Road tunnels are one of the key points of the road infrastructure of a town or region and greatly influence their economic development.

Europe has more tunnels, both in terms of the number of tunnels and in terms of the number of miles covered, than any other region in the world. Italy has over 1,200 road tunnels in operation comprising more than 700 km of tubes, France has over 900 tunnels with more than 300 km of tubes, Switzerland has over 340 tunnels, and so on. Numerous projects are currently at the design stage.

Although each tunnel is a special case, five classification criteria are used to determine the equipment needed to reach the level of security required:

- tunnel length
- traffic volume
- one or two-way traffic
- urban or non-urban tunnel
- level of service (or road class)
A major concern: design and maintenance of optimum tunnel safety & security

On an international level, only the road tunnel committee of the PIARC (World Road Association) examines and makes recommendations regarding the operation and safety of road tunnels. There is currently no European directive on road tunnel safety regulations. The official documents and directives of each individual country specify the equipment that must be installed to ensure the required safety level. Document 2000-63 dated August 25 2000 stipulates the safety equipment to be used in France. In Switzerland, recommendations are issued by the Federal Road Office, whereas in Germany, directives regarding road tunnel equipment and operation (RABT) list the equipment that must be installed in road tunnels. One of the areas in which Transparent Ready™ excels is the ability to interpret the available information and make fast decisions to ensure that tunnels are maintained in optimum condition and that they are absolutely safe. Transparent Ready™ is the concept of integrating Web technologies in Schneider Electric products to make them transparent to authorised users. Are you Transparent Ready? You will find the answer to this question in Chapter 2.

Electrical equipment: a fundamental requirement

Electrical equipment is absolutely essential to the operation of a road tunnel, yet it amounts to only 6% of total tunnel expenditure. It can be divided into four main categories:
- electrical power supply and distribution (chapter 4)
- automation (chapter 5)
- ventilation, excluding mechanical (chapter 6)
- specific equipment (lighting, automatic incident detection, video cameras, signalling, tolls, radio, and so on)

The choice of equipment to be installed is a determining factor in the long-term operation of the tunnels. The decisions made by the designers should therefore allow the operators to guarantee the required level of service and safety.

Products and equipment are now increasingly integrated in and interconnected with networks, making it more complicated to measure the overall security level and the global impact of any malfunction. Schneider Electric has greatly contributed to the development of dependability techniques that can be used to calculate justified confidence in a meaningful manner. These techniques also make it possible to compare several different installation architectures... since the most expensive one is not always the best! This theme is developed in Chapter 3 which covers the security aspect.

Finally, Chapter 7 describes how our specialists can help you design tunnels and maintain them in perfect operating order to ensure that they are absolutely safe. Our teams provide you with the methods, training and tools that will make it easier for you to:
- identify and formalise your objectives
- analyse the existing installation and understand its weaknesses
- help you make an informed choice based on the need for utmost dependability
The main challenge for tunnel operators and for the engineering firms responsible for tunnel design is to maintain tunnels in optimum condition and ensure maximum safety for their users. The ability to make fast decisions contributes greatly to achieving this objective.

Schneider Electric’s Transparent Ready™ solutions incorporate Web technologies in our products to make them “transparent” to all authorised users. Transparent Ready™ can provide a simple, fast and secure method of sharing information anywhere and at any time between all the authorised players concerned, by operating and maintaining tunnel equipment. Transparent Ready™ can therefore improve road tunnel safety.

Advantages of Transparent Ready™ for operators: increased safety

Fast, easy access to information due to:
- standard tools (PC, standard Web browser, mobile phone)
- optimised response times
- intuitive ergonomics

Secure access to shared information
- user rights control
- use of Virtual Private Network (VPN) for access from outside the tunnel
- more information without adversely affecting the Building and Energy Management load
- changing communication network architectures that can adapt to the different security levels required

Access to information anywhere and at any time
- from the control station: access to all the equipment data, including that not processed by the Building and Energy Management
- from each recess: maintenance specialists can access all the tunnel data for which they have the required access rights

Remote access to information anywhere and at any time
- for authorised users only
- from a remote control station, such as a regional control centre: the maintenance team is alerted in the event of a malfunction and can quickly make its diagnosis before proceeding to the site
- external partners-suppliers and operators-specialists can monitor the installations and determine the actions required to maximise their use

Advantages of Transparent Ready™ for systems contractors and integrators: quick and simple to implement

Fast, easy access to information
At the design and test stage, the use of Web standards and the provision of graphical object libraries facilitate the integration of Schneider Electric products. After the warranty period has expired, the use of Web standards guarantees easily upgradeable architectures, a long service life and continuous technology development.
Secure access to shared information
- user rights control
- use of Virtual Private Network (VPN) for access from outside the tunnel
- more information without adversely affecting the monitoring system load
- changing communication network architectures that can adapt to the different security levels required

Access to information anywhere and at any time
- during equipment installation, the Web pages embedded in the products can be accessed from any point in the network, ensuring faster implementation
- after commissioning and depending on their user rights, users can access all the information available on the network for remote diagnosis and maintenance purposes

Transparent Ready™ Solutions
Products with the following onboard units and functions:
- Web servers to make the data accessible from a standard Web browser
- functions used for e-services (diagnosis, optimisation, and so on) and for the automatic transmission of emails or SMS messages
- self-authentication
- self-diagnosis
- maintenance operation history log
- on-line maintenance documents

Application software providing a fast, simple method of integrating and interfacing with the Building and Energy Management

e-Services to:
- manage the history of the data generated by the equipment
- process the data and suggest improvements and methods of increasing efficiency (use of energy, maintenance plan)

Network architectures:
- in compliance with Web standards
- designed to optimise data transfer and storage
- with built-in safety requirements

Transparent Ready™ is an integral part of Schneider Electric’s power, ventilation and automated control offer
- solution optimisation according to tunnel topology (length, single tube/double tube, and so on)
- full integration of electrical power distribution and automation architecture into Building and Energy Management
- simple, upgradeable design, enabling the architecture to be adapted to the required security level
- adaptability via the use of Web standards
- Web pages embedded in products for configuration, data display, diagnosis and maintenance purposes
- real-time communication services optimising system performance
- diagnosis and maintenance communication services ensuring faster repair times
The disasters that occurred in the Mont Blanc tunnel between France and Italy, the Tauern tunnel in Austria or the Gothard tunnel in Switzerland have led us to reconsider our approach to tunnel security. Personal safety and the protection of property are the major concerns when designing, renovating and operating road tunnels. Electrical power is playing an increasingly critical role in keeping tunnel equipment in good working order. The availability of the electrical equipment is a key component in maintaining the level of security required.

