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PROJECT RISK MANAGEMENT – THE MOST IMPORTANT INSTRUMENT FOR SUCCESSFUL PROJECT CONTROL

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1 INTRODUCTION

"No construction project is risk-free. Risk can be managed, minimised, shared, transferred or accepted. It cannot be ignored." This fundamental statement for the success of major projects comes from the report "Constructing the Team" edited in 1994 by Sir Michael Latham [1]. This report contained improvement proposals for the English construction industry, which was then in a crisis.

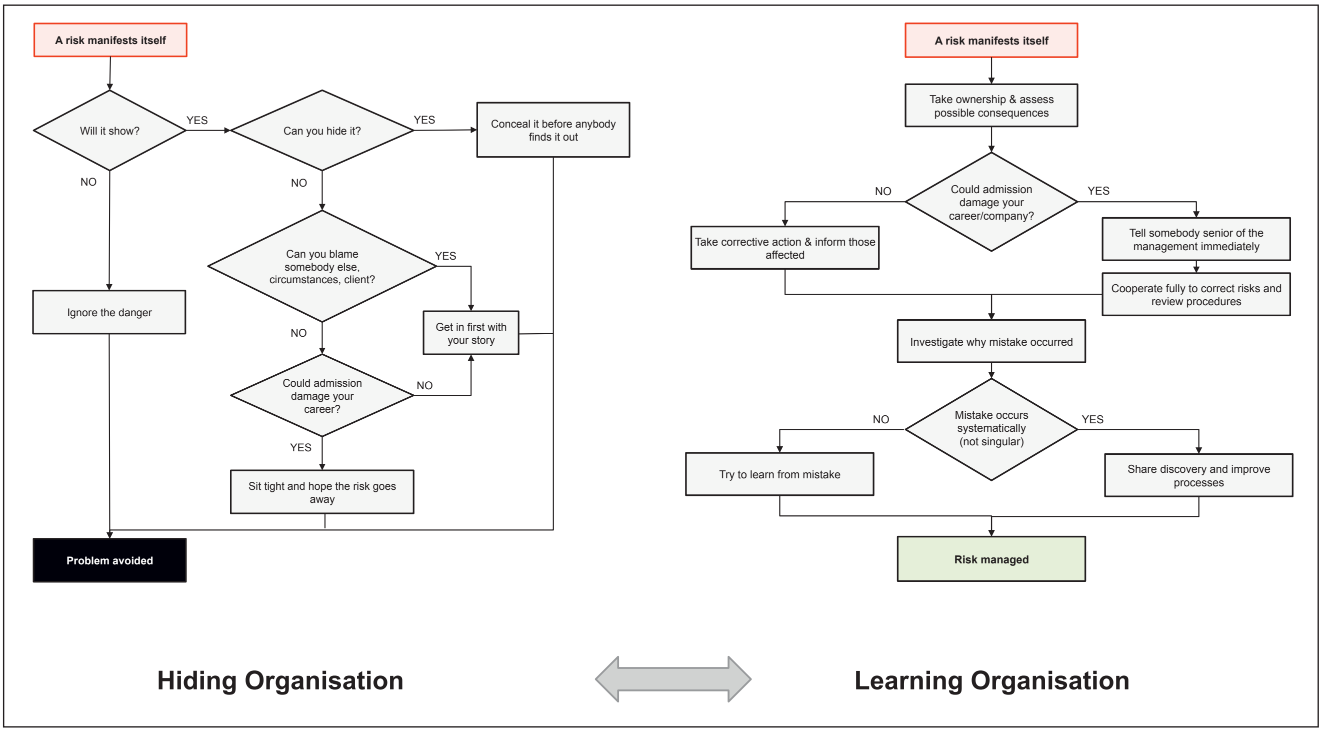
At the same time, the project leaders for the New Rail Link through the Alps (NRLA) were also concerned with basic questions of quality and project risk management [14]. Experience with the construction of the Gotthard rail tunnel, the Lötschberg and the Simplon Tunnel, the Gotthard road tunnel and the large hydropower systems in the Alps showed the importance of early identification of risks and the necessity of mitigation of hazards at the right time. Right from the earliest beginnings, the open and systematic handling of the project risks was taken into consideration in the NRLA project (see ▸**Fig. 1**). The dispatch concerning the construction of the transalpine rail link from 1990 had the following to say:

"The federal government cannot accept unnecessary risk. They have to concentrate on projects whose risks can be estimated to a certain degree. It is also incorrect to assume that every alignment is feasible in any case or that tunnels can be built without risk. Due to the preparatory work, all projects are to be considered as feasible. But they have different critical areas. The construction of the Gotthard Base Tunnel probably includes the smallest geological risks."

Project risk management was understood as an essential part of project management, demanding continuous attention from the beginning of the project, and was implemented in the appropriate project handbooks [2] and the NRLA Controlling Instructions (NCI) of the federal department of environment, transport, energy and communications (DETEC) [3]. In addition to the project sponsor, the constructor, the contractors, the future operator and experts were integrated into the process of project risk management at the appropriate phases.

2 BASICS

Professionally managed project risk management enables the affected organisation to create the following benefits (based on [4]):



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▸ **Fig. 1** *Simplified basic scheme for dealing with dangers – hiding versus learning organisation*

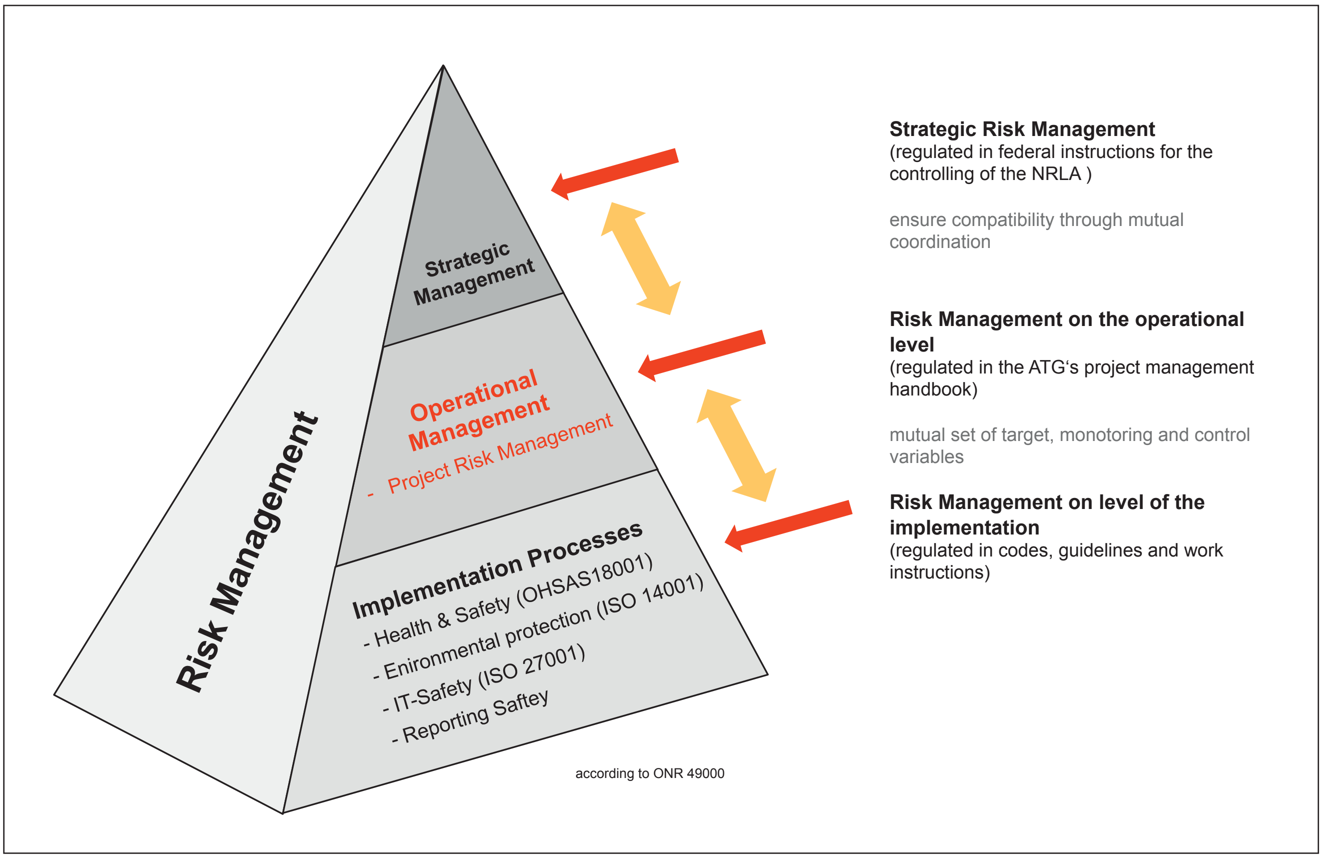

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Fig. 2 *Project risk management in the context of integrated overall risk management*

- » Promotion of proactive instead of reactive management,
- » Awareness on all sides of the identification of and overcoming of risks,
- » Improved identification of opportunities and dangers,
- » Achievement of improved compliance with the relevant legal and regulatory provisions and with international standards,
- » General improvement of reporting (including financial figures),
- » Improvement of the management of the organisation,
- » Promotion of the trust of the stakeholders,
- » Creation of reliable basics for design/planning and decision-making,
- » Improvement of control and monitoring mechanisms,
- » Effective assignment and use of resources to overcome risks,
- » Improvement of operational performance and effectiveness,
- » Improvement of occupational health and safety,
- » Improvement of incident management and damage prevention,
- » Minimisation of the number and consequences of damage incidents,
- » Increasing the resistance capability of the organisation,
- » Improved learning capacity of the organisation.

For a long-lasting project, the last point is of decisive significance. Mega-projects like the Gotthard Base Tunnel (GBT) can only be successfully managed by a "learning organisation" and never by a "hiding organisation" (see **Fig. 1**). Article 2.2 of the NCI [3] accordingly points out the requirement for transparency in order that risk can be overcome and the reserves can be managed.

