

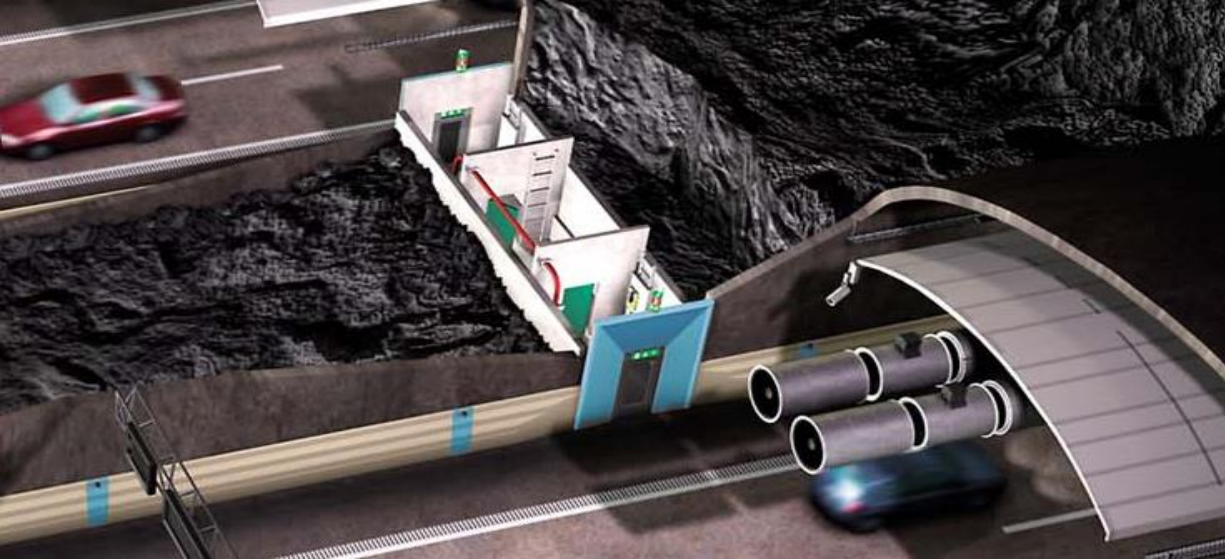
RAMS Analyses of Complex Technical Systems in Underground Facilities



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Introduction

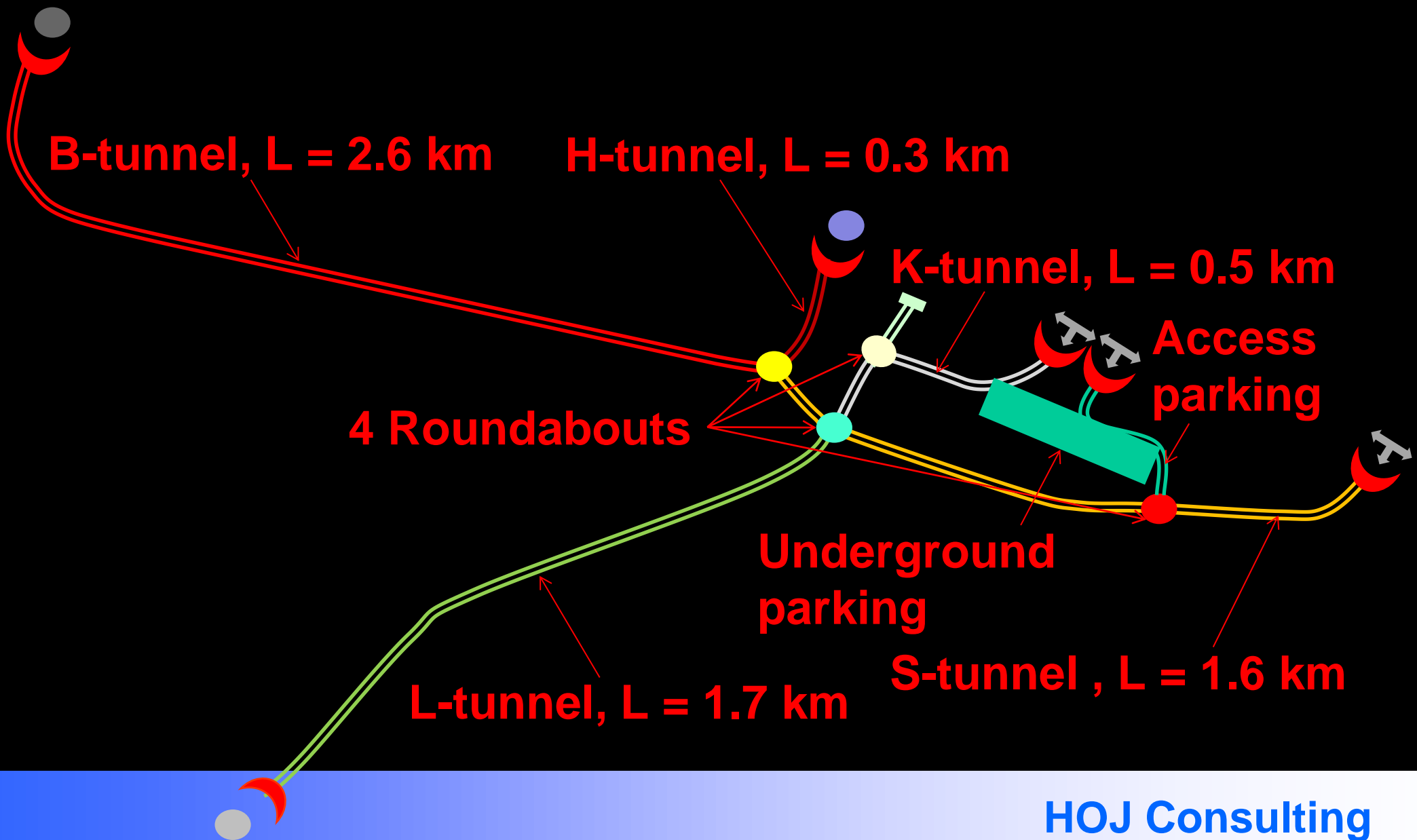
- **Underground facilities:**
- **Road, rail and metro tunnels, other underground facilities (shopping areas, underground access tunnels ...)**
- **Underground facilities might be complex in their geometry: network of tunnel tubes, etc**



