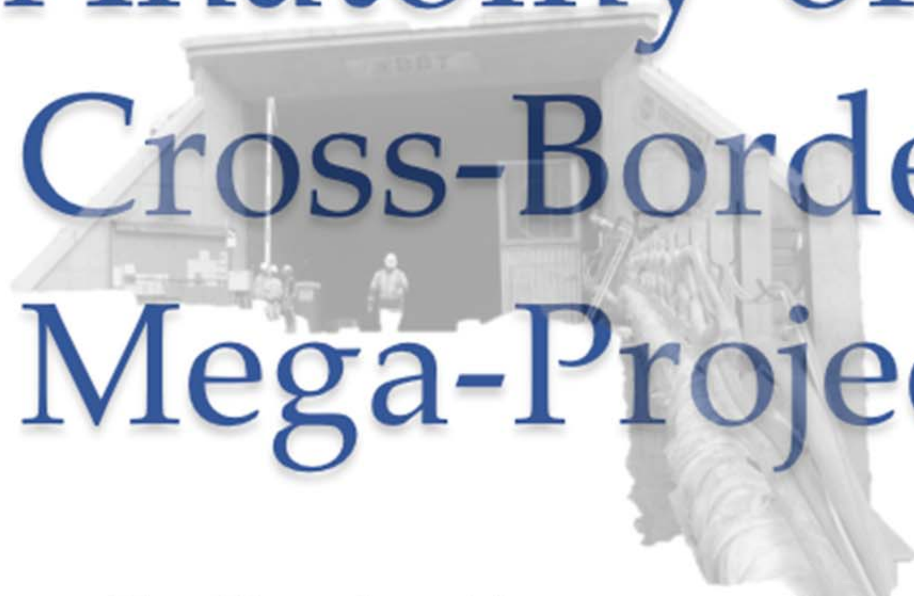
Anatomy of a Cross-Border Mega-Project



The Planning, Management and Construction of the Brenner Base Tunnel

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Anatomy of a Cross-Border Mega-Project:

The Planning, Management and Construction of the Brenner Base Tunnel

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2. <u>Glossary of Some Terms and Abbreviations</u>

2.1 GENERAL

BBT or BBT-SE **(italics)**
Brenner Base Tunnel – Societas Europas: the originators of the Brenner Base Tunnel project. A legal entity created in 2004 especially for the purpose of building the Brenner Base Tunnel. *BBT* is a partnership of four separate Italian and Austrian public entities.

BBT (no italics)
Brenner Base Tunnel, abbreviated. As in: "…the total cost of the BBT project…" or "…those working on the BBT…" The BBT is a 64km planned rail tunnel running under the Alps between Italy and Austria. It is currently under construction.

Originator
The organization with primary and final authority over a project, also refered to sometimes as the project owner or promoter. *BBT-SE* is the originator of the BBT project. The project originator receives from project financers and distributes to project expenses the funds necessary for project execution. The project originator enters into contracts with design, service, consulting, management and construction entities for the execution of the project. The project originator is responsible for ensuring that a project meets it budget, timeline, specifications and the requirements of relevant codes and standards.

The project originator typically is the project owner. However, in the case of a public, international development project with multiple major stakeholders, the concept of ownership becomes fuzzy. Project originator is a more accurate term than owner to define the role of *BBT*. Usually, an owner exists whom then conceives of a project. In the case of the BBT, the project existed first, since the 1990s, and then stakeholders established the originator, *BBT-SE,* in 2004 to take responsibility for the project.

Construction Site
The physical location of construction work. The BBT project has multiple distinct construction sites, usually named after nearby villages. Each construction site will host the works of several distinct construction lots.

Construction Lot
A grouped sub-portion of the total excavation and construction work of the BBT project as defined by BBT planners. Lots are usually grouped by specific location of the work within the geography of the whole project and by the timing of the work within the overall project schedule. A single construction contractor executes a single construction lot. The BBT project has many distinct construction lots of

varying magnitudes of cost, scope, and duration. Some lots are located at only a single construction site: Wolf 1, for example. Other lots span several separate construction sites, like Tulfes-Pfons, which spans multiple sites located between the Austrian towns of Tulfes and Pfons.

In addition to construction lots, the BBT project also has design lots. A design lot necessarily precedes a construction lot, and associated design and construction lots will usually have the same name. In a design lot, a single engineering design firm develops the drawings, the processes, and specification of the work later to be built by a constructor. No actual construction work takes place during the execution of a design lot.

Tender
The process by which a project owner or originator (usually *BBT,* in this case) releases a design, construction or other type of lot for bid. This is done by first assembling relevant documents defining and relating to the work, including drawings, specifications, definitions, geotechnical predictions, and other necessary information, as well as developing contract terms to control the work. The originator then provides this package of documentation and information – the tender documents – to potential contractors wishing to work on the BBT project. Once a tender is released, eligible contractors will respond to the tender by bidding on the work defined in the tender documents. The winning qualified bidder will then enter into a contract with the owner and execute the work.

Bid
The price provide by contractors to a project originator for the execution of the work described in the tender documents.

Contract
The set of documents detailing the scope, specifications and drawings that define the work of a lot (the tender documents become, in part, the contract documents). Contracts also include a document or documents defining the amount and the terms of the payment the contractor will receive from the originator in return for executing the work. They also contain the legal terms governing the execution of that work and the working relationship between the originator and the contractor. Contracts are a tool of communication establishing the expectations under which multiple parties can work together towards a common goal.

Contractor
Any company under contract with an originator to work on the originator's project. Contractors have responded with the winning bid to the originator's release of a tender.

The BBT project includes many types of contractors in agreements with *BBT:* service, consulting, design and construction contractors, to name a few. This paper mainly will discuss construction contractors.

Sub-Contractor
Any company under contract with a contractor, as defined above, for work on an originator's project.

Constructor
A firm executing construction work, as distinct from a firm providing design services, consulting services, or other types of service; a works contractor.

Works
The physical and mechanical operations of construction. For example: earth works, structural works, drainage works, etc.

2.2 COMPANIES

Swietelsky Tunnelbau GmbH
An Austrian construction company currently executing the works of the construction lot Wolf 2, at the construction site Wolf, in Austria. Swietelsky Tunnelbau is a subsidiary company owned by Swietelsky GmbH.

ÖBB AG
German language: Österreichische Bundesbahnen, abbreviated. The government/publically owned Austrian national railway. ÖBB AG owns 50% of the shares of *BBT-SE*, the entirety of the Austrian portion.

TFB AG
Italian language: Tunnel Ferroviario del Brennero, abbreviated. A corporation linking 3 separate Italian public entities, which was established to hold all of the Italian shares of *BBT-SE*. Rete Ferravario Italiana (RFI), the Italian national railway, owns 85.5% of TFB. The three Italian provinces of Bolzano, Trento and Verona separately own the remaining shares of TFB AG.

TEN-T
Trans-European Transport Network, abbreviated. A major transportation development initiative of the European Commission. The BBT project receives funding and other support from the TEN-T program.

2.3 CONSTRUCTION SITE ROLES

ÖBA
German language: Örtliche Bauaufsicht, abbreviated. An important participant in the execution of construction works. Usually an engineering firm with staff experienced in the type of work under construction (tunneling, in this case). The ÖBA is present on site every day when work is in progress. The ÖBA observes the

work of the constructor and helps assure the quality of the work, and accurate billing for it.

The ÖBA is under contract with the owner, but is best understood not as an advocate for the owner, but as third party between the owner and the constructor in service of the smooth execution of the works contract. The chief ÖBA personnel on site, the project coordinator representing *BBT* and the constructor's superintendent all operate together in the same level at the top of the on-site hierarchy.

Project Coordinator or Coordinator, for short
The top personal on a construction site representing *BBT*. In German, Bauloscontroller. College educated in engineering, usually to masters level. Smaller lots have only one coordinator. Larger lots have multiple coordinators.

Construction Superintendent, or Superintendent
The top personnel on site representing the works contractor. In German, Bauleitung. College educated in engineering to bachelors level or above. Both the *BBT* project coordinators and the constructors' construction superintendents have project management duties. I'll use the above terms to distinguish the roles.

Construction Supervisor, or Supervisor
Construction contractor personnel answering to the superintendent. Supervisors oversee the works, as opposed to superintendents who manage documentation and contractual issues. Supervisors typically have a special technical education in their field, including some education in contracts, billing and other administrative practices. They typically are not college educated. In Austria, this specialized high-school level technical education earns one the title of engineer. College educated engineers earn the more advanced title of diploma engineer. Further distinctions exist for masters and PhD engineers.

Technical Aid, or Technical, for short
A special field assistant to a coordinator, ÖBA engineer or construction supervisor. Technicals observe and record the quantities of concrete and anchoring bolts used to secure the face and walls of an excavation during the process of the work. In tunneling, these quantities are carefully and continuously monitored by the constructor and the ÖBA. The quantities are then used to create the constructor's monthly pay applications to the originator.

Bauführer
The Forman of a mining crew. During overnight shifts, the top person on site. The Bauführer reports to the supervisors and/or the superintendent.

2.4 ABBREVIATIONS

SE
Societas Europaea. The legal entity of a European international corporation. An SE can have multi-national ownership. An SE can relocate from nation to nation within Europe while maintain its legal identity. In SE is governed by the corporate and labor laws of the nation in which it has its corporate headquarters. *BBT*, the originator of the BBT project, is an SE. It is owned by Austria and Italy, and has already moved its headquarters once, from Austria to Italy in 2011.

GmbH
German language: Gesellschaft mit beschränkter Haftung. The equivalent of a limited liability company in Germanic countries, including Austria. For example, Swietelsky GmbH

AG
German language: Aktiengesellschaft. A corporation owned by shareholders.

J.V.
Joint Venture. The often-temporary legal partnership of multiple separate contractors, arranged for the purpose of working together under a single contract. For example, the Italian construction company Salini-Impregilio joined with the Austrian construction company Strabag AG to create Strabag-Impregilio J.V. The two companies established this partnership for the purpose of bidding on BBT construction lots.

“At a certain point in 2018 we’ll shake hands in the mountain, hopefully, Roland and me.”

3. <u>Introduction</u>

3.1 Project Coordinator

Andrea Lussu’s new office is in a sheet-metal building – four shipping containers arranged into two long building stories, with staircases added in the middle and at the ends. This is the temporary administrative headquarters of the Tulfes-Pfons construction lot of the Brenner Base Tunnel Project. It is located in a canyon along the Sill brook in the foothills of the Alps near Innsbruck, Austria. At the time of our interview there, Tulfes-Pfons is the biggest construction lot within the BBT project. Because of its scope, it is a kind of promotion for Lussu, a project coordinator for *BBT*. He is in the process of transitioning to Tufles-Pfons from the smaller Wolf lot, further south along the tunnel route, closer to the border with Italy.

Before our interview today Lussu is meeting with the constructor who holds the works contract for the Tulfes-Pfons lot, Strabag-Impregilio J.V. I wait, looking around the second floor, where the *BBT* conference rooms and offices are located. It feels like a small town high school with its straightforward layout of rows of doors opening off a single long hallway. The walls are hung with posters and charts. Next to Lussu’s office door hangs a poster presenting a history of surveying methods and machines – a compact bit of education with pictures of early transit levels and diagrams of modern satellite triangulation techniques. Across the hall hangs a colorful image of a mountain range cross-section. The rock within the mountain is depicted in zones bounded by irregular lines, within each zone a different color – yellow, blue, orange, pink. The colored zones are rock types, and the lines dividing them are the geological shape of the Alpine rock, bent up and folded in on itself by the continuous compression of the hard African tectonic plate against the softer European plate.

Lussu is one of several *BBT* staff that has agreed to be interviewed for this paper. As a project coordinator for this lot, he is part of the top echelon of on-site staff. *BBT* coordinators, together with construction superintendents from Strabag-Impregilio, will oversee the execution of Strabag-Impregilio's works contract with *BBT*. Lussu approves pay-applications, negotiates changes and additions to the work, and deals with the hundreds of other requirements and incidentals of managing a €377 Million, 55-month construction contract. The Tulfes-Pfons work package includes 38 kilometers of excavation in four distinct tunnels, and the launch of one roughly €20 Million tunnel boring machine. The actual construction zone stretches intermittently between the Austrian towns of Tulfes and Pfons, and includes 4 separate access portals.

Lussu is probably in his late thirties, young for this level of responsibility but evidently up to it. He seems busy yet focused as he opens up his office for us. It is a shared space with two desks and some bookshelves. Every surface is buried in paperwork with some computers rising out of the messes on the desks. Somehow, he still has space to move and work. The titles of two papers are visible at the edge of his desk: "Zyklischervortrieb versus kontinuierlichervortrieb – ein baubetriebliche Analysis" and "ÖNORM B2110 2009". [1] We sit. Out his office window I see the trusses of the bridge over the Sill brook and the trees and mountains beyond. Lussu sends an email and then tells me about his meeting that afternoon with Strabag-Impregilio.

It concerned the 1st monthly application for pay from Strabag-Impregilio to *BBT*. The constructor submitted for €27 Million. Lussu had anticipated a total bill of around €4 Million. This first pay period covers mobilization and some site preparation work for Strabag-Impregilio. At issue specifically is whether Strabag-Impregilio can bill all at once for the trucks and other equipment necessary to excavate the tunnels, or instead should spread the cost of those vehicles throughout the life of the contract. Lussu anticipated the latter: that *BBT* would be billed the costs of operation and depreciation of the vehicles. Strabag-Impregilio is asking for their entire purchase cost for the vehicles up front.

