Memo

Safety in the Fehmarnbelt tunnel

1. Introduction

The Fehmarnbelt tunnel will connect Denmark and Germany with a twin-track railway and a four-lane motorway beneath Fehmarnbelt. With a total length of approximately 18 kilometres, it will be the world's longest immersed tunnel for combined railway and road traffic to date.

Femern A/S's primary task is to build and operate a tunnel with a high level of safety. The overall safety objective is that a trip through the tunnel may not represent a greater risk to users than a trip on a corresponding normal section of railway or motorway in Denmark. The tunnel design developed by Femern A/S meets this objective.

This memo describes the fundamental aspects that influence the safety of the tunnel. Safety in the tunnel is achieved in interaction between the design and construction of the tunnel and the systems and equipment with which it is equipped, as well as the plans and procedures established for how the Danish and German emergency services work together and are deployed. The memo also describes the special conditions that apply for the road and railway respectively.

It also describes the conditions and basis for Femern A/S's preparation of the safety documentation and the necessary collaboration with the Danish and German emergency services and public authorities.

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2. **Fundamental safety requirements**

In pursuance of the State Treaty the Fehmarnbelt tunnel is designed based on Danish standards. This primarily means that the Eurocodes will form the basis. The Eurocodes are a set of standards developed by the EU as a common European standard for constructions. Approval of the construction by the German and Danish public authorities ensures that the design of the tunnel meets the two countries' safety requirements for constructions of this type.

In this context, a comprehensive safety documentation is prepared including risk analyses for the operation of the tunnel.

The project is required to comply with two principal European sets of regulations for tunnel safety on roads and railways in the European transport network. The first is the Directive on minimum safety requirements for tunnels in the Trans-European Road Network (2004/54/EC) and the second is the Commission Regulation concerning the technical specification for interoperability relating to 'safety in railway tunnels' of the railway system of the European Union (1303/2014/EU), abbreviated as: TSI SRT. In addition, the relevant national legislation of both countries shall be met.

Besides the compliance with all applicable requirements, a number of in-depth risk analyses formed the basis for the design of the tunnel. Risk analyses are used to assess and document the overall safety level for the Fixed Link at the time it is commissioned. In this respect, the total risk contributions from various accident scenarios are calculated and compared with risk
acceptance criteria that are calculated based on statistical data for existing motorways as well as the risk acceptance criteria for the railway infrastructure established by the EU.

The tunnel is designed so that dangerous goods can be transported safely in compliance with international and national laws and rules. It is also designed so that the consequences of accidents with flammable and chemical dangerous goods are limited by means of the various safety-related systems described in the following text. Before permission is obtained to place the tunnel into service, the relevant approving authorities in both Denmark and Germany will decide whether special rules or restrictions for the transportation of dangerous goods are to be established.

The Fehmarnbelt Fixed Link is a Danish-German project that requires approval in both countries. In Germany, the project is approved in a plan approval procedure by the Schleswig-Holstein road directorate (Landesbetrieb Straßenbau und Verkehr Schleswig-Holstein (LBV SH)), which results in an overall construction permit. In Denmark, the project was approved by the Danish Parliament in a Construction Act in 2016 (Act no. 575) and an implementation report describing how the project will be executed, and how environmental and nature protection considerations will be met on the Danish side during both the construction and operation phase.

In accordance with German rules, static approval (Bauaufsichtliche Genehmigung) of the structure is also required. Beginning as early as in the design phase, this consists of an independent expert assessment by an assessment body authorised by the German authorities.

The railway infrastructure is approved by the national safety authority, the Danish Transport Authority in Denmark, Trafikstyrelsen and the German Federal Railway Authority (Eisenbahn-Bundesamt (EBA)) in Germany. This approval procedure is supported throughout the project by regular independent assessments issued by the accredited European Assessment Body and Notified Body. The assessments concern both safety aspects and the verification that the project meets the EU's Technical Specifications for Interoperability (TSI), i.e. verification of EU conformity. In addition, the national assessment body, known as the Designated Body, will perform an independent assessment of the railway project's compliance with the so-called notified national technical rules (NNTR), which constitute additional specifications applicable to the railway infrastructure.

The road infrastructure is approved in Germany by the administrative road safety authority in Schleswig-Holstein and in Denmark by the Danish Road Directorate and the police.

