

Optimised maintenance intervals

P1-O1

Brief description

Optimised or preventive maintenance through regular care and inspection at defined maintenance intervals is based on empirical values and the expected service life of components and system parts.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Beyond the maintenance interval in the RABT, in the course of additional maintenance intervals or those based on experience, accident damage/defects can be repaired more quickly and additional visual and functional checks can be carried out.

Synergy effects

- Security
Failure or malfunction of the tunnel operating technology, structural damage, etc. entail additional risks that can be identified and eliminated more quickly through optimised maintenance intervals.
- Cross-object
No
- cross-threat
Yes

Feasibility

Responsible: Tunnel Manager

An organisational measure that is easy to implement in relation to other measures.

Brief description

Real-time monitoring of components and operational equipment enables identification of anomalies and patterns in their performance that indicate suboptimal use or impending system failure.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Predictive maintenance can be used to initiate the repair of affected systems and components or to replace them before a malfunction occurs.

Synergy effects

- Security
Failure or malfunction of the tunnel operating technology, structural damage, etc. entail additional risks that can be identified and eliminated more quickly and safely.
- Cross-object
No
- cross-threat
Yes

Feasibility

Responsible: Tunnel Manager

Delayed response or response only after component failure can be avoided by introducing a plant health system. This makes proactive and coordinated maintenance possible. The feasibility is organisationally, technically complex and relatively cost-intensive.

Maintenance and service management system (beyond the recommendations of the RABT)

P1-O3

Brief description

The introduction of a maintenance and servicing management system helps to ensure that all systems are regularly checked for their function. Systems for assessing asset health or communication with maintenance companies, if available, should be incorporated here.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

The availability of the tunnels can be improved, for example by ordering spare parts with long delivery times at an early stage or by informing maintenance companies at an early stage.

Synergy effects

- Security
Yes
- Cross-object
No
- cross-threat
Yes

Feasibility

Failures or malfunctions of the tunnel operating technology due to excessively long or faulty maintenance intervals can be implemented relatively easily. In particular, the unavailability of spare parts can be avoided through appropriate contractual agreements, which will, however, result in additional costs.

Installation of additional sensors to monitor the technical condition

P1-T1

Brief description

For the implementation of a maintenance and servicing management system, continuous monitoring sensors can be installed to regularly monitor all systems for their function and indicate anomalies.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

The availability of the tunnels can be improved if defective or faulty operating technology can be reacted to at an early stage.

Synergy effects

- Security
Yes
- Cross-object
No
- cross-threat
Yes

Feasibility

Failure or malfunction of the tunnel operating technology can be implemented relatively easily. The installation is relatively cost-intensive.

P2 - Preventing disruptive events

Access regulation for inventory documents	P2-O1
Brief description Prevent unauthorised access to sensitive information about the structure and functioning of operational equipment.	
Impact type <input type="checkbox"/> technical <input checked="" type="checkbox"/> organisational	
Resilience phase <input checked="" type="checkbox"/> prevent <input type="checkbox"/> protect <input type="checkbox"/> respond <input type="checkbox"/> recover <input type="checkbox"/> prepare	
Place of action <input checked="" type="checkbox"/> Tunnel construction incl. portals <input checked="" type="checkbox"/> Central system <input type="checkbox"/> Network element <input type="checkbox"/> regional environment	
Implementation <input checked="" type="checkbox"/> Building-management <input type="checkbox"/> Event-management <input type="checkbox"/> Traffic management <input type="checkbox"/> Natural hazards-management <input type="checkbox"/> Management level	
Use case <input checked="" type="checkbox"/> New building <input checked="" type="checkbox"/> Stock	
Time horizon <input checked="" type="checkbox"/> short term <input type="checkbox"/> medium-term <input type="checkbox"/> long-term <input type="checkbox"/> not relevant (for new construction)	
Effects on availability The theft of sensitive building and operational information can be used to exploit it for cyber-attacks or other acts of sabotage, massively limiting its availability or bringing it to a complete standstill.	
Synergy effects <ul style="list-style-type: none"><input type="radio"/> Security Yes<input type="radio"/> Cross-object Yes/No<input type="radio"/> cross-threat Yes	
Feasibility Relatively easy to implement through implementation of the BSI recommendations	

Restriction for transports of dangerous goods

P2-O2

Brief description

Restricting the passage of dangerous goods transports subject to labelling prevents incidents involving dangerous goods and leads to a reduction in the potential extent of damage. It must be taken into account that the rerouting of dangerous goods transports when increasing the availability of a tunnel structure can lead to economic follow-up costs due to additional transport time or additional emissions, depending on the alternative route.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

By restricting the transport of dangerous goods after an incident, the additional risk that may have arisen can be mitigated in order to continue operating the tunnel temporarily and thus achieve partial availability. Further information can be found in the AP report on minimum operating conditions.

Synergy effects

- Security
Yes
- Cross-object
No
- cross-threat
No

Feasibility

Relatively easy to implement in terms of organisation and costs.