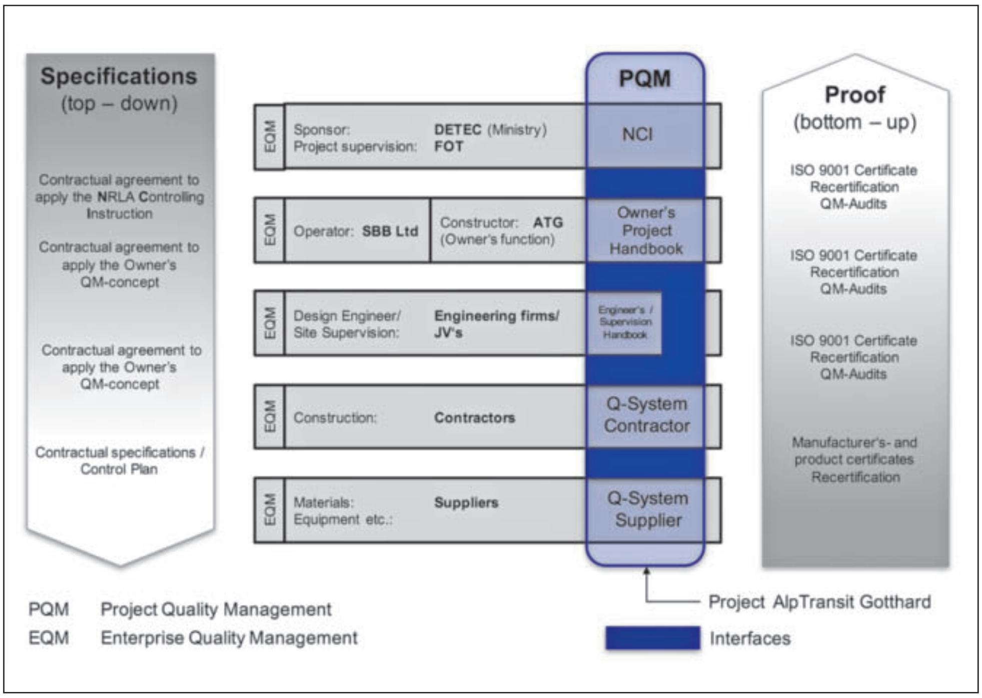
The task of integrated risk management for the AlpTransit Gotthard project was now to create a high-level, open and flexible framework for the use of project risk management in the various areas of application and levels of the organisation. A unified terminology and clearly defined processes were the basic precondition for the top management, the project management and all involved employees to be able to implement project risk management.

The federal government as the project sponsor (placer of the order) defined their requirements for risk management at the strategic level in the form of specifications and with the laying down of decisive control quantities and checking processes, which were documented in the NCI [3]. The constructor, AlpTransit Gotthard Ltd (ATG), then formulated the requirements for the implementation of risk management at the operative project level in their own project handbook [2], which was continuously updated to comply with the needs of project progress.

For all contract awards by ATG, the presence of a Quality Management (QM) system according to ISO 9001 was a suitability criterion. Over the entire duration of the project, ATG worked almost exclusively with ISO 9001-certified contractors. All contractors had their own enterprise QM system (EQM). This ensured that the subject of risk management was dealt with in the correct manner for each stage at every level of the project. The uniform handling of these individual EQM systems to a homogenised project-related quality management (PQM) system could only be carried out through an appropriate agreement in each contract, which obliged the contractor to fulfil the uniform standards of PQM specified by the client. This ensured that:

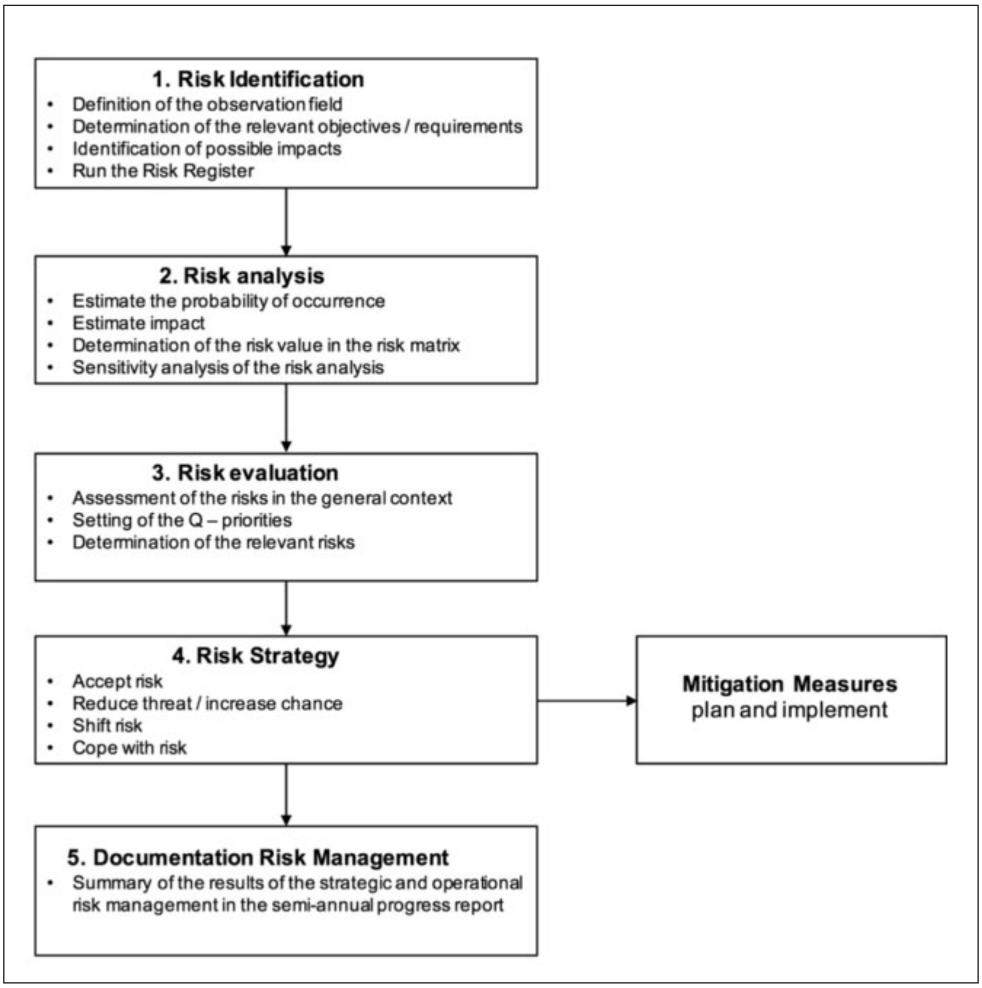
- The interfaces between the project partners were clearly specified and the responsibilities were unambiguously defined;
- A risk situation was identified early and assessed and evaluated in agreement;
- The quality focus points to accompany the risk management methods were determined.

The matching of the EQM systems to a uniform PQM system was implemented through contractual agreements, whether between the federal government and ATG, between ATG and the commissioned consultants or between ATG and the contractors. On the part of ATG, no manufacturer- or supplier-related requirements for risk management were made to the contractors. In this regard, the basis was the certified industry standard. The documents stated in ▶ Fig. 3 at the interface of EQM and PQM were intended to ensure that the risks would be identified, evaluated and assessed according to uniform basic principles in order to be able to introduce the required measures in good time.



Credit: [8]

▶ **Fig. 3** *Linking of the enterprise quality management (EQM) systems to a project-based quality management system (PQM)*



Credit: [3]

▶ **Fig. 4** *Process of risk management according to the NCI*

The NCI defined the term risk with neutral value (analogous to the later ISO 31000); this means that opportunities and threats were equally understood as risks. The risk management system was intended to include the following elements in the process steps to be handled according to ▶ **Fig. 4**:

» A structured risk analysis,
» Clear, thorough evaluation, assessment and documentation of risks,
» Coordinated planning and implementation of measures appropriate to the stage.

Written agreements were signed in the year 2000 between the federal government (as the sponsor), ATG (as the constructor) and SBB (as the future operator) based on an offer1998 for the construction of the Gotthard axis [5] handed over from ATG to the federal office of transportation (FOT). Part of this agreement with ATG was also a non-public appendix, which regulated the following targets:

» Performance,
» Standards, divided into:
  – Bid and operating concept,
  – Design of the permanent works, the rail technology equipment and the mechanical and electrical equipment,
  – Requirements for fire and catastrophe protection,
» Cost and deadline targets.

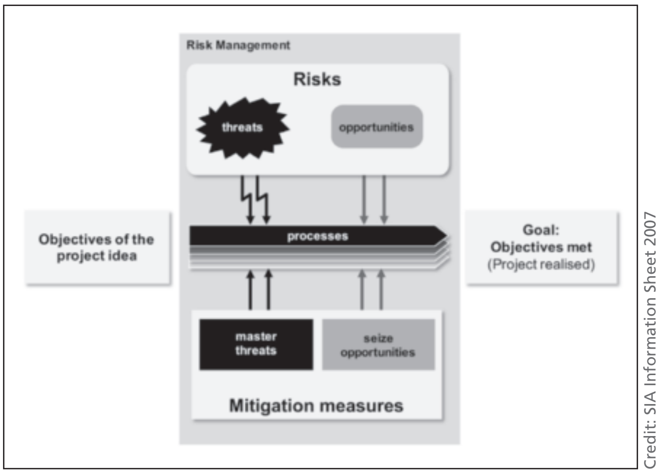
The constructor was obliged to pay attention to risks affecting the following five main project requirements:

a) Performance/standards,
b) Costs/finance,
c) Deadlines,
d) Milestones,
e) General preconditions.

3 RISK MANAGEMENT OF ATG

3.1 Methodical approach

ATG stated the following project aims in the project handbook [2]: "The AlpTransit Gotthard Ltd will implement the construction on the Gotthard axis to the agreed quality, as quickly as possible and at the minimum cost."



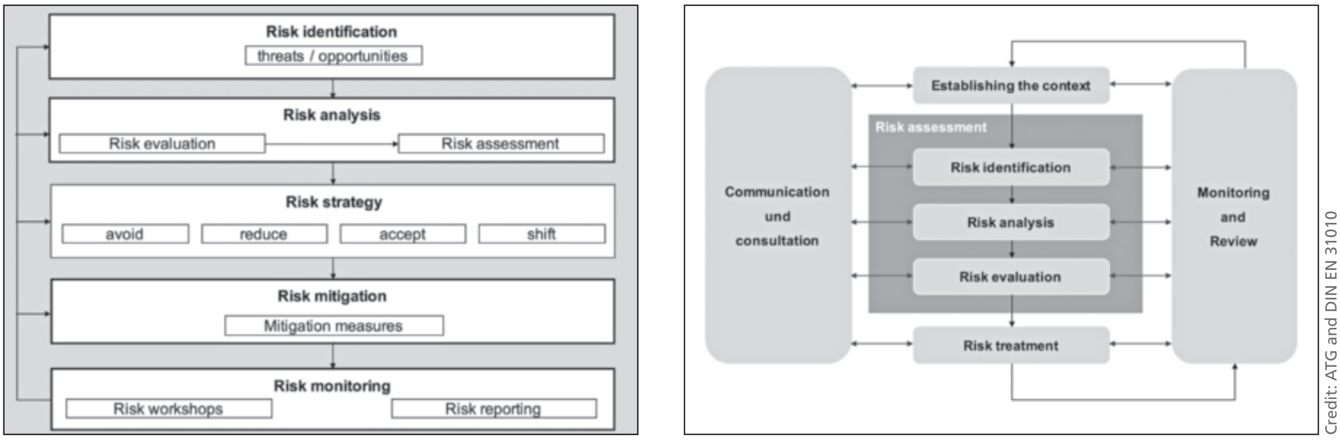
▶ **Fig. 5** *Basic principles of risk management*

Professional, process-oriented project management should support the achievement of aims. For each process, the following questions had to be continuously clarified:

1. What threats could hinder the achievement of the aim or even make it impossible; what threats have to be overcome?
2. What opportunities provide the achievement of the objectives, or what opportunities should be exploited?

