Tunnel Safety and MEP-Systems
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INTRODUCTION

Tunnel Engineering Consultants (TEC) is a Joint Venture of Royal HaskoningDHV (RHDHV) and Witteveen+Bos (W+B). TEC combines knowledge, expertise and experience of both companies (8000 professionals) within the field of large underground projects, large building projects, environmental impact assessment, legal aspects and project management.

TEC guarantees continuity and specialized knowledge of tunnel design and construction to solve complicated underground mobility challenges through an integral, innovative and sustainable project approach.

TEC is able to draw on the considerable expertise of two Dutch engineering consultancy firms and covering the entire range of civil, structural, architectural, mechanical, electrical, process automation and tunnel safety engineering required for small and large underground projects.

This TEC capability statement intends to give an impression of the experience of Tunnel Engineering Consultants in the field of tunnel related design and tunnel construction related consultancy. It will provide an overview of services that TEC can offer within the preparation and realization of tunnel project.

This specific document highlights an overview of the expertise on Mechanical & Electrical installations, tunnel safety, fire safety engineering, cyber security, RAMS and MBSE.
An expertise matrix and CV’s of M&E-engineers and FSE-experts are added.
**TEC PROFILE**

Tunnel Engineering Consultants v.o.f. (TEC) is specialised in consultancy works for underground infrastructure and tunnel projects. TEC is established in 1988 as a Joint Venture between two major engineering consultancy firms:

- Royal HaskoningDHV
- Witteveen+Bos Consulting Engineers b.v.

**Profile**

TEC’s key expertise is tunnels; in-situ land tunnels, bored as well as cut & cover and immersed tube tunnels. The Scope of work comprises tunnel design with construction supervision including the mechanical and electrical tunnel installations and tunnel safety. Together with the Dutch Ministry of Transport and Public Works – Tunnel engineering Department (Rijkswaterstaat), TEC developed advanced knowledge in tunnel engineering.

The participating firms employ more than 8000 professional engineers and specialists and have a total annual turnover of about 748 million EURO (2016). They have subsidiaries and branch offices in countries worldwide.

**Royal HaskoningDHV**

[www.royalhaskoningdhv.com](http://www.royalhaskoningdhv.com)

Royal HaskoningDHV is a leading independent, international project management and engineering consultancy service provider. Specialising in planning and transport, infrastructure, water, maritime, aviation, industry, energy, mining and buildings, each year we contribute to the delivery of some 30,000 projects around the world on behalf of our public and private sector clients.

Our 6,500 staff adds value to our client’s projects by providing a local professional service in more than 35 countries, via our fully integrated international office network. As leaders in sustainability and innovation, we are deeply committed to continuous improvement, business integrity and sustainable development, and work with our clients, stakeholders and communities to enhance society together.

Prior to the merger on 1 July 2012, Royal Haskoning and DHV have successfully delivered millions of world class projects during the past two centuries. With roots established in The Netherlands, the UK and South Africa, our combined experience and longevity spans more than 225 years. Now, as one company, we have the power to make a bigger difference in the world as we rise to the challenges of our 21st century planet, towards a better, brighter future.

Today Royal HaskoningDHV ranks in the top 10 of global, independently owned, non-listed companies and top 40 overall. This makes us the first choice consultancy provider for involvement in major world themes, such as ‘pit-to-port’, food and water scarcity, the development of mega-cities, and sustainable infrastructure and energy resources & supply, such as wave and hydro power. We are also well positioned to contribute to the latest business models, such as Public-Private Partnership.
Witteveen+Bos Consulting Engineers b.v.
www.witteveenbos.com

Witteveen+Bos is a private limited company whose shares are owned entirely by its employees, who are either participants, partners or senior partners. This unique ownership structure ensures above-average commitment, good financial performance and a high profile. It is a structure that appeals to our clients, because it gives them confidence in our commitment. Our net result is paid out entirely as a dividend to our shareholders, so they share in large measure in the company’s result.

The Witteveen+Bos organisation is built around the cells concept that we have shaped in the form of PMCs (product market combinations). Organisationally, the PMCs are clustered into four Business lines: Delta’s, coasts & rivers, Energy, water & environment, Built environment and Infrastructure & mobility.

Next to the offices in The Netherlands, Witteveen+Bos also has offices in Belgium, United Kingdom, Dubai, Singapore, Ghana, Kazakhstan, Indonesia, Russia and Latvia.

Witteveen+Bos is committed to being a first-rate consultancy and engineering firm. Performing at the very highest level is a precondition for achieving this goal. We think striving for the top is a healthy ambition. A national and international orientation towards products, markets and the labour market is essential to operating being the best in our field of work.