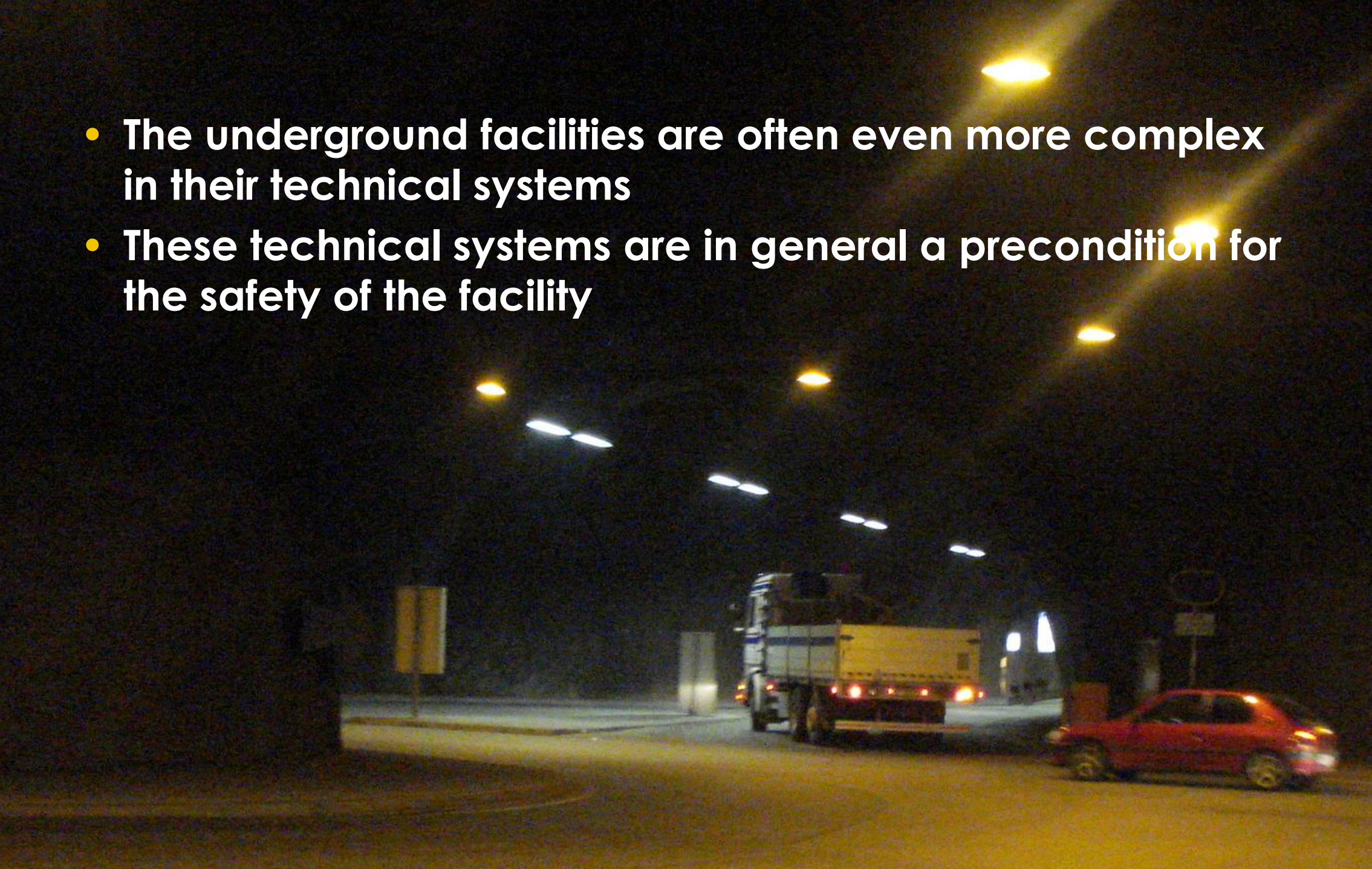
Complex: Composed of many components/units working together

