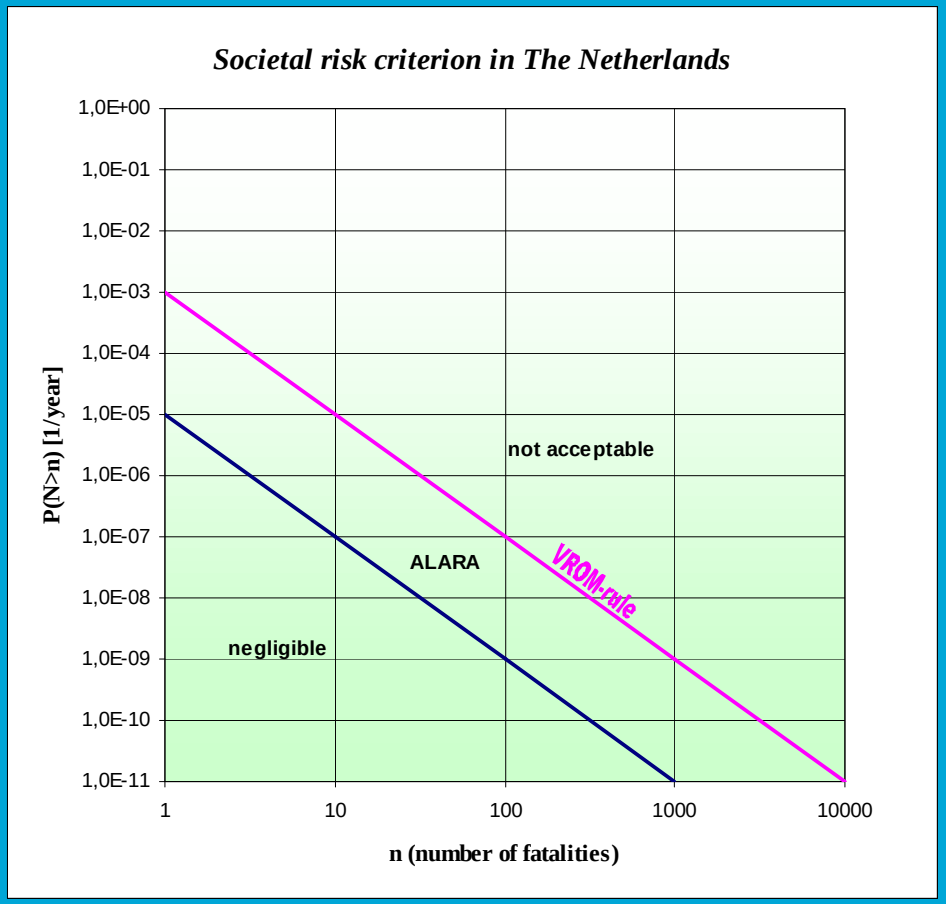
# Safety characteristics (3)

- Group risk
- Individual risk
- ALARA principle



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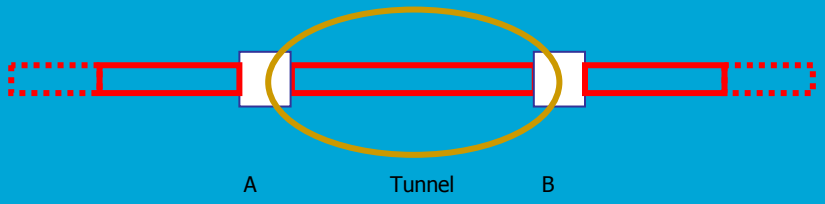
# Internal safety

- Integral approach
- **Safety Chain** - Prevention is better than cure
- **Self Rescue -** Main point on ability to evacuate oneself
- **Safe Haven** approach
- Normative scenarios for aid and assistance – not everyone can be rescued
- Clear responsibility for remaining risks



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# Safety Chain


- Pro-action Safety measures in planning stage (pre-construction)
- Prevention Measures and provisions to prevent accidents
- Preparation Preparation and provisions to mitigate accidents
- Repression Actions during accident
- Follow-up Dealing with post-accident situations

Think of detection, extinguish, self rescue measures etc. in all parts of the system.



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# Risk models

**Scenario analysis:**

Process analysis of one specific incident, incorporating all implemented safety measures, in a story wise manner.

**QRA-models**

- Failure Mode & Effect Analysis (FMEA)
- Event tree
- Fault tree
- Bayesian method
- Etc.



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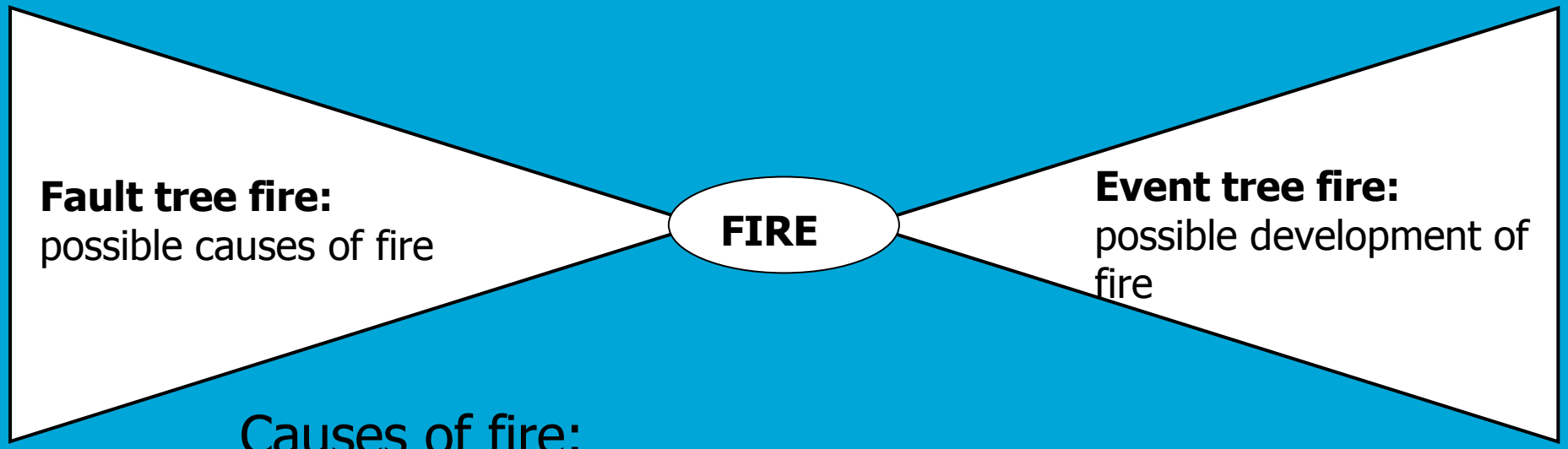
# FMEA

| Failure mode | Failure cause | Effect of failure |
|---|---|---|
| logistic problems | planning fault | time loss |
| collapse of concrete element | design fault | costs, time loss, fatalities |
| fixing concrete elements | element falls | costs, time loss, loss of quality, fatalities |
| huge deformations of elements | element collapses and falls | costs, time loss, loss of quality, fatalities |
| no right composition of concrete | production fault | costs, time loss, loss of quality |
| fire in building | gas leak | costs, time loss, loss of quality, fatalities |