Internationally, Witteveen+Bos have achieved a good position in the following areas:
- Preparation, transport and distribution of drinking water;
- Effluent treatment;
- Water management;
- Environmental technology and policy;
- Ports, dredging, coastal water engineering, river water engineering;
- Tunnels.
SERVICES

TEC provides a full range of consultancy services from feasibility studies, design, tender documents, tender evaluation, design reviews, value engineering, cost analysis, detailed design, and construction supervision to project management for underground engineering, related electrical and mechanical works, process automation, traffic engineering, cybersecurity and fire safety engineering. In addition, we are able to draw on the considerable expertise of two Dutch engineering consultancy firms covering the entire range of civil, structural and architectural engineering required for small and large building projects, environmental impact assessment, legal aspects and project management. Moreover, TEC has at their disposal specific expertise of the Dutch Ministry of Transport and Public works - Tunnel Engineering Department, a governmental organization involved as designer and owner / operator in over 25 road and railway tunnels and their installations in The Netherlands.
EXPERTISE

Electrical and Mechanical systems
- Power supply
- Lighting
- Tunnel- and portal drainage
- Ventilation
- Traffic management
- Fire fighting
- Communication
- Building services
- Command and control
- Operation and Maintenance

Safety and security aspects
- Integrated safety concepts
- Safety analysis
- Operational procedures
- Quantative risk and Scenario Analysis
- Integrated safety concepts
- Ventilation and CFD modelling
- Evacuation modelling
- Cybersecurity

Activities
- Conceptual design
- Plan approval design
- Preliminary design
- Detailed design
- Review of contractors design documents
- System integration
- Risk analyses
- Value engineering
- Tender documents
- Cost estimates
- Monitoring and construction supervision
- Project management
- Interface management

Tools
- Model Based Systems Engineering (MBSE);
- Reliability, Availability, Maintainability and Safety (RAMS);
- Life Cycle Costs (LCC);
- Building Information Modelling (BIM) – 3D-design;
- Virtual Reality (VR) tools Fire Safety Analysis
- Relatics – Requirements database.

Mechanical, Electrical & Plumbing (MEP) systems
- Power supply:
  - High voltage distribution
  - Low voltage distribution
  - Uninterrupted power supply (UPS)
- Emergency power
- Power factor correction
- Cabling
- Lightning and surge protection
- Earthing
- Equipotential bonding
- Cables and ducts

- Lighting:
  - Normal tunnel lighting: halogen lighting, fluorescent lighting, LED lighting;
  - Safety lighting;
  - Emergency lighting: illuminated indication signs (with sound beacon), spot lights for escape doors, luminaires in the emergency- and service gallery, green contour lighting around the escape doors, green contour lighting in the tunnel, sensors on escape doors, illuminated signage.

- Tunnel- and portal drainage:
  - Pump systems
  - Gullies
  - Separators
  - Sand traps
  - Pressure pipes
  - Apertures
  - Measurement and sensing equipment
  - Foam suppression
  - Hoisting equipment

- Ventilation:
  - Normal operation ventilation: jet fans, air flow monitors, visibility sensors, CO-measuring;
  - Emergency operation ventilation: exhaust fans, extraction dampers, ventilation ducts;
  - Escape gallery ventilation: overpressure fans.

- Traffic management:
  - Traffic Detection and Monitoring System: lane control systems, variable speed limit systems, traffic detection systems;
  - Vehicle Control System: tunnel dosing system, traffic lights, vertical barrier, moveable crash barrier, overheight detection, dynamic message signs.

- Fire fighting:
  - Pump system: jockey pumps, main fire pumps, connecting pipes with fittings and valves, instrumentation;
  - Water storage tanks;
  - Pressurized firefighting water distribution main;
  - Emergency cabinets: portable fire extinguishers, hydrants, fire hose reel;
  - Fixed fire suppression system;
  - Fire detection system;
  - Smoke/heat detectors.

- Communications:
  - CCTV: camera and design plans, media converter, storage, network & distribution;
  - Radio rebroadcast & emergency services communication: antenna system, combiners & repeater
- Telecommunication: intercom station, telephone station, server architecture.
- Public Address: loudspeakers, measurement microphone, audio distribution & amplifiers.

- Building services:
  - HVAC installations;
  - Security and access control installations;
  - Power distribution for building related installation;
  - Fire detection & evacuation installation;
  - Firefighting equipment;
  - Sanitary installation;
  - Communication installation;
  - Emergency and escape route lighting.

- Command and control:
  - Traffic Control Center;
  - Command system hardware;
  - Control system hardware;
  - Human Machine Interface;
  - PLC network;
  - Remote I/O network;
  - Transmission network;
  - Operator room design.
TUNNEL SAFETY APPROACH

Tunnel Systems for:
- A reliable and available tunnel;
- High standards;
- An integrated MEP design.

Traffic Management Systems to:
- Optimize traffic flow and capacity;
- Limit safety risks;
- Increase availability / maintenance.

Integral Safety Concept contains:
- International & local standards;
- References;
- Integral approach with all design disciplines;
- Based on functional assessment (performance based design, scenario’s);
- Stakeholder-involvement in early stage (client requirements).

Figure content Integral Safety Concept.
Results of Tunnel Safety approach:

- **Design**: Early and functional integration in civil and geometrical design;
- Design methods: Model Based System Engineering (Diamond Model).

**Safety**:
- Integral, complete and proven tunnel concept;
- Stakeholders are part of the process.

**Systems**:
- Reliable;
- Available;
- Maintainable;
- Operation control;
- Life Cycle Costs;
- Cost effectiveness (maintenance and construction costs).

