



### Tough decisions for mega-projects

A methodology for decision making on time-relevant measures at the Gotthard Base Tunnel

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### Project outline

The Gotthard Base Tunnel (GBT), at 57 km in length, is the longest railway tunnel on earth. It is the core piece of the north-south rail connection across the Alps, joining the economic regions of southern Germany and of northern Italy; with a population of over 30 million people. Entirely on Swiss territory, it has been planned and is being constructed by AlpTransit Gotthard, Ltd. (ATG), a subsidiary of the Swiss Federal Railways.

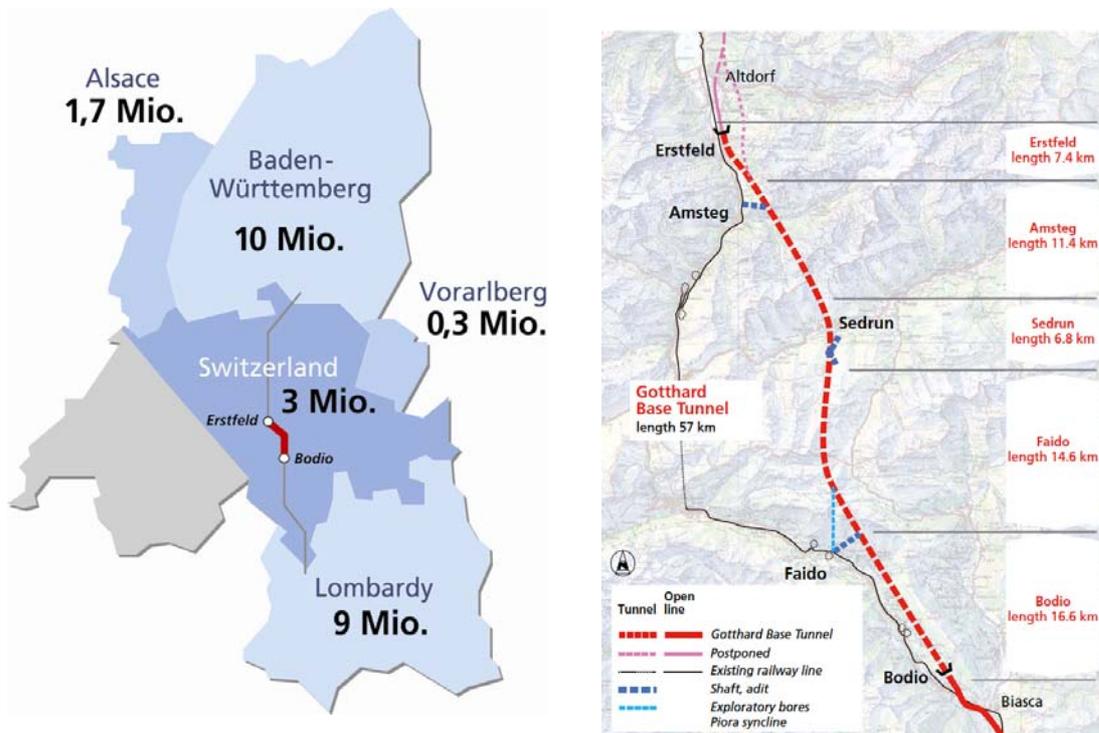


Fig. 1: Catchment Area of the Gotthard Base Tunnel and its location

Transalpine transportation being a crucial issue in the relationship between the European Union and Switzerland, the tunnel is one of the latter's main assets. It is also a cornerstone of the Swiss environmental and traffic safety policies, one of its main objectives being a massive transfer of freight from road to rail, thus easing the pressure on the north-south highway connection and especially on the Gotthard road tunnel, a 17 km long bidirectional highway tunnel.

Switzerland has therefore a predominant interest in an early start of exploitation of the Gotthard base tunnel, and time saving is one of the main tasks of ATG.