# Bow-tie model




Causes of fire:

- Fire due to maintenance
- Arson
- Fire due to technical defect
- Fire due to short circuit
- Fire due to accident



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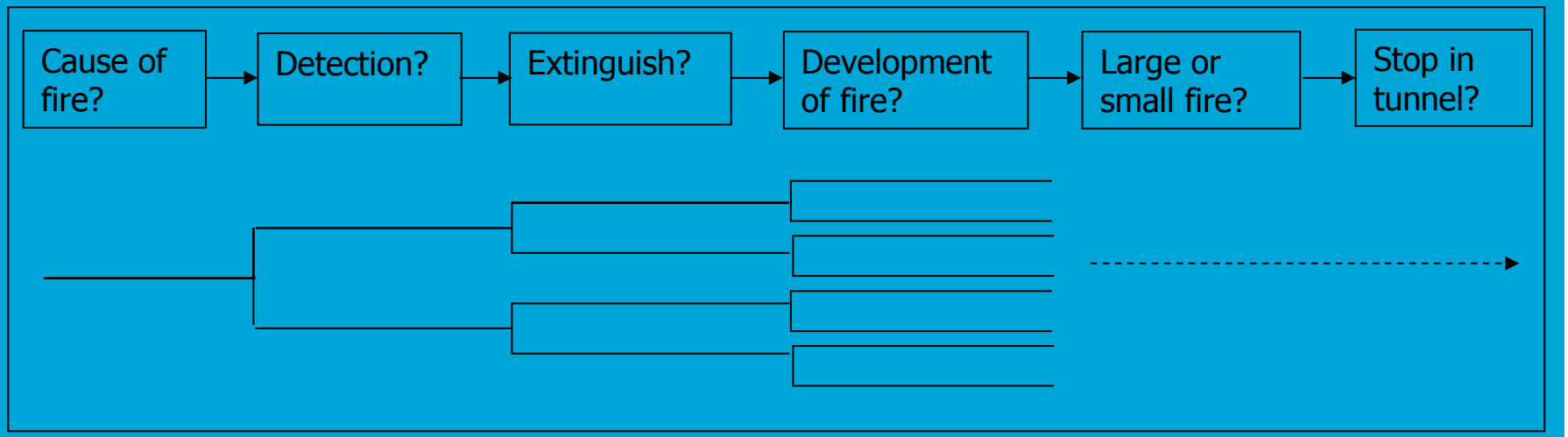
# Event tree

This represents the possible development of a fire in a metro system




Chance of failure of each step (probability) ⇒ Chance stop in tunnel



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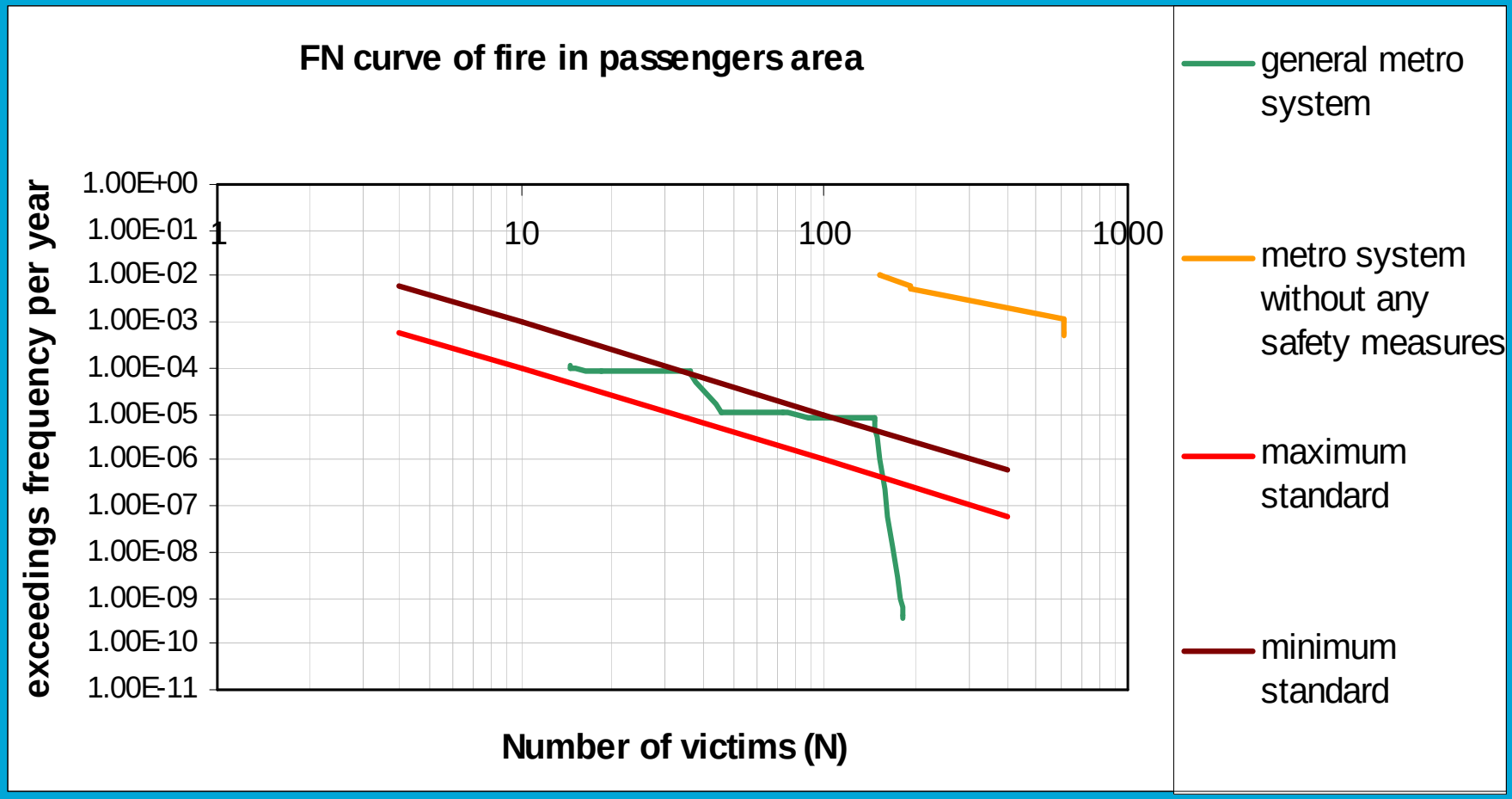
# QRA - Output