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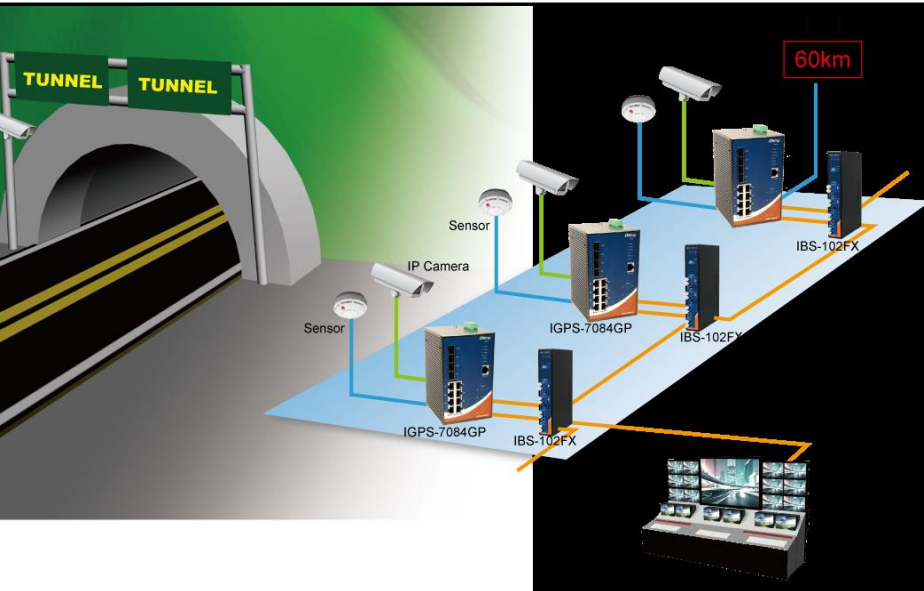


- The underground facilities are often even more complex in their technical systems
- These technical systems are in general a precondition for the safety of the facility



Safety Systems in Tunnels

- Different types of equipment
- Prevention, detection, self rescue, consequence mitigation, access, emergency response.



Prevention of traffic accidents, fires etc.

Detection of accidents and other

Self rescue / escape

Mitigation of consequences once an accident has happened

Access for assisted rescue

Emergency response and fire fighting

Safety systems in order to fulfil safety requirements

- Risk analyses as the basis for establishing level of safety equipment
- I.e. based on risk acceptance criteria
- Alternatively based on cost efficiency / ALARP
- Is the safety system/ component necessary or does it add an extra safety?
- Say, the underground facility is just acceptable, then all safety systems will be necessary