*Figure Tunnel Safety Approach*

*Figure visualization of the Diamond Model.*
FIRE SAFETY ENGINEERING

Our Fire Safety Engineering and Tunnel safety are involved in several underground transport and tunnelling projects in The Netherlands and International.

In these tunneling projects we developed integrated safety concepts in terms of ventilation and smoke management strategies based on evacuation and passenger flows analysis. Also risk assessments and quantitative risk analyses (QRA) are part of the scope. With the combined use of the available knowledge, skills, experience and supporting tools, we can carry out complex CFD and evacuation simulations and provide design solutions for the most challenging projects. This all in compliance with the international codes and standards.

Figure visualization of CFD simulations.

For tunneling and fire safety related tasks we do have broad experience to advise the client and engineers with a Fire Safety Engineering based approach supported by CFD-modelling, ventilation design, quantitative risk analyses and 3D-BIM orientated VR-evacuation and ventilation simulations.

is involved in several underground transport and tunnelling projects in The Netherlands and International.

Our Fire safety engineering expertise contains:
- CFD-modelling;
- Ventilation design;
- Risk assessments;
- Quantitative risk analyses (QRA);
- Evacuation simulations.

Some specific tools:
- 3D Transfer and evacuation modelling: for the modelling of transfer and evacuation scenarios in underground transport hubs and interchange stations the micro-simulation tool STEPS is used;
- CFD-modelling and complex transport hubs: for the Computational Fluid Dynamics (CFD). High quality CFD simulations can be offered by the combination of knowledge of fire dynamics and fire safety installations, smart BIM couplings, parallel (cluster) computing and state-of-the-art post-processing techniques;
For the ventilation strategies including design of the over-pressure installations, ventilation calculations are performed, supported with several specific software programs.

- For basic design of tunnelventilation the ProTuVem software is applicable for regular situations;
- For the interaction of tunnelventilation and safe evacuation galleries specific scripts and calculations methods are developed, Smoke free escape routes can be designed by determining the over-pressure lines ensuring an integrated ventilation design;
- For the study on the smoke behaviour and control around the tunnel portals more complex 3D-CFD modelling and simulations will be performed.

To assess the safety level of tunnels quantitative risk analyses supported by sensitivity analyses for the several safety measures can be performed. Risk models have been used in several tunnelling projects to support the compliance for the prescribed safety level in regulations.

All the validated FSE simulation results can be visualised by our 3D-VR-tool to support the engineering process, optimise the design and the compliance trajec,

![Figure 3D CFD-model and visibility conditions study](image)
CYBER SECURITY

According to regulations a tunnel needs to be proven to be safe before authorities give permission for it to be used. This means for instance that the traffic through the tunnel needs to be monitored continually. This in turn implies that all the Control Systems in the tunnel need to be continually available. During the design of the tunnel systems, this high availability needs to be taken into account. Whereas in the past it might have been sufficient to include redundancy in the design, nowadays cyber security needs to be addressed as well. Include cyber security aspects in the maintenance contracts in order to keep the systems secure in the long run. This means including an obligation to regularly update the software that is installed on the computer systems. This includes both the Operating System as well as the specialist software and the anti-malware. The contracts should also contain an obligation that all employees of the maintenance party who work on the tunnel systems should do so with “cyber hygiene” in mind.

At the highest level of abstraction, the requirements with respect to cyber security should specify the required protection level of the installation.

![Figure protection level of installations.](image)

Together with a risk assessment (which may result in a risk reduction overview) this defines the target security levels for the installation. The above diagram shows the interdependence between the required protection level, the target security levels, the capability security levels and the achieved security levels.

With respect to tunnels the possibility of accessing any or all of the tunnel systems remotely should be part of the requirements, because it has major impact on both the design and the construction of the tunnel networks.

Cyber security aspects that need to be considered and incorporated are:

- Design the tunnel system in such a way that it is possible to update them regularly without major interruptions in functionality and that they contain only the software that is necessary for the intended function of each system. This might imply removing any unnecessary software that was installed by default by the manufacturer (also known as stripping).
Design the systems in such a way that the logging generated contains enough information for the case an incident needs to be investigated. Logging information needs to be protected from tampering for instance by including a logging server in the network;

Include a configuration management database in the design and use it from the start of building the tunnel systems. This means having change management processes in place during the construction of the tunnel systems.

Results of applying Cyber Security measures
The most important result of these measures is that the required protection levels are met, which means that the risk of the systems being compromised has been reduced to an acceptable level. Also, these levels will remain valid during the lifetime of the installation. These measures result in defence in depth, of which the physical protection of the installation is the first layer. If, despite these measures, an incident does occur, then sufficient information will be available to perform an investigation into the incident and determine what went wrong and which further measures are needed to further protect the installation.
RAMS (RELIABILITY, AVAILABILITY, MAINTAINABILITY AND SAFETY)

RAMS stands for the consistency between the aspects: Reliability, Availability, Maintenance and Security (Safety). Based on these four aspects, for each product/system, the desired quality of primary performance is described, determined and monitored. Sometimes health, environment and costs are also involved. In that case we speak about RAMSHEC. Depending on what is relevant to the object, the RAMS analysis can be extended to RAMSHEEP.