Why a payment schedule for the millions of Euros in question hadn't been previously established somewhere within a contract the size of three telephone books isn't clear. Though this isn't a major conflict between the parties each has a stake. For Strabag-Impregilio, €27 Million would improve their cash flow at an early stage in the project, and perhaps permit an uncomplicated purchase of the equipment they need. But Lussu has to anticipate his monthly budget, so that *BBT*

[1] The first is a comparison of excavation by tunnel boring machine and by mining techniques, published as part of geotechnical symposium in Vienna. The second is an updated Austrian standard for construction contracts.

can manage its own cash flow. He can't put €27 Million on the table unless he had already asked for it months ago. The issue won't engender bad blood between the parties. It is, in a sense, part of a feeling-out normal to new contract partners. Strabag-Impregilio is testing Lussu to see what he will allow. Lussu feels confident they will resolve the issue in normal negotiation. He expects they will settle on a mid-point, much closer to his €4 Million than Strabag-Impregilio's €27 Million. "Probably €6 Million," he says. And, "I'm not paying for anything that hasn't been delivered to the site."

As we talk, I can see that he is serious about his work. He remains approachable and interested, willing discuss it. Lussu has been with *BBT*, the organization building the Brenner Base Tunnel, since 2007, when they hired him away from one of their design contractors. In that time he has designed structural and water treatment elements of the BBT project, overseen construction works at two previous sites, and participated in the development and release of tenders for works lots of the BBT project. Between June and September of 2014 he is transitioning between the Wolf 2 construction lot and Tulfes-Pfons. *BBT* is moving him to Tulfes-Pfons because, according to Lussu, he speaks German, Italian and English "very well."

This is true. Lussu is from South Tirol, a province in Northern Italy that borders Tirol, a province in Southwestern Austria. The Brenner Base Tunnel will join Tirol and South Tirol under the existing Brenner Pass, at the summit of which lies the border between Italy and Austria. Until the end of World War I, South Tirol and the entire Brenner Pass belonged to Austria. The Treaty of St. Germain divided

Tirol, and Austria lost the Southern part of the province to Italy. While this is not true of the nations of Italy and Austria, the two Tirolean provinces have similar cultural identities.[2] Many South Tiroleans – Italians – are native German speakers, so Lussu speaks both languages fluently. He also earned his Masters degree in the United States, which gives him command the three official languages of the Brenner Base Tunnel Project. At Tulfes-Pfons, he can communicate well with both the German and Italian representatives of BBT-SE and Strabag-Impregilio J.V., as well as in English, as necessary with project sponsors from the European Union.

Language, as it turns out, is an important factor in the planning and construction of the Brenner Tunnel. The challenges of a project of this scope extend well beyond the technical. "The mining part is easy," I was told by another interview subject, Harald Kögler. "That hasn't changed for 50 years." The physical bridging of Austria and Italy requires work, lots of it, but it is work that the miners and railway engineers of the Alps, the center of the tunneling world, know how to perform. More difficult is the cooperative bridging of two nations – two languages; two political bodies; two economies; two legal systems; two professional cultures – to work together on one project.

It is this second kind of bridging that has brought an unprecedented rate of European Union co-financing to the Brenner Tunnel Project. The BBT Project is one of many projects supported by the European Union under the Commission's major transportation development initiative, Trans-European Transport Network or TEN-

[2] So much so that activists maintain a re-unification movement almost 100 years after the division. Riding the train up the Brenner Pass in Austria riders see "EIN TIROL" spray-painted large on the rocks. And so far, ÖBB hasn't bothered to cover it up.

T. The TEN-T program gives funding priority and higher co-financing rates to cross-border projects. Since it's creation, TEN-T has identified the need for cross-border projects to join disparate national transportation systems and improve international traffic flow in Europe. It has also recognized the special challenges faced by cross-border projects, by multi-nationally funded, administered and executed construction projects. Their willingness to fund these projects at a high rate of co-financing is in response to their high importance and their organizational high difficulty.

An employee like Andrea Lussu is valuable to such a project officially because of his education, experience and language skills. Unofficially, as a South Tirolean, he has a special place in the project dynamic. South Tiroleans aren't just natively bi-lingual, they are bi-cultural too, and can cross easily between communication with Italians and Austrians. The Alps always have insulated Austrians and Italians from each other. Members of either culture can still bristle at the demeanor of the other. As best as I can infer from several allusions to some social friction within the project, Austrian professional straightforwardness conflicts sometimes with Italian temperament and oblique social mores, and vice versa. Lussu called the differing mentalities between Austrians and Italians one of the most difficult aspects of the project. He said everything has to be explained twice, once to Italians and once to Autrians. Though presumably Lussu and other South Tiroleans staffing the project can do it. This historically and still disputed territory of South Tirol has become a kind of solution to an elusive problem.

Lussu and I spoke for almost two hours. We discussed technical details of the project, tunneling strategies, and his responsibilities. We briefly discussed his work at Tulfes-Pfonss, but focused mainly on the specifics of his work at the previous construction site, Wolf. Wolf is now in the hands of Roland Arnold, Lussu's mentee. Lussu remains involved at Wolf while he resolves some issues that arose while he was coordinator there. That is why his transition to Tulfes-Pfons extends over a few months.

As I leave his office after the interview I see again the professional-looking graphics in the hallway – the surveying poster and the diagram of Alpine rock characteristics. I notice another small image hanging on the wall. Further down the hall next to a conference-room door someone has tacked up a low-quality printout of a photograph of a weight bench and weights. But this was not normal weight lifting equipment. The bar in the photo is actually a heavy rod of dark, corrugated steel, like #8 rebar. The weights clamped on either end are not real weights. They are flat, thick, square-ish steel plates with holes in the middle. In tunneling, these long anchor rods are driven then fixed into the walls of freshly excavated tunnels to stabilize the rock. The plates fit onto the exposed end of the driven rod and act as washers holding a welded steel wire net against the tunnel roof and walls.

The photo could have been taken in a miner's garage, or the makeshift gym on a construction site. Depending on the web penetration of tunneling humor, maybe the photo circulated on the internet, or maybe just on the BBT mailing list. During an earlier visit to the Wolf construction site I saw lots devoted to equipment staging, filled with piles of anchor rods and plates. Bringing tunneling paraphernalia home to build a weight bench must be the miner's equivalent of stealing paper clips from the office.

I leave the building to return to Innsbruck. The current Tulfes-Pfons headquarters is lost at the foot of a giant foothill of the Alps. Outside the door of the building, water rages down from the mountains before crossing under the enormous concrete web of the Autobahn and into the city of Innsbruck, where it meets the Inn. Across the bridge, outside of the headquarters building, I notice how quite this place was, considering the major works contract it serviced. The office is alone on a dirt lot, with a few cars. There are no fenced yards of materials storage or fleets of equipment rumbling near the hillside. There is only a shuttered concrete access portal at the back of the lot.

Lussu's office will eventually move to the Ahrental site, where excavations will begin for the tunnels joining the Innsbruck bypass to the main tunnels of the BBT, running south into Italy. For now, Strabag-Impegilio is still mobilizing the major works sites. Noise, traffic, dust and space considerations prevent major work at the Sillschlucht[3] site. For now, while preparatory work is underway at Ahrental, Lussu works in this quiet valley on his role in the construction of the longest rail tunnel in the world.

3.2 The Scope of This Paper

In addition to Andrea Lussu, I interviewed for this paper Roland Arnold and Harald Kögler. Arnold worked under Lussu at Wolf as Lussu's technical. With

[3] Schluct means canyon, in German.

Lussu's transition to Tulfes-Pfons, Arnold has become the coordinator for the Wolf 2 lot. Kögler is the construction manager for Swietelsky Tunnelbau, the constructor currently working at the Wolf site. He is Arnold's colleague across the works contract between *BBT* and Swietelsky. I also interviewed two construction planners working in the BBT project's Austrian headquarters in Innsbruck. Anton Rieder and Romed Insam's responsibilities extend beyond a single construction site to the whole of the Austrian works package. They participate in planning and designing the work of individual sites, as well as the schedule of the all the works together.

My research included a few more interviews with others outside of the *BBT* organization. I spoke to two people in the Herrenknecht company in Germany: Karin Bäppler and Mario Brand. Herrenknecht builds tunnel boring machines (TBMs). Dr. Bäppler leads their transportation design team, and Brand specializes in arranging the extensive back-up systems and services needed to support TBM operation. Brand's work in particular is relevant to this paper in that the Wolf construction site will need to undergo a major upgrading to accommodate future TBM operations on site. Unfortunately though the very interesting topic of TBM's in general won't receive much space in this paper, as they are beyond the scope. For this paper, I also spoke to the chair of tunneling at the University of Innsbruck, Dr. Dimitrios Kolymbas. Dr. Kolymbas wrote a very useful book on tunneling in general, and in his interview provided insights into tunneling techniques, the tunneling industry in Europe, and the culture of that industry.

The Brenner Base Tunnel project provides rich material for those interested in the way things work in tunneling, or construction in general. It is a huge project in scope, budget, and timeline. The study of tunnel construction is a broad topic in itself. The development of this project began in the 1990s on the European level. It includes a decade of intensive studies, pre-planning, and stakeholder coordination. Design and construction planning are ongoing and will continue, along with construction execution, into the 2020s. From the perspective of infrastructure planning and development, and mega-project management, the BBT project makes for a great case study.

However the project is too vast to cover all of the tempting angles in a single paper. This paper will provide an overview of the anatomy of the entire project, including: history and pre-planning, planning, design and construction. It will include some details of the construction works at the Wolf site. I have aimed in this paper for a journalistic perspective, synthesizing a sense of place and character with technical detail and analysis, as applicable. I think this combination of perspective best captures the richness of the Brenner Tunnel Project.

As Andrea Lussu turns over supervision of Wolf to Roland Arnold, he is still involved in the contractual and organizational management of two current issues from the Wolf site: the repurposing of rock excavated from the dig, and the price change for a special above-ground cover over a section of the Padaster Brook, which runs through the spoil deposit site. I mention these examples because managing these 'behind the headlines' details make up the day-to-day work of project coordinators like Lussu and Arnold. The story of these details is the story of the construction of the Brenner Tunnel.

Construction management is the node where the planning and design of a project join with its execution. For this reason, construction managers need to understand something of both sides of that union, which gives them a special perspective on the workings of the project.

This is not a paper about the technical aspects of tunneling. Rather, it is a snapshot of project: of the planning, the work, the decision-making and the relationships that define it. I intend it primarily to be of interest to those interested in the planning and managing of construction work and in the the dynamic process of getting the work done.

A note on some exclusions: this paper addresses the construction work under way at the time of the research, that is, excavation of the access tunnels leading toward the path of the main tunnels. It does not deal in detail with other types of work that preceded or will follow this work, such as geotechnical studies, environmental impact assessments, preparatory work, high-volume boring or equipment installation. While engaging to both professional and arm-chair builders, a description and definition of all of the technical aspects of tunneling work would fill this paper four times over. I have restricted the technical discussions in this paper to just a few topics that I consider illustrative of tunneling technical concerns, or that relate to broad project issues.

This paper does not deal in detail with the Italian portion of the BBT project. All of my research was conducted in Austria, and focused mainly on the Austrian works of the project. While facts and ideas relating to the Austrian side of the BBT project have relevance to the Italian side, the Italian and Austrian portions of the

BBT project are not necessarily analogous. The planning and organizational models, the project controls, the project resources, and the project culture all may differ to some extent - great or small – on the Italian side.

A look at the Italian planning and works is in order, and a comparing and contrasting of the two sides would be an interesting and useful undertaking. Since the relatively new organization, *BBT,* attempts to bring these disparate operations together under one umbrella, it would be fascinating to examine the ways in which that effort has been successful or not. Research could also try to assess the extent to which the unifying of processes is beneficial and/or detrimental in a cross-border project, both in terms of specific project outcomes, and the broader goal of enabling international cooperation in economic development. However, that is not the work of this paper, as it does not contain observations of the Italian process.

This paper is in no way comprehensive. As with any paper, the research content exceeded the written content. My research, in particular my interviews, focused in on the work of construction managers and on day-to-day workings on the Wolf construction site. Given the breadth required for this overview, I was not able to address the construction site work with as much depth as it deserves. Zeroing in on the work of the project coordinators on site exposes in my opinion some of the most interesting project dynamic including: project culture, best practices and dispute resolution. With this overview as a base, I hope to follow up with further written work addressing the Wolf construction site and project coordinators in depth. Here, however, I have limited the depth of the reporting to make room from breadth. Here we have a kind of primer and record of the BBT project as a whole.

3.3 An Introduction to Wolf

Fifteen years from now, in 2030, the Wolf construction site will have become a grass field between Austrian state road B 182 and the mountainside to the east. A small road will lead from B 182 through this pasture, past a helicopter pad, through the Wolf portal and into the side of the mountain. This access point will be inconspicuous and rarely used. Passing drivers won't see evidence of the work that once took place here. In the future, it will be used only occasionally – for maintenance and emergency (the reason for the helicopter pad) access to the three tubes of the Brenner Base Tunnel. The tubes will lie four kilometers deep into the mountainside, speeding rail traffic under the Alps between Italy and Austria.