Hazard analysis

P2-O3

Brief description

Comprehensive analysis of the relevant hazards (natural, man-made and other) in the planning phase, as well as at regular intervals throughout the operational life of a road tunnel, in order to be aware of changes in the hazard situation and to be able to react appropriately. Serves to reduce the frequency of disruptive events.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Through regular hazard analyses, necessary countermeasures can be identified and implemented to reduce the frequency of disruptive events or exclude them altogether.

Synergy effects

- Security
Yes
- Cross-object
No
- cross-threat
Yes

Feasibility

Very simple and inexpensive to implement.

Exposure analysis

P2-O4

Brief description

The exposure analysis is based on the hazard analysis and is used to assess how the tunnel is exposed to an identified hazard.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

If, based on the exposure analysis, it can be concluded that the tunnel is exposed to the hazard, the necessary countermeasures can be implemented to reduce or eliminate the frequency of disruptive events and maintain availability.

Synergy effects

- Security
Yes
- Cross-object
Yes/No
- cross-threat
Yes

Feasibility

Very simple and inexpensive to implement.

Agree availability values with service providers, e.g. electricity, data connection, water

P2-O5

Brief description

By agreeing on minimum availability levels for necessary resources such as electricity, communication and water, any bottlenecks that may limit the availability and thus the safety of tunnels can be proactively reduced.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Dangers resulting from the unavailability of essential operational resources can thus be avoided.

Synergy effects

- Security
Yes
- Cross-object
No
- cross-threat
Yes

Feasibility

Very simple but with additional costs from the necessary contract agreement.

Level monitoring**P2-T1****Brief description**

Information on (1) whether a tunnel is located in a floodplain of a watercourse and (2) on water levels at the respective watercourse can be used by the operator to reduce the frequency of disruptive events through the use of flood protection elements and to mitigate the traffic impact of flooding by taking early traffic measures such as dedicated diversion routes or recommending a switch to alternative modalities.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Reduces the impact of hydrological hazards

Synergy effects

- Security
Yes
- Cross-object
No
- cross-threat
No

Feasibility

Easy to implement: . Current information on water levels and flood hazards can be obtained from the transnational flood portal (<https://www.hochwasserzentralen.de/>) and the flood hazard maps.

Brief description

With the help of an automatic detection of overheated vehicle parts by means of infrared scanning, detected vehicles can be diverted before entering the tunnel.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Fire hazard due to overheated vehicle parts can be reduced or avoided altogether.

Synergy effects

- Security
 Yes
- Cross-object
 No
- cross-threat
 No

Feasibility

Cost estimate: For new construction and upgrading, approx. 150,000€ per lane and annual maintenance costs of approx. 5%.

Brief description

An avalanche barrier reduces the frequency of avalanches on exposed sections of the route. The basis for this is a preceding threat analysis in which avalanches were identified as a potential danger for a section of road.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Blocking of the track section, damage to the structure and operating technology and network element due to snow avalanches Departure is reduced.

Synergy effects

- Security
Yes
- Cross-object
No
- cross-threat
No

Feasibility

Good feasibility, but associated with additional costs

Rockfall protection

P2-T4

Brief description

Rockfall protection reduces the frequency of rockfalls on exposed sections of road. The basis for this is a previous threat analysis in which rockfall was identified as a real danger for a section of road.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Blocking of the track section, damage to the structure and operating technology and network element due to rockfall is reduced.

Synergy effects

- Security
Yes
- Cross-object
No
- cross-threat
No

Feasibility

Good feasibility, but associated with additional costs

Preventive avalanche blasting

P2-T5

Brief description

Preventive avalanche blasting, carried out under controlled conditions, helps to anticipate and thus prevent avalanches of unknown size or timing.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Blocking of the section, damage to the structure and operating technology and network element as a result of sudden avalanches is greatly reduced.

Synergy effects

- Security
Yes
- Cross-object
No
- cross-threat
No

Feasibility

Good feasibility, but associated with additional costs.

Higher clearance gauge**P2-T7****Brief description**

By aligning the clearance height in road tunnels to that of the open track of 4.7 m, unintentional ramming of operational equipment on the tunnel ceiling can be avoided. In addition, problems in connection with height control can be avoided as far as possible.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Protection against ramming due to excessive vehicle dimensions

Synergy effects

- Security
Yes
- Cross-object
No
- cross-threat
No

Feasibility

Only for new construction with considerable additional costs

Brief description

Detection of toxic, flammable or explosive gases in the tunnel by special gas measuring devices. The ignition or explosion of these can be prevented by appropriate defence measures (e.g. ventilation control). Likewise, the extent of the damage can be reduced by informing the emergency services in good time in the event of an incident.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Protection against fire, explosion, release of hazardous substances

Synergy effects

- Security
Yes
- Cross-object
No
- cross-threat
No

Feasibility

Rough estimated costs for new construction and upgrading: Investment costs: approx. 100,000 € per km and maintenance/year approx. 10%;

Test environment for software updates

P2-T9

Brief description

Software updates and changes to the configuration are first tested in a test environment and only transferred to the productive systems after the tests have been completed. Test environments can consist of physical and virtual components and should represent the real environment so accurately (state of HW, FW, SW, configuration) that errors can be detected before the new software is deployed in a tunnel.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Avoiding failure or malfunctions due to faulty or incompatible hardware and software in control centres

Synergy effects

- Security
Yes
- Cross-object
Yes
- cross-threat
No

Feasibility

Good feasibility, whereby the test environment (e.g. digital twin) causes relatively high costs.