RAMS is applicable to any system where business assurance is of importance to both the Client and the Contractor. On the client side this means that the specifications must be formulated in a way that the functional performance and the resulting costs match the type of object or project without reducing the contractor’s resolution of the design.

For contractor’s activities, this implies that the RAMS requirements are filled in and proven in a cost-effective manner. The design and/or procedures are optimized to minimize the cost of life cycle/management.

Some RAMS applications:
- Exploring critical parts to determine the most successful measures, for example, to improve reliability and availability. Successful in the least investment cost, the simplest adaptation to the current installation, the lowest maintenance cost, the occurrence of a redundant solution through a "small" improvement elsewhere in the system;
- Demonstrate that the design of the installation meets the required availability or reliability requirements. This afterwards, or just in the design to determine the most suitable variant in terms of, for example, business security (completing a Multi Criteria Analysis);
- Provide support to reduce management and maintenance costs (inspection, and maintenance intervals, spare parts, preventive replacements, brake pads). For example, the closure of a tunnel for maintenance involves high costs, with RAMS, the most optimal service maintenance can be given to limit the number of closures and shorten the closing time.

Some specific tools:
- Decomposition of the system, with the determination of the failure definitions, failure mechanisms and determination of the faulty data;
- FMEA Failure Mode and Effect Analysis (qualitative). Examination of the sensitivity of a subsystem or the composition of a function for faults;
- RA analysis, quantitative fault tree analysis. Provides availability and failure and maps which maintenance effort is required;
- RAM Reliability, Availability and Maintenance, fault analysis is usually performed based on availability and reliability (RA analysis). In this analysis, the maintenance aspect (M) is not a direct result, but an input parameter;
- FTA Fault Tree Analysis is a top down, deductive failure analysis in which an undesired state of a system is analysed using Boolean logic to combine a series of lower-level events;
- RCM Reliability Centered Maintenance. Provides a substantiated maintenance plan including spare parts management, which corresponds to the reliability and availability of the object.
Figure RAMS in the design process.

Results of RAMS:
- Optimizing design in early design phases;
- Reduce risks during design (easy implementation, low costs);
- Objective comparison of design choices;
- Support investments for reliability;
- Risk based formation of maintenance concept;
- Important in Design Build Finance and Maintain (DBFM) contracts.

Abbreviations:
- FMEA: Failure Mode and Effect Analysis
- RAM: Reliability, Availability and Maintenance
- RCM: Reliability Centered Maintenance
SE (SYSTEMS ENGINEERING)

Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem:

- Operations;
- Performance;
- Testing;
- Manufacturing;
- Cost & Schedule;
- Training & Support;
- Disposal.

Systems Engineering integrates all of the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation.

Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.

Figure V-model in SE process.

Results of SE:

- More systematic way of development;
- Better control of System Development incl. risk management, changes, configuration;
- Traceability at all levels;
- Operational & supportability aspects:
  - Effectiveness Analysis;
  - Risk management;
  - Operational - Maintainability, Availability, Safety etc.
MBSE (MODEL BASED SYSTEMS ENGINEERING)

Model Based Systems Engineering is a design method for complex (infrastructural) projects:

- Goes beyond Systems Engineering;
- Display system design in a model;
- Step-by-step filling of the model.

Model-based Systems Engineering provides a mechanisms for driving more systems engineering depth without increasing costs. Data-centric specifications enable automation and optimization, allowing SE engineers to focus on value added tasks and ensure a balanced approach is taken.

Unprecedented levels of systems understanding can be achieved through integrated analytics, tied to a model-centric technical baseline. MBSE is a formalized application of modelling to support:

- Top-down approach;
- Interdisciplinary approach;
- Complete definition of system requirements;
- Analysis;
- Design;
- V&V activities;
- Beginning in the conceptual design phase and continuing throughout development and later lifecycle phases.

*Figure V-model in MBSE process.*
Results of MBSE:

- Functional specification that meets the stakeholders' requirements and expectations;
- Perfect “match” of the new system within the organization and business (critical) processes;
- Good starting point for integration tests;
- Modular automation system in which both hardware and software are structured in a clear and safe way;
- Modifications and extensions can be implemented without unnecessary rework and additional risks;
- Clear understanding to the system developer (System Integrator or Contractor) of the purpose of the system.
PROJECT REFERENCES E&M WORKS

Traffic Control Centre for southern part of The Netherlands

Project
The Traffic Control Centre for the southern part of The Netherlands is located in Geldrop. This centre processes data received from the roadside installations in the provinces of Noord-Brabant and Limburg. These installations are linked to the traffic control centre by telemetry systems. The traffic control centre is used by the Ministry of Traffic and Public Works to inform, guide and direct road users.

Figure: Plan of the Traffic Control Centre

TEC’s scope of work
The work consisted of:
▪ Basic design
▪ Final design
▪ Development of tender documents
▪ Supervision, and
▪ Project management
Traffic Control Centre for eastern part of The Netherlands

Project
The Traffic Control Centre for the eastern part of The Netherlands is located in Wolfheze. This centre processes data received from the roadside installations in the provinces of Gelderland, Drenthe, Groningen and Friesland. These installations are linked to the traffic control centre by telemetry systems. The traffic control centre is used by the Ministry of Traffic and Public Works to inform, guide and direct road users.