At present, the oblong, less than one square kilometer footprint of the Wolf site houses a semi-permanent industrial plant supporting the multiple excavations ongoing inside the Wolf portal. The construction site includes a concrete production facility, water treatment plant, vehicle and equipment staging areas, maintenance sheds, offices and 24/7 traffic of excavation equipment and personnel. Construction work began at Wolf in 2010 with the minor re-routing of B 182 and other preparatory works. It will continue through 2026, when the Brenner Tunnel is scheduled to become operational. The volume of activity and infrastructure now at Wolf is just a fraction of what the site will support in 2017 and 2018, when it launches five tunnel boring machines into the mountain. Planners still do not know exactly how the small site will accommodate the additional staging areas, the multiplied concrete production capacity and the power plant required by the scheduled simultaneous mechanized excavation operations.

Wolf is one of several major construction sites[4] of the enormous Brenner Base Tunnel construction project currently underway in Austria and Italy. The completed tunnel will connect the city of Innsbruck in Austria to Fortezza in Italy by rail, travelling under the Brenner Pass in the Alps. Current cost estimates for the construction project approach €9 Billion. The Brenner Base Tunnel actually will be three distinct, parallel tunnels: two adjacent main tunnel tubes carrying north-south and south-north trains, and a smaller tunnel underneath the two main tubes. The smaller tunnel is being excavated first to explore the geological and tunneling characteristics of the path, as well as create a logistical tube to aid excavation and operation of the main tubes. Exploratory construction began in 2008, with the start of major construction works on the main tubes following in 2011. According to the current construction schedule, in 2022 excavation of all three tubes will be completed, and four years of rail and signaling equipment installation will begin. For the next 11 years, constructors contracted by *BBT* will use the Wolf site to stage, access and support their work inside the tunnel.

Wolf is on the critical path of the Brenner Base Tunnel construction schedule, meaning that delays in the works at Wolf would delay the entire project by the same duration. The site lies a few kilometers to the west of the path of the main tunnels. It is located approximately 1/3rd of the distance south of Innsbruck travelling towards Fortezza. From Wolf, excavation of the main tunnels and the exploratory

[4] Ahrental/Patsch, Sillschlucht, Tulfes, Ampass, Innsbruck and Wolf, in Austria. Aica, Mules and Fortezza/Isarco, in Italy.

tunnel will proceed both north and south, meeting separate excavations launched from other sites along the tunnel route, joining the excavations into continuous tubes.

At Wolf now, the constructor Swietelsky Tunnelbau is excavating the 4km access tunnel into the mountainside to meet the path of the main tubes under the mountain. The works at Wolf serve two major roles in the construction of the BBT: 1) They will provide launch-points and support systems for the five tunnel boring machines that will drive out of Wolf to the north and south in both of the main tubes and the exploratory tunnel tube; 2) Wolf serves as access point to the BBT project's largest spoil deposit site, Padastertal,[5] which is located 1km from the construction site in the mountains to the northeast. Two tunnels branch off of the Wolf access tunnel and lead away from the construction site and from the path of the main tubes. They go directly to Padastertal. Once the TMBs begin their drives, conveyor belts will bring the spoil from the boring, up the Wolf access tunnel, through one of these branch tunnels and into Padastertal deposit for permanent storage. The deposit is designed to hold 7.7 million m^3 of the BBT project's 22 million m^3 of rock waste.

All of this work at Wolf takes places within the context of the enormous Brenner Base Tunnel mega-project. The BBT project, in turn, is part of a larger European Union transportation development initiative, the Trans-European Transport Network (TEN-T). The BBT project as a whole, and the greater TEN-T initiative each influence the technical and organizational efforts underway at Wolf.

[5] "-tal" means valley, in German.

The work at Wolf exists not just within a single Alpine valley. It take place within a planning, design, political, financial and cultural context established by the larger umbrella projects of BBT and TEN-T. For that reason, I'll take some time now to define these larger projects, to allow a fuller understanding of the works at Wolf, when we get to them.

4. BBT Project Overview, Scope and Financing

4.1 GENERAL

4.1.1 The Brenner Base Tunnel

The most significant project within TEN-T's Priority Project #1, The Brenner Base Tunnel will run from the Tirolean capitol of Innsbruck to the city of Fortezza in Italy. It will take rail traffic underneath the historic Brenner Pass. European geography has, for millennia, funneled North-South/South-North international travel over the Brenner Pass. Merchants, armies and popes have crossed the Brenner Pass on foot, horses and in carriages. Modern transportation has increased tourism and taken land travelers off horseback and put them in trains and cars. But mountains still wall land access to and from Italy. Air or sea travel is the only way to reach Italy without crossing mountains.

A railway line and an autobahn cross the Brenner Pass now. The Brenner Pass is steep, which limits travel speeds along it. Scarce buildable space in the Alps has limited the rail line to a single track. The autobahn has only two lanes in each direction. Often, one of these lanes is clogged with freight trucks. The bottlenecking effect of the Brenner Pass is visible to anyone approaching the pass from either direction. The Alps have so far stymied modern transport advances, limiting their impact on improvements to travel efficiency between German, Austria and Italy. A tunnel under the pass would speed things up.

The late Karel Van Miert, the first coordinator for the Berlin-Palermo Axis wrote, "The goal is simply to enable as long a train as possible, and carrying the heaviest possible load, to cover the whole journey from Munich to Verona without stopping, using one locomotive," (Van Miert, 2007, 12). It takes about 80 minutes for a train to travel over the existing Brenner Pass railway line. Two locomotive are necessary to haul trains up the steep mountain. The low pitches and direct path of the Brenner Base Tunnel line will require only one locomotive, and reduce this travel time to less than 30 minutes. Although tunnel planners included safety features that will allow passenger rail trains to use the tunnel, the BBT is meant primarily for freight traffic. Passenger trains in the tunnel will travel at around 250 km/hr. Freight trains will travel at around 150 km/hr.

The roads and rail lines currently traveling over the Brenner Pass will continue to carry passengers and likely some freight. First of all, the towns along the existing Brenner Pass will not be reachable by traffic from the BBT. The operational BBT will have three "multi-functional stations" – including one accessed via Wolf along its route. But these will be for service and emergency use. They are not stations in the usual sense of the word. The trains won't schedule stops at these stations, and the stations will not process passengers or cargo. By design, the BBT is an expressway with no exits between Innsbruck and Fortezza. Travelers and goods going to or coming from stops along the Brenner Pass will still need to use the existing railways and roads over the pass.

Second, if market forces or scheduling considerations somehow make the BBT the wrong option for a shipper or rail freight operator, then freight may still travel on the Brenner Pass road or rails, even if that freight has no need to stop at villages or towns anywhere along the pass. Planners at *BBT* and TEN-T are actively addressing the tunnel's use and operation. A separate organization has been established called the Brenner Corridor[6] Platform (BCP). Part of the BCP's mandate is to optimize use of all available transport modes through the Brenner Corridor, include but not limited to the Brenner Base Tunnel.

4.1.2 Trans-European Transportation Network

The Brenner Base Tunnel project is one of hundreds of distinct projects within the European Commission's 40-year €600 Billion transportation initiative, the Trans-European Transportation Network (TEN-T). I'll present here a short history of the political, financial and planning process for the tunnel, starting with the TEN-T.

The TEN-T initiative includes transportation development and improvement projects throughout the European Union and neighboring countries. Among other things, the initiative aims to link disparate national transportation systems throughout the EU to create a cohesive international transportation network. A group established to develop TEN-T priorities wrote that the "EU should aspire to achieve a 'European system' and not a collection of national systems," ("High Level Group," 2003, pg.45).

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[6] The Brenner Corridor is the ca. 450km Alpine section of the Berlin-Palermo Axis between Munich and Verona. The BBT project is part of the Brenner Corridor.

Major initiatives under the umbrella of TEN-T include: the upgrade and expansion of existing road and rail lines; upgrading air infrastructure and improving air traffic control integration; developing the infrastructure that supports the use of inland waterways; and the Galileo program, the launch of 30 satellites to create a comprehensive global positioning network infrastructure in space.

The €600 Billion price tag mentioned above is the Commission's estimate for the total cost to realize its entire vision for a modern European transportation network. The Commission does not have €600 Billion to invest in transportation development; it has about €30 Billion for that investment over the life of the TEN-T initiative. For practical purposes, the TEN-T program has identified 30 "priority projects" that it believes best apply its limited resources towards realizing its vision. The priority projects span all of the several, above-mentioned major initiatives of the TEN-T program. The Commission estimates the total cost of the 30 priority projects at €250 Billion, €30 Billion of which it will pay for through its TEN-T program. The remaining costs are to be borne by the national budgets of the state (or states) within which a particular project is located. The Commission intends for its €30 Billion to act as project subsidies that will help lever the additional required project funds out of national budgets and private investors on a per-project basis. The TEN-T program has defined varying subsidy – or "co-financing" – rates for projects applying for TEN-T funding. The level of co-financing rates for a particular project reflects the level of priority that project has towards developing the Commission's vision for a modern transportation network.

For its priority projects, the Commission selected projects that best serve the general goals of the TEN-T program. These goals are: to improve European economic competitiveness by creating a modern international transportation system; to encourage a modal shift from road to rail and waterways in an effort to reduce transportation carbon emissions; and to encourage economic development by stimulating and contributing to infrastructure spending through-out the European Union.

4.2 SCOPE

4.2.1 Priority Project #1

Of TEN-T's list of 30 priority projects, project #1 is the creation of a continuous railway link from Berlin, Germany to Palermo, Italy, called the Berlin-Palermo Axis.[7] One of the organizational achievements of the TEN-T program has been to group its transportation development projects into distinct axes, and to appoint a coordinator for each axis. The axis concept and the work of the axis coordinators help ensure that TEN-T funds advance not only the individual projects they subsidize, but also the broad vision of TEN-T of which an individual project is only a piece. In keeping with the TEN-T goal of uniting Europe within one international transportation system, each axis identifies an international travel

[7] I'll use this terminology for simplicity's sake. Continual evolution of the Berlin-Palermo Axis has resulted in the axis lengthening and in the broadening of project types included in this priority axis. It is now called the Scandinavian-Mediterranean Corridor and includes additional territory and additional technological development projects. Also, the Connecting Europe Facility under the Innovations & Networks Executive Agency of the European Commission has replaced the TEN-T Executive Agency. However, the TEN-T program and the Berlin-Palermo Axis are still common terminology and still define the projects discussed in this paper.

route, usually one partly established by common use for passenger and freight passage. For example: the Berlin-Palermo Railway Axis, the Nordic Triangle Railway/Roadway Axis, and the High Speed Railway Axis of Southwest Europe. Eight of the top ten 30 TEN-T priority projects are transport axes[8] – rail, roadway or multi-modal.

For any individual rail, roadway or waterway project to receive significant TEN-T funding, it must fall on one of the axes identified by TEN-T. In this way the program ensures that its project support is coordinated to produce maximum impact in the creation of the international transportation network. A single identified axis will contain many distinct subprojects, all of which together create the complete axis. For example, the Berlin-Palermo Axis includes, in part: additional rail line projects near Berlin; the upgrading of rail capacity between Munich and Austria; another project adding capacity through the Lower Inn Valley in Austria; upgrades and additions to several parts of the Italian rail system; and the Brenner Base Tunnel project connecting Innsbruck, in southwest Austria to Fortezza in northern Italy.

The Berlin-Palermo Axis, once completed, will increase the efficiency of rail transport from the North Sea to the Mediterranean, and to all points on the route in between. The current North-South/South-North rail path has several obstacles to a speedy journey. A train can still make if from Berlin to Palermo, but traffic congestion, low train-volume capacity and geographic characteristics interfere at several points along the way. A train traveling the route often will have to wait,

[8] The other two are a 160km double-track railway line connecting the Port of Rotterdam to the Dutch/German border, and an airport in Melpensa, Italy.

slow down or stop along they way. The subprojects defined within the Berlin-Palermo Axis are located precisely at points at which interference to rail travel occurs. TEN-T and the nations along the Berlin-Palermo Axis – Germany, Austria and Italy – have conceived of these project specifically as means to eliminate or mitigate these interferences, called "bottlenecks" and "natural barriers" in TEN-T parlance.

In addition to physical obstacles to smooth rail travel on the Berlin-Palermo Axis (and throughout Europe in general), there exist technical and organizational obstacles. The European Union actively addresses both of these[9], with TEN-T tackling the technical obstacles. It requires that all new rail projects using TEN-T funds meet technical specifications for interoperability (TSI). European rail travel is electrically powered, and relies on electronic and computer signaling for communication and traffic control. All TEN-T rail projects, including the BBT project, must integrate the European Rail Transportation Management System (ERTMS) to meet TSI criteria. Projects funded by TEN-T must contract an independent certification organization to ensure that their project meets TSI. In this way, TEN-T ensures that its rail tracks are technically interoperable for all of the trains using them.

[9] The EU passed a law leading to the reorganization of many national railways. The law forbids the owners of rail lines to also operate rail service on the line. Austria re-organized ÖBB in 2004/2005, separating the single AG into several independent AGs and GmbHs – though all still 100% publicly owned. The goal of the law and the national rail reorganizations is to eliminate track use priority enjoyed by national rail services on the lines they once owned, and instead create a real market of supply and demand to control track use scheduling. The upshot being that, for example, a German train has just as much chance of using an Austrian rail line as does an Austrian train, creating a better system for international rail transport.

When completed, all of these separate projects and priorities taken together will complete the Berlin-Palermo Axis, of which the Brenner Base Tunnel is the flagship project. Other projects within the Berlin-Palermo axis are needed to upgrade the ability of the entire axis to keep pace with the new speeds and volumes that BBT will allow. At over €8 Billion Euros, the BBT project will be the most expensive project on the axis. At 64km in length it will be the biggest project on the axis in geographical size, as well as the longest rail tunnel in the world.[10] It is a "colossal investment" requiring "the commitment of several Member States[11] and very good cooperation between national administrations," ("High Level Group," 2003, pg. 13).