Avoid large longitudinal slopes**P2-T10****Brief description**

High longitudinal slopes increase the extent of damage in case of fire and accidents (increased speed profile)

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Reduction of accident frequency and fire risk

Synergy effects

- Security
Yes
- Cross-object
No
- cross-threat
No

Feasibility

Only feasible in new buildings during the planning phase depending on the boundary conditions
high costs

Brief description

Identify, classify and prioritise vulnerabilities in the tunnel structure, operational equipment and central systems, especially against the background of relevant threats identified in the hazard analysis. Findings from the analysis should inform monitoring and maintenance management to reduce damage scenarios and impacts on functionality.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Reduction of long downtimes

Synergy effects

- Security
 - Indirect effects
- Cross-object
 - No
- cross-threat
 - Yes

Feasibility

Easy to implement at low cost

Brief description

Protection against unauthorised access through access control and protection. e.g. key issuance to tunnel building and tunnel control room with recording of personal information (ID card, telephone number), access only after prior notice, two-factor identification, access monitoring by means of video (also of fire brigade key depots, exit from emergency exits).

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Protection against sabotage and theft

Synergy effects

- Security
 - Yes
- Cross-object
 - No
- cross-threat
 - Yes

Feasibility

Easy to implement at low cost

Brief description

Measures to counteract the consequences of a pandemic (and e.g. flu epidemics), which could result in a shortage of staff, e.g. operators.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Avoid missing (operating) staff

Synergy effects

- o Security
No
- o Cross-object
Yes
- o cross-threat
Yes

Feasibility

Easy to implement at low cost

Brief description

In the event of exceptional exposure, strong winds can impair the performance of the tunnel ventilation for the removal of smoke or pollutants. They can also endanger traffic safety when entering and leaving the tunnel. Windbreak panels can help reduce the wind load in the portal area and the tunnel interior for certain wind directions.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Protection against reduced ventilation performance in the event of a fire.

Synergy effects

- Security
No
- Cross-object
No
- cross-threat
No

Feasibility

Easy to implement at low cost

Brief description

In the event of exceptional exposure, strong winds can impair the performance of the tunnel ventilation to remove smoke or pollutants. They can also endanger traffic safety when entering and leaving the tunnel. Special weather stations can monitor the wind speed in the portal areas and react directly to wind loads with speed restrictions by integrating them into the traffic control system. Integration into the control centre also makes it possible to adapt the control of the ventilation to unfavourable flow conditions in the event of a fire.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Protection against reduced ventilation performance in the event of a fire.

Synergy effects

- o Security
No
- o Cross-object
No
- o cross-threat
No

Feasibility

Easy to implement at medium cost

Ram protection

P3-T3

Brief description

In order to prevent vehicles from hitting operational equipment elements, a solidly designed impact protection will be installed in the portal area before the entrance to the tunnel.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Damage to the structure and operating technology as a result of pile driving and excessive vehicle dimensions

Synergy effects

- Security
No
- Cross-object
No
- cross-threat
No

Feasibility

Easy to implement at medium cost

Brief description

Reduction of the extent of damage and thus also the duration of restoration through, for example, proof of slope and embankment stability in the portal area, conceptual and constructive measures to avoid inadmissible stresses through joints or friction-locked connections, design for sufficient overburdening in the rock, securing operational equipment against overturning. The basis for this is a preceding threat analysis in which earthquakes were identified as a real danger for the tunnel structure. As of today, there is no construction standard for the seismic design and construction of tunnels in Europe.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Damage to the structure, operating technology and people as a result of earthquake damage is reduced so that it is possible to return to the original availability more quickly.

Synergy effects

- Security
No
- Cross-object
No
- cross-threat
No

Feasibility

Easy to implement at medium cost

Protective measures against water ingress in the tunnel**P3-T5****Brief description**

Avoidance of structural damage due to water pressure, damage to operational equipment in case of leakage and traffic impacts in case of water in the tunnel. The basis for this is a preceding threat analysis in which high water levels were identified as a real danger for the tunnel structure. Protective measures against water and tunnel drainage must be planned in accordance with ZTV-ING. If there is a particular risk from hydrological natural hazards, an adapted design of the drainage system can be useful, especially for tunnels with low points along the longitudinal axis of the tunnel.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Damage to the structure, operating technology and people as a result of earthquake damage is reduced so that it is possible to return to the original availability more quickly.

Synergy effects

- Security
No
- Cross-object
No
- cross-threat
No

Feasibility

Easy to implement at medium cost

Brief description

Automatic fire-fighting systems in the form of high-pressure water mist systems can stop the development of a fire if used correctly, which keeps the size of the fire smaller and prevents it from spreading to other vehicles. This makes it much easier for the fire brigade to operate on site. Due to the containment of the fire and thus the heat development, the tunnel structure is also protected from damage.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Damage to the structure, operating technology and people as a result of fires is greatly reduced.