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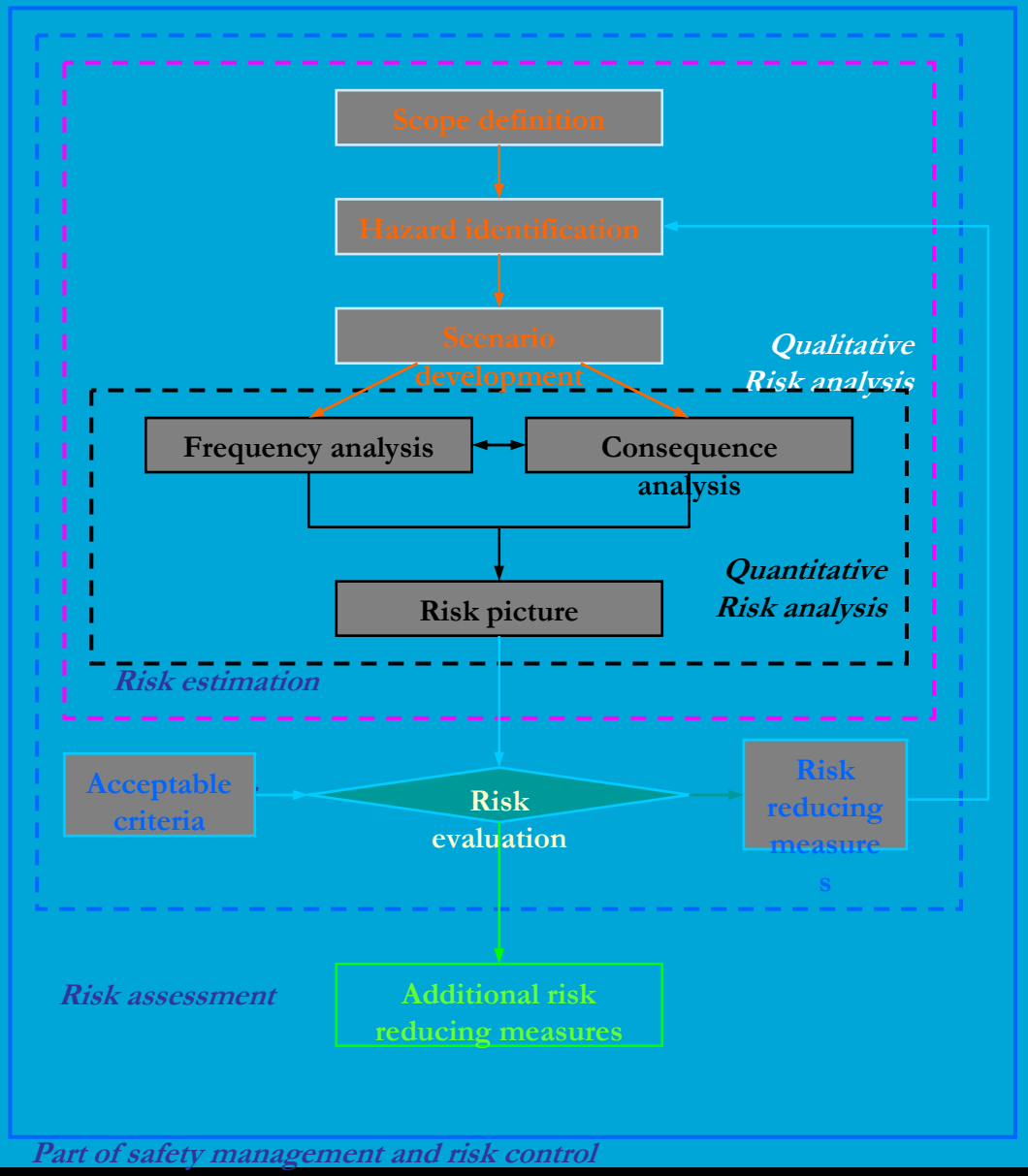
This risk approach is used in several working fields:

- Dikes
- Health Care
- Foods
- Traffic (aviation, roads, rail, metro)



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# Safety in the Netherlands

- Large incidents in tunnels worldwide
- Severe incidents in the Netherlands
  - Enschede (2000)
  - Volendam (2001)

**Focus for safety increased!**



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# Safety in tunnels (Netherlands)

Can tunnels be considered "safe"?

- No legislation (EU nor NL until 2007)
- No standard
- No standard risk model

Consequence:

- Different safety levels in similar/comparable projects.



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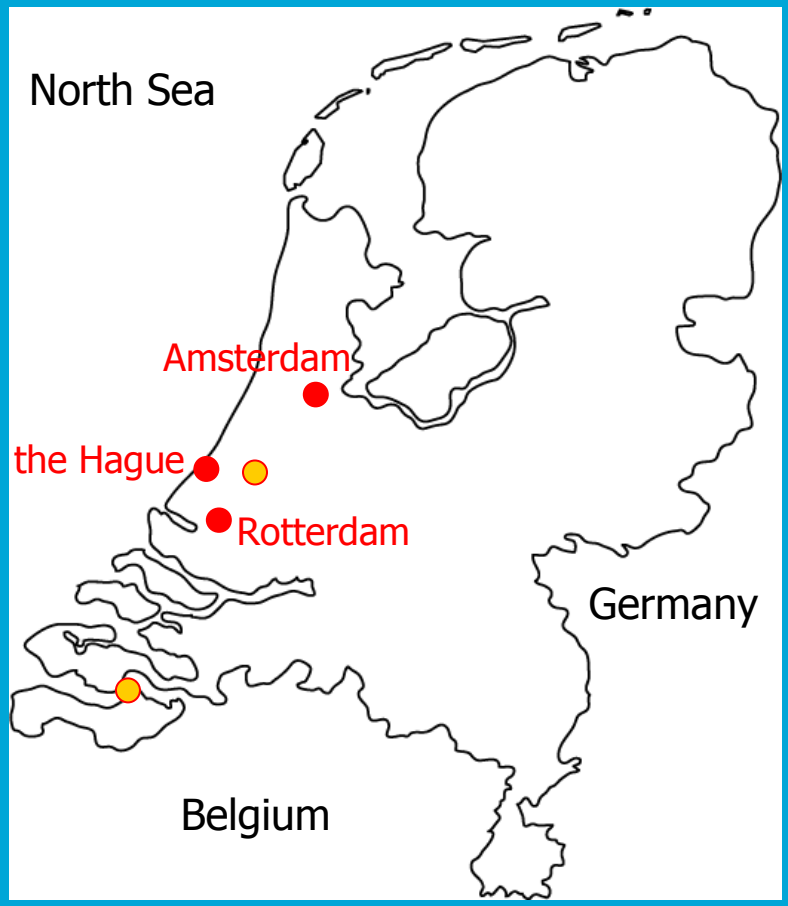
# Standard ?

