Embedded PCs process 40,000 data points on the Basel Nordtangente

The Basel N3 Nordtangente is one of the most ambitious and expensive sections of road ever been built in Switzerland. The 3.2 km long, four lane urban expressway linking Switzerland with France and Germany, and running below ground for the most part, cost around 1.2 billion euros. Around 124 million euros has been invested just in the operations and safety systems, which are controlled using Beckhoff technology.

Nearly 50 years after the start of planning and 13 years after the first shovel hit ground in 1994, the main section of the Nordtangente was opened to traffic in June 2007. A year later the Basel urban expressway was fully opened.

Consistent implementation integrates all functions into one comprehensive system

The Federal Highways Civil Engineering Office in the Department of Planning and Building Inspection in Canton Basel-City was responsible for planning the Nordtangente. Under the project management of Eugen Fuchs, detailed and forward-looking technical specifications were prepared for the required control equipment for the project. A particular challenge was that, because of the long period of time over which construction took place, modifications were made time and again regarding both the technology and the range of products available. As a result, technical installations implemented in 1999 were already being reworked and sometimes replaced in 2003. Because of the major accidents that have occurred in other European expressway tunnels, a fundamental reassessment of the safety concepts took place in 2000. The tunnel ventilation requirements also had to be reworked after the introduction of catalytic converters and the reduction in exhaust emissions that occurred as a result. The ventilation concept, originally only conceived for normal operations, has been designed for event mode (operations in the event of incidents), and in the event of fire, in particular.

The "General Technical Specification" (GTS) prepared by the Basel Federal Highways Civil Engineering Office includes guidance documents for planning and execution of information flow, signaling concepts, and control of the Nordtangente. It explicitly describes the requirements on the hierarchically-ordered operations, process, group management and field levels. In particular, these contain the process computers (master computers and group computers), including the linking of processes to the supervisory management system (node computers). Furthermore, the GTS controls the connection of the actuators and sensors at the field level to the group management level. The concept differs from that of other tunnel facilities

in terms of consistent implementation and integration into a complete system with functions and components that are clearly aligned with one another. For the safety of road users and the optimal flow of traffic, all electromechanical equipment and traffic management technology for both the Basel Nordtangente and Osttangente (tunnels and above-ground sections) have been brought together and integrated into the supervisory management system.

Complex network concept

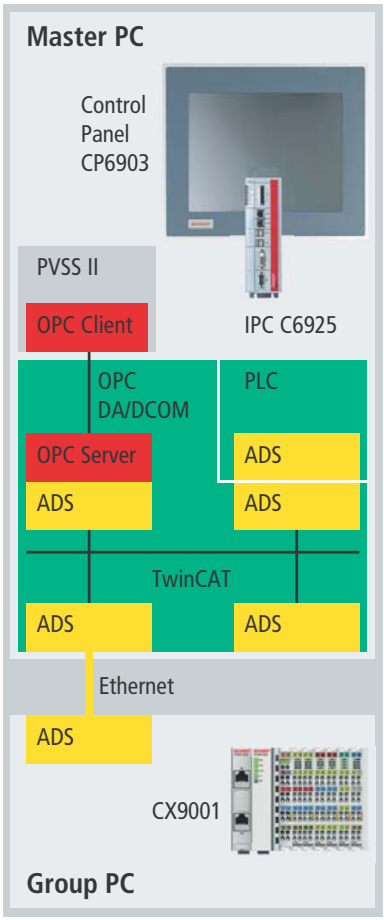
The process management system is structured in a strictly hierarchical manner. The reason for this hierarchical structure lies in the desire to establish autonomy for the individual levels, i.e., each level must functionally and technically form an independent unit and cannot be dependent on the fundamental functions of the level above. This ensures that in the event of failure at one level, the functionality of the level below is not affected. If normal operation of a system fails, a contingency level immediately takes over the functions. If, for example, the communications network fails, the most important signals are transmitted via exchanges between hardware.

In addition to the supervisory operations management system, individual systems for lighting, ventilation, safety, traffic management, energy supply/miscellaneous, and contingency level have been specified for the project in six electrical plants. Related individual systems are brought together in supervisory systems, but operate autonomously as much as possible.

Three different networks constitute the infrastructure for all of the Nordtangente systems:

- an Ethernet ring with a data transfer rate of 10 Gb/s
- a 100 Mb/s Ethernet ring for the contingency level (a second redundant communications route with its own optical fiber links)
- a 100 Mb/s Ethernet ring for each of the six system controls with its own optical fiber links

On the basis of the specifications established by the Basel Federal Highways Civil Engineering Office, all computers coupled to the 10 Gb Ethernet network have been linked via TCP/IP with a virtual local area network (V-LAN) for each system. Each system has access to its own network; the electrical plants are electrically isolated from one another. Communications on the operations management level take place via Ethernet using the Process Visualization and Control System (PVSSII). Communications between the systems level and the operations management level, and also within a level, take place via TCP/IP Ethernet/Fast Ethernet using OPC and the Beckhoff TwinCAT ADS software. From the systems level to the group management level communications similarly take place via Fast Ethernet and TwinCAT ADS.