The BBT project receives the highest rate of TEN-T construction co-financing subsidy – currently 40% for construction and 50% for studies. This is because the Brenner Base Tunnel meets so many of the priorities on the TEN-T program that it is difficult to distinguish which came first: TEN-T priorities or the Brenner Base Tunnel Project.[12] TEN-T regulations define eight distinct qualifications that a project can possess which would give it priority access to TEN-T funding. The BBT project meets all of them. Most notably, the BBT project promotes the modal shift from road to rail and ERTMS, it lies on a TEN-T priority axis, it eliminates a major bottleneck on that axis, it crosses a natural barrier, and it is a cross-border project.

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[10] At 57km the Gottard Tunnel in Switzerland will hold this title until the completion of the BBT. The longest tunnels in the world are aqueducts, not transportation tunnels. The combined lengths of urban metro system exceed aqueduct lengths, but can be considered neither single tunnels nor single tunneling projects.
[11] Members of the EU
[12] I mean this literally. Both the TEN-T initiative and the BBT project gained steam in the 1990s and evolved together into the present.

The project's cross-border qualification in particular gives it highest priority for TEN-T funding. Planners recognized that "cross-border projects are often held up through the intrinsic difficulty of coordinating, at [the] intergovernmental level, their timetable, their financial planning, and the related administrative procedures for such projects, ("High Level Group Report," 2003, pg. 7)

4.2.2 Planning the BBT

The idea of a tunnel under the Brenner massif has floated around for a century or more. (It has probably come up every time the Brenner Pass is snowed in.) Representatives from the Italian, Austrian and German national railways participated in a study of a new railway line that included a Brenner base tunnel in the 1970s. A feasibility study was completed in the late 1980s at the request of the Ministries for Transportation of the three countries. By the 1990s the EU was developing its vision for an international transportation system, and beginning to identify axes and specific important projects. Improving passage through the Brenner Corridor– although not necessarily so named at the time – including digging a tunnel under the Brenner Pass, was consistently identified as priority #1 in various EU transportation summits and white papers. The "Essen 14" list of fourteen important transportation projects were presented after a European Council meeting there in 1994. The Essen 14 were adopted as top TEN-T priorities as that program matured, with the Berlin-Palermo Axis at #1, and the Brenner Base Tunnel as the centerpiece of that axis.

While it had gained some traction over the years, it took the EU throwing the weight of the TEN-T initiative behind it to move the project forward into real development. The first challenges were not financial; they were organizational and political. Because it connected Italy to Austria and involved works in both countries under separate ministries of transport (and separate everything else), no single nation could undertake the project. TEN-T recognized this obstacle early on in pre-planning of the BBT. TEN-T made release of funding for project studies and planning contingent upon Austria and Italy demonstrating “sufficient political commitment” by formally advancing their partnership to develop the project, (“High Level Group,” 2003, pg. 19).

The two countries formed a European Economic Interest Group (EEIG) and began Phase 1 – Pre-Planning – for the BBT project 1999. *BBT-EEIG* drafted the preliminary project in 2002. Various formal declarations, memoranda and treaties followed, culminating with the State Treaty to build the BBT, signed by Italy and Austria in 2004. That same year *BBT-EEIG* became *BBT-SE*.

BBT-SE has both an Italian and an Austrian CEO, as well as a 12-member supervisory board. The Italian CEO Raffaele Zurlo is educated as an engineer and has worked in infrastructure building and finance, as well as for the Italian national railway. The Austrian CEO, Konrad Bergmeister is a professor of engineering and construction, with a professional engineering background leading technical programs for the Brenner autobahn. *BBT’s* 12 supervisors – 6 Italian, 6 Austrian – represent the national railways and transportation ministries of each country, as well as the provinces through which the BBT will pass. *BBTs* staff of about fifty includes administration, legal and financial departments, a single technical planning department, and separate Italian and Austrian construction departments. For this paper I spoke with planning engineers and Austrian construction engineers from the *BBT* staff. All were educated in engineering and had substantial tunneling backgrounds.

Phase II – Planning – began in 2003. During this phase *BBT* began "preparing the definitive project, obtaining all the necessary authorizations (including those for environmental impact studies), undertaking geological studies, submitting a finance and franchise model, carrying out all preparatory tasks at the start of the work and performing any necessary supplementary study," (Van Miert, 2007, pg.5). This work took years. With geological and environmental study results in hand, *BBT* undertook the first detailed project construction and budget plan. Development and approval sessions for this plan lasted from 2007 through 2009, when Austrian and Italian national authorities approved the plan.

The last step completed by *BBT* was the development and submission of the finance and franchise model. This didn't happen until 2010. As one might expect, discussions within each nation over exactly who would pay for the tunnel were the source of some delays in beginning the construction. Austria arranged to finance its portion in 2009 and Italy did so in late 2010. With the money located, *BBT* began Phase III – Construction – in 2011. Phase III, which continues today, began with the preparatory and logistical works at several construction sites. Major works began in 2012 with the opening of access portals and the access tunnels into the mountain, from which excavation of the main tunnels will launch.

4.2.3 Cooperation

As Austria and Italy signed treaties and agreements to work together on the tunnel, and as designers developed a technical plan for building the tunnel, TEN-T released more funding for studies, and eventually for work to begin on the exploratory tunnel. Preparatory works for this began at the Aica and Mules construction sites in Italy in 2007. Launch of a 6.3m double shield TBM from Aica followed in 2008. The TBM began the northward excavation of the exploratory tunnel. The exploratory tunnel follows a path parallel to and below that of the two main tunnels. These works expenditures demonstrate a high confidence in the continued progress of the BBT project despite certain major project elements not yet in place. The works began prior to a significant TEN-T subsidy approval for the BBT by the European Parliament, prior to submission and approval of the final project plan and environmental impact assessment, and prior to a comprehensive financial plan to pay for the construction of the tunnels.

This early planning process involved close coordination among the TEN-T coordinator for the Berlin-Palermo Axis, Karel Van Miert, *BBT-EEIG/SE* and the Brenner Corridor Platform, and major stakeholders along the Brenner Corridor, like the ministries of transport and rail operators of German, Austria and Italy. I refer to this group in general as BBT project planners, although this group is distinct from the staff in the planning department at *BBT* and the design companies contracted to undertake technical planning. The first is political and management group working to develop broad administrative and financing plans for the BBT project. The second are construction professionals responsible for developing a technical plan for the construction of the tunnel. Their roles overlap. The work of technical planners depends on budgets and approvals organized by political planners. These approvals and budgets rely on submissions of environmental compatibility, project feasibility, cost and schedule that are developed by technical specialists. The richness of this feedback loop is part of what makes a technical mega-project such a dynamic subject of study. We observe the individual capabilities and work of planners of all types as they move the project forward, and also the communication and responsiveness among the two types of planners necessary to navigate new territory in mutual dependence.

Political/organizational planners have made a great achievement in driving this project forward. This achievement lies in coordinating the visions, administrations and finances of the multiple stakeholders. Some of their planning efforts, however, were not successful. They hoped to unify for the BBT project the environmental approvals processes of Italy and Austria. Had they been successful *BBT* would have had to prepare and submit one assessment and gain a single approval. While some spoil disposal and water management environmental issues were combined for expedience, *BBT* had to make separate Italian and Austrian submissions and gain separate approvals for their environmental impact studies. (An all-purpose European environmental approval process still is part of the TEN-T vision, since there are more cross-border projects to develop.) Planners also hoped to engage private funding to create public-private partnerships in the development of the BBT and other transport infrastructure projects. In the case of the BBT project this proved "outside today's market possibilities," (Van Miert, 2007, pg. 6).

4.3 <u>Finances</u>

4.3.1 The Cost of the BBT

In 2013, *BBT* estimated the total cost of the BBT project at €8.756 Billion, which includes a €500 Million contingency.[13] *BBT* excludes financing costs from its estimates.[14] Cost estimates have changed over the years, and are now updated regularly to keep abreast of planning developments and market prices for work and materials (Cox, 2013, pg). In a 2008 presentation at a symposium dedicated to papers relating to the development of the Brenner Corridor, *BBT* Austrian CEO Konrad Bergmeister gave an estimated total cost for the project of €6.018 Billion. The breakdown of costs per phase was as follows: €18 Million for Phase I, including pre-planning work through 2003; €90 Million through 2008 for studies in Phase II, and €430 Million in technical planning and works for the exploratory tunnel;[15] €5.48 Billion for Phase III, for the technical planning and excavation of the main tunnels. Phase III costs include excavation work, rail equipment installation, telecommunications and monitoring systems, safety and lighting systems, electrical

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[13] In 2013 prices for labor, materials, etc.

[14] I was not able to determine details on *BBT* financing costs, or why they are excluded from cost estimates.

[15] The technical planning and works for the exploratory tunnel are considered "studies," and a part of Phase II, called Phase II(a) in *BBT* documents. This is significant because studies, and therefor the works of the exploratory tunnel are subsidized at the highest rate of TEN-T co-financing, 50%.

energy infrastructures, mechanical systems and the cost of disposing of the excavated spoil (Bergmeister, 2008, pg. 6).

An international design group contracted by BBT in 2005 to develop the initial project design created the first detailed cost estimates for the whole project. This report was submitted to Austrian and Italian authorities for approval to build the tunnel. This report contained the costs reported by Bergmeister at the 2008 symposium. After review of the first detailed project, national authorities approved the project in 2009. In the approval sessions, they conditioned their approval on the project adding some additional environmental impact mitigation measures.

For example, the Wolf construction site lies alongside a two-lane state road in a narrow valley. In the approval sessions, the province of Tirol required that construction traffic by kept off of this road and out of nearby villages. To accomplish this, BBT added a new exit off of the international autobahn leading directly into the construction site. This construction site access road included the excavation of a 1km tunnel – the Saxen Tunnel. Costs for the Saxen Tunnel and other additional environmental impact mitigation measures were not included in the 2005-2008 budget details.

In an email exchange discussing cost estimate timelines, Andrea Lussu wrote that

> even in the early project [2005-2008] most of the cost intensive parts were known (length, crossections, excavation volume deposits and so on). Therefore the cost estimate from 2009 doesn`t differ a lot from the one today (except [for] the integration of the approval requirements) (Lussu, 2014).

BBT released a second overall project design tender for the specific purpose of integrating the costs of the additional measures developed in the approval sessions. Work by another design firm on this integration process began in 2010 and was completed in 2013. By then, Phase III had already begun. Between the 2008 and 2013 cost estimates, an intermediate estimate for the entire project was agreed-upon in 2011 along with an overall financial model. This allowed construction to begin. This intermediate cost was €7.46 Billion (Cox, 2013 and Lussu, 2014).

To summarize, we have seen three overall cost estimates for the BBT project: €6.018 Billion in 2008; €7.46 Billion in 2011; and €8.756 Billion in 2013. The differences among these prices involve the costs of added environmental mitigation measures, different levels of contingencies applied, and changing market prices for materials and labor. *BBT* will continue to update its estimate for the overall project price. Barring some planning catastrophe, we wouldn't expect the base cost of the work to change significantly at this point. The scope, routes and methods are now established. Future price fluctuations will be due to changes in the market and to the finding of the exploratory tunnel boring process.

The geological investigations and smaller bore holes that are a standard part of tunnel geotechnical planning can only yield educated guesses as to the actual conditions miners or machines will find underground. Underground conditions strongly influence the level of difficulty and therefor the costs of tunneling work. *BBT* cost estimates have always included contingencies mainly to account for these geological risks. The boring of the exploratory tunnel also addresses these risks. *BBT* began boring the exploratory tunnel in 2008, and that work is scheduled to continue through 2018. Main tunnel costs estimates could continue to change as the exploratory tunnel experience provides further information for those estimates.

4.3.2 Paying for the BBT

The Brenner Base Tunnel is being funded in part by subsidies from the TEN-T program – up to 50% for studies and the exploratory tunnel work, and up to 40% for construction. European Union budgets run in 7-year cycles. TEN-T transport projects were given €26.25 Billion in the current (2014-2020) budget cycle. €5 Billion of that budget will likely go to just five individual projects within the entire TEN-T initiative ("Building the Core Transport Network, 2013). These five projects, including the Brenner Base Tunnel, are all cross-border projects.

TEN-T subsidy rates for individual projects have increased steadily over the years since the beginning of the TEN-T initiative in the 1990s. At that time subsidy rates for studies were also at 50%, but construction subsidy rates were at 10-20%. The success and progress of the TEN-T program and individual projects in particular, notably the BBT project, has resulted in regularly increasing EU funding for the TEN-T program, and increasing TEN-T subsidy rates for its projects.

Italy and Austria must each cover 30% of the construction costs. While each country has not yet banked its over-€2 Billion portion, they have committed some funds and developed partial financing programs for the project. Through its national railway funding framework, Austria has committed €1.545 Billion through 2018. Austria will pay for this commitment in part with its national transportation budget and a 65-year toll on A13, the Austrian portion of the Brenner Pass autobahn and on A12 near the German border.[16] Italy has committed €1.715 Billion through 2024. The Italian money will come from tolls on A22, the Stability Act,[17] and from the national transportation budget (Cox, 2013, pgs. 13-14). Each country will have to find additional money to meet the commitments it has already made, as well as make additional commitments in the last years of the BBT project.