Security, safety? As these concepts are sometimes confused, it may be useful to remind ourselves of a few definitions.

**Safety is only one element in the wider concept of security** which is made up of four components:
- **Availability**, the ability to accomplish a required function in given conditions and at a given time
- **Reliability**, the ability of an entity to accomplish a required function in given conditions during a given period of time
- **Maintainability**, the ability of an entity to be maintained (or restored to a state in which it can accomplish a required function) when a maintenance operation is performed with a given procedure and techniques during a given period of time
- **Security**, the ability of an entity to prevent a critical and/or dangerous incident from occurring in given conditions

The concept of safety is closely related to the concept of risk, which depends on the severity of the incident.

**Dependability**
Dependability facilitates safe design and optimum operation. It measures the quality of service delivered by a system in such a way that the user can have justified confidence in the system. Justified confidence is achieved via the qualitative and quantitative analyses of the various properties of the service delivered by the system.

Dependability studies are used to match network, electrical distribution or automation availability needs to the network to be installed. They are also used to compare two installation architectures. The most expensive one is not always the best... These studies can be applied to all types of electrical or automation networks.

The results from these studies are used to:
- ensure the highest level of availability at the lowest cost
- guarantee that systems operate correctly from the design stage
- minimise economic risk
- optimise the power supply and automation network architectures
- quantify, compare and optimise the solution selected
- check that the global system matches the specifications
- define the maintenance policy

**What is a security study?**
Irrespective of the tunnel operator or designer’s needs, a security study procedure consists of four successive phases:
- **Functional analysis**, which defines the functions to be studied, their interaction and constraints and the scope of the study
- **Dysfunctional analysis**, which describes the behaviour of each component in the event of a malfunction
modelling, through which the functional and dysfunctional behaviour of all the components can be analysed
- calculation or evaluation of security criteria

**Benefits of tunnel dependability**

**Operating requirements (non-exhaustive)**
- ventilation: ensure continuity of service
- electrical power: guarantee that the safety systems are in good working order
- EMC (electromagnetic compatibility) compliance: assess on-site design and installation
- remote monitoring: ensure Building and Energy Management availability for control purposes
- maintenance: optimise plant maintainability (basing team sizes on estimated reliability)
- spare parts management: optimise stock volume and/or sharing in line with availability objectives

**Requirements (non-exhaustive) of road tunnels in terms of dependability**

<table>
<thead>
<tr>
<th>Functions:</th>
<th>Dreaded events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incident detection</td>
<td>Non-detection of incidents</td>
</tr>
<tr>
<td>Smoke extraction</td>
<td>No control of smoke outlets</td>
</tr>
<tr>
<td>Provision of ancillary ventilation in recesses</td>
<td>No guarantee of pure air in recesses</td>
</tr>
<tr>
<td>Signalling management</td>
<td>Incorrect signalling</td>
</tr>
<tr>
<td>Lighting management</td>
<td>Inappropriate lighting</td>
</tr>
<tr>
<td>Maintained air quality</td>
<td>Ineffective ventilation</td>
</tr>
</tbody>
</table>

In this context, a dependability study can:
- define safety and availability objectives
- understand and identify risks
- anticipate consequences
- quantify, compare and optimise solutions
- modify the maintenance policy and determine preventive maintenance operations
- determine the quantity of spare parts to be kept in stock
- check that the global system matches the specifications

**Schneider Electric, a worldwide reputation**

Schneider Electric puts more than 30 years of experience in highly critical applications (nuclear, chemical, process, etc.) at your disposal

Operators, Main Contractor, Design and Engineering Department, Integrators and Contractors: our specialists are at your disposal to help you:
- identify and formalise your objectives
- analyse your existing installation and identify its weaknesses
- make an informed choice based on the need for utmost dependability
- train your own teams in dependability procedures
A tunnel is an infrastructure subjected to the constraints of an almost enclosed subterranean environment requiring the deployment of extensive human resources and equipment, whilst at the same time maintaining a high safety approach. The electrical power supply to the equipment installed in the tunnels is not fundamentally different from that used in other types of infrastructures or other industrial environments where similar regulations apply. The special nature of tunnel power supplies is due to the many different functions carried out by the various types of equipment used. This diversity involves determining the most appropriate method of supplying power to each type of equipment under normal circumstances and also under exceptional circumstances with deteriorated operating conditions (accident, power failure, strike, etc.). The supply of power to the equipment required for the smooth running of a tunnel must meet the statutory requirements and regulations (specifically the technical directives listed in joint-ministerial document no. 2000-63 dated August 25 2000), the specifications produced by utilities (for example EDF), as well as the recommendations issued by the CETU (French Center for Tunnel Studies).

**Power supply**

In all tunnels in which a ventilation system is installed, the power supply must be maintained in the event of external network failure (for example via a dual supply provided by two connections to separate feeders of the utility, or by installing a Genset with at least 4 hours of self-sufficient operation). The supply must also be maintained in the event of partial equipment failure. It must be able to ensure the continuous operation of equipment powered by the original source, without any interruption whatsoever. It must ensure that some of the ventilation equipment operates at full capacity, but the provision of reduced power for basic and emphasis lighting is admissible.