Figure: Plan of the Traffic Control Centre

TEC’s scope of work
The work consisted of:
- Basic design
- Final design
- Development of tender documents
- Supervision, and
- Project management
Dordrecht region tunnel & bridge installations renovation

**Project**
The technical installations of the traffic control systems in the Dordrecht region were outdated and needed to be replaced. Due to the fact that new and improved technology became available as well as new legislations for tunnel installations, the Tunnel Engineering Department of the Ministry of Transport and Public Works commissioned TEC to provide their services to renovate the control systems for the “Drecht” and “Noord” tunnel, as well as the bridge over the river “Noord”, the “Wantij” bridge and the “Papendrechtse” bridge.

The renovation of the installation systems and control units for the three motorway bridges included the energy supply (opening and closing), traffic lights for ships, traffic lights for cars, traffic barriers, hydraulic drive, emergency motor (in case the main motor breaks down), CCTV-installations (cameras), noise barrier installations, video screens and building installations (heating, ventilation, sanitary installations).

The renovation of the installation systems and control units for the two motorway tunnels included energy supply, ventilation, lighting, emergency buttons (to close off the tunnel), UPS (uninterruptible power supply), drainage, traffic installations (cameras, traffic sensory systems), communication (phones, speakers) and fire fighting installations.

*Figure: Installations*

**TEC’s scope of work**
- To prepare a conceptual design, a final design and tender documents.
- Control of detailed engineering and construction of the installations.
- Responsible for construction supervision management on site.
Botlek tunnel renovation, the Netherlands

Project
The project relates to the renovation of the emergency power installations and Speed Discrimination System of the Botlek tunnel.

The mechanical and electrical installations that required renovation consisted of:

- Energy power systems
- Distribution systems
- UPS-system
- Speed Discrimination System
- Plant control and control systems

Figure:

TEC’s scope of work

- To prepare a conceptual design, final design and tender documents.
- Control of detailed engineering and construction of the installations.
- Responsible for construction supervision management on site.
North-South Metro Line Amsterdam - The Netherlands [1994-2017]

Project
To relieve the existing public transport system (bus, tram, metro and ferry lines) in and around Amsterdam, the existing metro system will be complemented by an additional 5th line, the North-South line. The new line is expected to provide transport for approximately 200,000 people a day. The 1st part of the line extends from the A10 ring road in Amsterdam North to the A10 ring road in Amsterdam South and has a length of 9.5 km.
The line includes sections on an embankment, in open ramps, through in-situ, immersed and bored tunnels as well as through pneumatic caissons. The stations are at surface and at various depths, up to 30 m, under the streets of the ancient Amsterdam city center and extremely close to historic buildings.

Figure transportation and immersion of tunnelelement.

TEC’s scope of work
Safety Concept

An integrated safety approach has been developed by the TEC parent companies for the new underground North/South metro line based on the “Safe Haven” concept. As legislation in the Netherlands did not provide a safety framework for underground structures, a project specific concept has been developed. Evacuation and fire-safety design of the underground mass transit system (with bored and immersed tunnels, underground stations, rolling stock) are the main safety topics. A functional fire safety approach (FSE) has been followed. The leading principle of the safety concept is that all the measures will be taken to ensure that in case of emergency the trains will reach the stations. The tunnels are situated at such depth that emergency crews cannot be on hand immediately
in case of an incident. The passengers should therefore in all situations be transported to the stations. These stations are the Safe Havens. A rapid and safe evacuation from the stations is of utmost importance for the total safety concept. The depth of the platforms and spatial constraints required a solution in which safe evacuation will be supported by escalators and an emergency ventilation system. The stations are furthermore equipped with emergency power supplies, detection systems, smoke and heat extraction systems, fire proofing etc. to prevent or control incidents.

The TEC parent companies were responsible for the design of the Integral Safety Concept and all the safety assessments like: Fire safety analyses (FSE), Quantitative risk analyses, HAZOP, Hazard Logs, Safety Cases, evacuation simulations (3D), Smoke extraction and CFD modelling, program of safety requirements. The fire load assessment and structural integrity requirements were also part of the works performed. This concept has been developed in dialogue with both the legislation authorities and rescue services.
Systems

Functional and technical specifications for all the mechanical and electrical systems (MEP-systems) of the metro system are developed by TEC, taking into account the specific (safety) requirements and constraints of the underground structures.

Parts of the design-services are the following subsystems:
- Escalators and elevators;
- Smoke exhaust systems (emergency ventilation);
- Ventilation (HVAC);
- Electrical Power supply (trains and systems);
- Lighting systems;
- CCTV- and communication systems;
- Emergency stations;
- Pumping and drainage systems;
- Detection systems.