Under the 2008 State Treaty between Denmark and Germany on a Fixed Link across the Fehmarnbelt, it is Femern A/S’s task to prepare a safety concept. The safety concept is mentioned in Article 14, Paragraph 3, of the Treaty: 'The company shall be obliged to prepare a safety concept and agree on it with the competent authorities according to paragraph 1 above before the opening of the fixed link across the Fehmarnbelt. In particular, the safety concept shall include a description of the cooperation between the competent authorities and the company as well as plans for possible emergencies.'
The cooperation between Femern A/S and the competent authorities is organised in F-SURR (Femern – Sikkerhed, Uheld, Redning, Rydning) (Femern – Safety, Accidents, Rescue, Recovery).

Femern A/S must also, as part of compliance with the EU Road Tunnel Safety Directive, prepare safety documentation for the tunnel.

2.1 EU tunnel safety documentation

Under the Tunnel Safety Directive (2004/54/EC), tunnel safety documentation must be prepared for all European road tunnels. The documentation must include detailed descriptions of the technical design of the structure, a traffic forecast, a risk analysis, the organisation of and cooperation between emergency services and public authorities and a procedure for regular improvement and optimisation. In principle, compliance with Article 14 of the Treaty is a subset of the overall tunnel safety documentation, and both are prepared by Femern A/S in a coordinated process.

The tunnel safety documentation is a complex of many documents with references to relevant background reports, analyses, design requirements and technical documentation. The tunnel safety documentation is developed parallel to the design in the project phase and is updated and approved before the operation phase, after which it is regularly updated during the lifecycle of the tunnel.

According to the legislation, the same conditions apply to the safety documentation for the Fixed Link railway infrastructure. The European Railway Safety Directive (2004/49/EC) also requires the use of a common method of risk assessment and risk management of risks associated with the operation of the railway infrastructure. This method is implemented in all EU Member States by the CSM RA Regulation (EU-402-2013 Common Safety Method for Risk evaluation and Assessment). The correct application of the Regulation in the Fehmarnbelt project is documented by means of a safety assessment report issued by the above independent (CSM RA) Assessment Body. The report is submitted to the approving national railway safety authority, the Danish Transport Authority in Denmark, Trafikstyrelsen and Eisenbahn-Bundesamt in Germany, as a substantial part of Femern A/S’s application to these authorities for authorisation to place the railway infrastructure in service.

2.2 Basic elements of the safety documentation

Compliance with the statutory safety requirements for the railway and road tunnel infrastructure can be summarised in four general pillars. Examples of safety-related measures are subsequently given under each pillar. The four pillars are:

1) Prevention of accidents and incidents
   - The tunnel design and geometry, for example with one-way traffic in all tubes and emergency lanes and special lay-bys in the road area for service in the special elements
   - Dynamic traffic control
   - Continuous monitoring of tunnel traffic
   - Continuous monitoring of all technical facilities
- An effective, safe signalling system for the railway that is part of RailNet Denmark’s (Banedanmark) future signalling system, ERTMS

2) Limitation of accidents
   - Fire protection of structures
   - Water-based fire suppression system in road tunnel tubes
   - Efficient ventilation that also prevents smoke from spreading between tunnel tubes
   - Possibility of quickly implementing restrictions on traffic flow (speed, lane closure and/or closure of the tunnel)

3) Self-rescue and evacuation to safe areas
   - A short distance to safe areas everywhere in the tunnel
   - Road traffic and railway traffic can quickly be stopped or restricted
   - Direct information to drivers via an interrupt function for FM and DAB (car radio)
   - Direct information to evacuated persons and road users in the road tunnel via dynamic signs and loudspeaker announcements

4) Deployment of the emergency services
   - Many measures to facilitate deployment of the emergency services
   - A joined-up concept for cooperation and division of responsibilities
   - A joined-up communication concept
   - Full coverage throughout the tunnel for both Danish and German emergency radio

During the development of the design of the Fehmarnbelt tunnel, relevant safety measures were included that help reduce the risks that accompany the incident scenarios studied and assessed in connection with each of the four above pillars.

Measures under each of the four pillars are supported in several ways by Femern A/S's work on design, organisation and cooperation with relevant authorities. They are supported firstly by the tunnel's physical design, construction and equipment. Secondly via the procedures established for how the tunnel's service staff and emergency services are to use and benefit from the physical fixtures and equipment. And thirdly by the procedures established for cooperation and communication, both between the tunnel's service organisation and the emergency services, and between the emergency services and other authorities in Denmark and Germany.