In the case of tunnels with no ventilation, two options must be considered:
- the tunnel cannot be closed, due to the level of service required on the road in question, in which case the power supply must be maintained as above to ensure that all the equipment operates correctly, including the basic and emphasis lighting, although this may be dimmed
- the tunnel can be closed and there is therefore no need for any measures other than to provide an uninterrupted backed-up power supply as described above

**Power supply predictions**

The installation must be designed to ensure that a power supply failure will have no undesirable consequences for the:
- safety of users and persons working in the tunnel (operators, security service, etc.)
- traffic
- tunnel operation

The functions to be maintained under normal and deteriorated operating conditions must first be identified. This will require an estimate of the power that would be required. The architecture of the electrical networks needed to supply the estimated capacity must then be determined.
The power supply predictions fall into three categories:

- Predicted power requirements for the operation of the various units under normal service conditions. The supplies needed to run all the equipment must be taken into account.
  
  Example for a 2 km single-tube one-way urban tunnel:
  - Two 630 kVA dry-type transformers running in parallel for the ventilation system.
  - Two 250 kVA dry-type transformers running in parallel for the lighting system and other equipment.
  - One 30 kVA inverter.

- Predicted power requirements for a deteriorated situation in which a power supply source remains available (second supply network or Genset).
  
  Only one part of the equipment is supplied, whilst power to the other part is cut off. Some equipment will be able to operate in limited mode only (ventilation, lighting, and so on), but the supply to the monitoring and standby equipment must not be interrupted. The tunnel must remain operational within predefined limits. Experience has shown that the power required for this mode is about 35% to 50% of the normal capacity.

- Predicted power requirements for a deteriorated situation in which no power supply source is available.
  
  This mode must provide for the tunnel to be evacuated within predefined safety conditions. The supply to the tunnel control and monitoring equipment and to the security lighting must be maintained.

**Electrical supply source**

The electrical installation must be designed to ensure that the failure of one component does not cause the entire network or any « vital » component to fail.

There are two possible electrical supply sources:

- Connection to a utility's power grid (EDF, state-controlled corporation, and so on).
- Self-sufficient power supplies (inverter, Genset, and so on).

The equipment is generally powered from the mains supply connected to the utility; the self-sufficient power sources take over when the supply deteriorates, or under specific circumstances.

The measures to be taken depend on predetermined objectives and on the solutions available, which may be:

- An emergency power supply that does not cause a reduction in the available rated power (for example an EDF dual supply via two substations, each capable of providing the total capacity required).
- An emergency power supply that causes a reduction in the power available (for example one substation backing up another when a Genset takes over after the supply to certain equipment has been cut off).
- An emergency power supply running the equipment that is essential for the evacuation of users in the event of a serious incident.

To facilitate tunnel operation, it is advisable to use meters and submeters that provide separate measurements of the amount of energy used by the main systems (ventilation, lighting, control stations, etc...).
Electrical Power Supply

Tunnel power supply requirements

Connection to the utility's power grid
There are two different distribution methods:
- medium voltage distribution (MV): The voltage level varies according to the country. In France, the standard voltage is 20 kV
- low voltage distribution (LV): As for medium voltage, the voltage level varies according to the country. In France, the standard voltage is 400 V

The type of connection (MV or LV) depends on the power required for tunnel operation. Example of energy distribution in France, if the connection power is:
- $< 36 \text{ kVA}$, the connection is LV and invoiced at the blue rate
- between $36 \text{ kVA}$ and $250 \text{ kVA}$, the connection is LV and invoiced at the yellow rate
- $> 250 \text{ kVA}$, the connection is MV and invoiced at the green rate

The MV supply from the utility's power grid depends on the structure of the network. There are three different types of supply:
- single feeder (radial network): the MV/LV substation is supplied via a single incoming cubicle
- double feeder: the substation is supplied via two separate incomers
- ring main unit (loop): the supply to the substation is in series on the utility's line

Earthing system
The equipment cabling must obviously comply with the standards currently in force. Depending on the equipment used, the low voltage earthing systems are mostly:
- neutral-connected exposed conductive parts (TN system) for all equipment located in the tunnel itself
- unearthed neutral or impedance earthed neutral (IT system) for the equipment located in the service rooms (for example: ventilation) in the case of separated transformers

Low voltage distribution
For evenly distributed loads (for example, lighting, safety equipment, and so on), the maximum length of LV distribution is approximately 1,000 m. For concentrated loads (for example: ventilation), there are two possibilities:
- low power (for example, ventilation accelerator), the maximum length of LV distribution is approximately 400 m
- high power (large ventilators), the length is limited to a few dozen metres

In the case of a high-power ventilation system, or if variable speed controllers are used, a device to limit unwanted harmonics or voltage drops on the other equipment may be required.
Cabling
In the tunnels, cables can be installed in three ways, in compliance with current standards:

- in cable conduits or ducts beneath the walkway (this is the preferred solution when fire protection is required)
- in the ventilation shafts
- on cable trays

If possible, the MV, LV and low current cable routings should be separated (using different mediums) to reduce the risk of electric displacement and simplify operation.

Special lighting features
Lighting plays an important part in ensuring the safety and comfort of road tunnel users. One of the special features of tunnels is the need for continuous lighting day and night. In fact, natural light penetrates only a very short distance into most tunnels (about three times the largest transverse dimension), which is not sufficient to guide drivers. Artificial lighting must therefore be installed to provide good round-the-clock visibility.

The lighting power supply is a low voltage (LV) system. Power used for public lighting is generally supplied via transformers distributed and powered by a medium voltage feeder, but this would not be suitable for tunnels, due to the density of the light sources.
Depending on its architecture (length, single tube/double tube, and so on), the feeder circuit can consist of one or more supply substations at the tunnel entrances, or even within the tunnel itself, in the case of very long tunnels.