Comparing standards used in:

- RandstadRail (metro/LightRail)
  - Statenwegtunnel
  - Haagse tramtunnel
- North/Southline (metro-A'dam)

To rail and road projects :

- Westerscheldetunnel (WST- road)
- Green Hart tunnel (HSL- rail)



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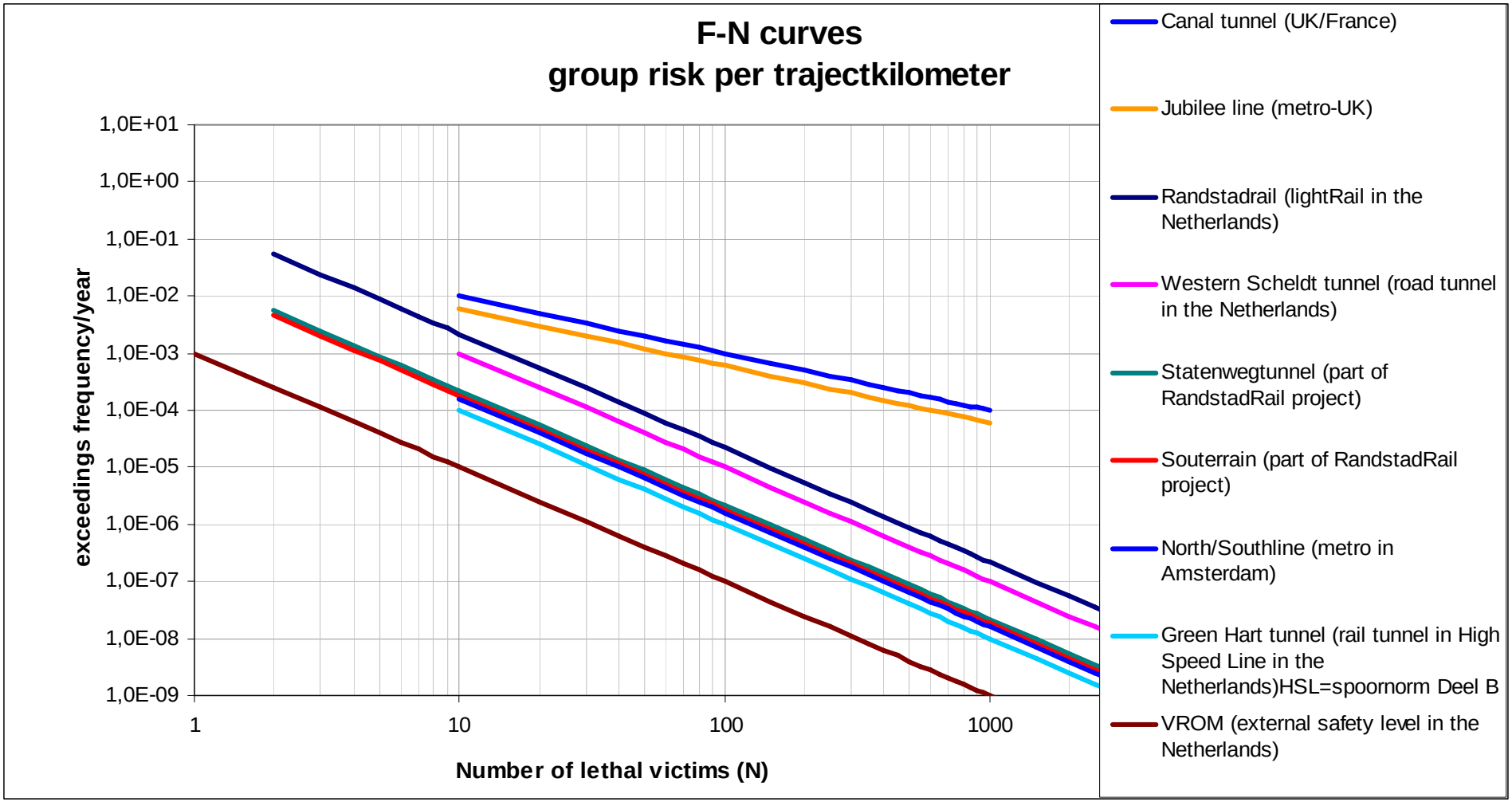
# Standard ?



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# Safety in tunnels - legislation

- EU Directives 2004/54/EG
- Implementation in Dutch Legislation + additional safety measures (valid on May 2006)

Additional measures:

- One direction of traffic
- Ventilation and Traffic control centre
- Shorter distance between:
  - emergency posts
  - emergency exits



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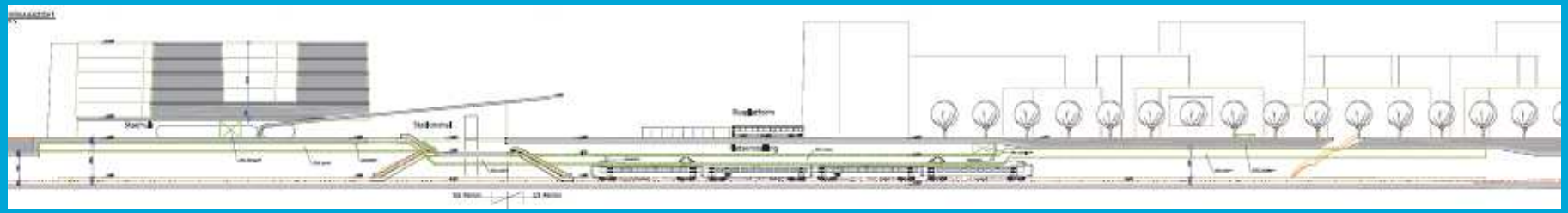
# Case 1: Spoorzone Delft