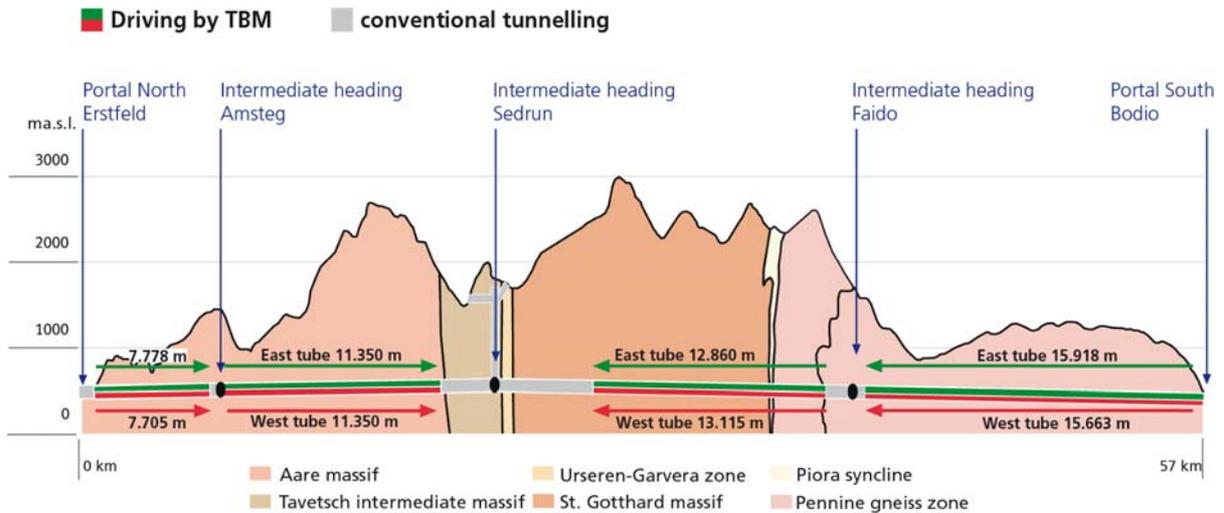


Fig. 2: Detailed map with different headings

The tunnel is being constructed starting from 5 access points: the portals of Bodio and Erstfeld, a horizontal adit at Amsteg on the north side, a vertical shaft of 800 m depth at Sedrun and an inclined adit of 2.7 km at Faido. Multi-functional stations (MFS) at the tunnel end of the Sedrun and Faido accesses shall serve as tunnel interchanges and for evacuation of passengers in case of accidents.