Uninterrupted backed-up lighting
The security and boundary lighting must be powered by an uninterrupted power supply and be self-sufficient for at least half an hour, in order to:

- ensure that tunnel users do not find themselves in total darkness following an external power outage
- allow users to reach the shelters quickly and easily in the event of an accident in the tunnel during an external power outage

Security and boundary lighting
The power supply to the security and/or boundary lighting must be maintained for at least half an hour in the event of an external power outage to ensure that it is not completely extinguished. In addition, the power supply must be installed according to the sectioning principle, with the length of each section not exceeding approximately 600 m.
As each tunnel has its own individual characteristics, there is no standard tunnel power supply diagram. A network study (see chapter 7: Expertise) is used to determine the appropriate architecture in terms of the required redundancy. However, the following three typical diagrams (based on existing tunnel diagrams) showing the main implementation principles may be useful.

Many variations are possible, depending on the characteristics of each tunnel which determine the type and amount of equipment to be used and generally define the amount of power likely to be required under both normal and deteriorated operating conditions.

A backed-up network means a network receiving an emergency supply from one or more Gensets and which can therefore withstand an interruption lasting only a few minutes.

A maintained network means a network connected to an emergency power supply via an inverter that ensures that the supply is not interrupted.

**Low voltage supply**
Power < 250 kVA to benefit from EDF’s yellow rate. The tunnel network (or part of the network) can be backed up by a Genset. An Uninterruptible Power Supply (UPS) is used to maintain critical equipment.
**Type 2**

**Two MV incomers. Multiple emergency supply possibilities**
- in MV, via cables above the transformers
- in LV, via cables below the transformers
- in MV and LV (double redundancy)

(in the event of an LV emergency supply, the power of each transformer must be equal to the overall backed-up power)

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**Type 3**

**“Unlimited” power**

Two mutually-supporting MV incomers supplying the MV/LV substations in double feeder mode. An open-loop or double open-loop solution is also possible. If a double feeder installation is used, the prior agreement of the utility must first be obtained.
Web technologies at the service of tunnel electrical power supplies

**Transparent Ready™**

Transparent Ready™ is the concept through which Schneider Electric integrates Web communication technologies (Ethernet, TCP/IP, HTML, and so on) in its products to make them transparent to authorised users. Transparent Ready™ provides access to information anywhere and at any time.

Data displayed via the Web browser running on a simple PC logged in from one of the tunnel recesses.

Electrical equipment using Transparent Ready™ technology can therefore be connected to the Ethernet network installed in the tunnel:
- via intelligent switchboards,
- via a PLC (in one of the tunnel recesses, for example) over a LAN or via conventional inputs/outputs,
- through gateways (PowerLogic System EGX), or PLCs, in the case of electrical switchgear, in the vicinity of the MV substations

Transparent Ready™ allows you to design an electrical supply architecture that can be fully integrated into the tunnel Building and Energy Management in compliance with the required security level. The operator and contractor can (during the commissioning tests) access all the Web pages embedded in the Schneider Electric products and view:
- the electrical supply network data (even if this is not controlled by the Building and Energy Management)
- the configuration and diagnosis of the various units (assisted maintenance)

Example of the use of Transparent Ready™ in the power supply:

**Requirement:** following an alarm from the Building and Energy Management, how can a problem with a main switchboard located in a service room a few miles away be diagnosed from the control station?

**Solution:** The PowerLogic products on board the main switchboard control and measure the power supply to the equipment (voltage, current, power, etc.). The switchboard is connected to the Ethernet network in the tunnel via a single network cable and its embedded Web pages display the information from its switchgear. It will already have been assigned an IP address by the tunnel network manager. All that is now needed is to indicate the IP address of the switchboard via a simple Web browser (for example Internet Explorer) from the control station. The pages embedded in PowerLogic are displayed and provide the operator with instant electrical values from which an immediate diagnosis can be made.
Schneider Electric's power supply offer

MV/LV distribution transformers
Requirements: Fire protection, Overload protection, Environment protection, Minimum maintenance.
Our offer includes a complete range of Trihal-coated oil-immersed self-extinguishable dry-type transformers (630 to 2500 kVA) to meet your most stringent requirements:
- star/delta/zigzag connection, twelve-phase secondary supply, depending on the harmonics control level required
- three-phase 20 kV primary supply, 400 V/230 V or 690 V secondary supply for motors/ventilators

Medium voltage switchboards:
Requirements: Transformer protection, Personal safety, Compliance with standards, Minimum maintenance, Small size.
Our offer includes modular ranges that can be customised to accommodate your changing requirements. Our products have been designed for remote control via their Sepam communication interface, which improves service continuity. The cubicles can be power-operated at the factory or later, when they have been installed, without any interruption to the service.
- the SM6 range (3 to 24 kV) comprises cubicles equipped with metal-clad SF6 (sulphur hexafluoride) switchgear. Apart from its technical specifications, SM6 meets the most stringent requirements in terms of:
  - personal safety,
  - ease of installation and operation
  - compactness
- the MCset range (1 to 24 kV) is particularly suitable for general distribution substations with a high Isc (>20 kA), for example in the vicinity of a power station or electric power transmission lines. MCSet is a metal-clad vacuum or SF6 draw-out switchgear assembly
  - it incorporates a high degree of personal protection, in compliance with the IEC 60298 resistance standard to protect operators (on 3 or 4 sides) in the event of a fault due to internal arcing
  - it is safe to use. MCset is a metal-clad compartmentalised switchgear assembly
  - straightforward, high-performance operation: easy to use, clear, reliable status information, safety interlocks

Reactive power correction and harmonics filtering.
Requirements: Improved energy quality (harmonics filtering, voltage drop reduction), lower energy costs.
The Rectiphase reactive power correction and harmonics filtering equipment can be used with both MV and LV equipment: LV (Varplus, Rectibloc) or MV (Propivar) fixed or automatic correction equipment.
Our products can:
- extend the service life of your equipment
- prevent nuisance tripping and damage to sensitive components

MGE UPS SYSTEMS SineWave active harmonics conditioners provide the solution to harmonics pollution:
- harmonics attenuation
- Cos φ enhancement
- extended equipment service life
- lower power consumption
Power supply network management, protection, remote control and monitoring

Requirements: Maximum network availability, Equipment protection, control and monitoring, ease of use.