Synergy effects

- Security
No
- Cross-object
No
- cross-threat
No

Feasibility

Cost estimate: New construction: investment costs of €100,000 per reservoir with pumping equipment and €3,000-4,000 per tunnel metre and tube for pipelines, nozzles and fittings. Maintenance costs of 5%

Flood protection elements**P3-T7****Brief description**

Flood protection elements can minimise traffic impact and the extent of damage during floods.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction
incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Protection against flooding to reduce damage to the structure and business equipment

Synergy effects

- Security
No
- Cross-object
No
- cross-threat
No

Feasibility

Easy to implement at medium cost

Brief description

Reduction of the extent of damage and thus also of the restoration period, e.g. by designing for explosion loads, construction of a facing shell made of micro-reinforced high-performance concrete, the use of fire-protective concrete, fire-protective cladding, use of damper concrete or double-shell construction.

Impact type

- technical organisational

Resilience phase

- prevent protect respond recover prepare

Place of action

- Tunnel construction incl. portals Central system Network element regional environment

Implementation

- Building-management Event-management Traffic management Natural hazards-management Management level

Use case

- New building Stock

Time horizon

- short term medium-term long-term not relevant (for new construction)

Effects on availability

Reduction of the extent of damage and thus also of the recovery period

Synergy effects

- Security
No
- Cross-object
No
- cross-threat
No

Feasibility

Easy to implement at high cost

Brief description

Reduction of the extent of damage and thus also of the restoration period, e.g. by designing for higher fire loads, construction of a facing shell made of micro-reinforced high-performance concrete, the use of fire-protective concrete, fire-protective cladding or double-shell construction.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Reduction of the extent of damage and thus also of the recovery period

Synergy effects

- Security
No
- Cross-object
No
- cross-threat
No

Feasibility

Easy to implement at low cost

Protection of safety-related equipment in the tunnel against physical access

P3-T10

Brief description

Access control reduces the extent of damage by quickly detecting unauthorised (malicious) access to operational equipment and preventing or reducing the effects of sabotage.

Physical monitoring, e.g. of manhole covers, can be carried out using fibre optics for early detection of manipulation or sabotage. Control by means of video surveillance or detection is also possible (for individual access points).

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Protection against manipulation, damage, theft

Synergy effects

- Security
No
- Cross-object
No
- cross-threat
No

Feasibility

Medium level of difficulty for implementation and costs

Soft stop barrier**P3-T11****Brief description**

Effectively prevents further vehicles from entering the tunnel, while red lights in front of the portal are often ignored and the barrier gates do not lower due to flowing traffic. The soft stop barrier was first used at the Sydney Harbour Tunnel in the form of a water curtain with a projected stop sign. The visual barrier effect can also be achieved by (red) illuminated LED strips in the carriageway at the portal. Such a system is currently being tested in Luxembourg.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Protection against entry in hazardous situations

Synergy effects

- Security
Yes
- Cross-object
No
- cross-threat
Yes

Feasibility

Easy to implement at medium cost

Brief description

Regular exercises help to prepare the rescue forces for operations in road tunnels. According to the RABT, realistic large-scale exercises should take place at least every 4 years, whereby accident scenarios with and without hazardous materials or fire incidents are usually tested. The measures serve to reduce the resulting extent of damage to users and structures. Effective protection of the structure (e.g. cooling of the concrete components) can improve the recovery time to the original functionality.

To avoid a complete tunnel closure for operational exercises, these can also be carried out at a fire training centre

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

In this way, emergency forces gain relevant experience and prepare themselves for extraordinary events (e.g. unavailability of BOS radio in the event of a major fire) in tunnels and go into the incident management prepared.

Synergy effects

- Security
Yes
- Cross-object
No
- cross-threat
Yes

Feasibility

Easy to implement at low cost

TLZ operators training, training of personnel for emergency operating from the master workshop

M1-O2

Brief description

The training measures are intended to prepare the operators for dealing with incidents. In addition to technical knowledge, they must also have a high level of resilience and decision-making skills, especially in the case of extraordinary events in the tunnel. With the help of a tunnel simulator, the handling of defined events in a tunnel can be specifically trained. In addition to the usual traffic threats, extraordinary hazardous situations should also be practised.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Operators thus gain relevant experience and prepare themselves for extraordinary events and go into event management prepared so that availability suffers only minor restrictions.