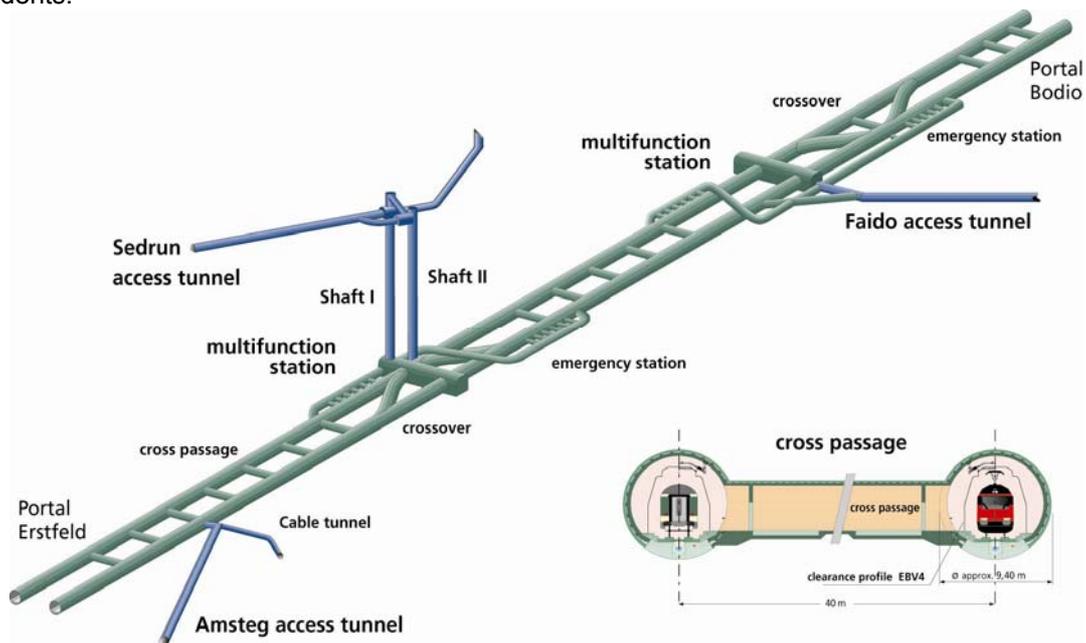


Fig. 3: Scheme of tunnel system, Gotthard Base Tunnel

According to the schedule of approval by the federal authority, excavation started at the five access points at different periods, and was done mostly by TBM. The only sector entirely excavated conventional tunnelling is Sedrun. This was due to the expected geological formations that were rather poor and not considered apt for TBM mining. In 2006 all headings except Erstfeld were under way.

### Contractual aspects

From a contractual point of view the construction of the Gotthard base tunnel is divided into three phases that are partly superimposed over each other: excavation and lining, secondary works and the rail system. Excavation and lining has been subdivided into five different sectors, according to the access points, the secondary works are divided into a series of contracts according to the work type

(industrial flooring, cross adit safety doors ecc.), where each contract regards the entire tunnel. Lastly, the rail system has been awarded as a total contract, including final design and all works. The employer ATG is therefore in charge of coordination between the different contractors, and, of course, bears the geological risk in terms of cost and delay. The contracts for the construction of the central sectors of Amsteg, Sedrun and Faido are designed for flexibility; allowing for a shift at the geographical interfaces between the different sectors headings. In the case of the headings of Faido and of Sedrun (south), the contracts regulate conditions for a shift of the interface between the two headings for up to 1 km. If a shift of more than 1 km is required in order to finish both headings without unnecessary delay, new agreements must be found between the employer and the contractors.

### Planning

The planning allows for some overlap between excavation and lining on one hand and secondary works on the other, while the rail contractor enters the tunnel once the above phases have been concluded. The rail contractor can for the main part of his work only enter the tunnel at the portals of Erstfeld and Bodio. Only some auxiliary work can be done through the intermediate adits of Amsteg, Sedrun and Faido.

The center part of the tunnel is the last to be accomplished, and determines the end of the railway technology works, and thus the start of revenue operations. The moment of completion of the Faido-Sedrun leg is therefore crucial. The completion of the Faido MFS is another milestone, as it allows for the rail contractor to finish the installation of power supply and the tunnel control system.