Sabine is an MV automatic loop reconfiguration system that can restore a power supply within a minimum period of time.

Easergy-T200 is a network control unit guaranteeing continuity of service supported by the following features:

- optimum integration of all its functions into a single unit
- perfect integration into MV switchgear
- readily available energy workshop designed to handle all the substation functions (power-operated switchgear, remote transmission equipment)

Sepam is a range of simple and reliable protection, control and monitoring units based on current and voltage measurement. It provides optimum service in the safest possible conditions. When Sepam is connected to a remote control and monitoring system, it can be used for:

- status and measurement monitoring
- remote control of operating units
- remote indication of operational messages (current alarms, tripping causes, operating sequence status)
- accurate time-dependent recording of status changes

PowerLogic System combines all the Schneider Electric power supply network management products that fall into the following three categories:

- energy management software
- network communication interfaces (use of Ethernet standards, TCP/IP)
- “intelligent” equipment (measurement systems, protection relays, circuit-breakers, PLCs, etc.)

PowerLogic System allows you to take control of your entire capital investment in the power supply network, manage energy consumption and check energy quality, operating costs and supply availability.

Low voltage switchboards

Requirements: Product reliability, safety, upgradeability and standardisation

Okken and Prisma offers provide innovative high-performance solutions (Masterpact, TeSys, Compact NS, Powerlogic, Multi9, and so on) that are simple to install, run, maintain and upgrade.

Okken main switchboards (up to 6300 A) are available in fixed, disconnectable, removable and draw-out versions. They provide the most appropriate solution for each type of load to be protected (motors, lighting, and so on) and each type of service factor. Okken switchboards include the main standards and usual configurations right from the design stage:

- power supply to the switchboard via busbar trunking systems and/or cables from above and/or below
- incoming unit in a dedicated pillar or an incomer/feeder combination pillar
- choice of partitioning for functional units (models 3b, 4b for incomers, 2b, 3b, 4a, 4b for feeders)
Requirements:
High-level availability, simple to maintain and operate
MGE UPS SYSTEMS products combine an inverter, active harmonics filter and conditioners, enabling them to achieve an exceptionally high availability and performance levels.

**Galaxy 3000 UPS** (10 to 30 kVA), Galaxy PW and 1000 PW (40 to 800 kVA)
- maximum battery life: 8 hours
- battery type: 5 or 10 years
- UPS and supply redundancy (static transfer system) to increase availability
- modular design allowing numerous variations

For very high power applications, the Galaxy range also offers solutions of up to 4800 kVA at various power levels (200 to 800 kVA).

**Prisma secondary and final switchboards** (up to 3200 A) are functional systems designed to create subdistribution and final switchboards. The strength of the Prisma functional system lies in its standard mountings and fittings. Prisma provides:
- optimum reliability
- almost unlimited adaptability and upgradeability
- possibility of integrating several functions (protection, control, technical management, monitoring, and so on) in the same switchboard.

**Uninterruptible Power Supply**

Requirements: High-level availability, simple to maintain and operate
MGE UPS SYSTEMS products combine an inverter, active harmonics filter and conditioners, enabling them to achieve an exceptionally high availability and performance levels.

**Galaxy 3000 UPS** (10 to 30 kVA), Galaxy PW and 1000 PW (40 to 800 kVA)
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- modular design allowing numerous variations

For very high power applications, the Galaxy range also offers solutions of up to 4800 kVA at various power levels (200 to 800 kVA).
Why install automation systems in tunnels?

The SCADA system is primarily a tool designed for the tunnel operator and is dedicated primarily to the safety of the structure and its users. The tool must be designed to supply the right information at the right time to facilitate the day-to-day operation of the tunnel and provide a real-time diagnosis of the installation so that maintenance operations can be started immediately in the event of an emergency, and in due course in the case of preventive maintenance. In the event of serious incidents (accidents, fires, and so on), the SCADA system should recommend various control scenarios to the operator to guarantee the highest possible level of safety. In fact, the chosen technical solutions must ensure uniformity throughout the entire system, allowing the various functionalities to be upgraded over time.

Automation requirements in road tunnels

Basic structure

The figure opposite shows a typical single-tube tunnel. Depending on the type of structure, the layout may change to include control rooms at each end of the tunnel. The service rooms are designed to house the electrical distribution equipment and the ventilation motor control systems (soft starter, variable speed controllers).

The recesses located at 200 m intervals house, amongst other things, the emergency call system, the fire extinguishing equipment, the lighting and the various detectors (smoke, temperature, and so on). Approximately 200 inputs/outputs are required to collect this information. All the information, including sound and images, is transmitted over the communication network.

Dependability:

a constant requirement in system design

Tunnel operation deteriorates whenever a control or monitoring system malfunction occurs. The severity level of the problem can be such that the tunnel has to be closed. Consequently, the system architecture must include dependability-related criteria that take into account the risk of losing information from one of the recesses and the risk of failure of one of the units in the automation chain (component, detector, PLC, and so on). To meet these criteria, an evaluation of the reliability and availability parameters of the units installed will be vital. The choice of redundant PLCs, dual communication networks, remote dual-connection inputs/outputs should be considered.