Institutionalised risk management with quarterly risk management meetings delivered the answers to these questions, which were then established in action plans. The risk management process introduced by ATG can also be found in the NCI, which only has slight deviations from the modern, widely used process of ISO 31000 (see ▶ **Fig. 6**). This standard had not yet been issued at the start of the NRLA project. Today, there are scarcely any reasons not to use the processes of ISO 31000.

ATG placed great value on the "four-eyes principle", which states that an activity should not finally be undertaken by one person alone, but rather a person who is independent of the



▶ **Figs 6a und b** *Risk management process according to ATG [9] (left) and according to DIN EN 31010 (ISO 31000)*

Group		Detailed Design and Tendering		Construction		Phase-independent
Threat No.	Opportunity No.	Civil Work	Rail Technology	Civil Work	Rail Technology	Executive Management
100	1100	Ground Conditions	Civil Work	Ground Conditions	Civil Work	Politics/Law/Finance
200	1200	Change Requests/Optimisation		Change Orders/Optimisation		Change Requests Government/ FOT/SBB
300	1300	Project Management ATG		Project Management ATG		Company management/ Organisation/Staff
400	1400	Detailed Design		Construction Design Design Engineer	Construction Design, Contractor	Processes/ Project Management
500	1500	Tendering		Site Supervision	Site Management	Contracts/Performance
600	1600	Construction Processes and Methods	Installation Methods and Logistics	Contractor/ Construction Work	Contractor/ Installation Work	Media/Communication
700	1700	Accidents/Incidents		Accidents/Incidents		Incidents/ Management of a Crisis
800	1800	Surroundings		Surroundings/Labour Market		Surroundings/Labour Market
900	1900	Miscellaneous		Miscellaneous		Miscellaneous

Table 1 *Categorisation of the risk register and the risk groups in the risk management system of ATG*

W:	Likelihood	1 low	2 medium	3 high
	Definition	Based on experience unlikely to occur	Cannot be ruled out during construction	Occurrence must be expected

A:	Consequences Benefit/Damage	1 low	2 medium	3 high
	Health and safety	No permanent impairment	Light permanent health impairment	Severe permanent health impairment or death
	Quality/Functionality	Insignificant impairment	Some impairment	Severe impairment
	Costs	Less than CHF 1 Mio.	CHF 1 Mio. to 10 Mio.	More than CHF 10 Mio.
	Deadlines	Less than 2 months	2 to 6 months	More than 6 months

Table 2 *Definition of the classification of probability of occurrence and extent of risk [10]*

acting person and the object being checked should check the facts of the matter. In the case of the GBT, the SIOP team (SIOP = safety-oriented checking), an organ legitimised by the independent expert guideline of the FOT, undertook this task (see XVI 2 "Quality management – measures to ensure the agreed quality").

3.2 Risk identification

The starting point for any assessment of risk was a clear definition of the context, which is delineated by the following definitions:

- Definition of the object of consideration (e.g. single elements of the project structure plan (PSP));
- Definition of the considered time period (project phases);
- Definition of the observation standpoint (area of responsibility).

For the predefined field of consideration, the individual threats and opportunities were identified and documented in the key document of risk management, the so-called risk register. For the purpose of unambiguous documentation, ATG specified nine risk categories. As far as possible, the associated subcategories were also standardised over the entire project.

The development and updating of the risk register was made autonomously by the various stakeholders with final mutual agreement, action planning and documentation in the quarterly common risk management meetings, again in compliance with the "four-eyes principle".

The federal government (FOT), in contrast to ATG, evaluated the risks in eight categories with different definitions (see ▶ **Fig. 17**):
» Ground conditions;
» Project variations/design changes;
» Legal changes;
» Interfaces;
» Legal process;
» Construction;
» Deadline changes;
» Developments.

This slightly different categorisation had the result that the risks of the constructor had to be converted into the structure of the FOT, which required a half-year recoding of the risk portfolio for the half-yearly status reports. If ever possible, the uppermost hierarchy of the risk register should be uniform at the levels of the project, from the sponsor to the constructor, consultants and contractors in order to avoid additional work and ensure traceability with simple means.

3.3 Risk evaluation

As part of the risk analysis, the project team estimated the probability of occurrence and the extent of deviation from objectives. From the variety of possible evaluation methods (qualitative, quantitative, semi-quantitative), the semi-quantitative method was selected, with the probability of occurrence being quantitatively transcribed in three categories (see ▶ **Table 2**). The extent of deviation from the cost and deadline objectives was defined with appropriate numerical ranges. For the criteria of occupational safety and quality/functionality, purely qualitative evaluation matrices were used.

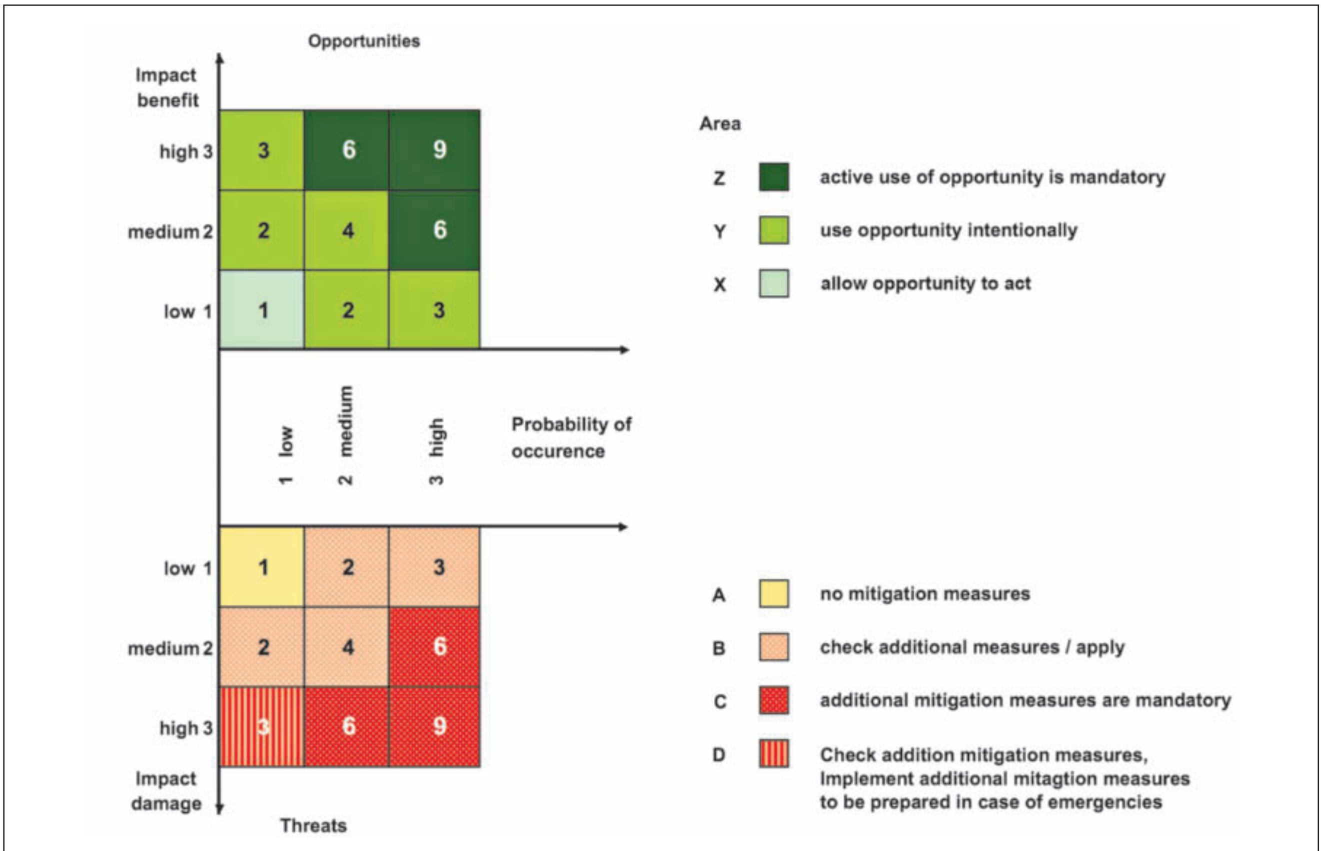
3.4 Risk assessment

Each class of probability occurrence (PO) and extent of damage (ED) was assigned a risk level of 1–3. Multiplication of the two risk levels of each chance or danger gave a risk value of 1–9, which can be shown clearly in a 3 × 3 risk matrix (see ▶ **Fig. 7**).

3.5 Risk strategy and planning mitigation measures

The type of mitigation measures planned depended on the corresponding risk level. ATG specified the following requirements for danger remediation.

The planning of measures included the following categories:
» Organisational measures (e.g. setting up of expert support committees, implementation of parallel activities, contractual risk precautions, collaboration with emergency services),



Credit: ATG

▶ **Fig. 7** *A 3 × 3 risk matrix of ATG with instructions for action [9]*

» Technical (process-oriented) measures (e.g. advance investigation, alteration of construction sequences),
» Strengthening of resources,
» Additional provision of machines, equipment and materials,
» Increasing/adaptation of the personnel resources (number, special capabilities).

3.6 Risk documentation

The main document of the risk management system is the risk register (see ▶ **Fig. 8**). At the start of the main contract works, this was produced de-centrally in the individual sections as an Excel spreadsheet. With increasing project progress and degree of detail in the register, this system turned out to be too cumbersome with regard to the aggregation of risks at the overall project level, so a Web-based database solution was introduced, which resulted in many advantages. The risk register comprised the risk description, the initial risk evaluation, a description of the mitigation measures, the residual risk value after the implementation of the planned measures, the parties responsible for implementation, the required verification documents and, finally, a completion note.

3.7 Reporting and communication

In a learning risk culture, risks are openly and completely discussed among the project partners. Regular communication has to be differentiated from communication in case of the occurrence of an incident. Changes to the risk evaluation are documented between the site and the management of ATG in the monthly report. Quarterly risk management meetings are held between the management and the local site management responsible for the site. The results of these meetings were provided to the board of directors in the form of a "cockpit" display. The main risks were communicated in the form of an easily readable portfolio display, in which changes compared to the previous report period were recognisable.