Safety systems in order to fulfil safety requirements

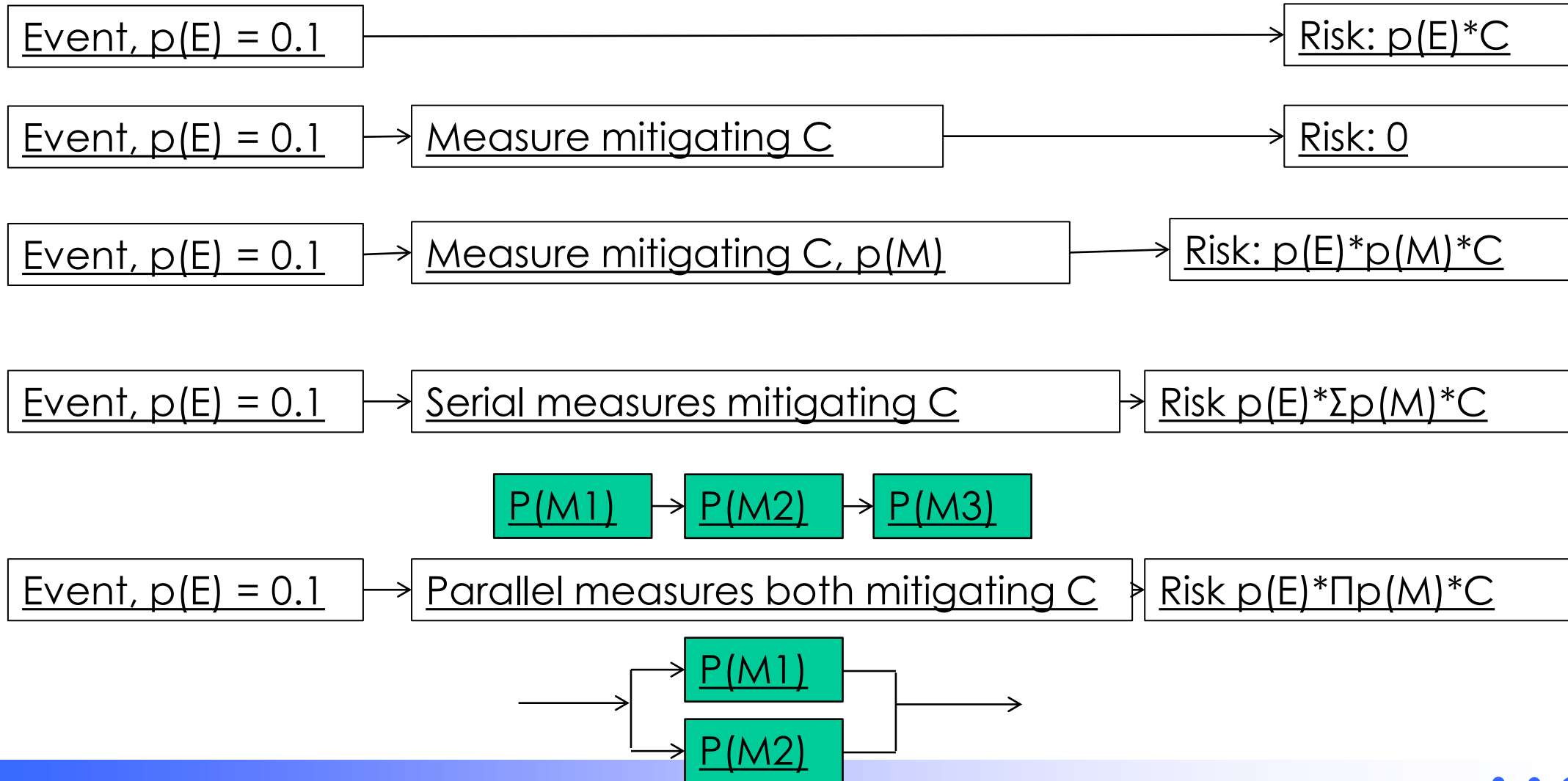
- **Safety systems without reserves:**

Failure of any system will result in a risk beyond the limit, whereby operation of the facility ought to be stopped

- **Safety systems with reserves:**

Failure of part of the system may be tolerated. As a condition for the operation, the extent of the partial failure must be specified.

Systems, reliability and availability



All $p(M)$ are $\ll 1$ and independent

Availability

- **Percentage of the time where the systems works – and that it is present (maintenance, repair, etc.)**
- **Some safety systems have inherent high availabilities (passive systems)**



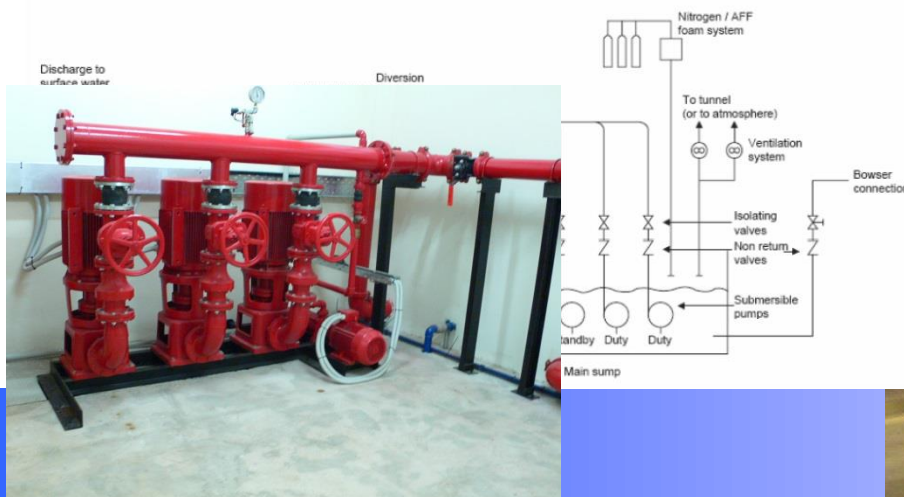
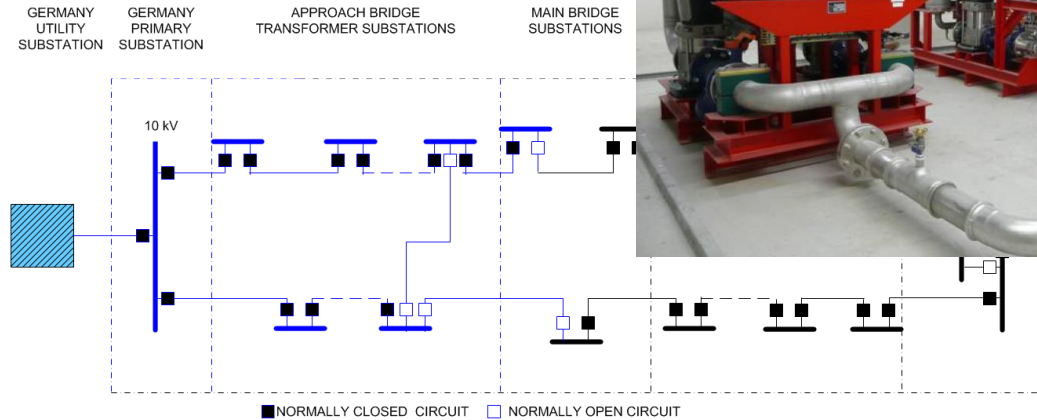
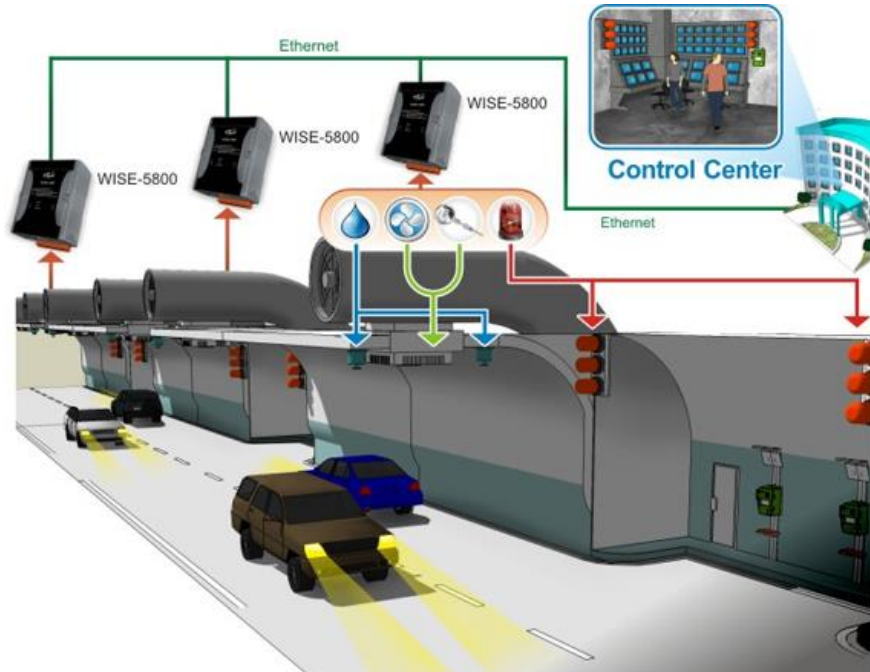
Structural fire protection by isolation and fire design: availability 1.0