The subsequent sections begin with an overall description of the tunnel's fixtures and technical equipment (section 3). The systems and the architecture included in this section are important to the four pillars of the safety concept in different ways. This is followed by a brief outline of the basis of the risk analyses (section 4). Finally, section 5 describes each of the four pillars of the safety concept in depth.
3. The tunnel's fixtures and technical equipment

3.1 Construction and geometry

The geometry of the Fehmarnbelt tunnel constitutes an important preventive safety element in itself. The tunnel comprises four separate tubes, one for each direction of travel and type of traffic. There is also a fifth tube in the form of a gallery between the motorway tubes to ensure that technical equipment in the tunnel can be inspected and serviced without disrupting the traffic and to improve the working environment.

The tunnel is designed and constructed in such a way that it is protected against flooding and damage from sinking ships, anchors, etc. It will also be forbidden to drop anchor in the tunnel area.

![Figure 1, Tunnel cross-section](image)

Both the road and railway tunnel tubes are connected to emergency exits at least every 110 m. This distance is considerably shorter than the EU standard requirement, which specifies 500 m distance between emergency exits.

The road and railway tunnel tubes are also lined with fire protection cladding, with the result that the structures can resist fire at temperatures of up to 1,350 degrees Celsius for three hours.

The restrictive Dutch fire curve RWS was chosen as the baseline requirement for the Fehmarnbelt tunnel. Most tunnels are designed to resist fires of 50 or 100 megawatts for a specific period of time, while the Fehmarnbelt tunnel is designed to resist fires of up to as much as 200 megawatts for three hours. For comparison, a fire in a standard car can develop power of approximately 5 megawatts, depending on the circumstances.

Road tunnel tubes

- One-way traffic prevents frontal collision and glare.
- Both road tunnel tubes have emergency lanes. As a result, stationary or stranded vehicles will not impede traffic flow.
- In the southbound road tubes, separate parking areas are established at regular intervals outside the emergency lane for service vehicles (in the so-called “special elements”) so that they do not disrupt normal traffic.
Specially designed step barriers are installed along the walls to reduce the likelihood of consequential accidents if a car hits the barrier. In the event of collision, the vehicle direction is straightened when it hits the step barrier without entering a spin or changing direction out of control.

Profile road markings (rumble strips) with haptic and acoustic warning effects will be used. The principle is familiar from motorways and trunk roads in Denmark and other countries.

There is very little overall gradient in the road tubes, which reduces the risk of brakes and turbochargers overheating in larger vehicles such as trucks and coaches.

Figure 2, Drawing of the southbound (outer) road tunnel tube. The ceiling contains a niche with jet fans, which are part of the ventilation system.

**Railway tubes**

- There are no points or crossings in the tunnel or directly before and after the portals at the tunnel entrances. This limits the risk of derailment.
- The emergency walkways on each side of the track in both railway tubes are designed to stabilise the train and prevent mechanical impact on the tunnel wall in the event of derailment.
In general, all critical structural parts are projected against fire-action, so that the load-bearing capacity of the structure is maintained in the event of fire. The structures are also designed to resist pressure impacts from an explosion.

3.2 Power supply

A stable, safe power supply is essential to the normal operation and safety systems of the tunnel. A number of measures have therefore been taken to ensure a stable, uninterrupted power supply.

The tunnel can be supplied with power from both the Danish and German sides, which produces significant reliability of supply, as Germany and East Denmark are connected to two different parts of the trans-European power network. There is also an emergency power supply to ensure uninterrupted switching between the two power networks and the necessary emergency power supply for emergency lighting, emergency radio and monitoring if the tunnel should completely lose its external power supply. The emergency power supply will ensure that all functions relevant for safety continue to operate in the event of an extensive power cut. For all critical systems, specific requirements are defined for how long it must be possible for them to have an emergency power supply. This is typically between two and eight hours. The emergency power supply period is designed in accordance with the evacuation scenarios included in the safety concept.