Requirement: system integration

The control and monitoring tool centralises the tunnel operation and maintenance information. The architecture selected must be accessible to all the functions via the use of standard communication protocols such as Modbus or Ethernet. The Transparent Ready™ function plays an important part in system integration.
As shown in the diagram opposite, an automation architecture corresponds to the level of dependability required. This architecture will also depend on the topology of the tunnel: single tube, double tube, length, and so on. It will be determined by:

- the choice of PLCs
- passive or active redundancy
- the acquisition of redundant inputs/outputs
- a double communication network

All the architectures submitted:

- are based on standard protocols and networks
- provide access to data and third-party system applications both in terms of design and in terms of operation and maintenance

### Example of a type 1 dependability architecture

This architecture is suitable for single-tube or double-tube tunnels with a length of between 1 and 3 km. It is designed around Premium PLCs. Its design must be appropriate to the security level already incorporated in each tunnel function (signalling, detection, ventilation, and so on). This automation concept requires the integration levels of the various functions to be known. An accurate functional analysis and a dedicated operating program ensure functional redundancy.

**Advantages**

- this solution provides a high level of security, but remains relatively inexpensive
- access to the PLC involved in this process is transparent for the control system in the event of a redundancy switchback

### Example of a type 2 dependability architecture

This architecture corresponds to a type 2 level of dependability and is designed around Quantum PLCs for use in automated tunnel control operations. The two PLCs operate in Hot Stand By redundancy mode.

The remote inputs/outputs are controlled by Momentum micro PLCs. All this equipment can communicate over an Ethernet optical fibre ring via Connexium interfaces.

**Advantages**

- hardware redundancy simplifies the integration of normal/emergency redundancy
- simplified application program development
- access to the PLC involved in this process is transparent for the control system in the event of a redundancy switchback
- redundancy switchback within 150 to 200 ms
- if one section of this network fails, the data flow is automatically rerouted to ensure continuity of communication
Example of a type 3 dependability architecture

This architecture corresponds to a type 3 level of dependability and was developed on the same basis as the type 2 architecture, but with the additional solution of redundant inputs/outputs in the recesses managed by Momentum micro PLCs.

Advantages:
- all the type 2 arguments
- recess input/output control redundancy

Example of a type 4 dependability architecture

This architecture corresponds to a type 4 level of dependability and was developed on the same basis as the type 3 architecture, but with the addition of a double Ethernet ring.

Advantages:
- all the advantages of type 3
- can withstand three successive network failures by reconfiguring the data flow

Customisable architecture for each type of tunnel

There is an automation architecture to suit every tunnel, depending on its length and whether it is a single-tube or double-tube structure or a multi-tunnel operation. This architecture normally depends on the reliability, availability and maintainability requirements of the tunnel. Schneider Electric has a high level of expertise in this field and can provide studies, simulations and functional analyses to help you choose the optimum architecture.
Schneider Electric's automation offer

High-performance automation product ranges for the construction of upgradeable, modular architectures open to all the universal communication standards on the market.

**Quantum PLC**
- designed for complex applications with high capacity requirements
- suitable for applications requiring a high degree of reliability and availability
- designed for “hot standby” redundant solutions
- regulation algorithm library
- open to redundant communication networks (fibre or copper)

**Premium PLC**
- designed for medium-capacity applications
- creates cost-effective solutions
- transparent architectures for intelligence decentralisation and function distribution
- easy to design, develop, operate and maintain

**Momentum inputs/outputs**
- designed to be integrated into distributed architectures
- intelligent inputs/outputs

**RT2-TX-R double transceiver**
- Used to connect a unit with a copper Ethernet link to two redundant Ethernet rings
- 3 copper ports
- dual supply option
- fault-indicating dry contact

**RS2 FX/FX switch**
- Supports ring redundancy, by rerouting the transmission of information in the event of ring failure.
- 2 optical fibre ports (ring)
- 5 copper ports (I/O equipment)
- dual supply option
- fault-indicating dry contact
- SNMP agent (network management)
- integrated Web server (diagnosis)

**RS1 FX/FX switch**
- Network PLC connection point
- 2 optical fibre ports (ring)
- 8 copper ports (I/O equipment)
- dual supply option
- fault-indicating dry contact
Why should road tunnels be ventilated?

**Ventilation under normal operating conditions**
The quality of the environment, safety, user comfort and the viability of the tunnel may deteriorate as a result of changes in the level of noxious substances in the atmosphere and sudden variations in the environment. The only way to cope with this type of pollution is to introduce fresh air into the tunnel to dilute the pollutants. The air flow required to ensure the required quality is obtained naturally or mechanically.

**Ventilation in the event of smoke extraction:**
The size and operating performance of the smoke extraction systems are fundamental to tunnel safety. In the event of a fire, the ventilation system must ensure that large volumes of polluted air are evacuated as quickly as possible. The equipment installed must be designed to operate for 2 hours at temperatures of 250°C, or even 400°C.

**The ventilation system must meet three criteria:**
- Exhaust emissions are diluted to a level acceptable to tunnel users
- Pollution in the vicinity of the tunnel remains low
- In the event of a fire in the tunnel, the smoke is contained and extracted

**Four methods of tunnel ventilation:**
- Natural ventilation
- Longitudinal ventilation
- Semi-transversal ventilation
- Transversal ventilation
Ventilation performance and availability

The general air entrainment solution must take into account:
- mechanical criteria in terms of the torque, inertia and speed of the ventilator
- environmental constraints (temperatures, humidity, and so on)
- system compliance with the specifications of the existing power supply network in terms of voltage, frequency, short-circuit power, and so on.

The choice of solution must ensure that the system can easily be connected to the mains by controlling the power factor and the harmonics rejection factor.

Equipment selection criteria

Electric motors

Asynchronous squirrel-cage motors are generally used for tunnel ventilation systems. They are specifically designed to operate in the face of very severe environmental constraints, in particular those related to temperature. Noise level is one of the selection criteria. The sturdy design of these motors must ensure enhanced availability and "do or die" operation.