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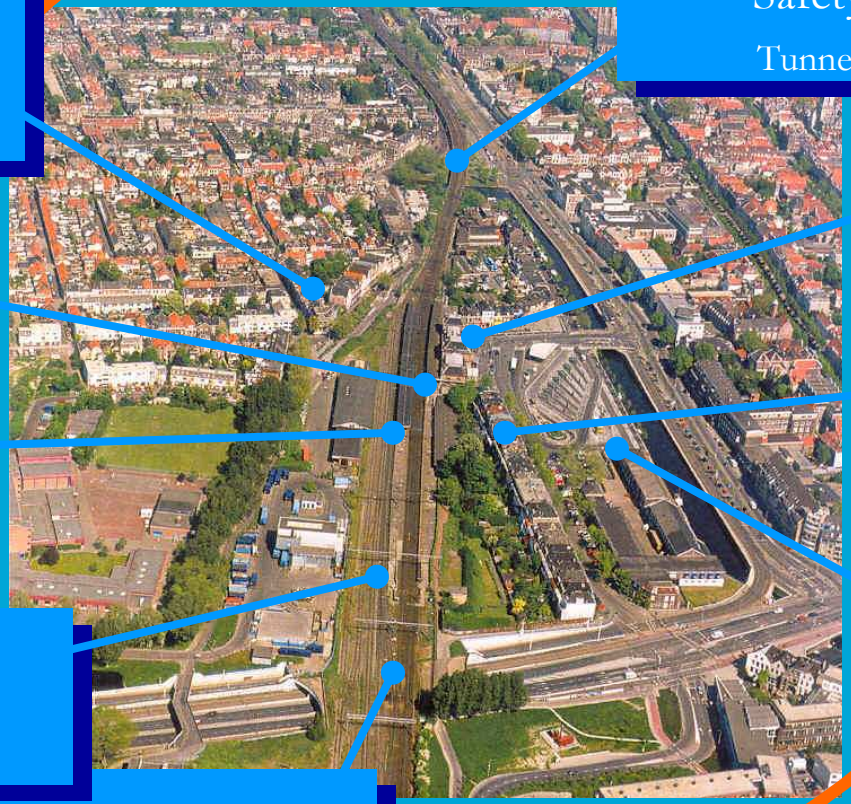
# Integral safety process



Tunnel Safety
Tunnel

External safety
surroundings

Social safety
Surroundings of station

Internal safety
Station

Public safety
Emergency services

Construction safety
Tunnel and buildings

Traffic safety
Surroundings of station

External safety
End of tunnel

Rail safety
Track



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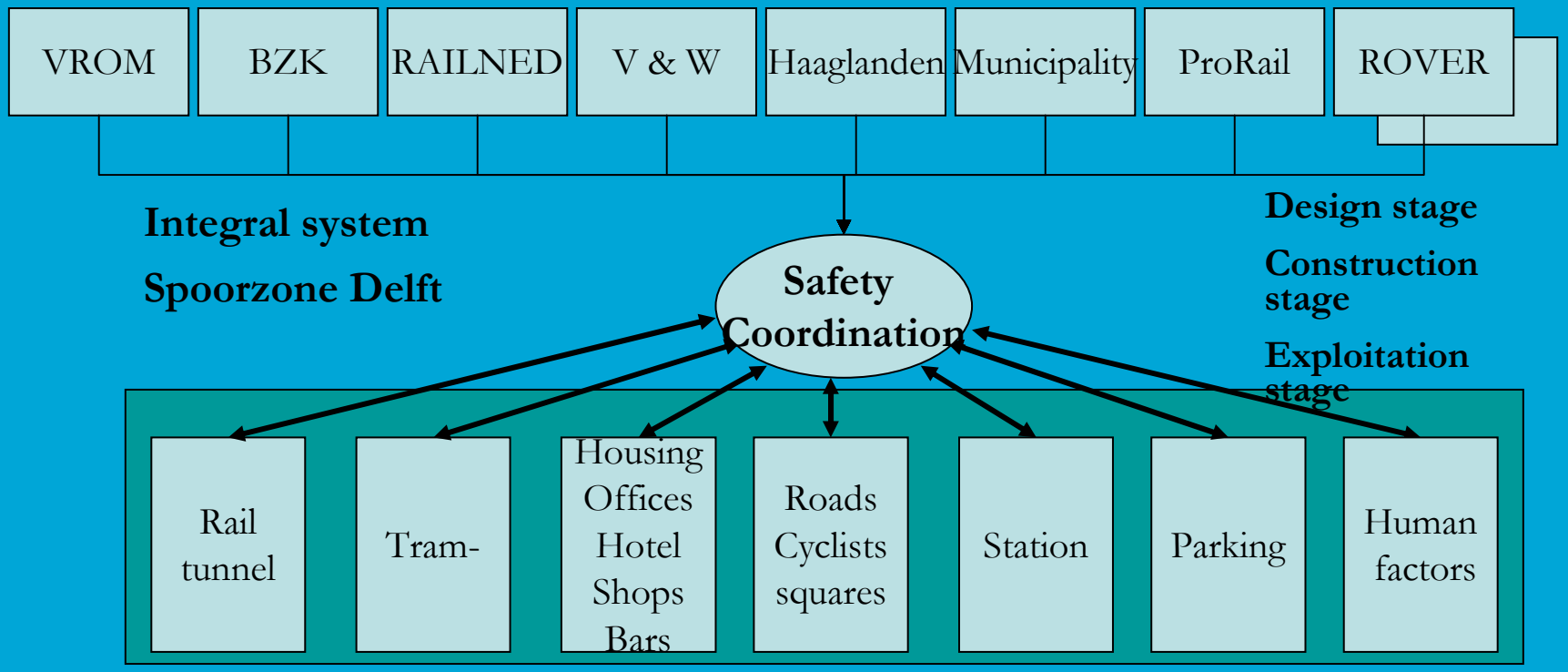
# Delft - Integral safety



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# Safety studies

- Safety concept (2001)
- Quickscan Safety (2002-2003)
- Self rescue concepts (CFD-calculations)
- Program of safety requirements (2006)