A situation with a simultaneous total outage of the power supply in both Germany and East Denmark is extremely unlikely. The use of ventilation and drainage pumps requires that the tunnel can be supplied with power from either the Danish side or the German side. If these systems cannot be used, the tunnel will be closed to normal traffic as a preventive safety measure.
Traction power for the railway is generally supplied from the Danish side. It is possible, to a limited extent, to supply traction power from the German side, but the number of trains that can run simultaneously will then be reduced.

### 3.3 Data network

A robust, fault-tolerant, redundant data network is installed throughout the tunnel and connects all technical equipment in the tunnel to the central data operating centres in the tunnel's two portal buildings and to the Fehmarnbelt tunnel control centre (also called the Link Control Centre, subsequently referred to as LCC). The data network is a ring-based network with a high level of redundancy. There are always at least two independent cable routes to where the equipment is located. The availability of the tunnel is conditional on LCC always being linked to the technical equipment in the tunnel for monitoring and control.

The data network is constantly monitored and protected against unauthorised access.

### 3.4 Technical monitoring

The tunnel is equipped with an extensive system of sensors and measuring points to monitor its technical equipment, environment, air quality, and traffic use. Installations relevant to safety (fire detection, emergency lighting, emergency communication and other systems) are protected against damage as a consequence of mechanical impact, heat or fire. Most of the equipment is also duplicated and redundant. Consequently, if equipment is out of operation due to service or failure, for example, data will be available from corresponding equipment nearby.

### 3.5 Information systems

Loudspeakers are installed in the road tunnel for announcements in the tunnel. Announcements may be prepared announcements in several languages or direct announcements from the tunnel's control centre (LCC). In addition, announcements in the public address system may be made to the entire road tunnel or selected geographical zones or sections of the tunnel, for example one announcement in the tube in which an accident has occurred and a different announcement in the non-incident tube.

A corresponding system exists for FM and DAB radio. An interrupt function, like that familiar from traffic news on the radio, can be used to give information to road users in the tunnel.

As an additional option, the variable traffic signs in the tunnel can be used to give information in the form of text, pictograms or animations to road users and/or evacuated persons in the tunnel. Information via signs can be zoned, and written information can be displayed in several different languages, for example in a cycle.

Functionality is implemented in LCC to coordinate and manage announcements and information between the various channels.
3.6 Communication systems

The tunnel is equipped throughout with a distributed aerial system that permits the use of both Danish and German national emergency services radio, mobile telephony and mobile broadband. The railway tunnel tubes are also equipped with coverage for GSM-R. This is the radio system used for communication between trains and the Train Control Centre (subsequently referred to as TCC) in Copenhagen.

The aerial system is based on special longitudinal aerial cables that are divided into independent 900-metre sections. The aerials are located below the ceiling in all tunnel tubes and technical areas.

The system permits several operators (from both Denmark and Germany) to establish mobile coverage in the tunnel.

Access to emergency services radio is further secured with redundancy. This ensures that radio coverage is not lost throughout the tunnel if, for example, a fire destroys the special longitudinal aerial cable in one location.

3.7 Permanent fire suppression system in road tunnel tubes

A permanent fire suppression system will be installed in the road tubes. The fire suppression system is controlled from LCC in the event of fire.

A permanent fire suppression system will have several positive effects. Depending on the extent of a fire, the system will be able to either suppress the fire or completely extinguish it. The system can also prevent the fire from spreading to other vehicles nearby and thus also reduce the risk of extreme temperatures developing. As a result of the system's fire suppression properties, it can also limit smoke generation, which improves drivers' rescue opportunities and the working conditions for the emergency services.

3.8 Ventilation system

The ventilation system installed in all tunnel tubes will not be in use in normal operation.

The natural ventilation from the traffic flow will normally supply the tunnel with sufficient fresh air. The piston effect of vehicles and trains will press the air in the tunnel out and suck fresh air in, thus ensuring good air quality. Natural ventilation can be supplemented everywhere by mechanical ventilation from the tunnel's ventilation system, for example if the road traffic flows slowly or comes to a standstill.

The ventilation system can be used to control the air flow in the tunnel in one direction or the other. The ventilation system is controlled from LCC. It is simple, reliable, powerful equipment with considerable reserve capacity, which can handle both normal conditions and especially critical situations.

If an incident with a fire is registered in a rail tube, the staff at LCC will immediately activate the ventilation system to produce positive pressure in the tubes not affected by the incident.
This pressure difference prevents any smoke from the incident tube spreading to the evacuation route and to the safe area in the road tunnel tube.