Active systems for fire protection: the systems will have some unavailability (often small)

Dependencies

- Say, $P(\text{accident})$ 0.5 /year, $P(\text{no power})$ 1 h/year
- By assumption of independence:
- $P(\text{accident in the same hours as no power}) = 0.00005$
- But $P(\text{accident given no power, i.e. no light ...})$ may well be much higher.
- The emergency power may have a long time between failures (based on standardised tests), but this may not be the same as the failure probability on demand

Is a road tunnel system complex?



- Traffic monitoring
- Camera
- Air quality monitoring
- Anemometers
- Smoke detection
- Fire detection
- Lighting
- Ventilation
- Traffic management
- Radio
- Drainage
- Signals
- Fire fighting
- Radio-Communication systems
- Mobile phone coverage
- Power supply

Reliability and availability of underground facilities

- The reliability of the safety systems must be taken into account in the consideration of the equipment level (possible redundancies)...
- If the required safety of the underground facility is achieved because we have introduced safety systems, then these systems must be available.
- If a crucial system/component is not functioning, then the underground facility is no longer available
 - and the operation must be restricted.
- Do we systematically apply this?

RAMS

- **What is RAMS / EN 50126**
- **RELIABILITY, AVAILABILITY, MAINTAINABILITY AND SAFETY**

A formalized system assessment – associated to different project phases in the lifetime of the system.

RAMS includes parts of general risk assessments

Basis

RAMS Process

Structure and procedure

RAMS

14 Phases in the life cycle of a technical facility:

Phases 1-5 → Formal „Risk Assessment“ – Decision making

Phase 6 → Planning risk reducing measures and technical equipment

Phases 7-10 → Implementing, Validation

Phase 11-14 → Operation, Maintenance, Adoptions.

S (SAFETY) in RAMS

Safety of users is ensured by performing a risk analysis:

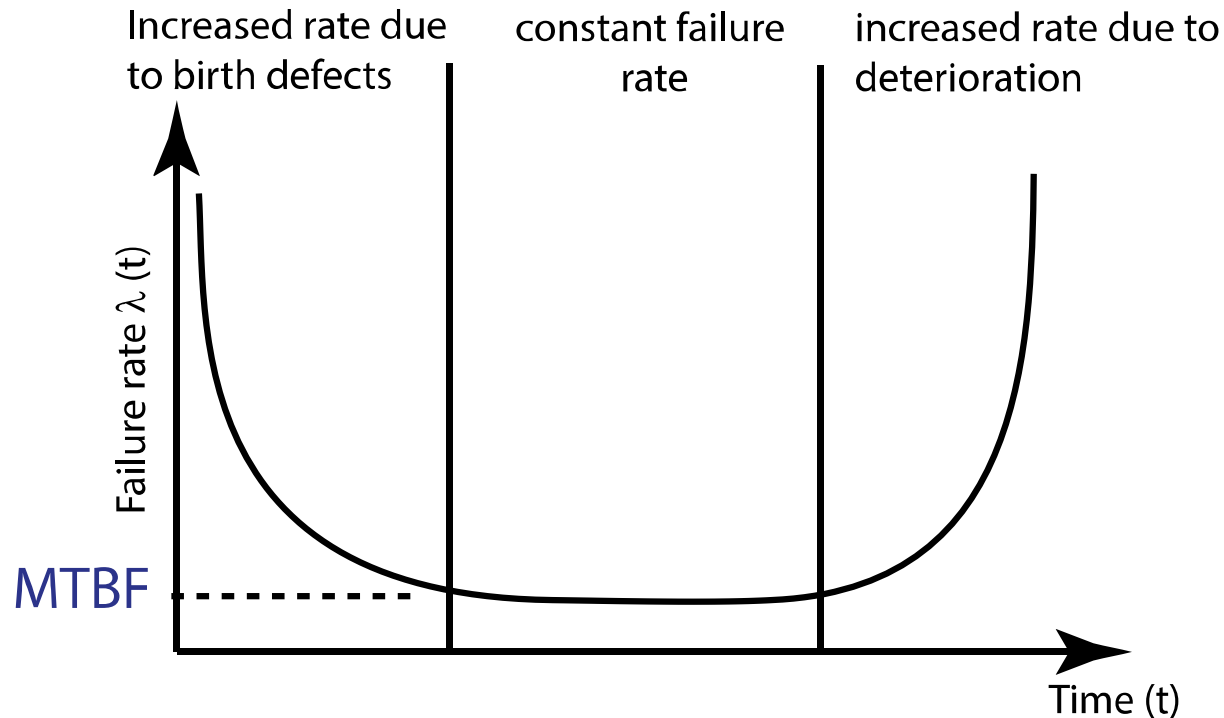
The risk to the users shall be determined based on the risk analysis.

The risk analyses can determine the equipment level and shall take the unavailability of safety related components into account.

The risk analysis should take the special system, operating and maintenance characteristics into account.

A (AVAILABILITY) in RAMS

- MTBF: Mean Time Between Failure (Weibull Modell)



- If we consider N_0 Elements at time $t=0$ and $N(t)$ elements at time t are still working, the survival probability $R(t)$ is assessed as:

$$\frac{N_0}{N(t)} = R(t) = e^{-\lambda t}$$

- The mean failure rate is in general assessed by experiments and observations:

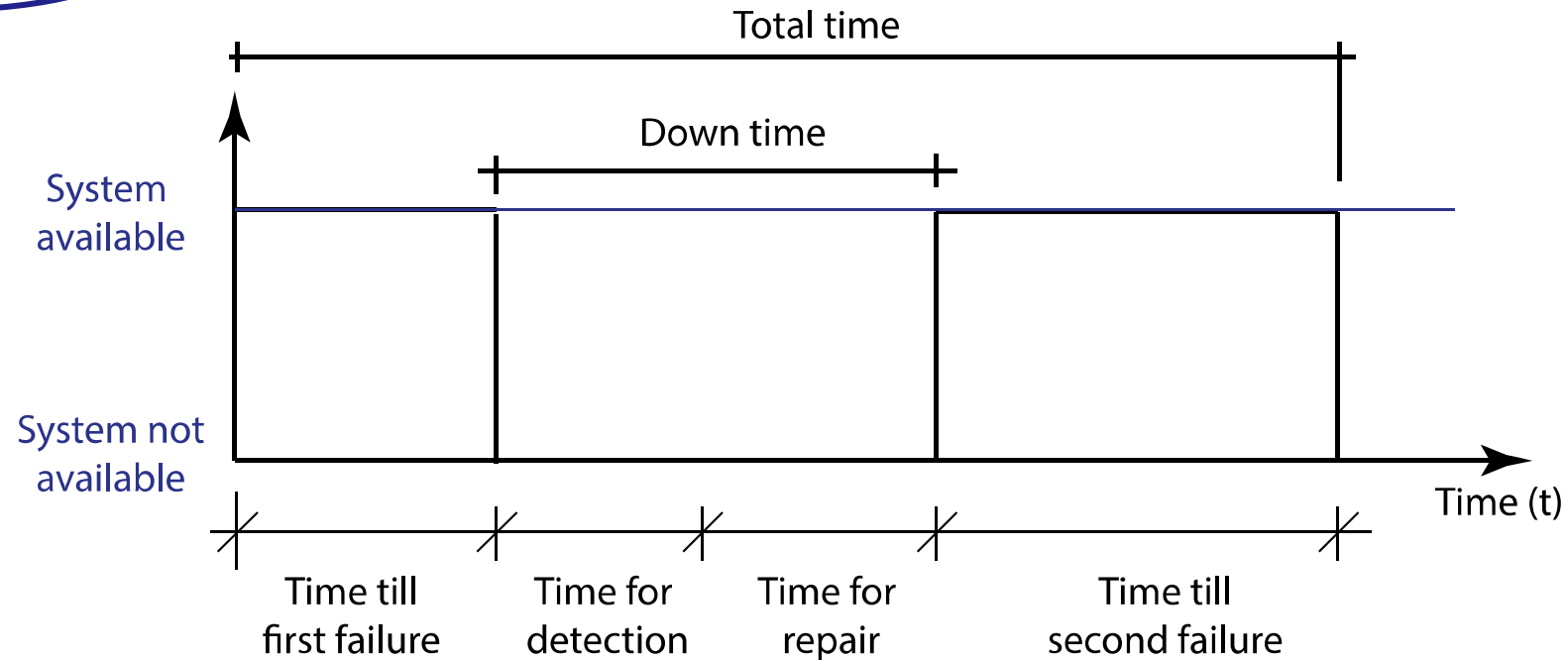
$$\frac{-\ln\left(\frac{N_0}{N(t)}\right)}{t} = \lambda$$