The risk portfolio and the measures were also communicated to the federal government as the project sponsor with the half-yearly status reports. The FOT then published their essential findings annually on their web page under the address www.bav.admin.ch [15].

In case of the occurrence of exceptional events (occurrence or significant danger), immediate communication was required (see ▶ **Fig. 11**). The immediate notification had to be made to the media relations office by phone, which was answered around the clock, with subsequent written notification (incident fax). The CEO of ATG decided whether the FOT and the board of directors had to be informed. The FOT differentiated between an immediate incident report by SMS and a prompt written incident report. The following incidents in particular activated an incident report:
» Fatal accidents,
» Disturbances to construction progress, strikes,
» Deviations from the planning approval,
» Changes to the transport regime.

In addition to these matters, incidents with significant effects on the works (quality aims), costs and deadlines also had to be reported, for example:
» An incident with general danger for the project aim;
» Compromise of the cost targets, if extra costs of more than 1 % of the outstanding investment volume would result, or exceed 1 % of the total investment volume at the end of the project,
» A delay to a deadline or a milestone of more than three months.

Incident reports had to state the location, time and nature of the incident, the affected parts of the project in the PSP structure, the consequences that had occurred and were to be expected, the (immediate) measures undertaken and further planned measures. ATG used a simple communication scheme for incident communication that was easy for all project parties to comprehend (see ▶ **Fig. 11**). Each manager was obliged to carry at all times the so-called "yellow sheet", which included important addresses and samples for the notification fax in addition to the communication scheme.

Incidents were announced in public through the central media relations office of the constructor after previously informing and discussing the matter with the project sponsor (FOT). The communications office was also the sole contact partner for initial communication by the police and media companies. This ensured the "one-voice" principle and protected the responsible persons on-site from media questions. In order to overcome incidents, it was also decided by the chairman of the board with the cooperation of further members of the management whether a task force was to be appointed. This

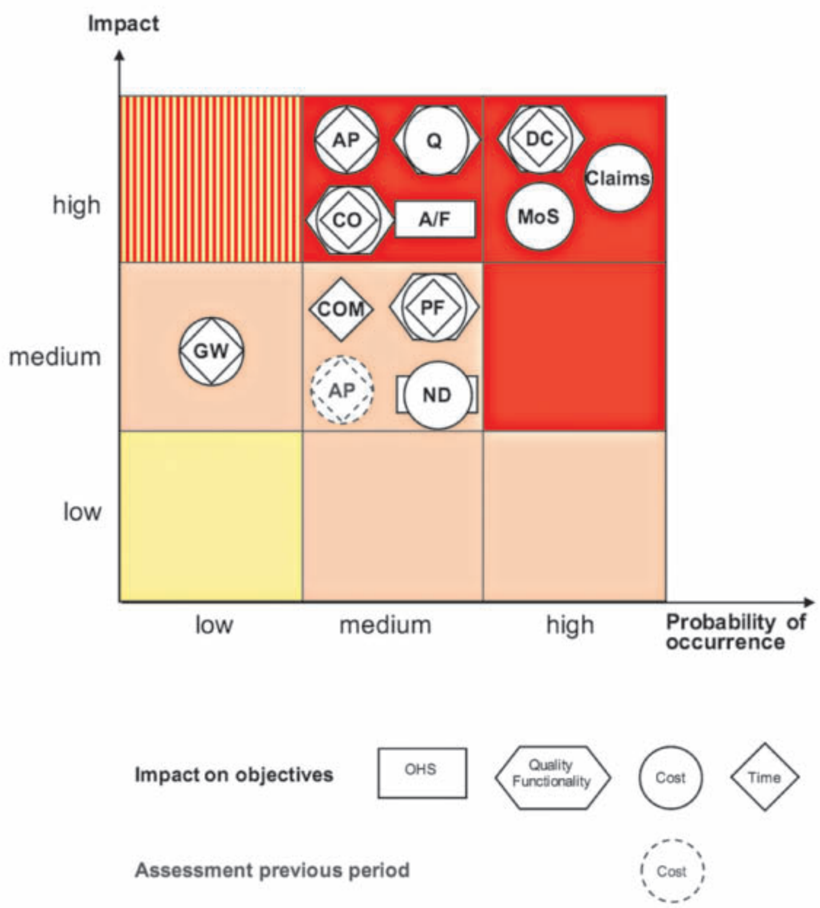
Threat level		Required action
6 and 9	(red)	Measures to reduce danger urgently required
4 3 (PO = 3, ED = 1) 2	(orange)	Check/implement measures as long as economically feasible (ALARP principle: "as low as reasonable practicable")
3 (PO = 1, ED = 3)	(red/yellow striped)	Special action is required for the field with a PO of 1 and an ED of 3: this danger scenario represents potential catastrophes, for which appropriate emergency planning has to be undertaken.
1	(yellow)	No particular measures; keep under observation.

▶ **Table 3** *Required action for remediation of threat (PO = probability of occurrence, ED = extent of damage)*

No.	Threats	Risk P	Risk I	Risk R	Risk Z	Planned mitigation measure (according to cotract, project, UQM) *Additional mitigation measures*	Residual risk P	Residual risk I	Residual risk R	Residual risk Z	Resp.	Deadline	Proof Documentation	done
100	**Ground conditions**													
110	**Geologie**													
111	Ground conditions worse than predicted (uutside of the contractual limits)													
111 a	TZM-Nord inkl. Clavanievzone	1	3	3	D	scooping the contractual options ***preparation of fallback solutions, expert panel AG TUS*** ***exploration drillings from northern side (Amsteg)***	1	3	3	D	site	constantly occasionally	support specification emergency program	X
111 b	Transition TZM-north / TZM-south	2	1	2	B						SUP/DE	constantly	support specification	X
111 c	TZM-south	1	2	2	B						SUP/DE	constantly	support specification	X
111 d	Transition TZM-south / UGZ	1	1	1	A						SUP/DE	constantly	support specification	X
111 e	Urseren-Garvera-Zone (UGZ)	1	2	2	B						SUP/DE	constantly	support specification	X
111 f	Transition UGZ / Gotthard Massiv (GM)	2	2	4	B	optimum selection of support types					SUP/DE	constantly	support specification	X
111 g	Gotthard Massif (GM)	2	2	4	B						SUP/DE	constantly	support specification	
X 111 h	Gotthard Massif (GM), option +1km (up to chainage 126.641)	2	2	4	B						SUP/DE	constantly	support specification	
X 111 i	Gotthard Massif (GM), behind chainage 126.641	2	2	4	B						SUP/DE	constantly	support specification	
116	occurence of highly permeable rock formations													
116 a	Urseren-Garvera-Zone (UGZ)	1	3	3	D	***exploration concept & additional measures***	1	2	2	B	SUP/DE	constantly	exploration protocol	X
116 b	Gotthard Massif (GM)	2	3	6	C	***exploration concept & additional measures***	2	2	4	B	SUP/DE	constantly	exploration protocol	X
X 116 c	Gotthard Massif (GM), option +1km (up to chainage 126.641)	2	3	6	C	***exploration concept & additional measures***	2	2	4	B	SUP/DE	constantly	exploration protocol	
X 116 d	Gotthard Massif (GM), behind chainage 126.641	2	3	6	C	***exploration concept & additional measures***	2	2	4	B	SUP/DE	constantly	exploration protocol	
120	**Fault zones**													
121	Number, position and behaviour of fault zones less favorable than													
121 a	area shaft II (TZM-South)	1	1	1	A	adapted support types								X
121 b	Area of multifunction station (TZM-South)	2	3	6	C	adapted support types ***optionally require design change,*** ***optionally additional work preparation, additional rock support,*** ***expanding of the catalog of auxiliary measures***	2	3	6	C	SUP/DE SUP/DE	constantly occasionally	support specification Design change request	X
121 c	Northern drive (TZM-north, TZM-south)	2	3	6	C	adapted support types ***see also 111a*** ***optionally require design change,*** ***optionally additional work preparation, additional rock support,*** ***expert panel AG TUS***	2	3	6	C	SUP/DE SUP/DE ATG ATG	constantly occasionally	support specification design change request	X
123	Not recognizing on time of highly permeable fault zones													
123 a	UGZ	1	3	3	D	systematic exploration ***Adaptation of exploration concept***	1	2	2	B	SUP/DE SUP/DE SUP/DE	autumn 04 occasionally occasionally	exploration concept	X
123 b	Gotthard Massif	2	3	6	C	systematic exploration	2	2	4	B	IG/ATG	autumn 04	exploration concept	X
X 123 c	Gotthard Massif (GM), option +1km (up to chainage 126.641)	2	3	6	C	***Adaptation of exploration concept***	2	2	4	B	SUP/DE			
X 123 d	Gotthard Massif (GM), behind chainage 126.641	2	3	6	C		2	2	4	B				
124	Hydrothermal decomposed rock	2	2	4	B	Exploration concept, gimprovement of ground conditions and adapted support types					SUP	constantly	support specification sheets	

Credit: [10]

▶ **Fig. 8** *Example of a risk register (Excel-based)*



Threats	
DC	Design changes (adaptation to the state of the art)
AP	Appeals against contract awards
CO	Insufficient coordination of civil works and railway technologies
ND	Natural disasters
A/F	Accidents / Failures
MoS	Management of spoil: • Insufficient deposit capacity • Insufficient quantity for gravel production • Insufficient quality for gravel production
Claims	Additional costs to the owner due to contractor's claims
GW	Ground conditions worse than foreseen
PF	Insufficient performance
COM	Difficulties during commissioning
Q	Unsatisfactory quality

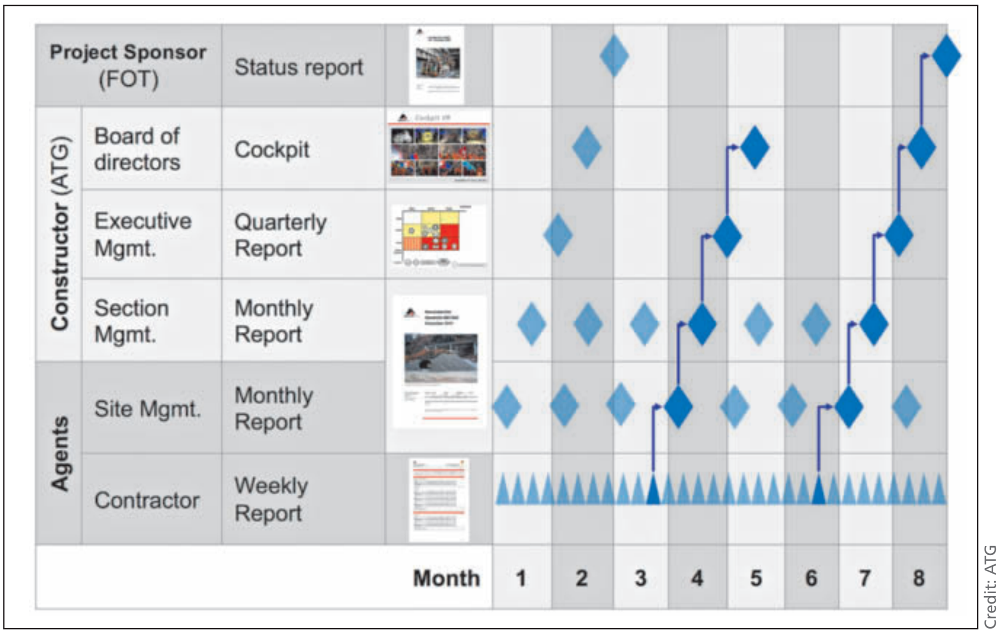
Credit: ATG

▶ **Fig. 9** *Example of a possible risk portfolio display for managers* was then usually led by the responsible board member.