All these systems are designed in compliance with the reliability and safety requirements as part of the integral RAMS and Life Cycle Cost (LCC) assessments.
Sharq Crossing Doha – Qatar [2013-2014]

**Project**
The new approximately 12 km bridge-tunnel connection Sharq Crossing is a vital part of the Greater Doha Transportation Master Plan. In recent years the city of Doha has seen considerable increase in population, car ownership and new city districts. It is forecast that the area will experience serious traffic problems in the near future. This Bridge-Tunnel Link is crossing the Doha Bay. The Link consists of three major bridges, two immersed tunnels, a marine interchange for the connection of one of the bridges to the two tunnels, two marine islands for the connection of the tunnels to the bridges and three land tunnels at the landing points. The Sharq Crossing contains two immersed tunnels (2*3 lane and 2*2 lane with escape lane) with a length of approx. 2.800m each. The 2x3 lane tunnel has a width of 45.5m and a height of 11.1m. The 2x2 lane tunnel has a width of 34.2m and a height of 11.1m. Each immersed tunnel is built up out of tunnel elements of 150m. The marine interchange is a subsea traffic junction connecting one of the bridges to the immersed tunnels and has an overall length of approx. 600 m and a width of around 100m. The land tunnels are connecting the bridges to the shore and linking the crossing into the local road network they have lengths varying from 1.000m to 1.500m.

**TEC's scope of work**
TEC prepared the validated concept Design of the 2 immersed tunnels of 3.1 and 2.8 km and the 3 cut-and-cover tunnels with a length of approximately 950-1250 m connecting the bridges to the main land and the Marine Interchange, connecting the 2 immersed tunnels and one of the bridges. The assignment also included the design of mechanical, electrical and plumbing (MEP) systems, the Integral Safety Concept, including ventilation. TEC worked together with HBI Haerter Ltd. (Zurich, Switzerland) for tunnel safety and tunnel ventilation.
The project included 5 phases. The recent sub consultancy agreement covered the first project phase: Concept Design Validation. TEC has executed the first phase in 5 months time, which started in September 2013 and was completed by January 2014.

![Figure interior of the tunnel.](image1)

![Figure Tunnel safety strategy and concept.](image2)
Increasing capacity Coentunnel route Amsterdam – The Netherlands [2011-2012]

Project
Over one hundred thousand cars were daily using the 1st Coen tunnel, which is much more than this motorway section can handle. In order to regenerate the traffic flow, the Dutch Public Works decided to expand this motorway section by the realization of the 2nd Coen tunnel and the renovation of the existing tunnel. In order to connect the tunnels to the A8 and A10 motorways, various connecting roads had to be realized as well. Rather than the actual technique, the challenge of the project is based on the requirement that the link must be fully operational during construction of the new tunnel, the rehabilitation of the old tunnel and the integration into the new expanded road network. Moreover this tunnel was the first tunnel in the Netherlands that to comply with the new Dutch Tunnel Standard including very stringent requirements in terms of verification and validation.

Figure overview first and second Coentunnel.

TEC’s scope of work
Through parent company Royal HaskoningDHV, TEC provided various design services:
1. Final Design for the traffic and tunnel systems (TTS) to realize an increased capacity for the Coen Tunnel route based on the System Design:
   - Design subsystems for TTS system, such as communication systems, control systems, power supplies, lighting and ventilation systems, building services, fire extinguishing, traffic and drainage systems, etc;
   - Technical design in text and/or single-core wiring diagrams and/or I/O lists, light calculations, cable calculations, power balance/energy matrix, capacity of pumping systems, water hammer analysis, etc;
   - Specification of procedures for verifying the requirements associated with the system;
   - Coordination interfaces and defining interface requirements;
   - Coordination space aspects and recesses for the traffic and tunnel systems;
   - Reliability, Availability, Maintainability, Safety, Health and Environmental analyses associated with the system.

2. System Design for the traffic and tunnel technical systems (TTS) to realize an increased capacity for the Coen Tunnel route based on requirements specified by the Ministry of Public Works:
Preparation of integrated design at level 0 (highest level of the System Engineering methodology) for the TTS system, applying the methodology of system engineering;

Preparation safety and tunnel scenarios (flow of events in time), including what-if analyses (analysis and evaluation of the effects of a failure of one or more of the related systems during each scenario step), in order to discriminate the critical events;

Preparation system scenarios on the basis of these safety and tunnel scenarios (response of the technical system) in which the integrated operation of the subsystems of the TTS system is shown;

Allocation of the requirements to the subsystems for the TTS system, such as communication systems, control systems, power supplies, lighting and ventilation systems, etc;

Identification of system interfaces;

Specification of the procedures for verifying the requirements associated with the system.

3. Master test plan traffic and tunnel systems

To fulfill the operational requirements and secure the safety aspects, the traffic and tunnel systems (TTS) will undergo a strict verification and validation process. This set of procedures will assure the quality and cohesion of the delivered (sub)systems and the integrated operation of the system.

The Master Test Plan’ (MTP) describes these processes at a strategic and tactical level, documents the verifications to be performed, at what level and who is responsible. In respect to the System Engineering methodology, the MTP is the leading document in the verification and validation.

Figure V-model design traffic and tunnel systems 2nd Coentunnel.
Road-Rail Tunnel Nijverdal – The Netherlands [2012-2013]

Project
The center of Nijverdal is one of the last city centers in the Netherlands that is split in two by a national highway/railway. This obviously has a detrimental effect on the livability, traffic flow and traffic safety in the Nijverdal center. To improve this situation, the city council, together with the Dutch Ministry of Transport and Public Works have initiated the “Combiplan” project that aims at abandoning the through traffic from crossing the city center.