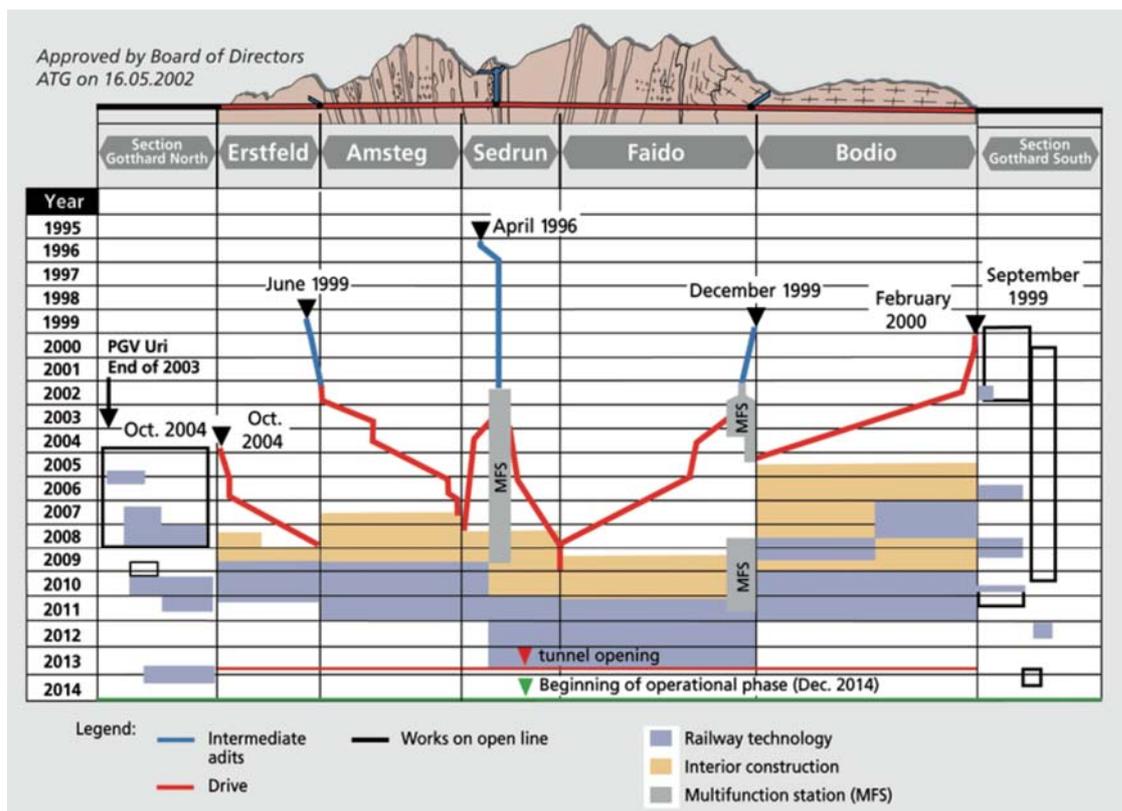


Fig. 4: General schedule 2002

Starting with the commencement of excavation in the MFS Faido during 2002, unexpected, adverse ground conditions caused major delays in construction of the Faido sector. At same time, in the Bodio sector, some difficult ground conditions were also encountered, which along with insufficient production rates also caused a delay to this sector. The southern half of the Gotthard Base Tunnel advanced more slowly than expected. On the other side, especially the southern leg of the Sedrun sector, was found to be geologically less challenging than planned, and was nearly one year ahead of schedule.

The delays in the southern half of the Gotthard Base Tunnel, along with the obstacles to project approval on the north end of the tunnel, caused a delay in the start of revenue generation, which was estimated in 2002 to be in the year 2014. By 2006 this date had changed to the end of 2017, but major geological uncertainties on the Faido-Sedrun leg (in particular, the Piora syncline and the Retico fault) called for careful assessment of this date.

### Quest for the most likely breakthrough

In the spring of 2006 the excavation of the Faido MFS was almost completed, and the Bodio TBM was expected to arrive at Faido for autumn 2006. The start of the same TBM after refurbishment and adaptation of the cutterheads to a larger diameter was planned for May 2007. The Faido leg of the GBT is considered as a geologically very delicate portion of the tunnel, as it contains the dolomite zone of the Piora syncline, and the geologically least investigated part of the entire tunnel with the highest overburden and with the important Retico fault, of which the geotechnical and hydrogeological characteristics are not known with precision.

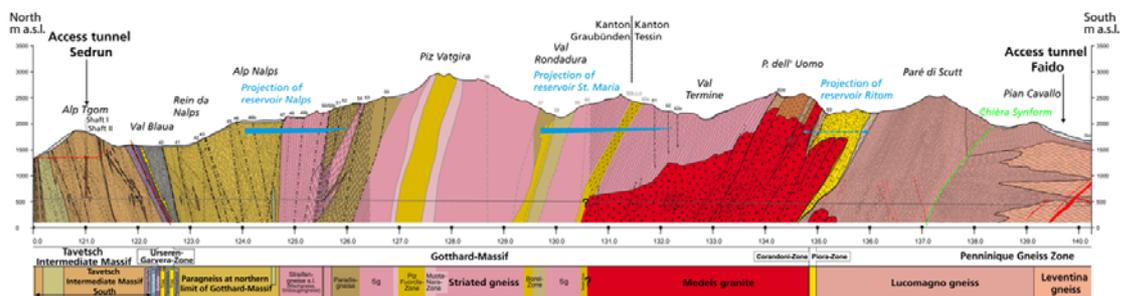


Fig. 5: Geological section of the Faido-Sedrun portion

2 kilometres east and 1'400 m above the tunnel axis, lays the Santa Maria dam, a 117 meter high concrete arch dam that is part of an important hydropower scheme. According to the water intake of the tunnel and the settlement behaviour of the rock mass, the necessity for protection of the dam may require a major slow-down of production due to exploratory drillings and the possibly necessary grouting of the rock adjacent to the tunnel. In 2006, the time required for the Faido TBM to reach their final chainage was therefore relatively uncertain.