In addition to limiting a fire, it is important to be able to control the generation and propagation of smoke or fumes. The ventilation system ensures that the smoke can be blown in the desired direction in a controlled manner, typically in the direction of travel, and that positive pressure can be created in the other tunnel tubes at the same time so that smoke does not enter the tubes unaffected by the accident. This prevents smoke from spreading between the tunnel tubes.

3.9 Fehmarnbelt tunnel control centre (LCC)

The Fehmarnbelt tunnel control centre (LCC), which is located at Rødbyhavn, will be the primary centre for control and monitoring of the entire tunnel. LCC has operator functions to manage and monitor road traffic, toll plazas and maintenance. LCC is staffed 24 hours a day. The monitoring ensures that irregularities in the tunnel are quickly detected and managed. Femern A/S’s operating staff take care of both day-to-day control of road traffic and continuous monitoring of all technical installations.

For example, it is possible to follow the positions of the trains in the tunnel from LCC. LCC is also responsible for monitoring the availability of the railway tunnel in relation to factors such as unauthorised entry, air quality, drainage water and other factors relevant to safety.

LCC is a central part of the operation of the Fehmarnbelt tunnel and it will be designed with focus on good, efficient working environment that gives the operators the best opportunities to maintain an overview of the entire area covered of the tunnel, portals, ramps and approach areas. Railway traffic itself is directed from TCC.

The control room system will be supplemented with the option to give parties such as the emergency services remote access to the system. Remote access can be used to display images from the video system, the current status of traffic flow (for example a sign plan), ventilation, environmental parameters, etc. The system will be available in a building at the portal on Fehmarn and from the emergency services' control centres in both countries.

3.10 Monitoring and control of road traffic

The road tunnel, portals, ramps and access to technical areas are equipped with an extensive video monitoring system. Fixed cameras are primarily used in the road tunnel, while remote-controlled cameras that can pan, tilt and zoom are primarily used outside the tunnel. The system is integrated with the alarm log so that an alarm in LCC can be accompanied by images from the location, where possible.

The road tunnel, portals and ramps are also covered by an automatic incident detection system. The system supports the traffic manager in LCC in the work of monitoring the Fixed Link and being able to quickly implement preventive measures if an incident or an accident is registered.
Automatic incident detection (AID) is a generic term for technologies for analysing road traffic. The technology may be based on advanced image analysis of signals from standard and thermographic video cameras, radar, laser scanning, etc. The essential feature is that identification of accidents in the road tunnel is based on automatic systems and not on someone constantly monitoring the traffic on a video screen. If an incident occurs, the operator will receive an alarm, and the video monitoring system will immediately display live images from the incident location. The video system can therefore both function as the operator's eyes on the road and be used as an image source (one of several sources) for automatic image analysis.

The tunnel is also equipped with installations for controlling and adapting the flow of road traffic. This is done via an Intelligent Traffic Management System (ITS), which is the technical term for technology and systems for monitoring and managing road traffic. For the Fehmarnbelt tunnel, it comprises variable traffic signs every 450 m inside the tunnel and in sign gantries at selected locations outside. The variable traffic signs can be used to set speed restrictions, close lanes and give warnings and information to drivers. The system does not think for itself, but it guides and helps the traffic manager at LCC to set the correct signage in connection with normal operation and maintenance activities in the tunnel, and in the event of abnormal conditions or accidents. For example, the ITS system has integrated rules for implementing a tunnel closure, a lane closure or speed restrictions to minimise the risk of consequential accidents. If the operator were to manage all the many signs manually, the task would be very complex and extensive.

Considerable development is currently taking place in this field, for which reason no specific technology has yet been fixed for AID and ITS systems.

### 3.11 Monitoring and direction of railway traffic

The railway traffic in the Fehmarnbelt tunnel is monitored and directed from Banedanmark’s train control centre in Copenhagen (TCC), which monitors and directs train traffic both inside and outside the tunnel and is in constant contact with the driver of each train. The train control centre in Denmark is also in constant contact with the corresponding train control centre in Germany.

The railway signalling system will be the future ERTMS (European Railway Traffic Management System) signalling system, which is a modern, digital signal system with a high level of safety. The ERTMS system, which is planned for rollout on the entire European railway network, permits the train control centres to constantly monitor trains’ speed and position and, if necessary, to take over the functions of the train driver by remote control, e.g. to permit TCC to stop the train. The interface point for the take-over of the railway traffic control between Denmark and Germany will be located on Fehmarn.