Synergy effects

- Security
Yes
- Cross-object
No
- cross-threat
Yes

Feasibility

Easy to implement at low cost

Video surveillance of tunnels with a length < 400 m**M1-O3****Brief description**

For critical tunnels, video surveillance can also be useful for a tunnel length < 400 m. The classification for the definition of critical tunnels can be done, for example, on the basis of a tunnel code number. Parameters such as JDTV, congestion probability, cross-section, possible access/exit points, accident figures or the expected traffic impact of unavailability can be taken into account.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

The extent of damage can be reduced by shortening the response time

Synergy effects

- Security
Yes
- Cross-object
No
- cross-threat
Yes

Feasibility

Easy to implement at low cost

Detect (potential) attacks (cyber security, sabotage)**M1-O4****Brief description**

Typical indicators to prepare for an attack are:

- Spying on the target / obtaining information
- Attempt to gain access (e.g. via the escape routes, by means of copied keys or via remote / maintenance access)
- Attempt to change passwords etc.
- Simultaneous failure / impairment of independent Systems

Impact type

- technical organisational

Resilience phase

- prevent protect respond recover prepare

Place of action

- Tunnel construction incl. portals Central system Network element regional environment

Implementation

- Building-management Event-management Traffic management Natural hazards-management Management level

Use case

- New building Stock

Time horizon

- short term medium-term long-term not relevant (for new construction)

Effects on availability

By shortening the reaction time, the extent of damage can be reduced and prevented

Synergy effects

- o Security
Yes
- o Cross-object
No
- o cross-threat
No

Feasibility

Medium difficulty at medium cost

Communicating restrictions to those affected**M1-O5****Brief description**

In the event of reduced availability, operators of critical infrastructures dependent on the tunnels should be informed immediately in order not to endanger the security of supply.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

To reduce the impact of limited availability on other sectors

Synergy effects

- Security
No
- Cross-object
No
- cross-threat
No

Feasibility

Easy to implement at low cost

Access control of security equipment**M1-T1****Brief description**

Access control reduces the extent of damage by quickly detecting unauthorised (malicious) access to operational equipment and preventing or reducing the effects of sabotage. Physical monitoring, e.g. of manhole covers, can be carried out using fibre optics for early detection of manipulation or sabotage. Control by means of video surveillance or detection is also possible) for individual access points).

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Protection against manipulation, damage, theft and their effect on availability

Synergy effects

- Security
No
- Cross-object
No
- cross-threat
Yes

Feasibility

Easy to implement at medium cost

Increasing the supply of extinguishing water

M1-T2

Brief description

According to the RABT, an extinguishing water supply with a size of 72m³ is provided. In order to have sufficient extinguishing water available in the event of exceptionally large fire incidents, an increase in the size of the storage tank can be envisaged. In addition, the extinguishing water is also used in the course of tunnel washing, which means that an insufficient supply of extinguishing water is available in the period thereafter (up to one day). (The tank is emptied by about half).

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Protection from fire

Synergy effects

- Security
No
- Cross-object
No
- cross-threat
Yes

Feasibility

New construction: Easy to implement at medium costs

Stock: Difficult to implement at high cost

Stationary or mobile emergency power generator**M1-T3****Brief description**

In order to be able to continue operating all safety-related equipment in the tunnel in the event of a power supply failure (greater power than UPS system required), a diesel-powered emergency generator can be used for a certain period of time.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Protection from fire

Synergy effects

- Security
No
- Cross-object
No
- cross-threat
Yes

Feasibility

Easy to implement at medium cost

Back-up Control Centre / Redundant Tunnel Control Center**M1-T4****Brief description**

The control of each tunnel can be taken over by another redundant TCC in case of failure of the associated permanently manned unit.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Protection against failure of the TLZ

Synergy effects

- Security
 No
- Cross-object
 Yes
- cross-threat
 Yes

Feasibility

Easy to implement at high cost

Video detection

M1-T5

Brief description

Video detection is a possibility to quickly and automatically detect events such as traffic accidents or fires with smoke development (especially relevant in case of low heat development). This allows for an early and adapted reaction to the situation.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Shortened reaction time and thus reduction of the impact on the extent of damage

Synergy effects

- Security
Yes
- Cross-object
No
- cross-threat
Yes

Feasibility

Easy to implement at medium cost

Acoustic Tunnel Monitoring (AKUT)

M1-T6

Brief description

Enables the detection of untypical noises in the tunnel such as squealing or burst tyres, slamming vehicle doors or voices through special microphones. In the event of a detection, video images of the affected area are immediately uploaded to the TLZ.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Shortened reaction time and thus reduction of the impact on the extent of damage

Synergy effects

- Security
Yes
- Cross-object
No
- cross-threat
Yes

Feasibility

Easy to implement at medium cost

Brief description

A detection of dangerous goods enables the identification of a dangerous goods transport even before it enters the tunnel. In this way, in the event of an incident, it is possible to react appropriately to the increased risk (e.g. due to higher fire load and special requirements for extinguishing work). Video detection cannot always be reliable when dangerous goods panels are soiled. An alternative is the detection of dangerous goods by Radio Frequency Identification (RFID) technology. Here, the vehicles themselves are equipped with an RFID transponder, which transmits the data stored on it to readers installed sufficiently far in front of the gantries.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Shortened response time and thus reduced impact on the extent of damage through preventive traffic management.