Meanwhile, the Sedrun south heading, advancing regularly by D&B, was still ahead of it's schedule, and no major difficulties were expected. It was therefore a must to start detailed studies on the possibility of a major shift in the interface, because there was the possibility of a gap of 1 to 2 years between the finish of the D&B excavation work at Sedrun and the arrival of the TBM from Faido to the interface. It had to be considered that the D&B excavation with logistical supply through a 800m vertical shaft is much more expensive than TBM excavation with a full rail supply system.

ATG formed a task force including the design and supervision team in order to tackle and answer the following questions in due time:

1. Which is the most likely chainage of the breakthrough (where the Faido TBM shall have to enter a dismantling cavern prepared previously by the Sedrun D&B teams).
2. Which cost consequences would be likely in case of a major shift in the interface?
3. Would such a shift lead to an earlier start of exploitation, and would the probability of the prognosis get better?

These questions had to be answered in time for ATG to be able to decide, whether a variation in the Sedrun and Faido contracts was necessary, to eventually provide for the necessary variation documents and to negotiate the variation at the latest possible time in order to prevent delays in the procurement of the necessary provisions.

### Task

The time available for the necessary analyses was relatively tight, as especially on the Sedrun heading an extension of length, would require major adaptations in the entire supply line, running from the surface through a 1.2 km adit, the vertical shaft, the Sedrun MFS and the tunnel section in progress. The potential requirements regarding in particular; cooling, ventilation, power supply were great. For up to 1 million tonnes of additional excavated material, new disposal areas had to be found and additional construction permits became necessary.

On the Faido side, as the most likely option was a shortening of the TBM portion, no major adaptations in site equipment were called for.

## **Methodology**

### *Time and place*

The effect of shifting the breakthrough from the southernmost contractually admitted position to the schedule-wise best location can be found by simply allowing the estimated timeline of the D&B heading to continue beyond the planned interface until it intersects with the TBM timeline, without unnecessary delay.

If it weren't for the many uncertainties regarding production rates, the estimate of time and place of this breakthrough would have been a very straightforward planning task: on a time-chainage diagram, the presumed schedules of the two headings could be drawn and easily intersected.

The problems were due to typical doubts in underground works:

- how trustworthy is the geological prognosis?
- how will geology influence on production rates of a given equipment and crew?
- how many major geological/hydrogeological events are to be expected, and what shall be the respective time loss?
- how will eventually necessary grouting measures affect the timeline, accordingly to the effects of water intake on surface structures?

All these questions had to be answered for the D&B heading of Sedrun, and for the TBM headings of Faido. According to the assumptions, the speed on either side would be influenced, and the time and place of the breakthrough would vary.

In order to limit the number of possible cases for each of the above questions, a three-scenario combination was decided upon: for each presumed event, a best case, a worst case and an intermediate case was contemplated. This led to a combination tree with, in the end, a series of possible scenarios on the Faido end, and a series of possibilities on the Sedrun end.

Each of those scenarios was tied to a timeline, and the number of theoretical combinations led to  $3^5 = 243$  scenarios for Faido, and to  $3^4 = 81$  scenarios for Sedrun. The total possible intersections therefore amounted to  $243 \times 81 = 19'683$ . As in the area, where (according to the analysis) both headings are likely to pass; the respective scenarios must match (it can be supposed that a scenario with best-case geology on the D&B side cannot reasonably be combined with a worst-case geology scenario on the TBM side in the same portion of tunnel), the number of realistically possible scenarios can be reduced by a factor of 3, leading to 6'561 plausible points of breakthrough in time and place.

In this context, the following two problems had to be solved. First, the different scenarios each have a different probability. This must be considered in order to find the most likely area and time of breakthrough. Second, the number of possible scenarios requires a useful tool for calculation of the timeline and the intersection spot, and for graphic representation of the results.