The two TCCs in Denmark and Germany are staffed 24 hours a day and are in constant contact with each other and with Femern A/S’s LCC.

TCC in Copenhagen monitors and manages the railway traffic in the tunnel, while LCC monitors the availability of the railway tunnel itself. In the event that the tunnel is not fully available
(for example if a road accident has occurred), TCC will rapidly be informed by LCC so that TCC can subsequently quickly reduce or completely stop the train traffic. When the situation has been remedied and LCC is ready to reopen the tunnel, TCC alone gives instructions to the individual trains in LCC’s area to resume travel. This division of responsibilities ensures a clear command hierarchy.

4. **Risk analysis**

The design and dimensioning of the tunnel are based on an extensive operational risk analysis. Based on data from Danish accident statistics, the Operational Risk Analysis (ORA) calculates that over 99% of the risk to users of the road link in the Fehmarnbelt tunnel will arise as a result of 'normal' road traffic accidents. Danish road traffic accident statistics were assessed in relation to the corresponding German statistics. The Danish statistics were assessed as the most stringent and were therefore chosen to form the basis of the risk calculations in the ORA.

European data shows that the risk of incidents with fire in road tunnels only constitutes a fraction of the remaining one per cent. A 'normal' road traffic accident is an accident that is typically caused by drivers driving too fast or being careless, in other words accidents that are not directly related to the fact that the drivers are driving in a tunnel. In the design of the tunnel, the focus was therefore on both preventing road traffic accidents and limiting any consequences of them, both for those involved and for the rest of the traffic.

The controlled, constantly monitored environment in the tunnel ensures, in combination with information systems such as variable traffic signs, that road users have optimum traffic conditions at all times. This eliminates an important cause of accidents as incidents that could lead to accidents can be quickly registered, and measures can be implemented to reduce or stop traffic.

Moreover, unlike drivers on a corresponding motorway onshore, road users will be unaffected by poor weather conditions such as fog, strong wind, ice, snow, rain or darkness. The probability of traffic jams in the Fehmarnbelt tunnel is relatively low as it is not a road characterised by local rush hour traffic such as an approach road to a city.

As the European accident statistics demonstrate, railway accidents occur very rarely and, among the few accidents that do occur, it is even rarer for there to be a fire in a train. In addition to the presence of fire suppression equipment in all trains, there are strict statutory requirements for fire protection of both rolling stock and the fixtures and fittings of trains (seats, floors, barriers between carriages, etc.).

In the railway tunnel itself, there are normally no combustible materials, and an attempt has been made to minimise the extent of technical installations. For example, the technical equipment of the railway is located in the special elements, partly for ease of maintenance, and partly, to protect technical installations against both fire and mechanical impact. Railway installations are monitored by TCC, while environmental and fire alarms are monitored by LCC. It will be extremely rare for fire to occur in the entire railway structure.
Overall, the results of ORA calculations show that the safety level of the Fehmarnbelt tunnel is very high and that the tunnel will be at least as safe to use as similar stretches of road or railway in the open countryside in Denmark.

5. **Compliance with safety requirements for railway and road tunnels**

Compliance with external safety requirements for the railway and road tunnel can be summarised in four general pillars. Examples of safety-related measures are subsequently given under each pillar. The four pillars are:

5.1 **Pillar 1 – Prevention of accidents and incidents**

The most important measure for ensuring a high level of safety in a traffic tunnel is to prevent any accidents and incidents from happening at all. In connection with the Fehmarnbelt tunnel, great efforts have been made to prevent and thus limit these risks, partly via measures in the technical design and partly via requirements and procedures for monitoring, control and traffic management in the built tunnel.

5.1.1 **Traffic monitoring and alarm systems**

The operators in LCC will have access to control and monitoring systems for all equipment in the tunnel. There are also systems for control of road traffic flow and communication systems for internal use and contact with police and emergency services on both sides of the Fehmarnbelt. In the event of abnormal situations that may lead to an accident, for example stationary vehicles or people in the road, the system immediately issues an alarm so that the operators can immediately react and take the necessary measures. There will be procedures for how different incidents are managed, and there will always be rapid intervention when an incident could lead to an accident.