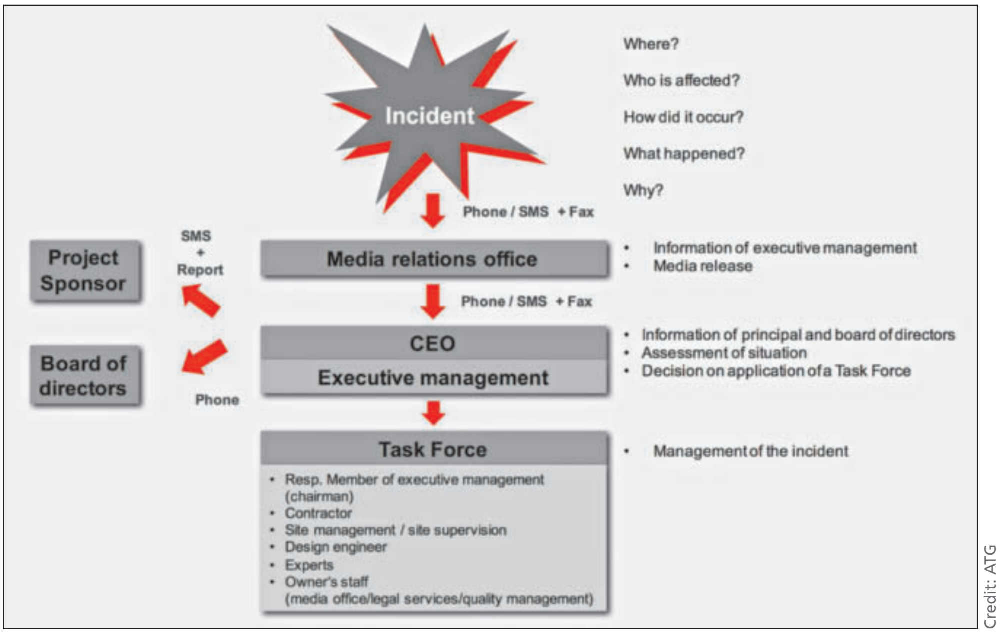
3.8 Documentation and evaluation of risks

The general risks were normally discussed at intersection (sections and lots) meetings and documented through the standard meeting and reporting system. Serious risks to construction, which demanded the appointment of special organisations (task forces), were normally documented in a subject-related final report from the task force.

The continuous improvement process was implemented at the level of the overall project through the instrument of the "quality notification". In daily business, the exchange of experience between sections took place at the monthly and quarterly meetings. With regard to future major projects, however, it would be beneficial in construction to introduce rapid transfer of knowledge about risks – for example, near-accidents – as is already the case today in other industries. The history of the construction of the GBT can offer plenty of material, which would justify further analysis for the purpose of a final gain of knowledge for future projects.



▶ **Fig. 10** *Scheme of regular reporting*



▶ **Fig. 11** *Incident communication according to the "yellow page" [8]*

4 APPLICATION EXAMPLES

4.1 Passing below the dams in the Sedrun area – remediation of dangers

Any tunnel drive in a water-saturated, jointed rock mass has an effect on the groundwater conditions. Water flows out of the joints in the rock mass into the cavity created in the rock mass. This results in reduced water pressures in the joints of the rock massif and an associated increase of the effective stresses in the rock mass. The consequence is that the joints close, leading to measureable deformations of the rock mass when integrated over larger distances. The resulting surface deformations can impair the functionality of buildings and structures or in an extreme case endanger their structural stability. This applied to a particular degree to three dams in the project area belonging to the (hydropower) Kraftwerke Vorderrhein Ltd (see VIII 9 "Passing under the dams").

Massive damage to the dams could have led to a long-lasting impairment of the tunnelling work for the GBT with ensuing costs in hundreds of millions and delays of many months to years. Due to the relevant experience with the Zeuzier dam, the probability of occurrence was categorised as "medium", which gave a risk level of 6, demanding essential countermeasures. The following measures were defined (see ▶ **Table 4**).

Type	Description	Reason
Organisational	» Appointment of an expert committee » Close information exchange with the owner of the dam to discuss the model results and the planned measures	» Task at the limits of the state of scientific knowledge at the time
Technical	» Installation of an all-year-round surface monitoring system at least two years before the start of tunnelling	» Collection of experience about the natural deformation behaviour » Creation of a data basis for refinement of the model
	» Annual surveying of more than 100 km of levelling sections above and below ground	
	» Provision of machinery and equipment for injection grouting jointed rock mass under high water pressures	» To prompt waterproofing measures if required
	» Planning of measures to remedy any damage to the dams	» Creation of a scope of action for the "worst case"

Table 4 *General plan of measures to reduce threats when tunnelling below dams*

Starting from 2000, the measures were consistently implemented for about 15 years. Thanks to the instrumented monitoring system, the settlement trough following the tunnel drive could be observed continuously. The continuously refined models enabled the threat potential to the affected dams to be predicted with reasonable precision.

On 13 September 2006, there was a water inflow with an initial rate of 13 l/s in the area directly affecting the Nalps dam. Due to the high threat potential, a grouting campaign was carried out for three months to reduce the inflow. The incoming water quantity could be reduced to less than 3 l/s. The deformations at the Nalps dam always remained in the acceptable range.

The question has to be asked whether the deformations would not also have remained in the acceptable range without grouting. Considering the critical location and the first occurrence of water ingress, a lack of action would certainly not have led to the satisfaction of the supervisory authorities and the power scheme operator that was determined later, and which enabled much more extensive measures to be saved. In summer 2010, in the last stretch of the TBM drive in Faido under the deepest overburden, heavy water inflow occurred (initially over 90 l/s).

Without the measures derived from risk management, particularly the measures to build up trust in the overall concept, the low ingress quantities laid down at the start of the project would have had to be maintained absolutely. The grouting campaigns necessary for this purpose would have had to be carried out only a few weeks before the already announced breakthrough date and this would have considerably damaged the reputation of the project.

Thanks to the refined models, the experience gained and the already mitigation to avoid damages to the Santa Maria dam, laborious grouting campaigns could be omitted in agreement with the power scheme operator and the federal supervisory authorities. The investment in measures to reduce risk paid off many times in any case.

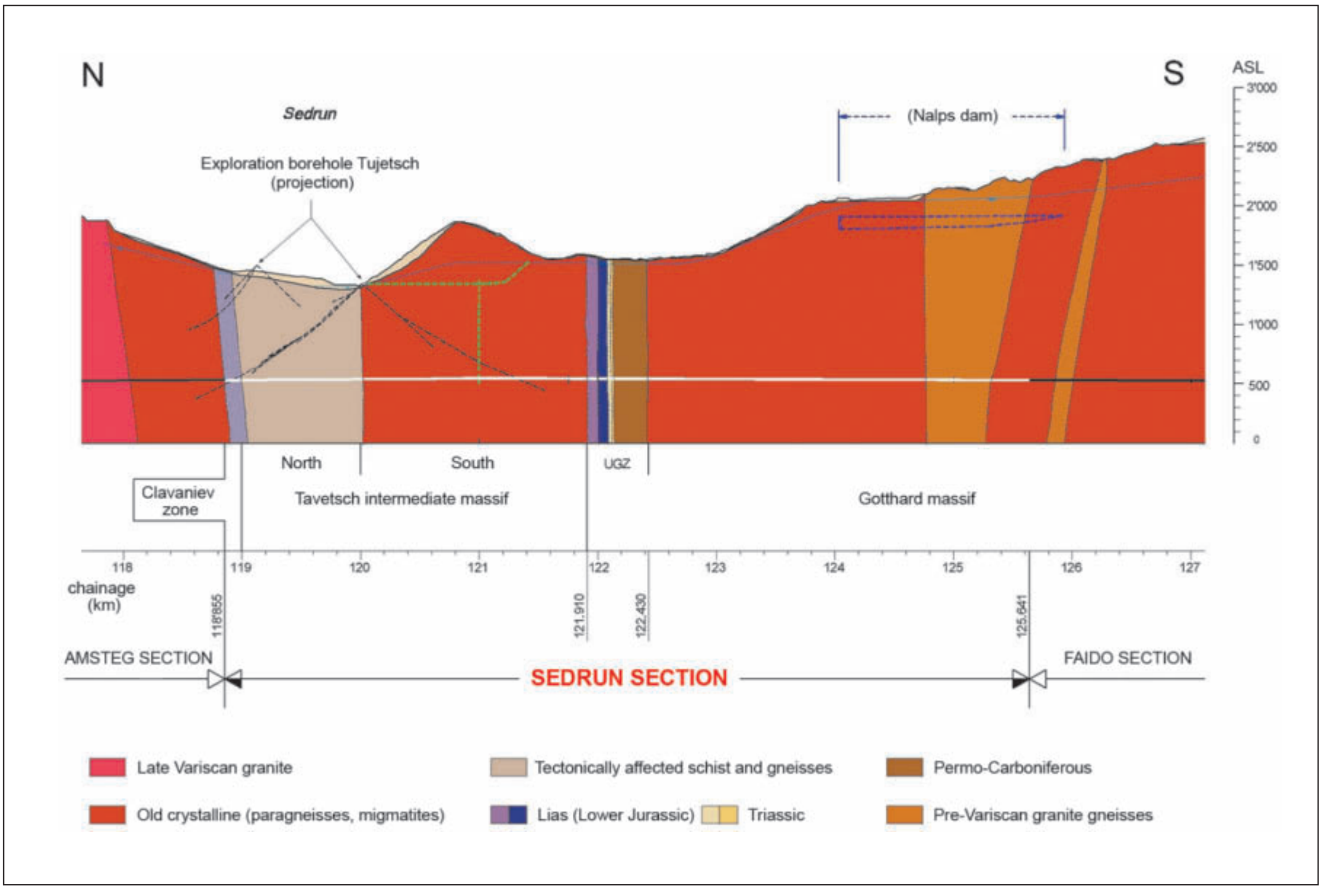
4.2 Lot interface movement Faido/Sedrun – grasping an opportunity