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# Quickscan Spoorzone Delft (1)

| Quickscan veiligheid ('++' = hoger veiligheidsniveau, '--' = lager veiligheidsniveau, 'OO' = gelijk veiligheidsniveau) | | |
|---|---|---|
| | **Spoorviaduct & omgeving** | **Nieuw gebied Delft Centraal** |
| ***Interne veiligheid*** | | |
| - Botsing | OO | |
| - Ontsporing | -- | ++ |
| - Brand | ++ | -- |
| - Aanrijding | OO | |
| - Ongevallen met in- en uitstappen | OO | |
| - Wateroverlast | OO | |
| - Explosie | ++ | -- |
| - Elektrocutie | OO | |
| - Gaslekkage en/of bedwelming | ++ | -- |
| - Onbeheerste stop | OO | |



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# Quickscan Spoorzone Delft (2)

| Quickscan veiligheid ('++' = hoger veiligheidsniveau '--' = lager veiligheidsniveau) | | |
|---|---|---|
| | **Spoorviaduct & omgeving** | **Nieuw gebied Delft Centraal** |
| ***Externe veiligheid*** | | |
| - Explosie | -- | ++ |
| - Vrijkomen van giftige stoffen | -- | ++ |
| - BLEVE | -- | ++ |
| - Brand | -- | ++ |
| - Ontsporing | -- | ++ |
| ***Sociale veiligheid*** | | |
| - Criminialiteit | -- | ++ |
| - Discomfort | -- | ++ |

# Case 2: Project HSL-Zuid

- Project organisation HSL-Zuid
- Characteristics project HSL-Zuid
  - Route with lots of civil structures (tunnels a.o.)
  - National and international transport
  - Type of contracts
- Bored tunnel Green Hart



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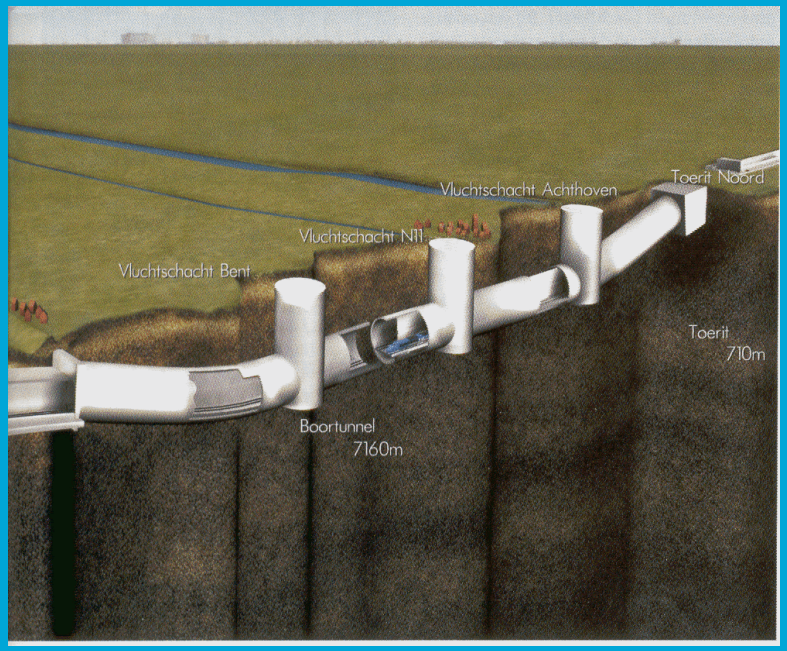
# Aiming at Safety

- Integral safety Plan (ISP)
- Safety standard
- Safety chain
- Type of accidents:
  - clash
  - fire
  - derailment
  - collision



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# Safety standard

1. Probabilistic approach
2. Deterministic approach

   ( Develop normative scenarios )
3. ALARA-principle (As Low As Reasonable Achievable)



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# Accident type: Derailment

- No level crossings
- Minimal amount of switches
- Train Control System
- Hotbox-detection in train
- Derailment provision in track
- Robustness of trains



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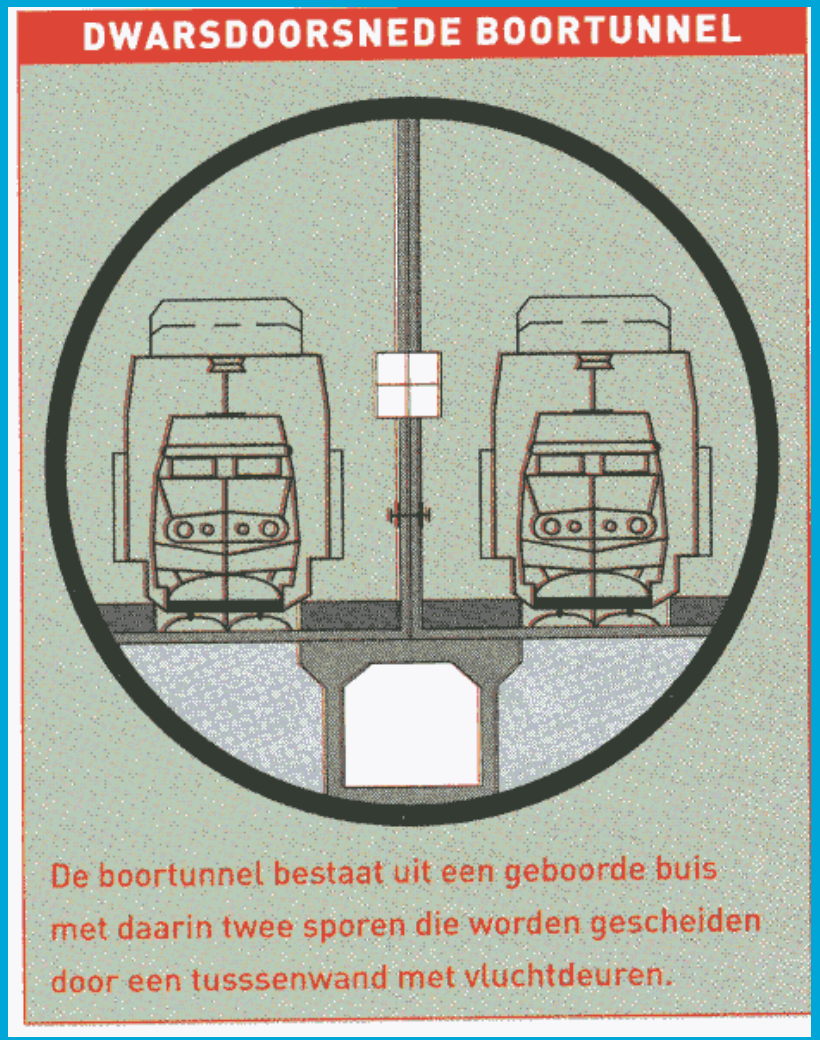
# Strategy by fire