Femern A/S’s service staff will continuously patrol the road tunnel in cars. The staff are trained to provide first aid and roadside assistance and to perform basic firefighting in connection with incidents in the road tunnel tubes. They can also support the operators in LCC by inspecting technical equipment in the tunnel.
Figure 4, A control centre. The example is from the Øresund bridge.

The monitoring systems in the tunnel will automatically register abnormal situations, for example if the traffic is moving more slowly, if a vehicle or train is stationary, or if there is a fire or an increased level of air pollution. Other monitoring systems located outside the tunnel register overheight vehicles, for example, and for the railway traffic, overheated axle bearings and wheels are detected before a train enters the tunnel tubes.
A safety distance of one block length is normally applied in the Danish railway network. For the railway tunnel, the safety distance has been increased to two block lengths, equivalent to a minimum distance of 3.6 km between trains, as an additional safety measure included in the safety concept.

5.2 **Pillar 2 – Limitation of accidents and incidents**

The Fehmarnbelt tunnel has been fundamentally designed to minimise the risk of accidents occurring and to minimise their consequences if they do occur.

If, despite the preventive measures taken, an incident or accident does occur, the tunnel has a number of measures to prevent the incident or accident from spreading or endangering other tunnel users. The Fehmarnbelt tunnel will be equipped with a number of technical facilities and systems designed to limit the consequences of such events (see Figure 6).

The fundamental measure in this context is separate tunnel tubes for each type of traffic and direction of travel. Consequently, an incident will generally only affect one of the four traffic tubes, after which the other tunnel tubes can function as a safe area for evacuated persons and as an access route for the emergency services.

5.2.1 **Road area**

If a fire occurs, vehicles in the road tunnel after the fire location can leave the tunnel in the direction of travel. Vehicles that may have to stop before a fire location will not be exposed to smoke as the ventilation system will blow fresh air in from behind and drive the smoke forwards in the tunnel. Passengers in these vehicles can leave their vehicles and proceed via the emergency exits to the smoke-free safe area, which is the adjacent road tunnel tube.
that is not affected by the accident. From here, everyone can be quickly evacuated from the tunnel.

The permanent fire suppression system in the road tunnel can also, in most cases, either extinguish or suppress the fire so that it does not spread or get out of control.

The tunnel is also equipped with emergency telephones and fire extinguishers at all emergency exits that road users can use themselves before help reaches them.

Figure 6, Tunnel installations to limit the consequences of critical incidents

5.2.2 Railway area

In the event of fire in the railway tunnel or in a train, TCC will immediately be notified by the train crew and cause the railway traffic heading towards the tunnel to be stopped. Trains located inside the tunnel will either continue or reverse out without being affected by the fire.

At the same time, LCC will be notified and subsequently cause the road barriers to close and prevent further road traffic from entering the tunnel. LCC will immediately activate the ventilation system to build up positive pressure in the tubes that are not affected by the incident. This prevents spreading of smoke from the incident tube.

In addition to the tunnel installations described, measures can be implemented in the tunnel to reduce the consequences for road users, train passengers and emergency services personnel.

- In the event of fire or reasoned suspicion of fire, LCC notifies the Danish and German alarm centres.
- All affected users of the road tunnel will receive warnings and instructions via signage, loudspeakers and radio transmission in the tunnel.
• At each emergency exit in the road tunnel, there is an emergency cabinet with an emergency telephone, alarm-push button connected to LCC, and fire extinguishers.
• At each emergency exit in the railway tunnel tubes, there is an emergency telephone with direct contact to TCC. This can be used in the rare situation that the railway's direct radio contact, GSM-R, cannot be used.
• At each fourth emergency exit door in the railway tunnel, there will be facilities for monitoring the status of the railway traction power and, if necessary, manually interrupting and earthing the traction power so that the emergency services can work safely.
• The traction power can also be controlled remotely from Banedanmark's control centre for traction power in Copenhagen, from the control centre in Rødby and from Sund & Bælt's control centre for traction power in Halskov.
• In the railway tunnel tubes, there are power sockets for the emergency services' tools, as well as empty conduits with outtakes between the individual tunnel tubes for the fire service’s fire suppression water supply.

5.3  Pillar 3 – Self-rescue to safe areas after an accident
Femern A/S has optimised the tunnel's design to make self-rescue simple, fast and efficient. Road users, passengers and train crew in the Fehmarnbelt tunnel can easily reach a safe area in the event of an accident until the emergency services arrive and provide assistance.