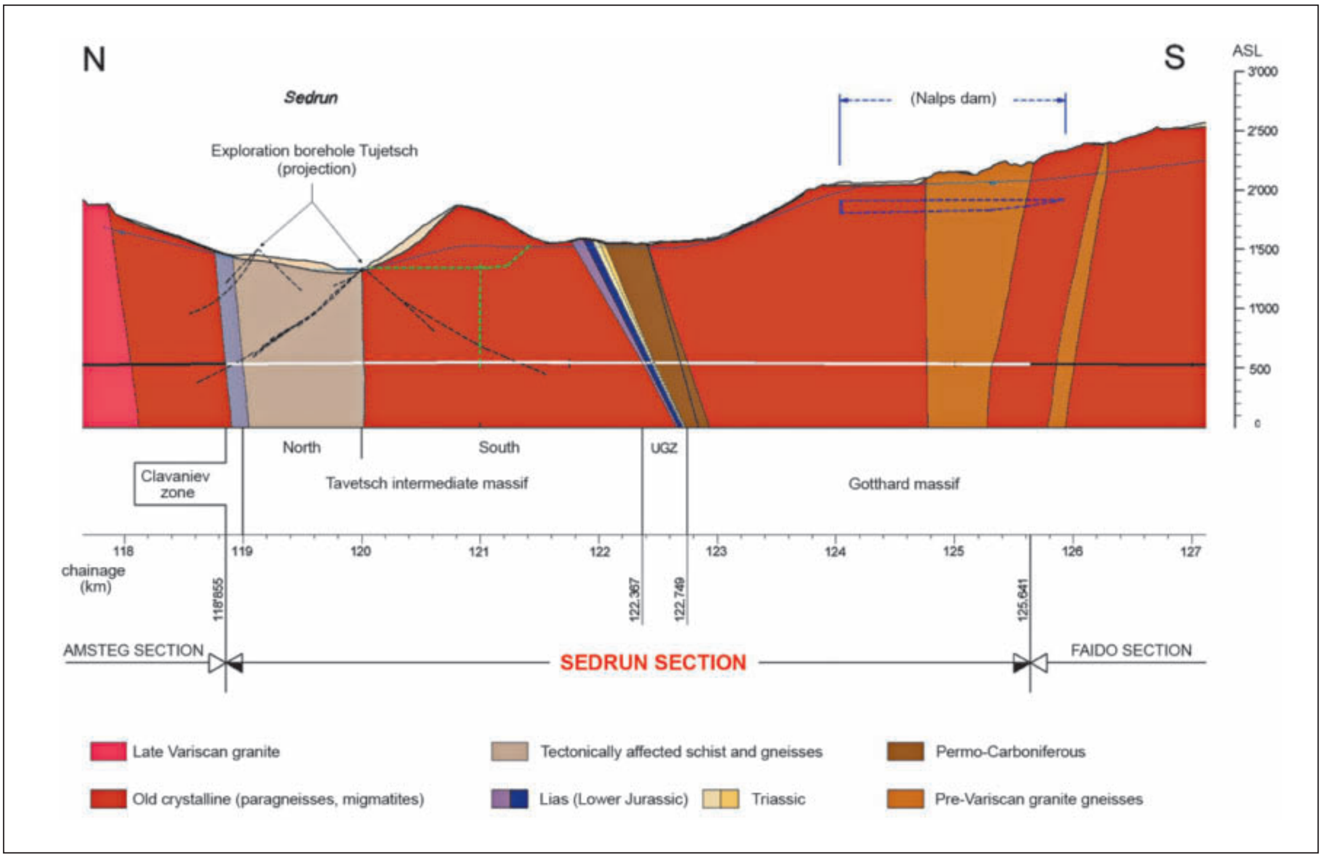
In the south drive in the Sedrun section, the Urseren-Garvera zone (UGZ), which was already known from the driving of the Gotthard road tunnel, was expected to be encountered along a length of about 510 m. Squeezing behaviour was forecast similar to that in the Tavetsch intermediate massif north, with correspondingly slow advance rates of about 1 m/working day. In the course of driving the tunnel, however, the UGZ was actually encountered 465 m further to the south than originally forecast with an extent of only 305 m, or about 60 % of the length forecast from surface outcrops. Finally, the entire UGZ showed no squeezing behaviour.

These favourable effects led to the drive running about one year ahead of the contract schedule within a short time (see **Fig. 13**). This situation had a favourable financial effect on the project and with great probability offered the opportunity of reducing the overall construction time on the project by more than six months.

In early 2005, it also became obvious that the completion of excavation of the multifunction station (MFS) Faido would be delayed by more than two years due to considerable geological difficulties. This meant a correspondingly late start for the TBM from the MFS to drive the single-track running tunnels toward Sedrun. From the experience gained in the TBM drive in Bodio, it could not be assumed that such a delay could be recovered by higher advance rates than agreed in the contract. The danger of a delayed start of operation of the entire tunnel would thus have a high probability of occurrence combined with serious effects. The threat was at risk level 9 and countermeasures were essential.

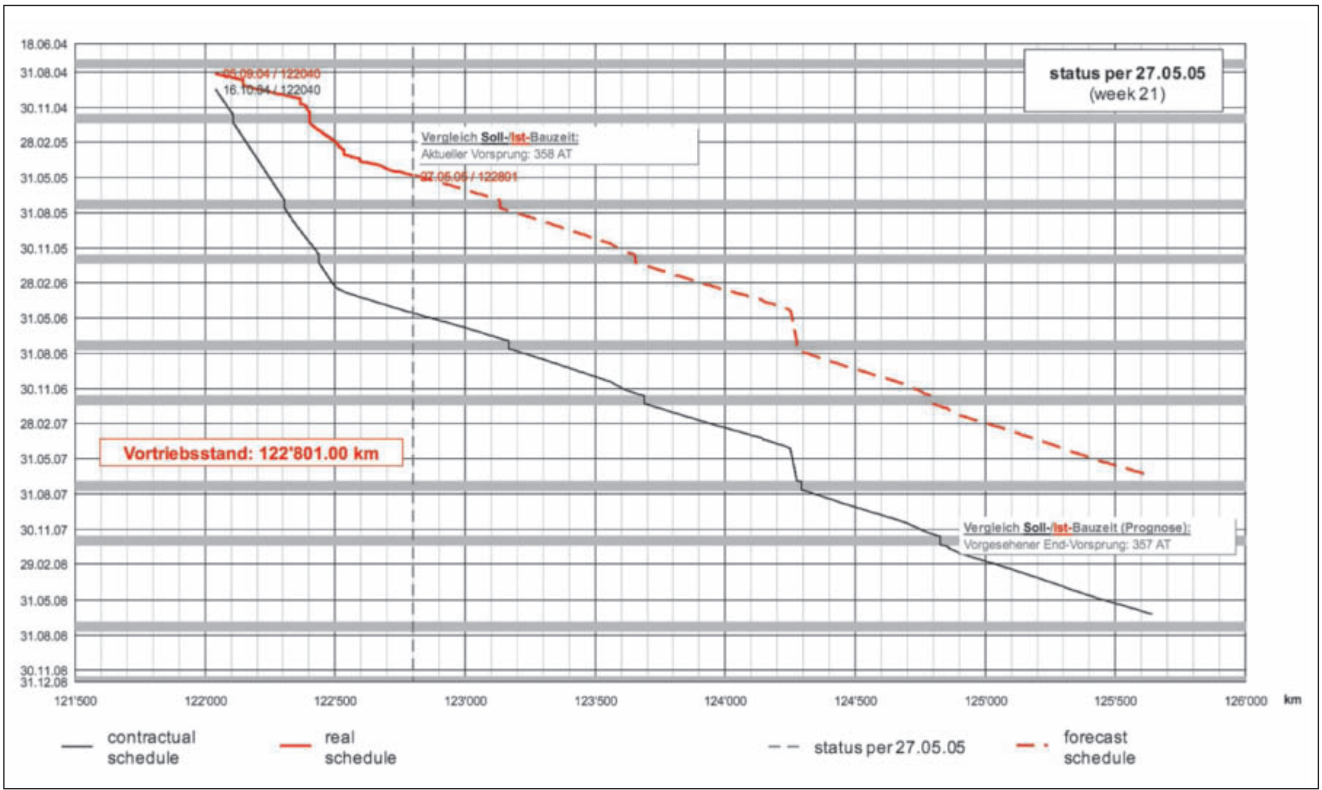
The Sedrun south drive, which was advancing more quickly at the time, offered practically the only chance of activating countermeasures. The obvious idea was to consider an additional drive passing the contract interface to the Faido section. An extended drive of 1 km had indeed been agreed with the contractor for the Sedrun section as a contract option, but





Credit: [10]

Figs 12a und b *Ground conditions on the south drive in Sedrun, top: forecast; bottom: actual situation at the end of May 2005*



Credit: [10]

▶ **Fig. 13** *Time-to-distance diagram for the south drive in Sedrun as of 27 May 2005 (east tunnel)*

even with the activation of this option a time difference of more than two years would arise at the Sedrun south/Faido lot interface. This gap could only be closed with additional tunnelling from Sedrun, which was not included in the contract, in order to be able to bring forward the start of operation in the GBT by six months to one year. Thanks to the early identification of this chance in the course of the risk management process, it was possible to adapt the project design in time, investigate solutions for new landfill capacity with the affected people of Sedrun, carry out the planning approval procedure and negotiate and change the change order with the contractor.

At the end of October 2009, the tunnelling works under the change order could start and continued for about one year. Thanks to the altogether about 2 km of additional distance tunnelled from Sedrun, (of which 1 km under the original contract and 1 km under the change order), the preconditions were created for the decision made shortly after the main breakthrough on 15 October 2010 to bring forward the start of operation in the GBT by one year from the end of 2017 to the end of 2016.

5 DEVELOPMENT OF RISKS DURING PROJECT IMPLEMENTATION

The works for the GBT will go into operation in the ordered quality. The "four-eyes principle" (see text section 3.1 "Methodical approach") in the design and construction phases, continuous quality controls during construction and the RAMS processes for the M&E installation works made this success possible. The handling of risks to occupational health and safety is described elsewhere, so the following discussion is solely concerned with the development of deadline and cost risks.