Recalling Andrea Lussu's discussion with Strabag-Impregilo, we can see now that Lussu did not resist paying the entirety of Strabag-Impregilio's €27 Million first month's pay application out of stubbornness or a desire for control. In fact, he is unable to bring this amount to the table without prior planning. As national budgets and TEN-T subsidies become available to the project, *BBT* shareholders vote on how to spend those funds in the project. When the over-€8 Billion 2013 budget estimate came in from the environmental mitigation integration planning and design process, Austria and Italy added to their financial commitments for the project. Only then could *BBT* technical planners release tenders for the 3 largest construction lots to date – Tulfes-Pfons, Pfons-Brenner and Isarco. Similarly, project coordinators on site must schedule their work and expenditures of money in *BBT* accounts.

The Brenner Base Tunnel is a "truly European" project (Ruyters, in *BrennerCongress* 2010, pg. 11). Reading early TEN-T white papers detailing the reasons Europe should invest in an international transportation system, I noted the admonishments for funds to support international cooperation and long-term planning. It is a far-sighted program. It seemed as if the spirit of the TEN-T

[16] I was shocked by the €11 toll on A12 while driving from Bavaria to Vorarlberg.
[17] Largely an austerity measure; a 2013 Italian law in response to the financial crisis in Europe.

program, especially its cross-border initiatives, mirrored the spirit of the EU itself in its challenges and intent. The rigorous clarity of vision and commitment to public infrastructure, the professionalism and cooperation demonstrated by those involved in the project, should serve as an example to the paralyzed policy makers and public budgets in the United States. Many would Europeans would rather see the EU spend its over-€3 Billion share of BBT costs elsewhere. Some would rather not pay this money to the EU in the first place. Others resist development in the Alps for environmental and way-of-life concerns. These considerations not withstanding, the BBT project demonstrates exemplary cooperation. Italy and Austria will bare enormous expense and effort, which will never be paid back in kind, for a project that will benefit Germany and other European (and non-European) states as much as if not more than it will benefit themselves. It is a spectacular organizational and technical feat, and it will leave the European community with stronger transnational potential and a very useful tunnel.

5. **<u>Construction Planning and Construction</u>**

5.1 <u>General</u>

5.1.1 Documents

During our interview at their Innsbruck offices, *BBT* planners Romed Insam and Anton Rieder provided several large prints detailing elements of the BBT project. These prints included a topographical plan view of the entire tunnel route, two plan views of the total Austrian and total Italian construction works, as well as a plan view of the Wolf works specifically. Each plan provides information about the planning and works it depicts. The overall plan shows the locations of all the construction sites in relation to each other, and the overall distance and layout of the railway line. The two Italian and Austrian works plans include a more detailed plan of each construction site, and information about each construction lot within the national works. Since the BBT is one long tunnel composed of many separate construction projects, the national plans are useful for showing where the separate lots join within the tunnel path. For example, the Austria plan lists ten Austrian construction lots and includes a list of every the sub-projects within each lot. The lots are color-coded, and a glance at the railway plan shows where the separate lots meet. Finally, the Wolf plan shows in detail the Wolf work color-coded on the Austrian plan. I have the Wolf 2 plan, so it shows the details of the design for the excavation of the access tunnel to the path of the main tunnels.[18] Only taken together, regularly cross-referencing the plans with each other, can one assemble a

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[18] Versus a plan of Wolf 1 which would have shown detail of the Padastertal deposit access tunnel and the Saxen tunnel.

logical sense of the way all of the works of the BBT project will come together to create the completed tunnel. Documentation and drawings are crucial organization and communication tools in any construction project.

Perhaps the most interesting of prints shown to me was the 2013 Bauprogram. Bauprogram translates to construction schedule. The colorful print was the size of a big foldout map. It is a kind of map, but not of geography. It's a map of activity. On the charts x-axis is longitudinal location, and on the charts y-axis is time, moving down the axis from early to later. The BBT Bauprogram has 19 years on its y-axis, from the beginning of 2007 to the end of 2025. It has 61 kilometers on its x-axis, the distance the Innsbruck portal to the Aica portal. In the body of the graph every construction sub-project of the overall project is shown in location and time. Earlier works are above later works, and each work is located on the x-axis of position in its position within the tunnel length. Major construction lots are color-coded blocks surrounding the sub-projects they include. The Wolf 2 lot is white block near the middle of the chart, with a diagonal line running down the page to the right. The diagonal line represents the timing and linear progress of the Wolf access tunnel excavation. The Bauprogram is sort of a high-functioning Gant chart for longitudinal projects, like tunnels.

Having studied the BBT project for months prior to our interview, the drawings provided by Insam and Rieder were a revelation. Until studying these documents, I could not conceive of how a project of this scale could be organized and understood enough to actually execute it. Similarly, it is not possible to explain all of the works of the BBT project, and their interrelation in location and time without the aid of drawings.

However, one can get a sense of the major concepts organizing the construction of the BBT. I will begin with a breakdown of the basic design features of the tunnel. Then I will move on to an explanation of the plan for the overall construction. Explanation of this plan will include discussion of the BBT projects tendering procedures. By the time I discuss the works at Wolf, readers will know where those works fit in with the greater project. I will detail the construction works of the different lots at Wolf, which include early preparatory lots, Wolf 1, the current lot, Wolf 2, and the future lot, Wolf 3, which is also called the Pfons-Brenner lot. In discussing the works at Wolf, we will also discuss some general technical aspects of tunnel construction, as well as get a picture of the culture and communications on the construction site.

We will start here with the basic design features.

5.1.2 Design Features of the BBT

The BBT runs from 55 kilometers from Innsbruck to Fortezza. A train can enter in Innsbuck and exit in Fortezza. However, freight traffic coming towards the BBT from Germany will approach from the East and will bypass the city of Innsbruck and go directly into the BBT at Tulfes, exiting at Fortezza. The stretch beginning in Tulfes runs west and connects to the BBT south of Innsbruck. This stretch is called the Innsbruck bypass tunnel, and adds an additional 9km to the length of the BBT system. Taken together, the BBT becomes a 64km system and the longest rail tunnel in the world.

In discussing the BBT system, I will distinguish the path of the main tunnels and the Innsbruck bypass tunnel. The path of the main tunnels is the primary 55km run of the BBT, running essentially south into Italy. There are two important distinctions to be made between the path of the main tunnels and the Innsbruck bypass: 1) the Innsbruck bypass has already been built;[19] and 2) the path of the main tunnels includes three separate tunnel tubes, while the Innsbruck bypass tunnel is a single tube. The three tubes of the main line include the North-South tube containing one set of tracks, the South-North tube containing one set of tracks, and the exploratory tunnel tube, which will not carry a train. The single Innsbruck bypass tunnel tube contains two sets of tracks for trains travelling in opposite directions. The bypass tunnel does not include an exploratory tunnel.

While the Brenner Base Tunnel system includes both the main path and the Innsbruck bypass, it is the main path that is currently under construction, and it is the main path that this paper discusses in detail. The design features mentioned here all refer to features of the main path tunnels, the 55km between Innsbruck and Fortezza. That said, some current work of the BBT project concerns the already constructed bypass tunnel. That work includes two components: 1) an upgrade to the bypass tunnel to bring it up to the safety standards of the BBT; and 2) the connecting tunnels leading from the bypass tunnel to the BBT. Both of those

[19] It opened in 1994. It is also part of the Brenner Corridor.

components are currently in progress. They are part of the Tulfes-Pfons construction lot. The rest of the BBT is brand new or under construction.

The main path of the BBT includes three tunnels: the main tubes, which will carry trains, and the exploratory tube, which will not. The main tubes run in a parallel path 70m apart from each other. The exploratory tube runs between the main tubes and 12 meters below them. This configuration of 3 tubes is unique to the BBT project. The 57km Gottard Tunnel in nearby Switzerland has only two tubes, one for each direction of travel. It doesn't include an exploratory tube. Another option would have been to create a single large tube with tracks in both directions, similar to the Innsbruck bypass tunnel. This option does not meet modern design and safety standards for passenger transport.[20]

The unique exploratory tube provides the BBT project with 3 distinct advantages: 1) since it is being built 1st, it will give accurate geotechnical information for use is developing the tenders for the excavation of the main tubes;[21] 2) the completed exploratory tunnel tube can be used as a logistical support to the main tunnel excavation by providing a separate path for spoil removal as well as a complete drainage link for all of the construction run-off; 3) The completed exploratory tube can also serve as a logistical support to tunnel maintenance and operations. Equipment that services the main tunnels can be located in the exploratory tube, so that it can be repaired or replaced without interrupting main tunnel operations.

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[20] For this reason, the single-tube Innsbruck bypass tunnel requires the addition of an adjacent, parallel emergency access/escape tunnel.

[21] Not to mention it receives a 50% subsidy from the TEN-T program.

The actual way the exploratory tunnel will be used has not yet been settled. It is an interesting feature of the intensively engineered BBT project that such uncertainties remain even while construction is already underway. These uncertainties should not be taken as a shortcoming of the process. Rather, they demonstrate the flexibility of the project. In a project the scale and scope of the BBT, flexibility is a virtue. Balancing flexibility with thorough planning is an art.

The main tubes and the exploratory tubes run together for 55 km in a cluster on parallel paths. The exploratory tunnel runs below the level of the main tunnels. The main tunnels are divided by a 70m separation. Every 333m, or three times per kilometer, a connecting tube runs between the two main tubes. These connecting tunnels are a safety feature. In the event of a spill, fire or other dangerous situation in one of the main tubes, occupants of that tube can cross into the other tube.

In Alpine regions, tunnel accidents capture the public imagination in the same way airline accidents do here in the United States. Modern tunnels have extensive safety equipment and features of many types. These range from video, signaling and alert systems, fire suppression, contingency planning and more. For a great overview and explanation of tunnel safety features (and of tunneling in general, for that matter) see the book Tunneling and Tunneling Mechanics by Dimitrios Kolymbas. I will not define or describe all of these features here, except in a short, interesting diversion on ventilation and tunnel fire safety as it relates to the BBT connecting tunnels mentioned above.

In an emergency, occupants can cross from the dangerous to the safe tube, using the connecting tunnels spaced three per kilometer. Emergency alert systems will ensure the immediate cessation of regular tunnel traffic. A train coming the other direction won't flatten those who have crossed into the next tunnel. However, simply being in the next tube does not ensure safety. A fire or spill in a tunnel or other confined space is dangerous because it consumes limited oxygen or poisons the air. A fire, spill or the associated air problems could easily spread through the rest of the tunnel system, and follow the escaping occupants into the next tube.

For this reason, the connecting tunnels are sealed at each end by special doors. These doors were developed for the twin-tube Gottard Tunnel project, and were later adopted by BBT designers for the same purpose. The doors have to be air tight, and fireproof. They have another requirement as well.

During normal operation, the BBT main tubes will be passively ventilated by the passage of the trains through the confined space. However, during an emergency event, three ventilation stations housed in caverns along the tunnel route will start up ventilators that Andrea Lussu described as jet engines. These jets will pump positive pressure into the *safe* tube, to ensure that smoke or poison gas can't spread into it from the damaged tube. This creates in essence a powerful wind blowing through the connecting tunnels. Normal doors could not be used in this situation. If they were normally hinged, they could be difficult to open or close against the positive pressure. In addition to their sealing and fire-protection qualities, the doors must slide open and closed easily in the dynamic pressure situation.

The three tunnels are the main feature of the BBT system. In order to excavate and operate the main tunnels, significant logistical works are also included in the system. These logistical works include, primarily, the access tunnels and the multi-function stations. Access tunnels bring construction equipment from the surface down to the main tunnels at several points along their path. During operation, the access tunnels will serve as emergency or service access points to the tunnel path. The three multi-function stations (MFS) are located at the points at which the three major access tunnels meet the path of the main tunnels. The two main tubes are connected at regular intervals by the connecting tunnels. The exploratory tube is only connected at the main tubes at the multi-function stations. While the main path of the tunnel is 'simply' three tubes running in parallel (and the connecting tubes), the areas near the multi-function stations are characterized by a network of underground passages joining the 3 tubes of the BBT with each other and with the access roads.

In addition to the main tubes, the exploratory tunnel, the access tunnels and multi-function stations, the BBT system includes logistical caverns. A cavern is place within a tunnel path where the tunnel cross-section widens significantly to accommodate some additional function. The multi-function stations are in essence long caverns, since the tunnel cross-sections increase at the stations to accommodate the additional infrastructure of the stations. Other caverns exist throughout the system. Perhaps most notably, at each point from which a tunnel boring machine (TBM) will launch, an assembly cavern is excavated. Tunnel boring machines are huge. They are basically giant worms whose heads are the size of the designed excavation cross-section. They are over a hundred, sometimes hundreds of meters long. They are brought into the assembly caverns in pieces, assembled, and launched out the other end of the cavern, continuing the tunnel excavation. Other types of caverns exist where multiple tunnels come together or split off from each other, such as around the multi-function stations, and at points within the system where utilities and materials are stored, either for construction or operation of the tunnel. For example, ventilation caverns are located at three points within the system. The caverns house the tunnel ventilation jets.