Communication architecture of the master and group computers

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Eugen Fuchs, Project Manager, Basel Civil Engineering Office: "The decision to comprehensively utilize Beckhoff hardware components was made on the basis of their robustness and proven deployment in industry."

Hardware and software redundancy guarantees reliability

In terms of software, the communication links are all structured in accordance with the client-server principle. This means that the communications client (an IS server) links with the communications server (a master computer for each system and electrical plant). The server is able to manage a number of links to several clients simultaneously. The use of automatic supervisory circuits has been avoided as far as possible; supervisory functions have been implemented at the process level in order to minimize the number of special cases.

The redundancy principle as implemented is not based purely on hardware redundancy, but incorporates software redundancy as well. A second server collects the relevant data, independently of the first, and executes the corresponding functions. The redundant system stops short of activating the components that are already active. A sophisticated monitoring procedure detects any failure of the computer that is in control; in this event the second computer takes over the functions of the first. The first computer changes its status to that of a redundant server and no longer executes any active commands or switching procedures. Should, for whatever reason, the first server not alter its status, it is locked out by the second, i.e. two servers never execute automatic switching commands at the same time. The operations stations recognize the status of each server and communicate exclusively with the active server.

Robust and reliable control platform

The Basel Federal Highways Civil Engineering Office specified Beckhoff automation components after a fundamental evaluation of the market. "The decision to comprehensively utilize Beckhoff hardware components was made on the basis of their robustness and proven deployment in industry," explains Eugen Fuchs, the Civil Engineering Office manager responsible for the project. "Further positive points include the many opportunities for software coupling using Microsoft's Windows XP Embedded and Windows CE operating systems, the IEC 61131-3-based software PLC TwinCAT, and OPC or OLE for process control (Object Linking Embedded)."

Ticos AG, based in Feuerthalen, Switzerland, was contracted to create the complete software system; the company has experience with large control packages for tunnel facilities operating across plant systems. Ticos' managing director Kurt Salvisberg stresses: "We received very good specifications from our client. In the implementation we were also able to specify very clear structures so that we only had to replicate these in our programming."

The operations management level with its node computers represents the supervisory management system (IS) that enables the central control, visualization and monitoring of all the other systems. Each IS node computer is therefore equipped with a local visualization capability.

The systems level is structured in technical data terms as a systems network with TCP/IP Ethernet, and encompasses the master computers. Control of the systems takes place at the systems level in an autonomous and decentralized manner, i.e. even in the event of a failure at the operations management level, the master computers autonomously execute control of the processes that are subordinate to them. A total of 35 Beckhoff C6925 series Industrial PCs are deployed as the master computers, together with Beckhoff type CP6903 control panels for visualization purposes.

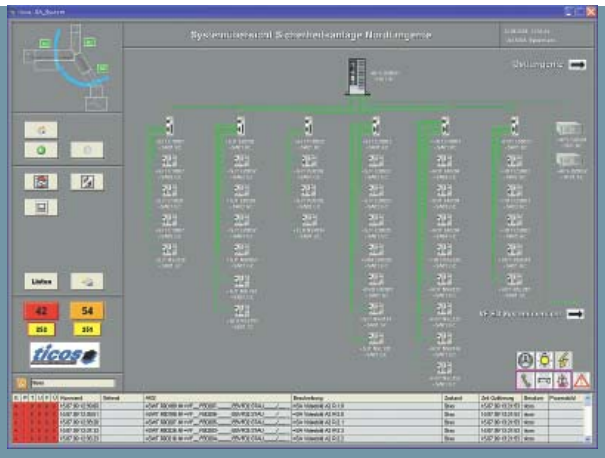
The group management level positioned below the operations management level consists of compact Beckhoff CX9001 Embedded PCs. Via TCP/IP Ethernet these control the actuators and sensors connected to the Beckhoff Bus Terminals, such as e.g. relays, contactors, etc. Windows CE is the operating system for the CX9001 group management computers with TwinCAT as the software PLC. At the group management level there are 185 total CX9001 Embedded PCs with implementation of nearly 40,000 physical data points.