Synergy effects

- Security
Yes
- Cross-object
No
- cross-threat
Yes

Feasibility

Easy to implement at medium cost

Brief description

The different components of the ITCC integration (hazard assessment, strategy management, incident management) allow the operator to assess the current situation in the tunnel and to estimate the resulting hazard potential in order to react appropriately. For this purpose, various sensor data and analysis methods can be linked, e.g. number and types of vehicles in the tunnel, driving behaviour, operating parameters, tunnel characteristics and system status. With the help of a so-called real-time safety management system, an earlier initiation of the self-rescue phase can be achieved by reducing the cognitive load of the operators and shortening their reaction time.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Overstraining of the operating staff due to too much information can be reduced.

Synergy effects

- Security
Yes
- Cross-object
Yes
- cross-threat
Yes

Feasibility

New construction: Easy to implement at medium costs
Stock :Moderately difficult to implement at medium cost

Brief description

Examples:

- Closing off cable ducts
- Protection of important cables (e.g. retraction into "armoured tubes")
- Burglar / vandalism-proof doors
- See "Structural separation of breakdown bays and Operating equipment"

Impact type

- technical organisational

Resilience phase

- prevent protect respond recover prepare

Place of action

- Tunnel construction incl. portals Central system Network element regional environment

Implementation

- Building-management Event-management Traffic management Natural hazards-management Management level

Use case

- New building Stock

Time horizon

- short term medium-term long-term not relevant (for new construction)

Effects on availability

Protection against manipulation, damage, theft

Synergy effects

- o Security
Yes
- o Cross-object
No
- o cross-threat
Yes

Feasibility

Easy to implement at medium cost

Separate service pipe for maintenance work**M1-T10****Brief description**

A separate service pipe can make service work more efficient and safer.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Protection against manipulation, damage, theft

Synergy effects

- Security
Yes
- Cross-object
No
- cross-threat
Yes

Feasibility

Not realisable in existing buildings
Considerable additional costs for new buildings

Brief description

In the case of defined emergency scenarios, where administrative procedures (such as an EU-wide tender) can be suspended in order to restore functionality more quickly.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Reducing bureaucratic hurdles to accelerate rehabilitation

Synergy effects

- Security
Yes
- Cross-object
No
- cross-threat
Yes

Feasibility

Effortful feasibility at low cost

Brief description

Accelerated construction approval after events (possibly overriding administrative procedures and award guidelines in "crisis situations", such as supply shortages or separation effects or lack of suitable diversion routes) to speed up the recovery process, i.e. to enable a quick return to baseline functionality.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Reducing bureaucratic hurdles to accelerate rehabilitation

Synergy effects

- Security
 - Yes
- Cross-object
 - No
- cross-threat
 - Yes

Feasibility

Effortful feasibility at low cost

Brief description

Pre-defined diversion routes (e.g. in the AGAP) can minimise regional traffic impacts during an event or during the recovery process. Factors such as additional travel time, additional emissions, but also the suitability of the low-ranking road network to cope with the increased traffic volume should be taken into account.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Identification of efficient alternative routes leads to improved regional availability and reduces congestion on the downstream network

Synergy effects

- Security
Yes
- Cross-object
No
- cross-threat
Yes

Feasibility

Easy to implement at low cost

Brief description

In the event of prolonged unavailability, mobility can also be maintained by using alternative modes of transport. For this purpose, multimodal alternative routes are defined and associated communication strategies are developed.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Multimodal alternative routes lead to improved regional availability and reduce congestion on the downstream network

Synergy effects

- Security
 Yes
- Cross-object
 No
- cross-threat
 Yes

Feasibility

Moderately difficult to implement at low cost

Side strip clearance**M2-O5****Brief description**

The temporary release of the hard shoulder as an additional lane serves to increase traffic capacity. Special attention must be paid to all structural, operational and safety requirements.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Increased availability during traffic peaks

Synergy effects

- Security
No
- Cross-object
No
- cross-threat
Yes

Feasibility

Simple to medium feasibility with low costs

Brief description

The definition of minimum operating conditions enables the operator to make quick decisions on the measures to be taken to ensure the minimum safety level in the respective tunnel in the event of damage scenarios occurring. The measures (combinations) can include operational, organisational or traffic aspects and accelerate the process of restoring functionality. In addition, a basis for the argumentation towards decision-makers, superiors and politics as well as greater certainty of action is created.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Enables temporary operation to maintain minimum availability until return to full availability.

Synergy effects

- Security
 Yes
- Cross-object
 No
- cross-threat
 Yes

Feasibility

Medium feasibility at medium cost

Spare parts storage

M2-O7

Brief description

Keeping spare parts on hand can significantly shorten the recovery time due to their rapid availability for certain damage scenarios.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Enables a quick return to full availability by bypassing any supply bottlenecks.

Synergy effects

- Security
Yes
- Cross-object
No
- cross-threat
Yes

Feasibility

Medium feasibility at medium cost

Use of modular systems for multiple tunnels

M2-O8

Brief description

The use of the same equipment elements for several tunnels considerably facilitates the stocking of spare parts, as modular systems can be used at different objects.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Enables a quick return to full availability by bypassing any supply bottlenecks.