![Figure overview road- and railtunnel.](image)

The Nijverdal Combiplan project includes a 400 m long tunnel section, with an open-tunnel section and approach ramps on both ends. The tunnel will accommodate 2 x 2 traffic lanes, each of which will be in a separate tube. The tunnel will also accommodate the double track railway line.

The entire project also includes all associated works on the surface and is realized under Design & Built. The contractor for the project invited TEC to provide the structural design for the road and railway tunnel. TEC has undertaken this assignment using System Engineering methodology.

TEC's scope of work
Through parent company Royal HaskoningDHV, TEC was responsible for the integrated M&E design for the road tunnel.

The services comprise:
- Conceptual, preliminary and final design Tunnel Technical Installations;
- Development scenario-analyses;
- Technical management;
- Preparation of the System Development Plan;
- Reliability, availability, maintainability and safety analyses, including Fault Tree Analyses and Failure Mode and Effects Analysis;
- Support with methodology of System Engineering;
- Support with development of Software.
**Sluiskil Tunnel Terneuzen - The Netherlands [2009-2015]**

**Project**
The Sluiskiltunnel is built alongside the present bridge over the Channel from Gent to Terneuzen. It provides a better connection between the harbours of Antwerp and Rotterdam. As this Channel is sailed by many Ocean Bulk Carriers the bridge was opened for 5 hours per day. A tunnel provides a permanent available connection for the increasing (cargo) traffic. The Sluiskiltunnel is a 1600 m twin bored tunnel with a diameter of approximately 11 m. On both sides of the Gent-Terneuzen Channel ramps of about 300 m are built. The tunnel is built in soft subsoil in a polder area.

![Figure entrance of the bored tunnel.](image)

**TEC's scope of work**
Through parent company Witteveen+Bos, TEC was the consultant to the Owner of the project:
The services comprise:
- Preparation reference design (civil and M&E) and tender documentation;
- Checking detailed design and construction supervision.
Westerscheldetunnel System Design and Renovation 2017 – The Netherlands [2012]

Project
The project contains maintenance and renovation of the Westerschelde Complex during the period 2013-2033. The new maintenance contract will be set up through a tender. The renovation of the tunnel will take place in 2017 and concerns replacement of several tunnel technical installations. The maintenance will be carried out, causing no traffic jams for the current traffic flow. Apart from design and project management, support was given for the tendering procedure (amongst others defining selection and allocation criteria).

Figure southern entrance of the Westerschelde tunnel.

TEC’s scope of work
Through parent company Royal HaskoningDHV, TEC provided various design services, including setting up the System Design and the Tunnel Technical Installations. The System Design was carried out for the benefit of maintenance and renovation of the Westerschelde Complex, based on the (historical) data provided by the client and demand specifications of Rijkswaterstaat (part of the Dutch Ministry of Infrastructure and the Environment). The work was carried out following the Systems Engineering model. For the Renovation part a questionnaire has also been drawn up, which is an integral part of the Maintenance Contract. In addition to the design work carried out and the associated project management, support has also been given to the procurement process (including market consultation, selection requirements, award criteria and procurement).

Figure view of western tube of the Westerschelde tunnel.
Fehmarnbelt immersed tunnel - Denmark-Germany [2009-2012]

Project
Realizing the last missing link between the mainland of Europe and Scandinavia, an immersed tunnel between Denmark and Germany. From 2028 the distance between the two countries will be reduced to just 12 minutes. With its 19 km, the Fehmarnbelt tunnel will be the longest combined road and tunnel in the world. The tunnel consists of a 2x2 lane motorway with emergency lanes, an escape- and service gallery and 2 single track train tubes. Safety aspects of such a tunnel request an enlightened approach to safety. The combination of car- and rail traffic in one tube diameter has the advantage that in case of an emergency, several non-incident tubes can act as safe escape. The safety requirements have mayor effect on the design of the tunnel technical installations, which have to comply with European laws and regulations.

Figure location of the new Fehmarnbelt tunnel.

TEC's scope of work
The project was carried out by the joint venture RAT, consisting of Ramboll, Arup and Tunnel Engineering Consultants. TEC was responsible for the conceptual design of the tunnel technical installations (E&M), the integration of systems in the civil construction, costs, implementation planning and the operation and maintenance plan.
In addition, TEC performed life-cycle calculations for the annual maintenance costs over the complete lifecycle of the tunnel.

Figure cross section of the Fehmarnbelt tunnel.

Project
The city of Maastricht has initiated the redevelopment of the inner-urban area between the market and the western bank of the river the Maas. The development includes the realization of a tunnel, a four-storied underground car parking station, with a shopping centre and municipal offices above it. The cut-and-cover tunnel has a length of 400m, which includes separate entry and exit lanes which amounts to 700 metres of which 400 meters is closed.

![Figure: Junction on the Southern side inside the tunnel tube.](image)

TEC's scope of work
Through parent company Royal HaskoningDHV, TEC was invited to advice on the maintenance of the E&M installations of the tunnel. In cooperation with the Maastricht municipality management department, TEC provided consultancy services regarding the management of all technical installations in the tunnel as well as those used for tunnel surveillance. The following installations are maintained: fire ventilation, tunnel lighting, C2000 system, PA system, fire alarm installation, CCTV installation, controls, standstill detection, escape route marking and escape route lighting.