- Only valid if the components are maintained, etc.

A (AVAILABILITY) in RAMS

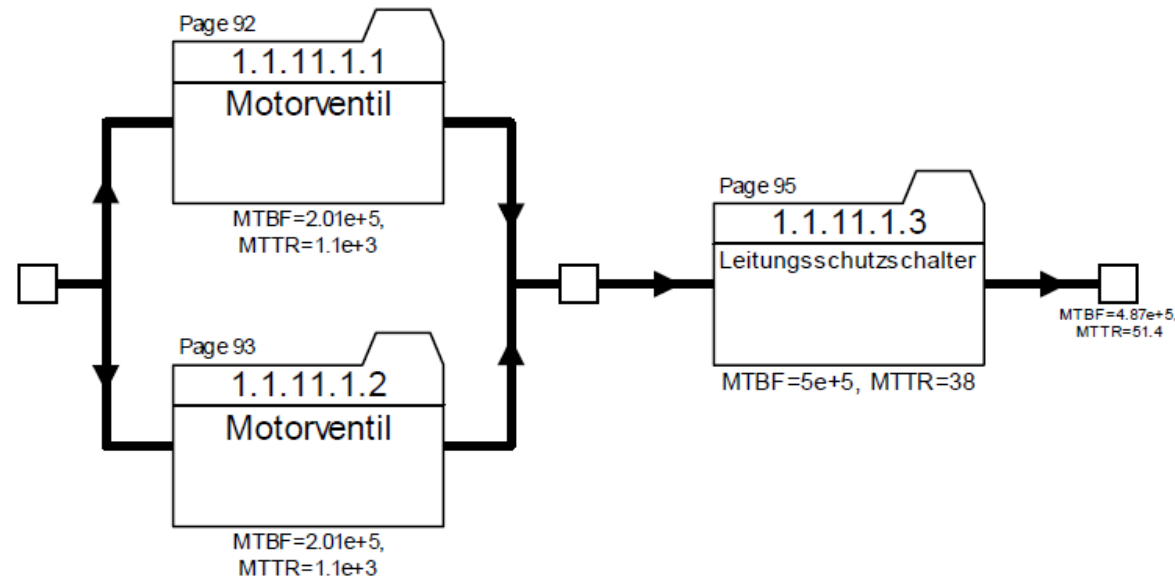
$$1 - A = \frac{MTBF}{MTBF + \text{Down time}}$$

Down time



A (AVAILABILITY) in RAMS

Availability is then assessed by representing the system (e.g with Reliability Block Diagram, Fault Tree Analysis, etc.)



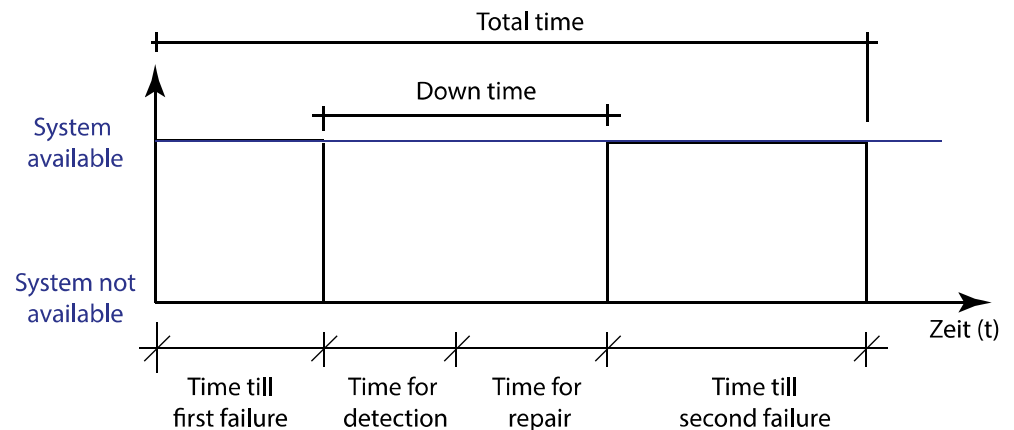
Aspects of common cause failures etc. can/should be considered.