Since the beginning of the project the deadlines and cost objectives did indeed have to be defined "to the day" and "to the franc" according to the principles of the project organisation AlpTransit Gotthard. But it was also commonly agreed among all project leaders, that a considerable spread has to be provided with these figures. Despite the most careful preparatory work, it could not be ruled out that threats would appear that are not represented in the cost and deadline targets (unidentified or unquantifiable threats = unknown). By contrast, the conditions could turn out to be extremely favourable and then it could be assumed that opportunities could be grasped. For this reason, the risk spreads – both for costs and for deadlines – were quantified and communicated again and again at the start of the project.

5.1 Deadline risks

The most significant risks to the deadlines derive from the ground conditions until breakthrough, the approval and acquisition processes, and the danger of massive changes to the order. In the course of risk management, these deadline risks were correspondingly quantified and communicated in the status reports in the form of an easily readable diagram with a forecast fan (see ▶ **Fig. 14**).

For a long time, a deadline uncertainty of two additional years was assumed (for a short while, three years due to the expected additional measures for passing below the dams) and an opportunity of being one year ahead. As is shown in ▶ **Fig. 15**, the start of services in 2016 achieved the upper limit of the range defined at the time of awarding the main contracts.

The main drivers for the occurrence of deadline risks were the ground conditions in the south (Bodio and Faido) and the planning approval process in the canton of Uri. While risk zones for tunnel construction (TZM north and Piora syncline) could be driven through without problems thanks to careful planning of measures (advance probing and adapted project design), delays due to ground conditions mostly occurred where no one had assumed an increased risk from the available knowledge. In particular, there were no early indications of the extremely difficult ground conditions in the area of the MFS Faido. In this sense, the poor ground conditions that were encountered were certainly a case of the occurrence of acceptable residual risks.

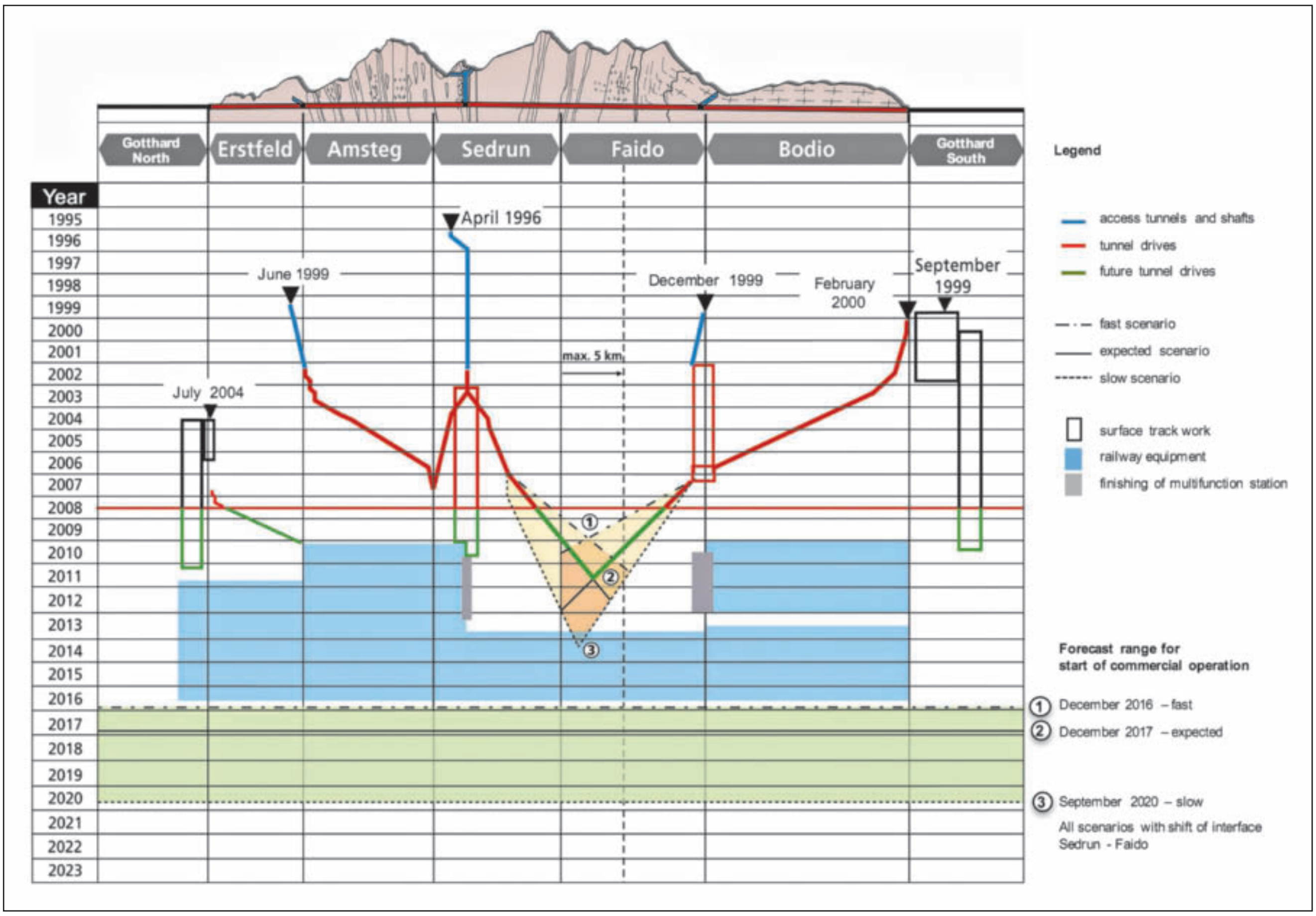
While the first planning approval procedure for the intermediate starting point in Sedrun could be conducted within the forecast time of twelve months, all the subsequent processes lasted considerably longer. It took seven to ten years to find an acceptable solution for the directly affected people on the north side of the GBT. In addition, the last main lot in Erstfeld was hindered by an appeal process against the award of the lot, which lasted more than one year and made another deadline risk real.

On the other hand, the initially favourable ground conditions on the south drive in Sedrun offered the chance of moving the lot interface from Sedrun towards Faido. This measure to accelerate the programme first made the date for the start of services in 2016 possible. With hindsight, this was a key decision on the project and underlines the importance of suitable intermediate starting points, which leads to flexibility between lot sections.

5.2 Cost risks

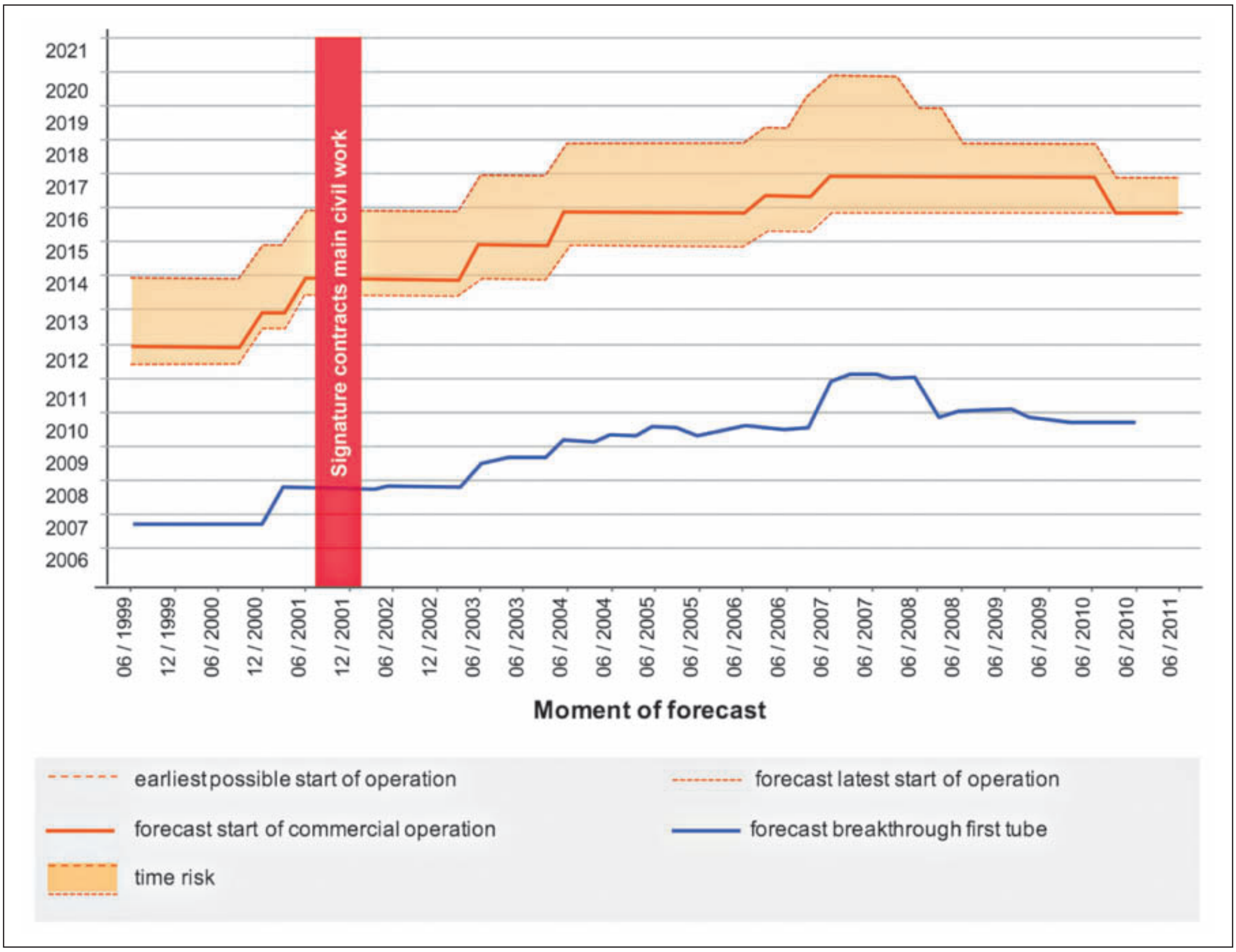
In the early phases of the project, the risk spread was derived from the precision demanded by the SIA standards and legal judgements (see ▶ **Table 5**) – a method which is questionable for mega-projects with a long duration of construction.

For such special projects, the cost spread already has to be derived from individual risk analyses from the preliminary design phase, and these have to recognise the long duration of construction in particular. Such a method applied to the early stages of a mega-project with a construction volume of more than CHF 1 billion would normally show considerably higher risk potential than the precision figures stated in the standard. This consideration was finally accepted by the FOT, and the



Credit: ATG

▶ **Fig. 14** *Display of the deadline risks in the status report*



Credit: H. Ehrbar

▶ **Fig. 15** *Development of deadline risks during the construction period*

cost spreads for the early project phases were increased (see ▶ **Table 5**).