### *Delphi method*

In order to tie the scenarios to a probability, the Delphi method was decided upon, rather than a purely probabilistic method: as opposed to the situation in an early project stage, where knowledge of the concrete situation is little, the team was confronted with a situation where a comparison between geological forecast and reality had been made for the Bodio headings, as well as comparison between contractual TBM production rates and real production rates, to cite but two examples. This allowed for an interrogation of a number of experts, ranging from the design manager, to chief supervisors, to the geologists, to the employer's resident and to the proof check engineer. All these experts were asked to estimate a probability for the three postulated cases of all scenarios (best, intermediate, worst). Among the number of judgments, the extreme values were eliminated, and the average of the remaining was considered the probability of a single scenario.

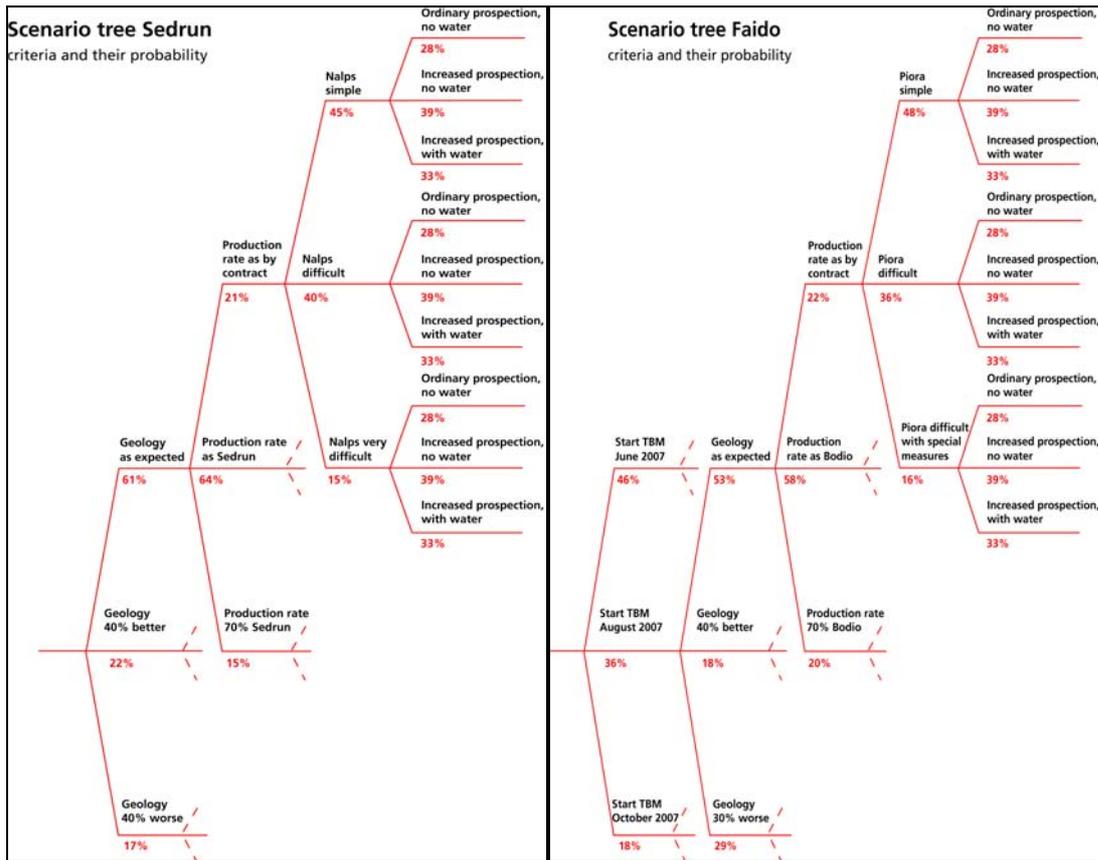


Fig. 6: Scenario trees for the Sedrun and Faido section

*Calculation tools*

For the construction management at the Gotthard base tunnel, all sites use the same database. One of the assets of this database software is a timeline programming tool that allows for the elaboration of various scenarios. A custom made application eased the dealing with a large number of scenarios, and in due time the intersection area for all scenarios could be established. Each intersection had now a probability, and the area of maximum probability density was to be considered the most likely time and place of breakthrough. This evaluation and representation was accomplished with a commercial mathematical software.