Synergy effects

- Security
Yes
- Cross-object
No
- cross-threat
Yes

Feasibility

Medium feasibility at medium cost

Brief description

By concluding framework contracts for the performance of repair work, functionality can be restored in a shorter time due to the rapid availability in the event of damage scenarios that have occurred. As a rule, up to now there have only been requirements for maintenance companies for the response time, but not for the restoration period. In particular, operators without their own operational staff or those who do not keep spare parts on hand can benefit considerably from clearly defined contracts.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Enables quick maintenance

Synergy effects

- Security
Yes
- Cross-object
Yes
- cross-threat
Yes

Feasibility

Medium feasibility at medium cost

Brief description

In the event of failure of individual systems, the affected equipment must be checked by the electrician. In-house electricians or electrotechnically instructed personnel are available to the tunnel manager on standby duty as the first point of contact in order to obtain a rapid initial assessment of the damage in the event of a malfunction or incident and to be able to intervene if necessary.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Enables quick assessment of the situation and maintenance

Synergy effects

- Security
Yes
- Cross-object
Yes
- cross-threat
Yes

Feasibility

Easy to implement at medium cost

Operation in temporary two-way traffic**M2-O10****Brief description**

Measure to quickly restore a certain traffic flow.

Impact type technical organisational**Resilience phase** prevent protect respond recover prepare**Place of action** Tunnel construction incl. portals Central system Network element regional environment**Implementation** Building-management Event-management Traffic management Natural hazards-management Management level**Use case** New building Stock**Time horizon** short term medium-term long-term not relevant (for new construction)**Effects on availability**

Maintaining reduced availability after an event until repairs are carried out

Synergy effects

- Security
Yes
- Cross-object
No
- cross-threat
Yes

Feasibility

Medium feasibility at medium cost

Brief description

For use in the event of an incident, fixed rates can be agreed precisely for this case in order to process the award quickly and efficiently and not have to pay any surcharges for this special case.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Reduction of times to full repair

Synergy effects

- Security
Yes
- Cross-object
No
- cross-threat
Yes

Feasibility

Easy to implement at medium cost

Brief description

Tunnel cross-sections that are equipped with a passable shoulder have the following advantages from an availability perspective:

- A broken-down vehicle can stop on the hard shoulder and does not block moving traffic.
- Maintenance/repair work can often be carried out without lane closures.
- Possibly enable temporary hard shoulder clearance (see M2-O5)
- Possibly enable 2+2 traffic routing when one tube is closed (see M2-T2)

There are also safety advantages:

- A broken-down vehicle parked on the hard shoulder poses less of a risk.
- The access of the emergency services can be made much faster on the hard shoulder.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Reduction of times to full repair

Synergy effects

- Security
 - Yes
- Cross-object
 - No
- cross-threat
 - Yes

Feasibility

Medium feasibility with high costs

Brief description

If a tube of a twin-tube tunnel with directional traffic guidance has to be closed, temporary operation in two-way traffic is an effective measure for partially maintaining functionality. The prerequisite for this is the appropriate safety equipment of the tunnel with the following additional requirements and components:

- Ventilation dimensioning for GV
- Adaptable entrance lighting at both portals
- Crossing system for changing lanes
- (Variable) traffic signs for both directions of travel
- Poss. (structural) centre separation

Impact type

- technical organisational

Resilience phase

- prevent protect respond recover prepare

Place of action

- Tunnel construction incl. portals Central system Network element regional environment

Implementation

- Building-management Event-management Traffic management Natural hazards-management Management level

Use case

- New building Stock

Time horizon

- short term medium-term long-term not relevant (for new construction)

Effects on availability

Operation in temporary two-way traffic enables the partial maintenance of traffic flow in both directions. This means that partial availability can be restored quickly.

Synergy effects

- Security
 - Operation in oncoming traffic generally entails additional risks compared to directional traffic, which is why risk-reducing measures must be taken in any case.
- Cross-object
 - No
- cross-threat
 - Yes

Feasibility

Additional safety-related equipment elements are usually required. Particular attention must be paid to the adequate dimensioning of the ventilation.

Brief description

In order to efficiently manage disruptive events in a holistic manner, responsible persons are defined in all areas of action.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Shortened reaction times

Synergy effects

- Security
Yes
- Cross-object
Yes
- cross-threat
Yes

Feasibility

Easy to implement at low cost

Establish a culture of resilience**F-O2****Brief description**

Establish a culture of resilience among the administrative authority, tunnel managers and the investigating body (excluding the safety officer). Through resilience awareness trainings, tunnel operators are trained to identify potentials for increasing resilience.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Shortened response times through holistic resilience approach

Synergy effects

- Security
Yes
- Cross-object
Yes
- cross-threat
Yes

Feasibility

Easy to implement at low cost

Brief description

Reduce the frequency of incidents in the tunnel and accelerate the self-rescue and rescue phases through correct user behaviour.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Sensitising users to the correct behaviour in the event of an incident

Synergy effects

- Security
Yes
- Cross-object
Yes
- cross-threat
Yes

Feasibility

Easy to implement at low cost

Brief description

Regular exchange of best practices between tunnel owners and operators of other road tunnels and incident services to improve incident management, but also exchange of experience on the use and implementation of various technical systems and organisational measures.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Exchange of experience leads to broad knowledge on all aspects and thus to improved overall resilience and availability

Synergy effects

- Security
Yes
- Cross-object
Yes
- cross-threat
Yes

Feasibility

Easy to implement at low cost

Brief description

Security Awareness raising through regular discourse and integration in the various aspects of everyday work, e.g. through training, the introduction of a reporting system to identify organisational and vulnerability issues.