Understanding these different design features will help understand the work of building the tunnel. *BBT* must plan, design, excavate and build out each component. This entire process must be coordinated in a way that brings the whole together into one continuous tunnel system. This involves intensive planning and review to ensure, say, the TBM cavern is large enough to accommodate positioning and hoisting of TBM parts. Romed Insam, one of the people interviewed as part of this research, works for *BBT* in part as a kind of continuity director.[22]

I learned of a few instances during the BBT project that illustrate the challenges faced by designers and construction planners. In one case, two separate construction lots used two separate sizes of drainage pipe in the tunnel. When the pipes are eventually joined they will form one continuous drainage system. These drainage systems are cleaned by machine. To maintain this hybrid-sized drainage system will require one machine for each pipe size. The cleaning of drainage pipes:

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[22] A person working in film that makes sure, for example, that a bottle on a table is set in the same place for each take of a scene. Except, as Lussu pointed out, Insam watches not a bottle, but an €8 Billion project.

a detail beneath a thousand more significant details. But when it is time to clean the drainage system this is the detail that someone will curse.   It will cost *BBT* extra money, and it was an avoidable mistake. I would say that while each individual mistake is avoidable, it is also not possible to avoid every avoidable mistake. The chances missing something are just too big within a project of this size.

Another example demonstrates *BBT* catching a problem before it is too late. The Wolf access tunnel has two routes leading off of it towards the Padastertal deposit. It used to include only one. The access begins heading east directly inside the Wolf portal. It curves to the south and travels four kilometers into the mountain and down to where the main tunnels will run. From this curve, a tunnel branches off in the other direction, to the north, and leads into the Padastertal deposit. This is the Padaster Tunnel. But *BBT* engineers realized that the curve of the access tunnel leading to the Padaster Tunnel was too tight for a conveyer belt system to follow. Another tunnel leading to the Padastertal deposit, one that runs in a straight line with the access tunnel, was added to the works at Wolf. Now a single conveyor line can carry the spoil from main tunnel boring operations up the Wolf access tunnel and to the deposit. A rigorous design and review process alone is not enough to succeed in coordinating the project. It also requires experienced staff and consultants who have best chance of catching a missed detail, because maybe they've seen that problem before. In our interview, Andrea Lussu described this coordination of a large scope as one of the most difficult technical aspects of the entire project.

> The most difficult aspect of design and construction of BBT is that the project is so big. The whole project goes over 10 years[23] and it costs eight billion with 200 kilometers[24] of tunnel. Then you have to think: you have different companies that do different works. And the challenge is that you have to get a tunnel that's one tunnel, and looks the same in every part. (Lussu, 2014).

5.1.3 Building the BBT

Aside from work on the exploratory tunnel and some early preparatory works, construction on the BBT began in 2011. The process will continue through 2025. *BBT* plans the tunnel to become operational in 2026. The access tunnels will be excavated first, then the networks around the multi-function stations leading excavation crews to the paths of the 3 tunnels of the main system, then the excavations beginning the main tunnel paths. Caverns will be excavated as necessary at their different points on the routes. Notably, where conventional excavation ends and machine excavation begins *BBT* will excavate assembly caverns. Each of the three main access tunnels includes the excavation of assembly caverns.

In addition to the work of building the tunnel system itself, construction also involves building the aboveground construction sites that stage and service the underground work. This aboveground work includes preparation of the spoil disposal sites and preparatory works, like moving roads and rivers.

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[23] Exclusive of planning.
[24] Total tunnel tube length taking into account the many separate tubes and components of the entire 64 km system.

BBT has divided all of this work up into construction lots. Basically, the work proceeds as follows:

1. Small lot reparatory works above ground to create the construction sites and build tunnel portals.
2. Larger lots for the development of the access tunnels, which proceed from previously established construction sites.
3. Major excavation lots for the main tunnels once the access tunnels are completed.
4. Construction of final linings and other final concrete infrastructures within the tunnels.
5. Rail, Equipment and Energy Installations.

BBT has established its construction sites and is now in the phase of excavating the access tunnels. Excavation of the main tunnels will begin in earnest in 2016. Sometime in 2018, main tunnel excavation from Ahrental will meet main tunnel excavation from Wolf, and Roland Arnold will shake hands with his colleague and mentor, Andrea Lussu. The specific location of this handshake depends on the speed of progress in both the Wolf III and Ahrental IV lots.

5.1.4 **TENDERING**

For each construction lot, *BBT* releases an international tender. This creates a competitive bidding process that ensures *BBT* pays market prices for its work. International tendering is required when spending public money. Tendering out the separate lots also spreads risk away from *BBT* and into many separate baskets. In this way, a failure of one constructor is not catastrophic for the project.   One of my advisors, Professor Tautschnig, pointed out that an international tender is also in keepin with the spirit of the BBT project as economic development. It spreads the benefit of the work among many constructors. [25]

In order to respond to a tender with a bid, a constructor must meet certain qualification standards. Each bid includes a statement of qualification. Generally, these include an explanation of how the constructor will execute the project and proof of experience on similar projects. Bidders must also be able to bond the work. Strabag-Impregilio had to produce a guarantee three-times the value of the Tulfe-Pfons lot – an over €1 Billion bond. Likely this was part of their reason for entering a joint venture.

When *BBT* receives bids they evaluate the qualification of the bidder. A bidder must reach a qualification of 50% of the possible points. If not, the bid is returned with the price unopened. Among qualified bidders, the lowest price gets the job.

The tendering procedure is rigorous and long. Designs are turned into tenders over months. Tenders are released for 3 months, then the bids received are evaluated. A separate team within BBT than that which released the tender performs evaluation. Evaluation can take months to ensure that the bids are correct and complete. Once *BBT* has selected the lowest price qualified bidder, they announce the winner. In Austria they must wait 35 days before signing the contract.

[25] As a counter example to this, Italy released over €4 Billion worth of work to a single contractor as part of a separate project, the Apennines line, (Lunardi, et al. *BBT Symposium 2008*).

In this time, bidders who did not win can file complaints about the tendering process. If no legitimate complaint is lodged, the contract is signed and work can begin on the works defined in the tender.

Most of the tenders at Wolf are design/bid/build. This means that *BBT* designers have developed most of the processes and details of the work prior to releasing the tender. Bidders give a price for the work defined by *BBT.* Another type of tender is a design/build tender. This means that *BBT* defines the outcome of the work, and lets the bidder respond with the methods of achieving that outcome. These types of tenders take longer to review and approve, since reviewers must evaluate both a process and a price, instead of just a price. Each type of tender has risks and advantages for both parties.

All of the major *BBT* works tenders are design/bid/build tenders, except for two. The Isarco construction lot and the installation of signaling equipment will likely be design/build tenders. The Isarco lot in Italy (which looks on the Bauprogram like a nest of snakes) is so complex in the interaction of its works that *BBT* deems it best to allow constructors to define their processes. The pool of qualified modern rail signaling expertise is small in the Alps, probably since the technology is new and quickly evolving. Therefor *BBT* would reduce its pool of bidders if it contracted one of the few qualified firms to design the tender prior to release for works construction. This is also the tactic followed by the Gottard Tunnel for rail signaling.

The constructor Swietelsky has won three separate design/bid/build type tenders at the Wolf site. For this reason, the constructor and the *BBT* staff on site have developed a good and familiar working relationship. However, this working relationship has no baring on the decision of who will work on Wolf III (Pfons-Brenner). I discussed this with Roland Arnold, the current project coordinator at Wolf for *BBT*. He believes that fairness with public money and ensuring a market price for *BBT* is important. While he acknowledges that a good working relationship is important, he says that just focusing on that without proper procedural controls is too soft. "The middle way is the best way," he says. (Arnold, 2014).

5.1.5 Tunneling Contracts

Tunneling contracts in Austria are high functioning, and designed to promote a good working relationship between originator and constructor, as well as "decision making at the tunnel face." For an excellent explanation of tunneling contracts, see the 2011 paper on tunneling contracting guidelines published by the Austrian Society for Geomechanics, *The Austrian Practice of NATM Tunneling Contracts.* This paper emphasizes the necessity for flexibility in tunneling contracts, to allow for flexibility in dealing with changing ground conditions during construction. The complexity of the interaction between tunneling measures and the ground is "impossible to control by previously defined 'if-then' solutions," the kind typical of above-ground-construction contracts.

At Wolf, I observed strong, positive relations among the *BBT* staff, the staff of the constructor, Swietelsky, and the ÖBA. Austrian tunneling contracts prevent conflicts of interest by clearly distributing risk, automatically adjusting payment in relation to rock characteristics, and pre-pricing time- and work- dependent costs. These high-functioning Austrian tunneling contracts leave room for constructive relations among the staff. Disputes have less chance of developing in such an environment. When and if they do, built-up capital of trust and productivity can be applied directly to the problem. This increases the possibility of resolution within the project, thus decreasing the need for outside intervention and the attendant costs and delays.[26]

5.2 <u>Some Technical Aspects</u>

5.2.1 TBMs

The Brenner Base Tunnel will be excavated by both mining and boring operations. Boring will be performed by tunnel boring machines. Excavation will be approximately 30% mining and 70% TBM. One TBM is already in operation. It was launched from Aica, Italy in 2008, and is currently driving north towards Innsbruck as it bores the exploratory tunnel. A second machine will launch southward from Ahrental in 2015, as part of the Tulfes-Pfons lot.

The machines that will drive the main tunnels will be launched from three points along the route of the main tunnels: Ahrental and Wolf in Austria, and Mules in Italy. The two machines that will drive south from Ahrental are already on order

[26] The *BrennerCongress 2012* includes several papers addressing working relationships on construction sites, and the value of developing trust. Unfortunately, I lost my copy of this publication, and can't cite the specific author or authors who make this point about trust.

from the Herrenchnecht Company in Germany. These machines are 8.1m in diameter.

At the time of this writing, Herrenchnecht is in the process of reviewing and verifying the machine specifications provided for the Tulfes-Pfons machine. The Brenner Base Tunnel project consists almost exclusively of design-bid-build type tenders. In the case of a tunnel, this means that the means of excavation are established prior to awarding work to a constructor. And in the case of a bored excavation, this means that the type and function of the machine is specified in a separate design contract. The constructors will purchase and own the tunnel boring machines, but they will not specify the machine.

This arrangement has pros and cons for both parties – the constructor and the owner. With a machine specified by its client, the constructor bears less risk in the event of problems with the specifications. On the other hand, the constructor may have expertise and experience that could have contributed to optimizing the machine for the ground, ultimately leading to a more smooth and efficient dig. The constructor can bid more easily on a pre-specified machine, and the client can review multiple bids more easily, since they are comparing only prices, not prices and machines. But the client too can lose out on the benefits of a constructor's expertise, if the constructor is not consulted in the design phase of the tunnel-boring machine.

In my opinion, it is one of the successes of *BBT's* approach to this huge project that they have stacked the deck with expertise. *BBT* itself is staffed with engineers and tunnel experts. The work is designed and constructed by experts, and the completed designs and works in progress are reviewed and overseen by the experts at *BBT*, independent experts, and expert consultants. I found that tunneling is in fact a small world, with the Alps at its center. The BBT project benefits from a rich and active network.

According to Dr. Bappler at the Herrenchnect Company, not all machines are ordered by qualified design and construction teams. She tells of senseless specifications, and of project teams without the basic knowledge to communicate through the machine design process. Like the rise of home building box stores and do-it-yourself installation kits, the process automation promised by tunnel boring machines tempts project teams to substitute knowledge and expertise with equipment. Rather then cultivating a qualified project team and performing rigorous planning, some who want to build a tunnel hope that Herrenchnect can do it for them – just send us the machine!

Automated tunneling is not yet, and will probably never be a reality. This sentiment is written in Kolymbas' book "Tunneling and Tunnel Mechanics," and many I spoke to during the course of this research echoed it. Tunneling machines bring the process closer to automation. The first challenge in this effort is that machines are designed for specific ground types – a machine designed to dig through sand under a river will not also dig through hard rock. An open TMB cannot dig in ground saturated with pressurized water. But the types of ground that a specially designed machine can bore through are increasing. The next challenge, the one currently being explored as projects demand this feature, is for a convertible machine: a machine that can change from one type to another as the ground changes in a dig. However, even with highly versatile and automatically adapting machines, tunneling will always require expert personal during planning and design, and expert personal on the ground to respond to changing conditions during the excavation.

5.2.2 WATER

The Alps are the drinking fountain of Central Europe, collecting rainwater and sending it out in all directions in clean, rushing rivers. Hiking in the Alps, these rivers are everywhere, cascading off the mountainsides. Water visibly seeps out of the rock on mountain faces and collects in gorges, valleys and canyons. It flows down into the bigger rivers in the valleys between the mountain ranges and out into the rest of Central Europe.

A geology professor in Innsbruck told me that water rains onto the Alps, and then ten 10 years later that rain filters out at 2000 L/s into the aqueduct bringing drinking water to Innsbruck. Innsbruck drinks the water without any additional mechanical or chemical treatment. Springs of fresh water sprout out all over the city from little brass pipes and fall into stone cisterns. Locals talk about the quality of the drinking water in the Alps. They cite this, along with the clean air landscape as reasons they would never want to live anywhere else.

While the water is an Alpine treasure, it poses two significant challenges for the BBT project. First, like the precious farmland and traditional Alpine community life, water must be protected. Blasting chemical residues, blasted mineral content, oil and diesel from equipment operation, and other contaminants mix with the run-off in tunnel excavations and flow through the construction zone. At each construction site water is treat prior to being released into nearby rivers.