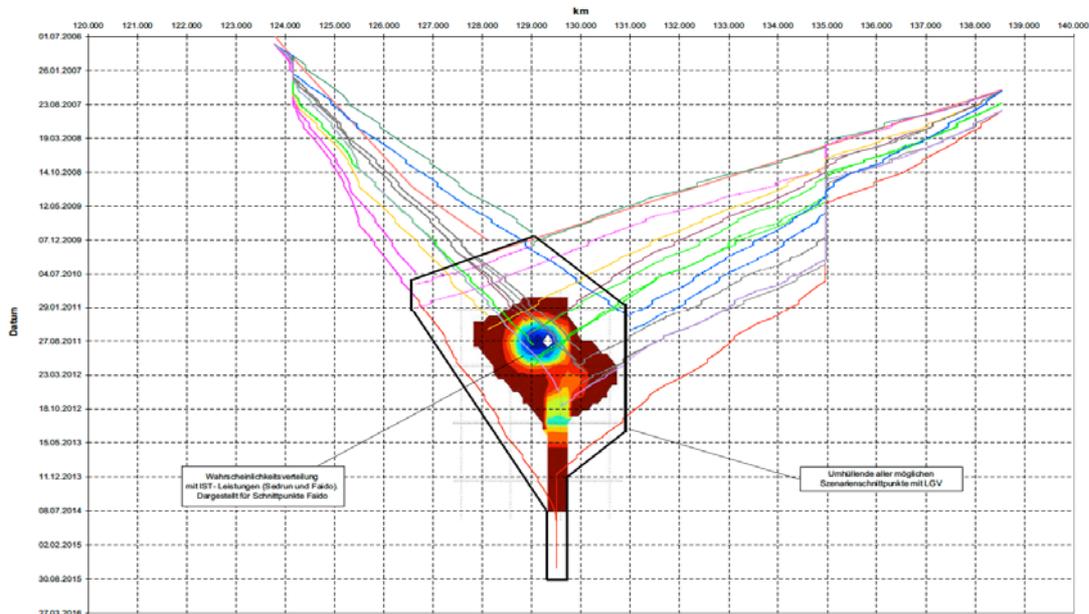


Fig. 7: Probability density and typical scenarios

### *Reduction of intersections for subsequent analyses*

In order to be able to handle the next steps, in particular the cost estimate and the effect on the rail-related works, a choice of typical and representative intersections was made (most likely, southernmost, northernmost, early, late), and all others left out of further analysis.

### *Potential consequences on overall schedule*

As the breakthrough is a milestone on the project's critical path, once its time and location is established, the effect on the subsequent project activities can be reviewed and the overall schedule accordingly adapted. As at the time of the study, the rail system contract had not yet been awarded, the effects of the different intersection locations and times had to be analyzed on a rather theoretical basis. The main issue for the rail works is the time of breakthrough, not its precise place, as the works are organized by entire tunnel legs, and as the breakthrough is situated, in any case, within the Faido-Sedrun portion.

### **Consequences on cost**

#### *Direct cost (production related cost)*

As seen before, the shifting of the interface may require additional equipment, and the production cost of a D&B heading in difficult logistical conditions is likely to be more expensive than the cost of a TBM heading with rail-bound supplies. This difference was estimated in discussions with the two contractors, on the basis of the existing contracts.

Another cost element to be considered, is the cost of muck disposal, including transportation to the final location: while the availability of space for muck around the south portal is sufficient, space is scarce at the top of the Sedrun shaft. A detailed analysis of possibilities and eventual requirements of additional disposal locations had to be carried out, including the effects on cost.

#### *Indirect cost (time related cost)*

Extension of delay leads to supplementary remuneration to the contractor for equipment and overhead cost (Sedrun heading). On the other hand, a limitation of the extension of delay (as is the case with the Faido heading) leads to a reduction of remuneration to the contractor. This balance must be completed with the effects on cost on the employer's side, such as internal cost of the employer's own organization, the design and supervision cost.