The most important factor affecting fast self-rescue is the distance to the nearest emergency exit. The emergency exits that provide access between the tunnel tubes will be located at a maximum interval of approximately 110 metres, which is much shorter than authorities as well as standards normally require.

5.3.1  Self-rescue in the road tunnel
In the road tunnel tubes, road users will be given information via signage, variable information boards, loudspeakers and radio. Should a serious situation arise in one tunnel tube, everyone who is affected by the incident and is prevented from driving out of the tunnel themselves will be requested to leave their vehicle and evacuate via the nearest emergency exit. The emergency exits lead to a safe area in the adjacent road tunnel tube. They can remain there safely until the emergency services arrive.
Figure 7, Illustration of the self-rescue concept for the road tunnel. Green markings indicate the safe area for evacuated persons.

5.3.2 Self-rescue in the railway tunnel

In the event of a fire in a train in the tunnel, the passengers will be asked to seek safety in the train carriages not affected by the fire. The train will continue travelling out of the tunnel directly to the so-called firefighting point just outside the tunnel on open land. From this point the passengers can safely leave the train using evacuation paths that lead to a rescue site in the open land.

If a fire occurs in a train and cannot be suppressed with the fire suppression equipment carried by the train, and the train is unable to leave the tunnel, it will be necessary to evacuate the train. The train crew is trained for such situations and will immediately initiate evacuation by instructing and guiding the passengers to follow the signage of the escape way, and, via the emergency walkways and emergency exits, to go to the safe area in the emergency lane in the inner road tunnel tube. The emergency exits from the inner rail tunnel tube provide direct access to the safe area in the emergency lane in the inner road tunnel tube. The passengers are therefore able to leave the fire site long before they suffer injuries from any smoke generation in the tube with the accident. From the safe area in the road tunnel tube, everyone can be safely evacuated from the tunnel using buses or on foot. The evacuation from the train will be feasible within a few minutes.

If the incident occurs in the outer railway tube, the passengers cross the inner railway tube on the rescue route. At the emergency exits, there are steps and walkways leading across the railway track so that passengers can cross the track unimpeded to the safe area in the road tunnel.
When LCC registers an incident in the railway tube, entry to the road tunnel tubes will be blocked with barriers to prevent further vehicle traffic. The speed can be lowered via the variable traffic signs, and the remaining traffic in the road tunnel is guided to the overtaking lane furthest from the emergency lane. The emergency lane then constitutes a safe area as the vehicle traffic is stationary at the tunnel entrance and the last vehicles in the tunnel tube are guided away from the emergency lane.

5.4 Pillar 4 – Deployment of the emergency services

In the event of an incident in the Fehmarnbelt tunnel, the emergency services have to be able to reach the area as quickly as possible. Short response times and well-established cooperation procedures with clear division of tasks and responsibilities are essential in such critical situations.

Up to the opening of the tunnel, Femern A/S is responsible for preparing a safety concept in cooperation with the competent Danish and German authorities, for example the fire services, rescue services and police. A joint Danish-German steering committee (called F-SURR (Femern – Sikkerhed, Øhøld, Redning, Rydning) (Femern – Safety, Accidents, Rescue, Recovery)) has been set up, along with a number of working groups, for example for emergency plans, digital communication, exercise planning, etc.

The safety concept describes the project-specific risk factors and accident scenarios so that the authorities have a basis on which to determine the extent of emergency services required correctly.

F-SURR has commissioned analyses, studies, workshops, plan rehearsals, exercises, etc. in order to establish a decision-making basis for the safety concept.
In the period up to the construction and operation phases, the specific emergency plans and procedures will be established so that the organisational framework for the Danish and German emergency services' joint deployment in the event of accidents is established.

In this connection, the emergency authorities will make the necessary agreements permitting efficient cross-border cooperation. The Danish and German emergency authorities have the ultimate responsibility for approving the safety concept for the construction and operation phases.

As is the case for all other road and railway tunnel structures, there will be continuous evaluation and optimisation of all safety-related matters in all phases of the project.

The authorities will perform regular inspections in the operation phase and there will be continuous training activities and test exercises to ensure that the emergency services personnel can be deployed in the best possible manner in the event of incidents and accidents.