Another important water protection concern is that the increased drainage created by adding three big tunnel tubes through the Alpine aquifer will reduce its level. Tunnels collect and redistribute water that once might have fed local rivers and replenished Alpine lakes. In our interview Lussu said, "No one cares about the advance rate of the tunnel excavation that day, but if a river stops flowing where it used to it will be in all the papers." For this reason, during the environmental assessment phase of the project, the water table in the Alps was extensively studied. Computer models simulated the influence of tunnel drainage on the level of the aquifer. The province of Tirol allowed construction to proceed because models showed no significant detrimental effects on the level in the aquifer. During construction *BBT* regularly monitors water levels throughout the aquifer.

Tunnels do collect water. This collection is related to that slow filtration process that cleans the Innsbruck drinking water supply. Water is present in fractures large and small throughout the Alpine rock mass. Uninterrupted by human intervention, it will follow a slow path through fractures and permeabilities in the rock, and eventually find it's way to a spring. When the rock is cut during excavation, it bleeds water. Different rock types have different hydraulic permeability. Since the BBT passes through several major rock types, the water flows differ from site to site.

Part of the job of tunnel linings installed after excavation is to waterproof the tunnel, as needed. The most expensive type of waterproofing is to wrap the entire cross section in a waterproof layer between the initial and final linings. This is usually reserved for tunnels under hydrostatic pressure.[27] BBT tunnels are not hydrostatic pressure, so they will use a less rigorous form of water resistance. Only the crown of the tunnel lining will be waterproofed. Flow from the tunnel walls will run down the outer surface of the final lining and into drainage pipes. While this option is cheaper to install, it does require the drainage and treating of all of the tunnel runoff. For the BBT project on the Austrian side, drainage will be treated in a huge plant in Ahrental during the last years of construction and the first years of operation. After a few years, the runoff water presumably will no longer carry construction-related impurities, and treatment can cease.

5.3 Construction

5.3.1 The Wolf Site

The website maintained by BBT-SE includes an option for arranging a visit to one of two of the project's active construction site: Wolf in Austria or Mules in Italy. Tours take place on a Tuesday or a Thursday, have a minimum group requirement of 8 people and cost €5 per person. The BBT-SE project coordinators staffing the sites conduct the tours. Arranging a tour of a BBT site used to cost visitors nothing at all, until regional tour guides learned they could include tunnel construction tours as part of their packages. They began flooding the sites with half-interested tourists

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[27] This does not mean the tunnel runs underwater, per se. I just means the ground is saturated, as in an aquifer.

and taking up too much of the coordinators' time. Fees and limits were set to cull some of these visits.

For my first visit to a BBT site, I used the website's tour-booking links to arrange a tour of Wolf. I scraped together a group of 8 international exchange students who were also studying in Innsbruck, so that we could meet the minimum group requirement. The ride on ÖBB costs about €8 and takes less than 20 minutes from Innsbruck Haupbanhof to Steinach-am-Brenner, using tracks going up the Brenner Pass. After the base tunnel opens in 2026, passenger trains will still use these tracks to reach the towns along the Brenner Pass, and Italy beyond. The base tunnel will exist primarily to re-route international freight traffic under the mountain – speeding the passage of the freight and reducing congestion on the tracks and roads travelling over the Brenner Pass.

Andrea Lussu, then the project coordinator at Wolf, met us with a van at the station in Steinach-am-Benner. The village has a small stone train station with two tracks and a cramped canteen selling snacks, bottled water and beer across the counter. The village of Steinach has an *M-Preis* and new looking houses. Mountains and the small farms typical of Tirol and the Alps surround it. The Brenner Pass autobahn towers over the town in the valley, stacked on long concrete columns high on the mountainside to the east.

Earlier that year, an Austrian friend, Klaus, took me into the mountains to tour some small Tirolean villages. Klaus called farming in Tirol "an obligatory hobby." Buildable land is scarce in the Alps, and tracts extend onto impressively steep mountainsides. Sheep graze on green high green pastures. Locals joke that the people in the next village have one leg longer than the other from standing for generations on a slope. Tirolean law requires that land used for farming must remain farmland, and that custodians of the land be trained and registered as farmers. In other words, a lawyer from Vienna couldn't easily buy a farm in Tirol for a vacation home. Village houses often have a home conjoined with a workshop. The living quarters exterior is stuccoed, and the workshop is covered in wood planks. These "bauhauses" are an iconic sight in Tirolean villages. Many have hay-drying racks, made of wooden spokes mortised around a long pole, lashed high on their exterior walls. Tirol supplies Austria (and Europe) with fresh apples, schnapps, farm-raised wurst, speck and meat, and other fruits and vegetables. A farming culture and economy that has largely been erased in the United States thrives in Tirol. By calling farming a hobby Klaus probably meant to imply that farmers in Tirol, like farmers in most of the developed world, derive most of their income from a regular job. But a millennium of tradition has stamped farming into the landscape and people of Tirol, despite Austria's modern economy.

As Lussu drove us from the train station towards Wolf we passed by the green fields, grazing sheep and hay-drying shacks dotted around the valley in every available spot. A construction project of historic scale is taking place in one of the most cherished and picturesque landscapes on Earth. Much of the preparatory works of the BBT project were required by environmental impact plan to mitigate the effects of construction on the land and communities neighboring the works. Space and environmental limitations are a consistent challenge for project logistics.

Wolf is about 5 minutes by car from Steinach-am-Brenner. We drove south, up the valley, on a two-lane state road, B 182. Planners tucked the construction site against the valley's eastern mountains. B 182 bounds the site on its western side. In order to keep construction traffic off of the small state road and out of the towns around Wolf, planners added an access road exiting directly off of the autobahn, leading down the mountains and into the construction site. This access road required the excavation of a1 km tunnel – the Saxen Tunnel. The tunnel opens out of the mountains below the autobahn. An exit ramp descends out of the tunnel onto a bridge over B 182, then down into Wolf. The Saxen tunnel was part of the first major construction lot at Wolf, "Wolf 1".[28] Even earlier work included re-routing B 182 into a small bend to make room for the excavated spoil from the Saxen tunnel, some construction site offices and a concrete mixing plant.

Now, when construction traffic brings materials or equipment to the Wolf site it enters down out of the Saxen tunnel. It passes the hill of stored spoil on the left and a maintenance shed on the right. A billboard-sized sign, visible from the state road, hangs from the shed. It reads, "HIER ENTSTEHT DER BRENNER BASISTUNNEL." The shed is made of stacked shipping crates with a sheet metal gable roof. The crates are orange, the brand color of Swietelsky Tunnelbau GmbH. Behind Strabag and Purr, Swietelsky is the third largest Austrian construction company. In two separate tenders released by *BBT*, Swietelsky won two consecutive works contracts at the Wolf site. The construction lots are called Wolf 1

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[28] While the Saxen tunnel was part of Wolf 1, the access road leading to the tunnel from the highway was not. It was one of several earlier, smaller logistical lots.

and Wolf 2.[29] During out visit, Swietelsky was mobilized on site at Wolf in the process of the work of Wolf 2. *BBT* staff and equipment on site are usually limited to a few people – the project coordinator and his assistants – a van for tours, and an office in a house standing at the top edge of the construction site. Most of the rest of the buildings, equipment and hundred-or-so personnel on site belong to Swietelsky.

Our tour of the site with Lussu began in a conference room in a modular building. The 8 of us sat in chairs around a long table while Lussu ran through a PowerPoint presentation about the tunnel project and the works and progress at Wolf. Lussu had translated the presentation into English for our benefit. After the presentation we went across the hall and suited up with muck-boots, reflective jackets, helmets and headlamps. We were each given a handbag-sized hard plastic case containing bottled air and a locator beacon.

At Wolf, a portal has been opened in the mountains on the eastern side of the site. From here, Swietelsky is excavating a 4km tunnel into the mountain in the southeast direction. This is the Wolf access tunnel. It ends deep inside the mountains, in a spot directly in line with the path of the future main tubes of the Brenner Base Tunnel. With our muck-boots and emergency kits, Lussu drove us from the construction office to the tunnel portal. The Wolf River splits the Wolf site down the middle, north to south. In the van, we crossed a small road bridge to reach the entrance to the Wolf access tunnel. It was a short ride, and slow. Swietelsky personnel and equipment were everywhere, moving in and out of the portal and

[29] In fact Swietelsky has worked on a total of three lots at Wolf: Wolf 1, Wolf 2 and the earlier logistical lot re-routing B 182. Swietelsky Bau, not Swietelsky Tunnelbau, executed this lot. A joint venture of Swietelsky Bau and Swietelsky Tunnelbau executed Wolf 1. Swietelsky Tunnelbau alone is working on Wolf 2.

among the roads and buildings of the construction site. A separate construction company built the portal prior to Wolf 1 in one of a series of smaller logistical lots, which prepared the site for the works of Wolf 1 and beyond.

The train tracks of the existing Brenner Pass line run along the mountainside on the eastern boundary of the Wolf site. The Wolf access tunnel opens into these mountains and passes directly beneath the rail lines. The portal to the access tunnel is a large rectangular hole in the side of the mountain, surrounded by concrete on the sides and above. The thick concrete roof of the portal acts as a bridge carrying the weight of the trains on the Brenner Pass line above. This support bridge had to be built first, before excavation on the access tunnel itself could begin.

As we stood on the ramp leading up to the access tunnel and Lussu explained safety rules (watch out for giant trucks), a freight train glided slowly up the Brenner Pass. More than a decade from now, this freight traffic will be underground. For now, it crosses over the portal, while below excavation crews and equipment pass in and out of it, digging the tunnel.

Our visit took place during the works of Wolf 2. During Wolf 1, Swietelsky had mined about 200 meters of the Wolf access tunnel, and a the nearly 800 meter Padastertal tunnel leading from just inside access tunnel portal to the Padastertal deposit. Part of the work of Wolf 2 consists of driving the access tunnel to its full length and depth, to the point where it will intersect with the path of the main tunnels. The planner added the Padastertal tunnel (Wolf 1) first, so that spoil from the Wolf 2 excavation could be brought directly to the deposit without the need to carry it on surface roads. When we toured the tunnel with Lussu, the Padastertal tunnel was complete, and Swietelsky miners had taken the Wolf access tunnel about 1km into its 4 km run.

5.3.2 Miners

A mining crew has six or seven members. In the case of a drill and blast face, like the tunnels at the Wolf site, these workers operate the drilling jumbo, place and detonate dynamite, clear blast debris, anchor bolt the tunnel walls and apply shotcrete. After a review by geologists and surveys of the rock behaviors during mining, the cycle is repeated. This is called a round, and each round advances the tunnel face. The distance mined in a single round, and the number of rounds per day translates to the tunnel's daily advance rate. Roughly speaking, an 8-hour shift might include 2 or 3 rounds of a meter or two per round. This changes based on rock and other conditions.

"In New York you have finance. In California you have Silicone Valley. In Carinthia we have miners." Most of Sweitelsky's miners come from a single valley Corinthia, Austria. According to Harald Kögler, each member of a mining crew can do any job on the round, operate any machine. Typically, members of the mining crew are responsible for every aspect of the advance work in the tunnel. However, in the case of Wolf II, Swietelsky has subcontracted the removal from the tunnel of the blast debris. Miners load the spoil into trucks operated by the subcontractor, which trucks the rock to the disposal site.

Swietelsky chose to subcontract the rock removal to mitigate their up-front equipment costs, since they wouldn't have to supply the trucks at the start of operations. Furthermore, the subcontractor makes it easier for Swietelsky to manage the changing debris quantities. Wolf II has multiple tunnel faces – the access tunnel and the second Padastertal connection – as well as logistical caverns. Depending on the work schedule and how many faces are being worked at once, the quantity of debris changes. Rather than idle its own equipment and manpower, it is simpler for Swietelsky to reduce its order with the subcontractor.

Each tunnel face requires 4 separate mining crews. The mining operations run day and night. In 24 hours, three crews will work an eight-hour shift each. A fourth crew is away with time off. Generally, one crew rotates into time off every ten days, while the crew that was off returns to the tunnel face. This work rotation is known as "decade," in reference to the 10-day cycle. Swietelsky's miners work the decade cycle, although their decade runs in eight day cycles. Every eight days, one of the mining crews rotates home. When they are working at BBT, hours from home, the miners stay 2 to 4 to a room in apartments near the construction site.

At the time of this research, miners had their pick of jobs in the region. Crews are not under contract, and can leave a job on short notice. While the wages for miners are generally set, the site manager can apply different incentive, like meal tickets and bonuses, to keep the miners happy, motivated and working for

Swietelsky. In an exceptional project like mining the longest rail tunnel in the world, Kögler pointed out the distinctly unexceptional fact that managing the personalities, moods and unexpected absences of his employees is the most challenging aspect of his work.

5.3.3 The Wolf Access Tunnel

Lussu brought us in the van inside the tunnel, where there was as much activity as outside, if not more. The access tunnel has a round profile and a cross-sectional area of almost 120m^2. A dirt roadway runs the length of the tunnel. The roadway is as wide as the tunnel, about 12 meters. Excavation and personnel-moving vehicles passed each other in either directing – going towards or away from the work. People moved around on foot at the edge of the roadway, sometimes crossing it. There was room for utilities and equipment staging along the side of the roadway, at the tunnel wall. The roof arched about 8 meters above the surface of the road. A huge inflated ventilation duct hung above our heads, suspended from the roof.

Andre drove into the tunnel to a point near the face and parked off to the side of the roadway. At our feet as we climbed out of the van, a trench collected run-off from the tunnel walls and excavation equipment. A pump sucked the water into pipes anchored to the wall. Swietelsky pumps 60 liters per second out of the Wolf access tunnel then out into an on-site treatment facility.[30]

[30] According to Lussu, other construction sites within the BBT project handle up to 300 L/s.