### *Risk analysis*

Finally, contracts of a duration of over 10 years, of a high economic value (over 1.5 billion US\$) and a high complexity are notoriously vulnerable to end-of-contract claims. The benefit of a shortening of construction time, and of a more accurate estimate of the end of contract, can and must be considered.

### **Results**

#### *Time and place of the interface (Fig. 8)*

The analysis shows that

- in case of renunciation on an additional shift of the interface, the opening of the GBT to revenue operation is likely to need postponement to 2018.
- in case of an additional shift of the interface, the most likely area of breakthrough would lie around chainage 129.0 and is to be expected at Summer 2011. This scenario would allow for opening of the GBT to revenue operation by the end of 2017.
- in case of an additional shift, the uncertainty of the prognosis of the moment of breakthrough (and thus, of the opening of the tunnel) is narrowed by approximately 30 months as opposed to the case of a renunciation on an additional shift.

### *Cost*

The results of the studies show clearly that the shift of the Sedrun-Faido interface will cause additional costs. These will be compensated by an important reduction of the potential risks related to a longer construction time. The shift of the interface is a measure of risk reduction.

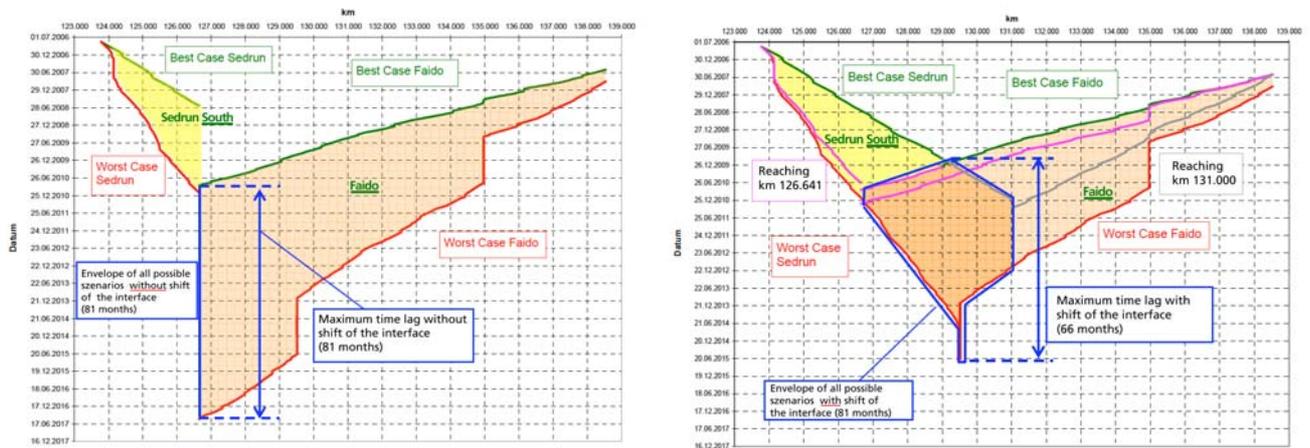


Fig. 8.: Envelope of all scenarios without and with shift of the interface

### Decision of the employer

Following the recommendation of the task force, the board of directors of ATG decided to invest the necessary amount in the Sedrun sector in order to allow for an extension of the Sedrun headings by up to a maximum of 2.5 km (to be decided upon in 2 steps). Furthermore, it was decided the analysis to be kept up to date periodically, in order to monitor the evolution and continuously narrow down the estimated moment of breakthrough.

### Conclusion

The stakeholders of a very large project with a duration of over 15 years and an investment of several billion US\$ are confronted with the necessity to assess possibilities of cutting down construction time at various stages. Long and deep tunnels intrinsically suffer from a lack of knowledge of the expected ground conditions. Detailed studies about the estimated dates of end of construction and the first costs must be made at the earliest project stages and have to be updated periodically from then on. While before the start of construction “purely” probabilistic methods may be the only means of estimating, once construction has started, the accumulated knowledge must be considered. An appropriate construction management software, which not only stocks data, but allows for the elaboration of scenarios (in time and in cost), is most useful and often necessary. The uncertainty of the geological forecast and of the real production rates of the various contractors involved, calls for contracts and contractual practices with the flexibility required in order to optimize delays without unbearable cost consequences.

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