The field level consists of decentrally installed Bus Terminal stations. The special features of the Bus Terminals used include, alongside the analog Bus Terminals, DALI communication terminals that are used to control the lighting. All measurement inputs have been implemented as extensively as possible in terms of current inputs (4 to 20 mA), with the objective of creating clearly measurable interfaces.

Proven in daily operation

The hierarchical system structure, as well as the distributed concept of the solution, prove themselves daily in terms of trouble-free operations. The process images of the control system represent the individual systems and contain the appropriate

After a history of some 50 years of planning and building, the main section of the Basel Nordtangente became operational in mid-2007. With the opening of the Luzerner-Ring junction, the historic Basel Nordtangente project is complete. Of the 3.18 km length of the urban expressway, a total of 2.79 km take the form of tunnels or bridges. The Nordtangente starts from France with a 240 m long above-ground section and then moves into the Großbasel Tunnel (1432 m). On the east side of the St. Johann rail station, the section proceeds under the very busy Voltastrasse to the Rhine. In this section the 600 m long St. Johann link also branches off underground. At the Rhine, the expressway emerges from the tunnel and proceeds via the two-level 266 m long Dreirosen Bridge into the 1092 m long Kleinbasel Tunnel. The last section guides the expressway onto the existing ramp of the Osttangente. Thanks to its five junctions, the Nordtangente can not only accommodate the through traffic to and from France, but also a large proportion of the urban traffic and can thereby alleviate the levels of noise and traffic suffered by some residential areas.



System overview of the Nordtangente safety system. There are 185 total CX9001 Embedded PCs in the group management level with implementation of nearly 40,000 I/O connections.

graphical elements for status displays and interventions, instigated by sensor signals from the field level. The systems, while acting autonomously, also work together with the control technology in an optimal manner: important alarms and faults are forwarded via remote alarm systems.

For example, all relevant information, including the air speed measurements that are necessary for ventilation system operation, are available for the ventilation plant process images.

Tunnel control package includes a wealth of functions

One of the central elements for safety is the control of the tunnel ventilation. The safety of the tunnel user and the sequence of events that occur in the event of a fire are massively affected by ensuring the best possible flow conditions. The measuring units in the tunnel provide information to the control system at all times concerning the current flow and pressure conditions. From this data the control system calculates the necessary switching procedures for the 82 jet fans (with a total of more than 2 MW of power) in order to achieve the optimal pressure conditions. In this manner the escape routes are maintained to be free of smoke in the event of fire, and any migration of smoke into the adjacent service tunnels can be prevented.

The safety system records all information relevant to safety for forwarding to the police: the latter are, e.g., immediately informed if an emergency exit door is activated, if a vehicle is stationary in the tunnel, or if a fire extinguisher is taken out of its cradle.

Similarly, the control system for the lighting plant makes available all the relevant information that is necessary for operating the various lighting systems: e.g. manual or automatic activation of various modes of operation, such as emergency operation or fire/accident. Light sensors measure the external level of brightness and regulate the adaptation level of the lighting so that the human eye can become accustomed to the reduced light levels when entering the tunnel. Light sensors in the tunnel measure the effective level of illumination and by this means permit corrections for any contamination and aging of the lighting equipment.

A complex traffic management system undertakes the control of the traffic, so that all operating states that occur can be dealt with without causing any difficulties for the user. The signaling system serves in the first place to close the tunnel, i.e. the tunnel's entries and exits, to warn the road users of a variety of hazardous situations, to close individual lanes, to transfer people or vehicles to the adjacent service tunnels, etc.

The "Energy Supply/Miscellaneous" system monitors all infrastructure systems of the electrical plants, such as building fire alarm systems, system safeguards, energy inputs, transformers, measuring units for the central building and infrastructure systems.

Integration of existing sub-systems optimizes monitoring and reduces costs

During project implementation, the existing Osttangente sub-systems put together in the years 1970 to 2003 have been linked onto the IS. By virtue of this comprehensive integration, all information and intervention options are available on a common platform to the operators. All current and future data points are recorded in a consistent and cost-effective manner by the flexible Beckhoff group computers using the extensive selection of terminals. Roland Gysin of "North-West Switzerland Federal Highways AG" (NSNW), who is responsible for the operation and maintenance of the urban expressway, comments on the experience to date: "The system runs very stably, and we very seldom have any malfunctions. Previously we paid more for maintenance of just the management system than maintenance costs us for all the systems today."

The investment for all the operations and safety systems is running at about 124 million euros. A large part of this investment has in fact been for the safety of the tunnel user. The many measurement, control and regulation tasks could be fulfilled along with a level of future-proofing using Beckhoff technology. The complex status of the expressway monitoring system enables rapid and targeted intervention in the event of a malfunction and thus offers the maximum possible level of safety.

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