The NRLA dispatch from 1990 [14], however, went considerably further and described a cost spread of –10 %/+30 % to +40 %. As shown by current experience, that assumption was certainly justified and the considerations at that time can be recognised as a good example.

In the course of 2006, the management board of ATG decided to evaluate the risk portfolio for the remaining duration of the project in detail together with the project engineers. This method of consideration led to an increase both of the presumed final costs and the risk potential. In addition, the risk analysis based on a deterministic risk evaluation carried out in 2007 was backed up with a second study based on a probabilistic approach.

The results were negotiated with the FOT and this led to changes to the financing of the NRLA project, which restored the finance lacking for the risk potential from change orders by the FOT and dangers that occurred. Thanks to the subsequent

Phase	Cost document	Spread	
		Original	Actual
Preliminary design	Cost estimate	+15 %/–15 %	+25 %/–25 %
Approval design	Cost estimate according to approval design	+15 %/–10 %	+15 %/–15 %
Detailed design	Cost estimate according to design for construction	+10 %/–10 %	+10 %/–10 %
Design for construction	Contract	+7 %/–0 %	+7 %/–5 %
Invoicing	Final invoice	+/–0 %	+/–0 %

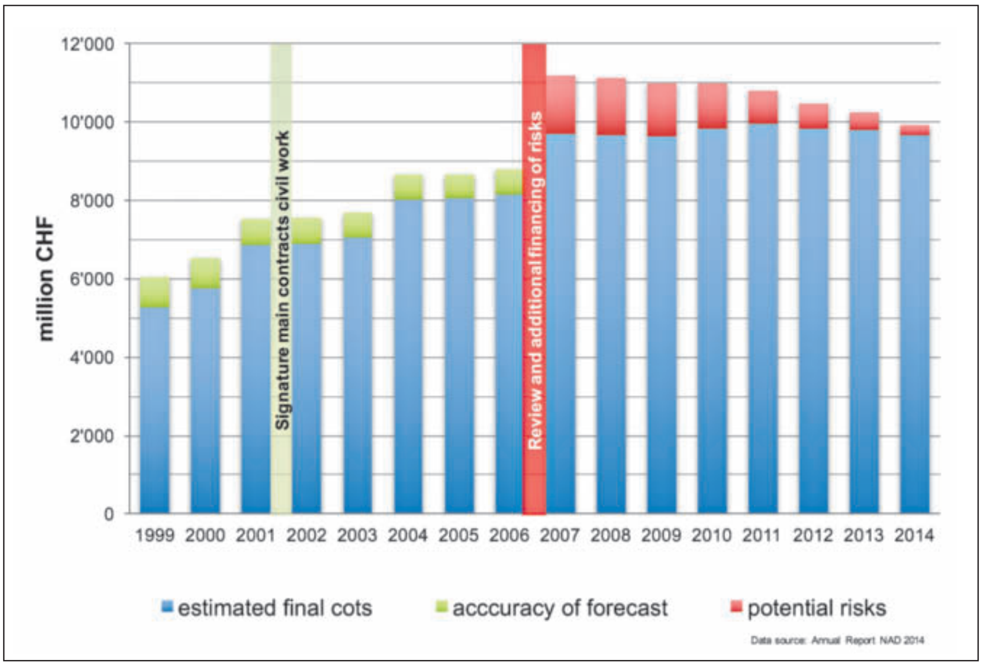
▶ **Table 5** *Development of the theoretical cost spread* favourable development of risks and chances in the Gotthard axis, the forecast for the final cost of the NRLA project could be reduced by the federal government in two steps by CHF 500 million at the end of 2014 (see ▸ **Fig. 17**), which freed up money for other public transport projects.

6 ASSESSMENT AND RECOMMENDATIONS

The professional risk management system formed a central part of the integrated management system of ATG from the beginning of the GBT project. Risk analyses were carried out at each stage of the project and the appropriate measures for the stage were planned. Thanks to this procedure, the project organisation was always prepared to overcome undesirable events.

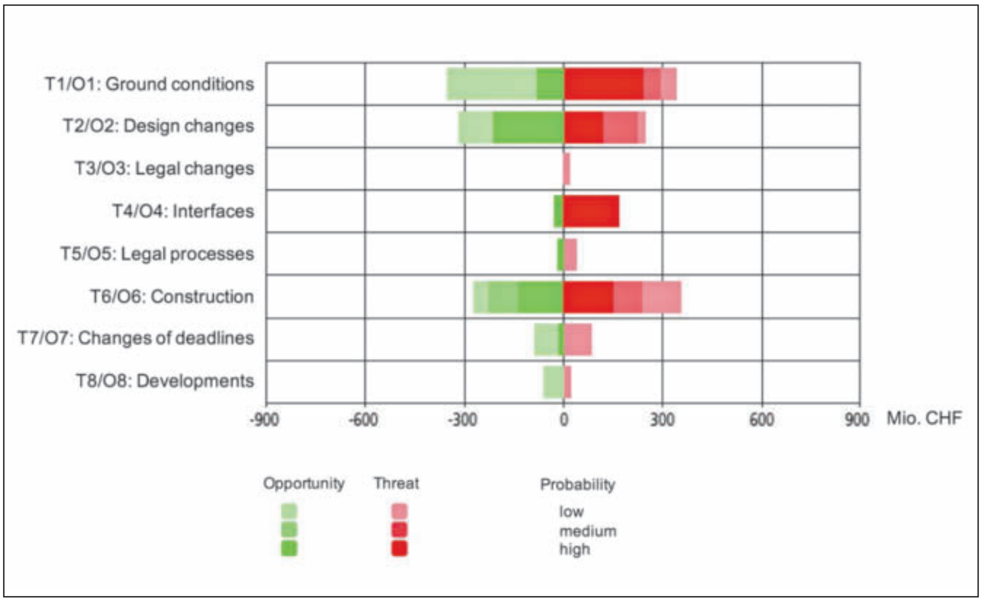
The use of integrated risk management turned out to be absolutely sustainable, meaning the involvement of all project parties (client, design engineers, site management, contractors and the SIOP team and later the operator). Only this approach could ensure that each contract party could make their contribution to the planning of measures at the right time. That threats were pointed out, which resulted from the organisation of the relevant partner, was not harmful to good collaboration but, on the contrary, made a positive contribution to reciprocal understanding, trust and partnership.

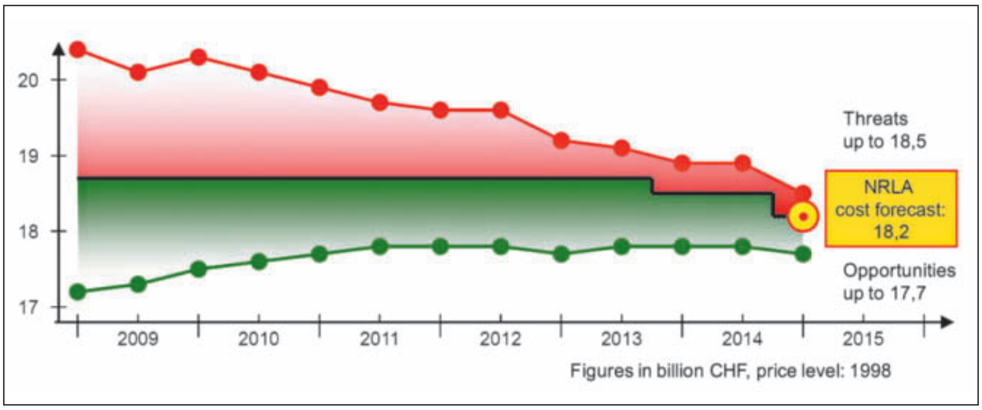
The fact that the risk management system for the longest tunnel in the world



Credit: Jahresbericht NAD 2014

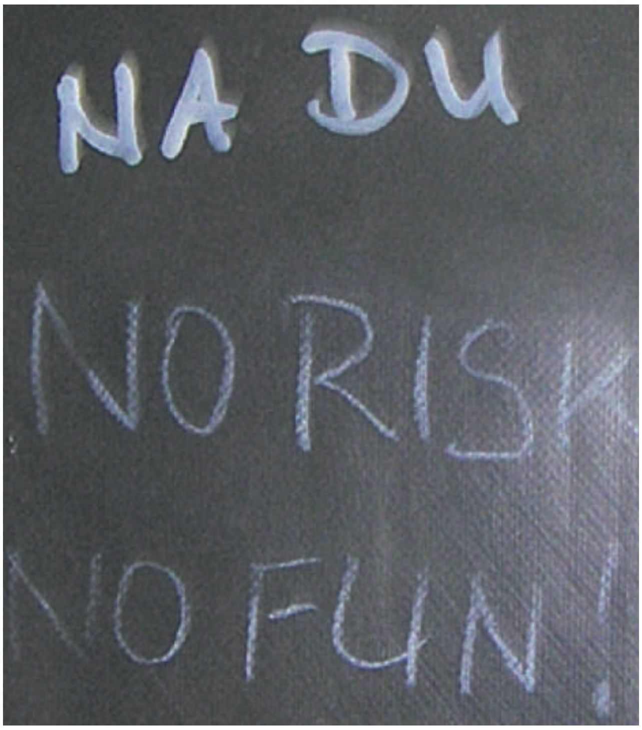
▸ **Fig. 16** *Development of the presumed final costs [12] and the risk potential at the GBT*





Credit: www.bav.admin.ch

▸ **Figs 17a und b** *Display of the financial risk potential by the FOT*



Credit: H. Ehrbar

Fig. 18 *A not very serious attitude to risk from the tunnellers at the site in Sedrun*

was based on a simple semi-quantitative approach with a 3 × 3 matrix may seem surprising. Qualitative approaches were only chosen in exceptional cases (e.g. the shifting of the Sedrun/Faido lot interface, second opinion for the re-evaluation of the risk portfolio). The fact is that this simple matrix method was an absolutely reliable control instrument and made a great contribution to the success of the project. The simple, clear system was popular with all partners and turned out to be much more valuable than a complex mathematical system, which only a few could comprehend and make use of and would thus be consigned to a black box in a computer that has no ability to think. From this experience, the matrix system method that was used can certainly be recommended for further use. The use of a 4 × 4 or, in an extreme case, a 5 × 5 matrix would also have been possible but would not have produced any particular added value for the case of the GBT.

In summary, it can be asserted that project risk management at the GBT was based on the following basic principles:

1. Risk management was recognised from the beginning as an important management task.
2. A culture of learning was created.
3. Risk management was understood as a thinking task for all project parties and not as a calculation task for a computer without the capacity for thinking.

Project risk management – the most important instrument for successful project control – proved a great success and is not subject to any copyright. Its application on future major projects can only be recommended.

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