1. Prevention
2. Self rescue
3. Aid and assistance



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# Ability to evacuate oneself

- 5 different fire curves
- Evacuation time from train: 2 minutes
- Width of emergency route: 1,50 meter
- Distance to emergency door: 150 meter



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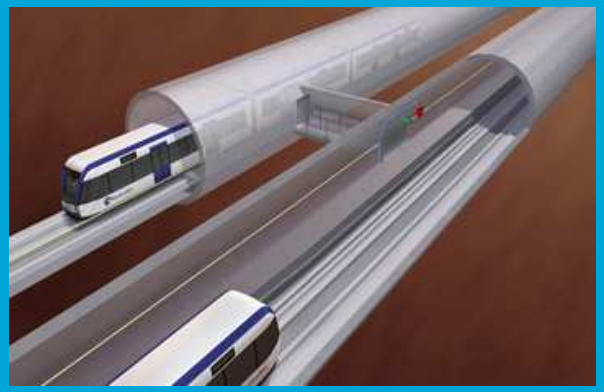
# Case 3: Randstadrail

- Lightrail system Rotterdam - Den Haag
- Tunnel of 3 km (incl. TBM driven part)
- Via Central Station, Statenweg Station to Kleiweg



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# Characteristics metro system

- Closed system (vehicles, operator, etc.)
- Stations every 1000 meter (or less)
- Travel time of 1,5 –2 minutes between stations)

Consideration:

" What scenario to facilitate to evacuate oneself?"



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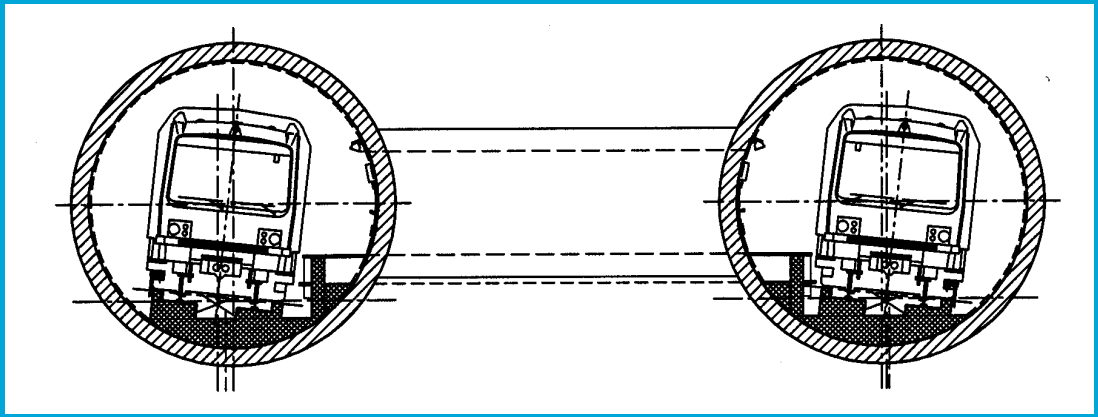
# Option: Evacuation from tube



- Greater diameter:
  - Wider escape routes
  - More room for smoke outlet
- Installation of ventilation
- More cross connections



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# Safe Haven Concept

- Measures to prevent departure of malfunctioning metro trains
- Measures to prevent metro train from stopping in the tunnel
- Exploitation model in which the metro train is always able to reach the next station (**free ride**)
- Optimal ability to evacuate oneself in stations



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# Use of scenario analysis (1)

- How is fire started?: historical data
- How can fire be detected?
- How do metro trains fail and come to a halt in tunnels?
- How could the ability to evacuate oneself and the aid and assistance at stations be optimized?
- What else is there to improve?



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# Use of scenario analysis (2)

- Systems at the station for detection of heat in the lower bodywork of the metros
- Convert emergency break bridge
- Improve maintenance procedures
- Surveillance in trains and on platforms with cameras or personnel
- Material requirements for redundancy



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# Case 4: Utrechtse Baan



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# Risks layered use of land

Risks during construction period (crossing road)

- Distraction of road users
- Dropping construction parts / waste
- Collision of assisting constructions
- Overload of assisting constructions
- Fire



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# Risks multispace use

## Risks during normal use (1)

- Explosion LPG-lorry under / in front of superstructure
- Burning vehicle under / in front of superstructure
- Inconvenience for users of building
- Distraction road users
- Abrupt transition open-closed
- Falling objects from buildings on road

# Risks layered use of land

Risks during normal use (2)

- Fire central under superstructure
- Maintenance road surface
- Maintenance facade of building



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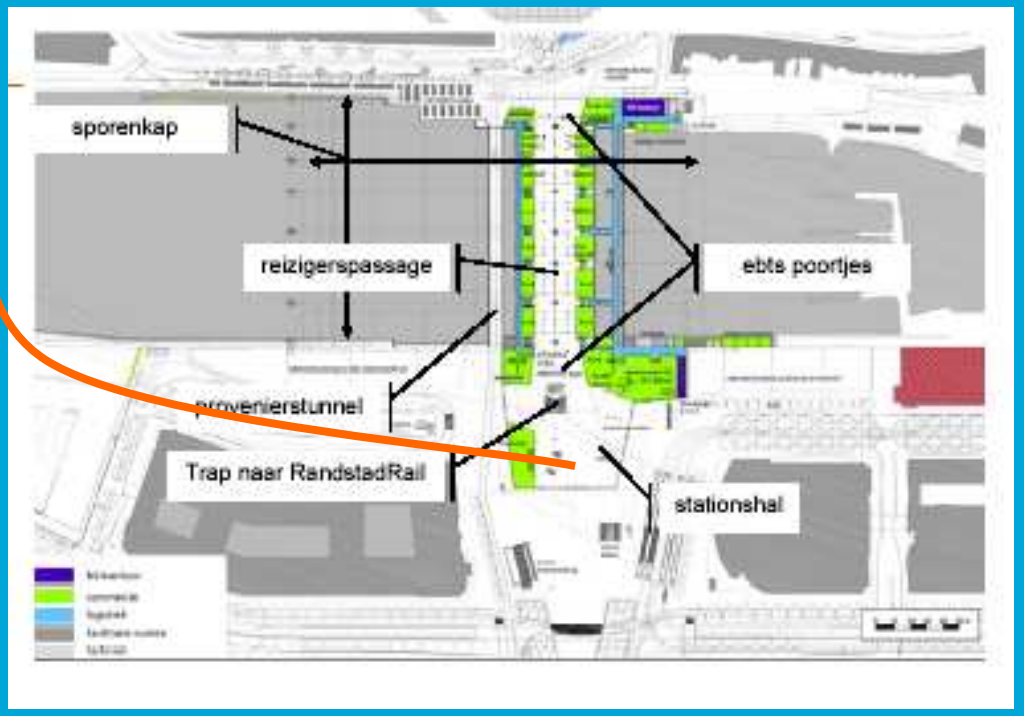
# Case 5: Rotterdam CS