Motors are used in two ways:
- within the air flow (Jet, Booster), where they must withstand temperatures of up to 400°C for two hours and be distributed to reach approximately 100 kW
- outside the air flow (injection, extraction), where they must withstand temperatures of up to 250°C for two hours and be able to reach 1500 kW

All the smoke-extraction motors must be approved by the CTICM (Industrial Technical Centre for Mechanical Design).

Electrical supply and motor start-up

The choice and dimensions of the components used each time a motor is started up must take account of the characteristics of the mains supply in terms of:
- voltage and frequency:
- short-circuit power
- existing harmonics factor
- disturbance level (voltage sags, brown-outs, lightning, and so on)

The power supply consists mainly of:
- a main circuit-breaker (isolation and protection)
- a voltage-matching transformer
- a circuit-breaker for each frequency converter

The power supply architecture must take into account the motor direct starter, soft starter and frequency converter selected to control:
- the harmonics rejection factor
- the power factor

Examples:
- filter installation according to harmonics level
- use of a star/delta two secondary-winding transformer connected to a twelve-phase frequency converter. This solution is used to reduce the harmonics rejection factor (suppressing the 5th and 7th harmonics).

The electrical supply architecture selected depends on a preliminary study of the mains supply.
Motor control

Motor control function:
- ventilator start-up time control
- rotational speed control
- in normal ventilation mode
- in smoke-extraction mode

Different motor control solutions:
The soft starter:
- limits the motor start-up current (3 In)
- ensures a ventilator soft start
- limits the mechanical constraints of the transmission units
- ensures a decrease in speed
- cannot be used to adjust ventilator speed
- authorises and controls the mains supply bypass

The frequency converter:
- starts up the motor according to a predefined acceleration law
- controls the ventilator speed in all operating modes
- protects the motor
- starts up the high-inertia ventilators

Variable speed drives design tailored to tunnel environment:
- ambient temperature
- can operate for 1 hour at 70°C (according to specifications and derating)
- dimensions
- loss removal
- noise level limitation

Dependability-related design:
- passive or active redundancy
- reliability and availability
- motor protection control

Variable speed applied to ventilators
High-inertia ventilator starters
- soft start
- mechanical transfer protection

Ventilator starters on low short-circuit power supply
- starter current limitation

Live restart

Continuous operation not permissible at critical speeds

Electricity consumption according to speed
Schneider Electric's ventilation offer

Global ventilation entrainment solution
Schneider Electric can offer designers, design and engineering offices and engineers a solution incorporating all the equipment, studies and services they require. This global solution ranges from mains supply connection to ventilator shaft coupling.
Because we can select and match each component and architecture, we can guarantee a successful outcome.

Products
These products are specifically designed for:
- electrical equipment contractors
- ventilation system manufacturers

Medium voltage switchboard
(see chapter 4 Electrical Power Supply)
Transformer
(see chapter 4 Electrical Power Supply)
Low voltage switchboard
(see chapter 4 Electrical Power Supply)

ATS 48 soft starter
- available up to 1200 kW
- 230 V to 690 V, three-phase

ATV 38 frequency converters
- available up to 315 kW
- 380 V to 460 V, three-phase

ATV 68 frequency converters
- available up to 1500 kW
- supply voltage: 380 V, 460 V, 690 V, three-phase

Electric motors
Smoke duty motor
Motor within the airflow
- can withstand a temperature of 400°C for 2 hours
- available up to 280 mm axis height

Special H series
Motor external to the airflow
- can withstand a temperature of 250°C for 2 hours
- available up to 630 mm axis height

These ranges are supplied in France in partnership with WEG as part of the Altium package.

Services
(see chapter 7: Expertise)
For many years, there has been a continuous increase in road traffic and, in particular, in the transport of hazardous materials. An accident involving these types of materials in a tunnel may have serious and costly consequences in terms of human life, the environment, damage to the tunnel itself and the disruption of tunnel traffic. That is why the main concern of tunnel operators is to maintain optimum tunnel safety.

In addition, road tunnel traffic regulations vary considerably from one country to another. In most cases, no general rules or regulations apply to all tunnels at a national level, which is why each tunnel is a special case.

The reliability and availability of the various systems (lighting, ventilation, signalling, and so on) depend on their design (choice of equipment, network architectures, and so on) and on the way in which they are run (operating methods, monitoring, maintenance, and so on).

To determine, implement and maintain optimum safety conditions, Schneider Electric offers its internationally renowned expertise in the four major stages in the life of a tunnel which range from initial design to renovation.

Schneider Electric offers a wide range of services, from consultancy to implementing the maintenance policy, including dependability and network studies.
Studies
During the different stages of a project, a number of studies must be carried out to ensure optimum safety conditions when the tunnel is in operation.

One of the major concerns when the project is underway is to choose the technical solutions that best deal with the safety issues, in compliance with the statutory regulations in force, whilst remaining economically viable. The selection stage is all the more important because it will affect the daily operation of the tunnel for many dozens of years to come.

Schneider Electric puts at your disposal its dependability know-how acquired as a result of its work in the field of nuclear security systems. This systemic approach allows us to control the complexity of a process by dividing it into three key phases:

- functional analysis (study of the functions, their interaction and constraints)
- dysfunctional analysis (study of the behaviour of components in the event of a malfunction)
- system modelling

This enables us to implement the solution that will ensure that operators have “justified confidence” in their tunnels. In addition, a dependability study provides you with all the information that will enable you to optimise the availability and cost-effectiveness of your tunnel.

Schneider Electric provides the methodological assistance to give you all the help you need to make the right choices.

Implementation
The implementation phase is a key stage in the construction of a tunnel, as it is during this period that the equipment is installed. The results of this stage determine whether the ultimate objective of “tunnel operation with optimum safety at a reasonable cost” is met.