M (MAINTAINABILITY) in RAMS

- Maintenance and repair have an influence on availability (down time)
- Maintenance has an indirect or direct influence on safety
- The analytical model of the complex system can help to minimize the maintenance times

Procedures for Maintenance

Stockholding



A (AVAILABILITY) in RAMS

Is “more” truly “more” in terms of availability?

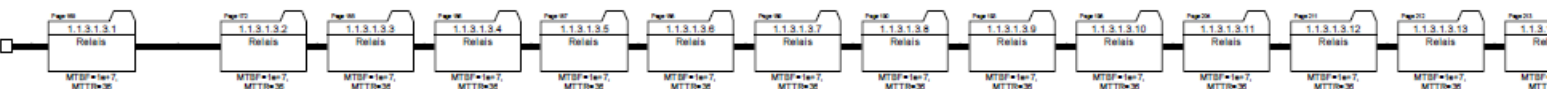
The more components (serial) the less available a system is.

More safety related components can also lead to more “false negative” alarms and accordingly down-times.

More safety related components can help to increase safety – but it is of important that the benefit of these components is explicitly modeled.

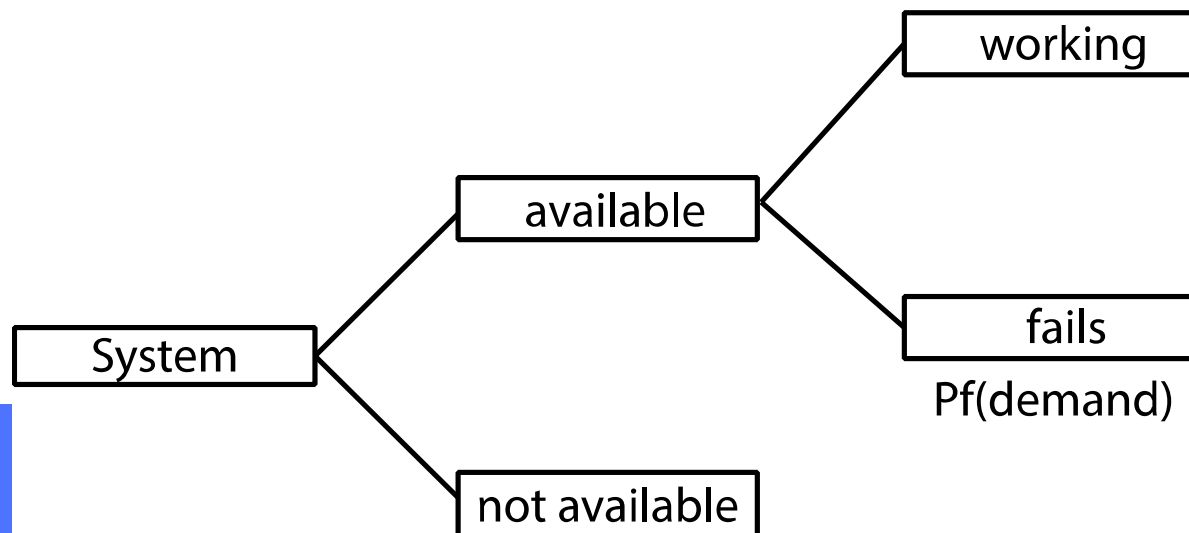
In systems we can increase availability by using fail safe components.
In complex systems fail safety can not be reached specified.

Spannungsumschaltung
von BMFS Master bzw. Slave



R (RELIABILITY) in RAMS

- Reliability/ Availability are close connected.
- Availability often use as proxy for reliability
- System which are used on demand may be available for the general function but fail in event case.
- Failures might be caused by other causes then MTBF do consider!
- Representation of the system should consider both aspects.
- Useful to differentiate on demand components, continuous working components and combinations.



Outlook

- Until now, RAMS analyses have been used in Railway tunnels and Metro tunnels, but not systematically in Road tunnels - Why?
- Railway systems are more complex?
- Railways are more system related / more "top controlled"?
- Focus on time tables / avoidance of delays.
- Different traditions?
- Different safety culture?
- Would a similar consideration be beneficial?
- Will it become relevant in case of more sophisticated/active controlled safety systems?

Points of view

- The need for a systematic consideration of “RAMS” exists in all complex underground facilities.
- In road tunnels the need is increasing due to the ever increasing equipment level and the demands for safety.
- Without a systematic consideration the availability of often (unconsciously) assumed to be 1.0
- A proper consideration of minimum availability for continued operation is often missing in practice.
- Risk analyses have become common, -by logic the risk analyses cannot be conducted without a consideration of the availability.
- Conversely the acceptable level of unavailability of safety systems cannot be decided without risk analyses.

Points of view

- A kind of RAMS process can ensure
 - a better understanding of the function of the system and system interaction (e.g. common cause failures)
 - a more robust system design (maximize availability)
 - more safety for road users.

Conclusion

- We hope we with this presentation have given some food for thought
- - or for discussion.
- Thank you for your attention!