Rotterdam Centraal

- Train (+1),
- Shops (0)
- Metro(-1),
- Bus (0),
- Taxi (0),
- Cycles (-1),
- Kantoor(+1),
- Café, (+1)

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# Concluding Remarks

- **Safety process**:
  - Cooperation stakeholders for guaranteeing safety (design as well as the exploitation stage)
  - Already in the design stage the safety aspect should be taken into account.
- **Cost-effective** and systematic approach. Safety is expensive!
- **Interaction** between components of the system.
- Human factors

Arnhem (22-11-06)



Rotterdam (21-11-06)



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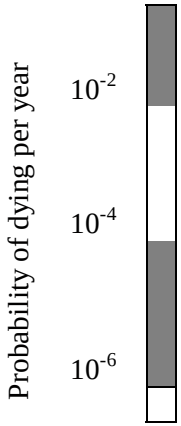
# Policy factor




| Statistics of causes of death | Acceptance of risk | Policy factor |
|---|---|---|
| Mountaineering | high ↑ voluntariness ↓ low; yes ↑ direct benefit ↓ no | $\beta_i = 100$ |
| illness | | $\beta_i = 10$ |
| motoring | | $\beta_i = 1$ |
| flying | | $\beta_i = 0{,}1$ |
| factory | | $\beta_i = 0{,}01$ |



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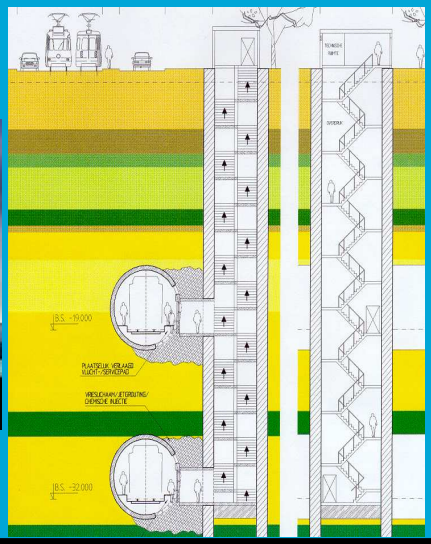
# North/Southline

- Metro line from the north of Amsterdam to the south (9km)
- Bore tunnel of 6km in length
- Separate directions of traffic
- Cross section or a station each 350m



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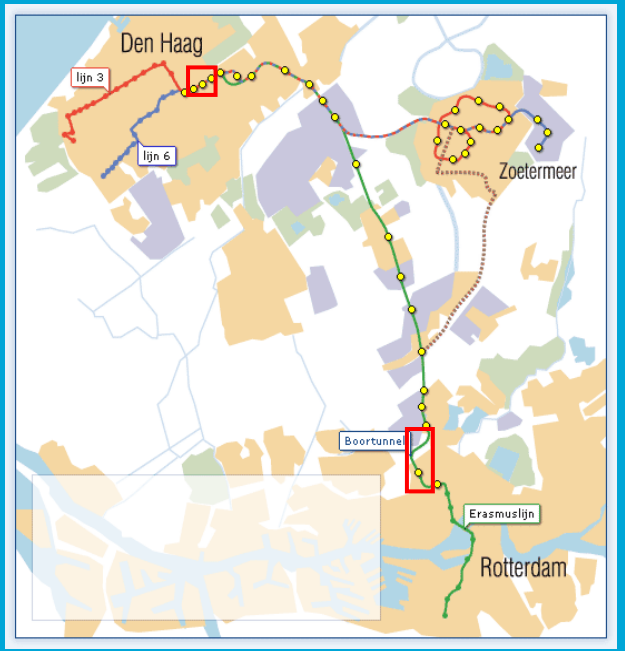
# RandstadRail

- LightRail connection between the Hague, Rotterdam and Zoetermeer.
- Both tram as LightRail vehicles
- Two tunnels:
  - Haagse tramtunnel
  - Statenwegtunnel




*RandstadRail track*



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# Haagse tramtunnel – the Hague

- Tramtunnel through the centre of the Hague (1,2 km)
- Two directions of traffic in tunnel (level -2)
- Each 60m emergency exits to the above laying car park (level -1)



*Haagse tramtunnel*



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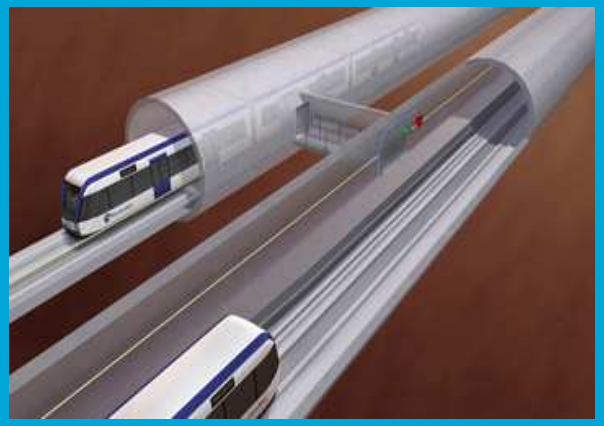
# Statenwegtunnel - Rotterdam

- The bore tunnel connects Rotterdam Central Station to LightRail track to the Hague.
- Connected to Rotterdams metro system
- Bore tunnel: separate directions of traffic with a length of 3km.
- Every 350m cross-sections.

*Track Statenwegtunnel Rotterdam*





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# Safety in tunnels- Dutch legislation

Wet aanvullende regels veiligheid Wegtunnels (WARVW)

- Part A (Process demands)
- Part B (Safety demands/standards for road and rail tunnels)

Two research methods (compulsory):

- Scenario analysis (road/rail tunnels)
- Quantitative risk assessment (no standard model)

# Normative scenario for fire

Maximum of 2000 persons on the train

- Fire in the back of the train
- Safe within 15 minutes
  - Train stops outside of the tunnel
  - Train stops within 5 minutes from the start of the fire in the tunnel; evacuation within 10 minutes



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