Optimum safety:
The implementation phase of a tunnel requires a global approach to safety, similar to that used for high-risk industrial sites (nuclear, chemical, oil, etc.). The implementation of such measures guarantees personal safety and protects equipment in tunnels where access by the emergency services is far more difficult than in the open air. It also ensures that the tunnel is operational under all possible working conditions. Schneider Electric helps you meet all the rigorous requirements of the tunnel industry by applying this approach to safety to the electrical and automation systems.

It also:
- reduces economic risks
- ensures that the systems run smoothly from the moment they are designed
- guarantees optimum availability at a controlled cost
The implementation phase therefore allows operators to have justified confidence in their equipment due to its controlled:
- dependability
- safety
- reliability
- maintainability

Cost optimisation:
As the costs of maintaining overall tunnel security are high, tunnel operators must keep them under control if they are to remain within their budget. Schneider Electric offers its range of Performance services which will allow you to optimise your operating costs and electrical plant investments. You will then really be able to maximise and deploy your energy resources to increase your productivity by:
- managing your energy supply
- improving availability and quality
- reducing your energy consumption
- rationalising energy procurement

Operation
Apart from certain tragic events (Mont Blanc, St Gothard, Tauern) which are the exception, many more incidents of lesser importance are encountered, which, when analysed, nevertheless reveal weaknesses in tunnel operation. This type of analysis can provide a number of remedies that may prevent future disasters.

Schneider Electric offers a range of services to help **minimise such risks** by enabling you to:
- know the exact state of your installed electrical equipment
- check that your equipment conforms to current standards and legislation
- ensure the smooth-running of your tunnel by performing preventive maintenance on your electrical equipment
- optimise the operational performance of your installed equipment

The plant audit undertaken by our specialists assesses the state of your electrical equipment and provides you with the information you need to carry out an accurate analysis of the state of the equipment to enable you to:
- check compliance with current standards and regulations
- identify any potential problems
- determine your maintenance and renovation priorities in the light of all the information provided
- optimise operating costs and plan future investment
- enhance the reliability of your equipment

Our expertise does not stop here. We can recommend the measures required to ensure that your installation complies with current standards and regulations.

Preventive maintenance of electrical equipment tailored to the level of performance required for the various electrical installation substations guarantees tunnel safety. Schneider Electric offers a maintenance package at a reasonable price based on:
- a maintenance plan drawn up when the tunnel was constructed, which takes into consideration the degree of criticality of the equipment
Renovation

During its "lifetime", a tunnel will require varying degrees of renovation work. Irrespective of the care taken over its design, technology advances, equipment evolves, standards and regulations develop, operating conditions change and the structure itself ages. Depending on the renovation work involved, a certain amount of disruption to tunnel operation is inevitable and road traffic may be suspended for varying lengths of time.

That is why it is important to think ahead and prepare well in advance the various sections of the tunnel to be renovated in order to minimise the disruption period and use this opportunity to upgrade the technical equipment in the tunnel.

**Anticipate:**
Schneider Electric’s equipment diagnosis informs you of the ability of the existing equipment to ensure energy availability in compliance with current standards and to guarantee the safety and security of the tunnel structure and its users. The detailed analysis and comprehensive report inform you of the nature and level of any potential fault and the remedial measures to be taken. You will therefore have all the information you need to determine and plan the modifications and improvements to be made to the equipment.
You can also plan the capital budget required.

**Optimise:**
To restore equipment to its original condition without disrupting tunnel traffic, Schneider Electric provides an equipment reconditioning service that enables you to:
- extend the service life of your equipment
- reduce the frequency, duration and cost of maintenance operations
- renovate equipment nearing the end of its useful life
## Expertise

### Methodological assistance
- Specifications
- Plant audit
- Electrical network diagnosis
- Time limitation study
- Project management assistance

### Technical expertise
- Dependability

### Power supply network
- Power supply network architecture (better reliability and availability)
- Power supply network study
- Quality enhancement
- Network monitoring
- Harmonics filtering
- Reactive power correction
- Load shedding, regulation
- Modification of contracts in the light of energy consumption
- Energy supply management
- Determination of installed equipment status (ED + automation)
- Emergency equipment

### Ventilation
- Feasibility study:
  - Pre dimensioning
  - Technical and commercial evaluation of the various solutions
  - Dependability level evaluation
  - Availability rate evaluation
- Implementation study:
- Power supply network study
- Shafting study
- Dimensioning
- Implementation services:
- Laboratory tests
- On-site installation monitoring
- Commissioning
- Acceptance tests

### Automation systems
- Automation architecture
- Automation study

### Others
- Fault diagnosis
- Optimisation of road traffic flows
- Tunnel energy consumption monitoring (single and multiple sites): Bill Forecast

### Optimised spare parts management
- Network inventory: Networking, via a secure Internet site, of spare parts from several manufacturers in the same region.
- Customised stock: Acquisition, management and optimisation, on your behalf, of the stock of spare parts to be made available on the production site. For equivalent stock, cost reduction of approximately 30%.
- Stock sharing: Stock located less than an hour from the sites is shared by several manufacturers.
  - Spare parts availability guarantee
  - 24 hours a day / 365 days a year.
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Schneider Electric's in-tunnel offer

Variables speed controllers
- ATS 48 soft starter
- ATV 38, ATV 68

Electric motors
- Smoke duty motor
- Special H series

Low voltage switchboards
- Okken switchboard
- Prisma switchboard

Power supply network management
- PowerLogic System

MV/LV distribution transformers
- Trihal range

MV supply network management and reconfiguration
- Iseargy range
### PLCs
- Premium range
- Quantum range
- Momentum inputs-outputs

### Ethernet Connectors
- RT2-TX-R double transceiver
- RS2 FX/FX switch
- RS1 FX/FX switch

### Medium Voltage Switchboard
- SM6 switchboard
- MCset switchboard

### Reactive Power Correction and Harmonics Filtering
- Rectiphase offer
- MGE UPS SYSTEMS SineWave active harmonics conditioners

### UPS
- MGE UPS SYSTEMS