See PIARC (Security of Road Infrastructure)

Impact type

- technical organisational

Resilience phase

- prevent protect respond recover prepare

Place of action

- Tunnel construction incl. portals Central system Network element regional environment

Implementation

- Building-management Event-management Traffic management Natural hazards-management Management level

Use case

- New building Stock

Time horizon

- short term medium-term long-term not relevant (for new construction)

Effects on availability

Exchange of experience leads to broad knowledge on all aspects and thus to improved overall resilience and availability.

Synergy effects

- Security
Yes
- Cross-object
Yes
- cross-threat
Yes

Feasibility

Easy to implement at low cost

Brief description

A cost budget must be made available by the management level for the implementation of the resilience measures.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Prerequisite for the implementation of the measures and to improve availability.

Synergy effects

- Security
Yes
- Cross-object
Yes
- cross-threat
Yes

Feasibility

Easy to implement at medium cost

Reappraisal of past events ("learning")

F-07

Brief description

Identify potential for improvement in the management of disruptive events as well as the restoration of the structure, operational technology and traffic.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Leads to improved resilience and thus improved availability

Synergy effects

- Security
Yes
- Cross-object
Yes
- cross-threat
Yes

Feasibility

Easy to implement at low cost

Brief description

Regular review and, if necessary, updating of the AGAP and the safety documentation in accordance with the "Guideline for the preparation of safety documentation in accordance with RABT 2006".

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Leads to improved resilience and thus improved availability

Synergy effects

- Security
Yes
- Cross-object
Yes
- cross-threat
Yes

Feasibility

Easy to implement at low cost

Brief description

Integration of the measures, e.g. by including minimum operating conditions, diversion routes and multimodal alternative routes, etc.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction
incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Leads to improved resilience and thus improved availability

Synergy effects

- Security
Yes
- Cross-object
Yes
- cross-threat
Yes

Feasibility

Easy to implement at low cost

Brief description

Germany-wide database to record the frequency and extent of damage and characteristics of defined traffic events or occurrences of natural events/ man-made events to improve the data basis for safety assessments and trend analyses, as well as proof of the effectiveness of measures. The event database should cover all tunnels monitored in the TLZ and be accessible to authorities, tunnel owners and operators, and planners.

Impact type

- technical organisational

Resilience phase

- prevent protect respond recover prepare

Place of action

- Tunnel construction incl. portals Central system Network element regional environment

Implementation

- Building-management Event-management Traffic management Natural hazards-management Management level

Use case

- New building Stock

Time horizon

- short term medium-term long-term not relevant (for new construction)

Effects on availability

Improved data basis on actual threats leads to improved resilience and thus to improved availability

Synergy effects

- Security
 Yes
- Cross-object
 Yes
- cross-threat
 Yes

Feasibility

Easy to implement at low cost

Brief description

Resilience measures, especially leadership and culture, can be discussed with other departments and experiences can be shared. In particular, the involvement of critical infrastructure operators should be strengthened.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Broadening the view of interdependencies with other CRITIS to become aware of the role of tunnels in security of supply and promoting close exchange promotes resilience improvement.

Synergy effects

- Security
Yes
- Cross-object
Yes
- cross-threat
Yes

Feasibility

Easy to implement at low cost

Cost sharing with other affected parties / beneficiaries of protective measures

F-O12

Brief description

The costs of measures that have a cross-sectoral effect can be shared within the framework of agreements.

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Implementability through cost sharing is improved.

Synergy effects

- Security
Yes
- Cross-object
Yes
- cross-threat
Yes

Feasibility

Easy to implement at low cost

Brief description

The volume of information to be processed by the operators has risen sharply with increasingly centralised monitoring and a growing number of tunnel structures. In order to optimally support the operators in monitoring, diagnosis and event management, and thus minimise the potential hazards by initiating suitable measures, the available information must be filtered and processed. This way, all important information can be made available to the operator.

(See ESIMAS research project)

Impact type

technical organisational

Resilience phase

prevent protect respond recover prepare

Place of action

Tunnel construction incl. portals Central system Network element regional environment

Implementation

Building-management Event-management Traffic management Natural hazards-management Management level

Use case

New building Stock

Time horizon

short term medium-term long-term not relevant (for new construction)

Effects on availability

Improved response times reduce the impact of events on availability

Synergy effects

- Security
Yes
- Cross-object
Yes
- cross-threat
Yes

Feasibility

Easy to implement at low cost