The services comprise:
- Supervision of the maintenance contract with the contractor;
- Planning corrective maintenance;
- Inspection and evaluation of the work by the contractor;
- Initiation of supplementary work related to improvement of the installation and changes in the use of the tunnel;
- Coordination of work that must be implemented within the interface between the car park and the super structure.
Thomassen Tunnel Rotterdam - The Netherlands [1998-2004]

Project
The extension of the A15 motorway to the so-called Maasvlakte crosses the Caland Canal. For this crossing a tunnel has been constructed with a total length of 1500 m accommodating 2x3 road lanes and a service/escape duct. The tunnel is suited for transport of dangerous goods (category I).
The enclosed part of the tunnel is 1100 m. The section below the canal will be constructed with the immersed tunnel technique, with six elements of 115 m.

Figure view of tunnel tube with 3 lanes of the Thomassen tunnel.

TEC’s scope of work
TEC was responsible for the integrated E&M design for the complete tunnel.

The services comprise:
- Functional and design requirements;
- Preliminary design and final design, including calculations, drawings and schemes;
- Risk analyses;
- Tender documents;
- Cost estimates;
- Review of contractors detailed design;
- Monitoring and construction supervision.
Mexico City New International Airport - Mexico [2015-2016]

**Project**
The new airport will replace the Mexico City International Airport, which is at full capacity. The new airport will have three runways to start and will be expandable to up to six runways. With three runways in simultaneous use the airport will be able to serve up to 50 million passengers per year. The site for the new airport is located at the east of Mexico City. It is positioned within an area that was formally covered by Lake Texcoco; the lake has now dried up but the resulting ground and groundwater conditions are challenging.
The design of the tunnels is challenging due to the soft soil conditions, heavy airplane loads crossing the tunnels and severe seismic conditions. The safety concept and MEP design was developed by TEC.

![Figure overview terminals new international airport.](image)

**TEC's scope of work**
TEC is a subconsultant for the NAICM project and is responsible for the design of the tunnels and the installations during the conceptual and final design phase of the project. Support and checking is provided in the detailed design phase. The tunnels in the project are constructed with the cut & cover method.

The services comprise the following tunnels:
- Two Ground Service Equipment (GSE) tunnels with a length of 1300m. The GSE tunnels will be used by airport busses, catering trucks and tow-vehicles;
- Two airport utility tunnels parallel to the GSE tunnels;
- A public road tunnel used by supply trucks, passenger cars and busses carrying employees to the Support Area;
- A third GSE tunnel to connect the Maintenance Area with the Airport Support Area and Cargo.
**Shen Zhong Link – China [2015-2016]**

**Project**
The People’s Government of the Guangdong Province plans to build a sea-crossing link between Shenzhen and Shongshan. This Shen-Zhong Link is located about 30 km to the south of the Humen Bridge in Guangzhou and about 38 km to the north of the Hong Kong-Zhuhai-Macao Bridge (HZMB) Link.

The new link will shorten the commuting distance of two economic circles sitting on the east and west shores of the Pearl River. The link is not only a corridor for Shenzhen and Zhongshan, but is also for strategic importance to the Nansha, Qianhai, Cuiheng and Hengqin areas of the city of Guangzhou, Shenzhen, Zhongshan and Zhuhai respectively. Upon completion of the link, the travel time from Shenzhen to Zhongshan will be significantly reduced, from more than two hours to twenty minutes in clear traffic.

The connection has a length of 24 km, has 4 lanes in both directions and starts at a new artificial island south of the Shenzhen airport where the link is connected with the Guangzhou-Shenzhen Riverside Expressway. From there it passes underneath the Dachan waterway, the Airport Secondary Fairway and the Fanshi Waterway with a tunnel. At the West Artificial Island the tunnel switches to a bridge crossing the Lingdin West Fairway and the Hengmen East Waterway with a suspension bridge, approach bridges and a cable stayed bridge. At the Hengmen Interchange the link is connected with the Zhongshan-Kaiping Highway.

The immersed tunnel possesses 2 traffic tubes and a central gallery with a total width of 46 m and a length of 5.25 km. For the deep sections, reaching water depths of 35 m, full steel sandwich elements turned out to be most economical. For the less deep and wider sections single shell elements were proposed. As this will be the first full steel tunnel in China the cross-sections were developed in detail.
TEC's scope of work

TEC, in combination with the Guangdong Highway Reconnaissance Planning Design Institute and Information Based Architecture, prepared a set of design documents covering all aspects of the tunnels, islands and bridges.

The TEC, GDDI and IBA joint venture ended second in the competition. The client amongst others valued the technical depth of the study and the practical knowledge and experience brought in from other large tunnelling projects.

The TEC scope of services covered the integral design of the immersed tunnel and the artificial islands. The following items were prepared by TEC and were included in the competition documents:

- Architectural design and landscaping;
- Structural safety and foundation design;
- Mechanical and electrical installations;
- Life safety;
- Construction methodology and schedule;
- Construction cost estimate.

Figure overview Shen Zhong Link.