Lussu himself designed the Wolf site's treatment process and facility, and Swietelsky built it. Treatment includes 24 hours of settling and CO_2 introduction to lower the water's pH. Computerized equipment monitors treated water for ammonia and pH before it is released on site into the Wolf River. The computers report monitor readings automatically, in real-time to the environmental ministry of Tirol, in Innsbruck. The ministry can shut down the treated out-flow into the Wolf River remotely from their offices in Innsbruck. Other equipment automatically fills sample jars with treated water. Researchers from the University of Innsbruck collect these jars periodically and test them for turbidity.

Inside the access tunnel the walls are wet and the dirt road surface is muddy. Miners are excavating the Wolf access tunnel with the drill and blast method. They have sprayed the walls of the excavated rock with shotcrete, so they are grey-black and rough. Beneath the shotcrete lining, regular bumps of steel support arches are visible. The overall effect is of being inside a giant corrugated-steel culvert pipe.

The dirty grey shotcrete walls and the dirt floor, everything dripping wet, overpower the lights attached to the tunnel wall. Illuminated, it is still black. With the portal visible a few hundred meters behind me, I still felt uneasy. The Wolf access tunnel will eventually advance four kilometers and descend almost twenty meters into the rock before it reaches the path of the main tunnels. From there, the tunnels will proceed into the earthly equivalent of deep space. Tunneling work on this scale brings humans to a frontier. Even inside the first kilometer of the access tunnel, beneath the rush of activity, the shouting and the combined roar of diesel engines and the ventilation fan, the knowledge of being underground needles at my instincts, like someone staring at the back of my head. The air tastes different, and I have the sense I am not supposed to be there. The work of miners must be more than the sum and duration of their physical efforts. Being underground must also cause a kind of spiritual wearing-down.

Beyond our van lay a short walk to the tunnel face. On our way we came to a concrete cylinder about the size of a mini-van. It lay on the ground beside the roadway. Lussu took gave us a look in the door in one of the round ends. Benches lined the two short walls. Cabinets held emergency supplies – food, water, blankets, etc. The capsule would serve as a refuge in case of collapse or a poison gas event. It stored compressed breathable air and supplies to maintain life inside while trapped miners await rescue.

At the face the mining crew was preparing for an application of shotcrete to the just-excavated crown. We were able to walk up the incline from the roadway on the invert and stand near the tunnel face. The face was black rock with folded ribbons of white quartz. Behind us the truck with the shotcrete arm moved into position. The machine has a long articulating arm with a nozzle at the end, and hoses lashed to the arm. We moved back to be out of range of the rebound, the dust and the mist. The application began with firing up the machine's pump, a loud roar, accompanied by shouts and pointing of the crew on the ground, indicating where to begin spraying. The long arm bounced as it registered the changes in position ordered by the operator in the cab, and the reaction from the spraying concrete. We left the face, returned to van and drove back out into the light.

6. <u>Conclusions and Topics for Further Study</u>

With this research I tried to get answers to questions that might bring the reader closer the details of the project, and inside some of the decision making that confronts planners and construction mangers. I approached the research with a real interest in the work of the BBT staff, and in the coming-together of all of the disparate parts of a massive project like the BBT. I wanted to understand what it takes to plan and execute a project on the scale and scope of the BBT. I wanted to understand 'what do planners need to know before they begin?'

I wondered if *BBT* had a specific planning and construction policy that preceded the beginning of construction and informed the work of the construction planners and on-site project coordinators. What I found was that the work of *BBT* in building this tunnel is not policy-driven. The planning and construction do follow a set of repeating steps – study, design, review, revise, construct – that are applied to each major construction lot, and will lead the project from start to finish. But the overall synthesis of these steps into a completed tunnel, and the activities on site during construction, these not controlled from a blueprint or a policy. They were not planned in advance. Project synthesis is accomplished through the experience and capabilities of the individuals working on the project on a day-to-day basis.

The construction plan for this mega-project is not a top-down, pre-written playbook, but rather it depends on the real-time talents and professionalism of the people building it. The personnel working on the BBT have defined roles, but the borders of their responsibilities changes depending on what needs doing, so their capabilities are necessarily broad, and exceed their job descriptions. I believe this supports their ability to do the work in front of them, maintaining perspective on the project as a whole, and the work of others around them.

The environment in which they work has some characteristics that support their success: short chain of command, high-functioning contracts between the client (*BBT*) and the constructors, availability of expert consulting resources, and a broadly qualified and experienced staff. Those are the ingredients I found when I went in search originally of a management plan.

Like any big construction project, the BBT project requires vision, planning, cooperation and coordination. However, I believe the technical aspects and the unknowns of tunneling work add an additional challenging dimension and seriousness to the undertaking. (I'm reminded, here, of the feeling of being underground). I think that this challenge is actually part of the success of the BBT project. It discourages cutting corners and demands a capable, focused project team.

I look forward to the opportunity to explore this topic further. In particular, I hope to develop some of my research that went deeper into details at the Wolf construction sites, and explores the experiences of the project coordinators there. A closer look at the construction site might better illustrate this relationship between the challenging work and project culture. Furthermore, I know from the interviews that the project staff themselves have perspectives on the project as a whole that are worth some synthesis and analysis.

In particular, further discussion is in order on the cooperation between Austrian and Italian processes within *BBT* and on a technical level. The multi-national nature of the project is both part of what makes it special and part of what makes it difficult. Furthermore, the challenge of any project is one of cooperation and teamwork, so the experience of Italians and Austrians is instructive in general as it relates to understanding constructive project culture. The 2012 *BrennerCongress* devoted space to dispute resolution, which is really a discussion of relationships. As Lussu put it in our interview, "If the personal communication in the group works well, then normally the lot is going quite good. If the personal situation is bad between the people who are working, then normally it goes bad, (Lussu, 2014). I see the technical challenge of tunneling work and the development of community around this challenge as the crucible in which these complex issues might find some resolution. This takes place on the construction site.

7. <u>Appendix</u>

7.1 Maps and Schematics

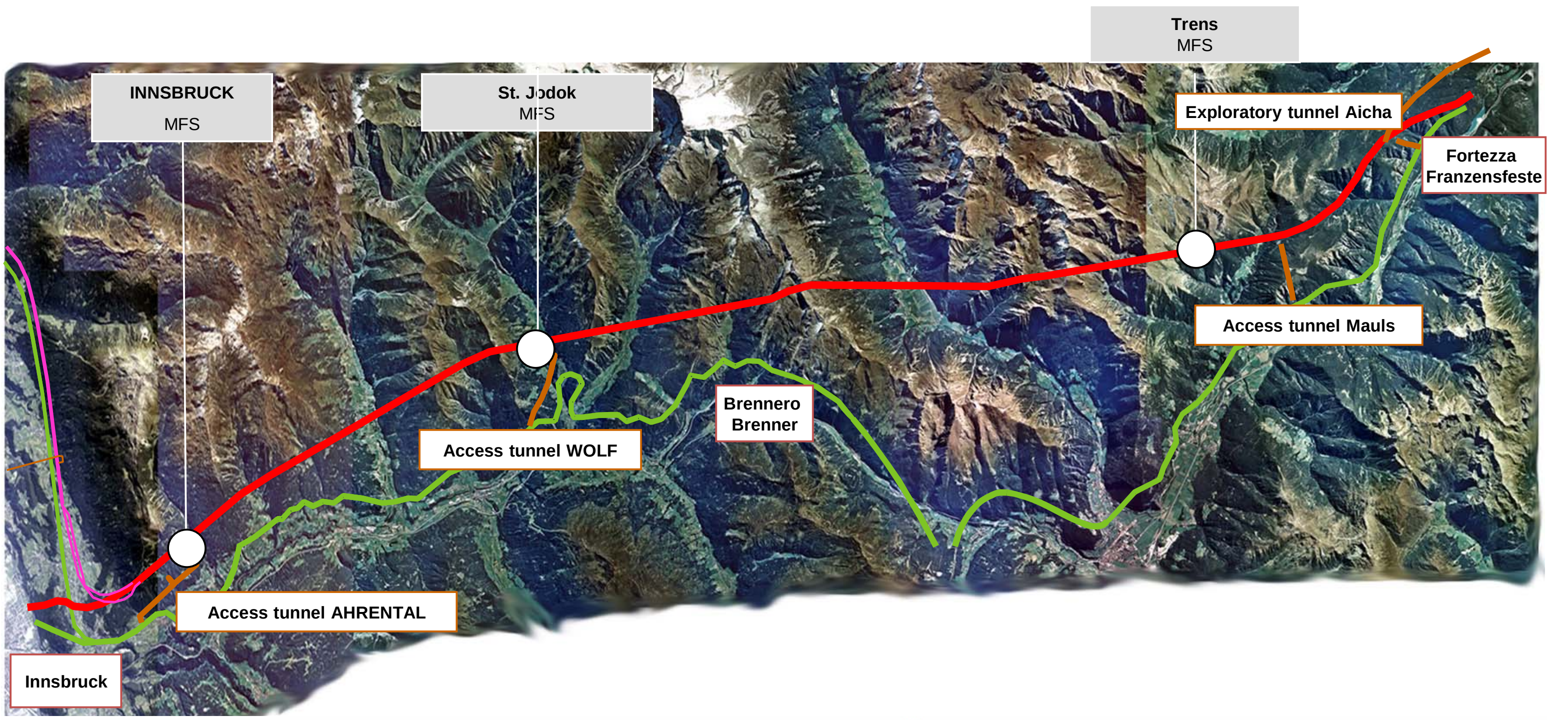
7.2 Images of Wolf

7.3 Charts and Organograms

7.4 Bibliography

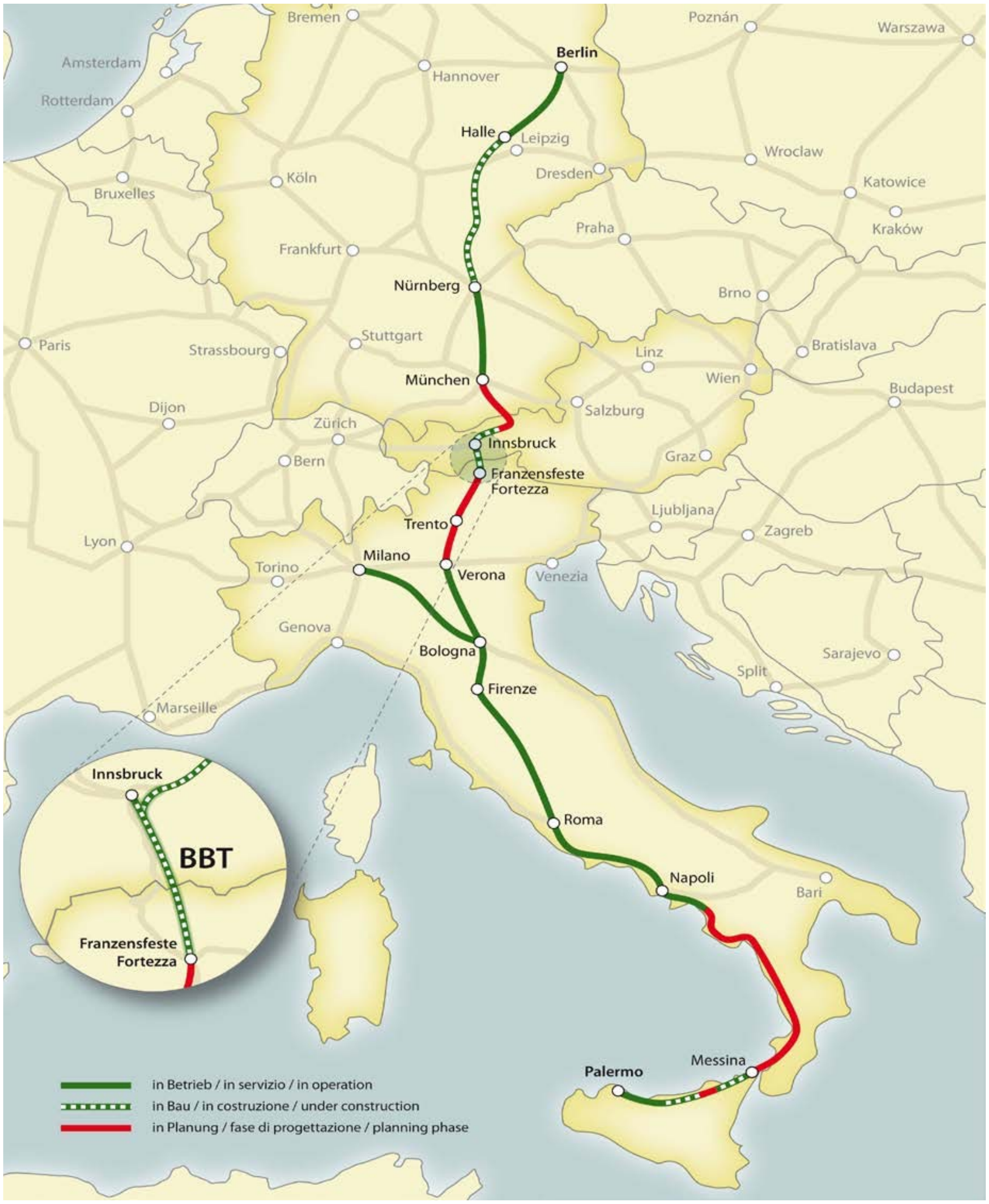
7.1 Maps and Schematics

The Path (in red) of the Brenner Base Tunnel. From *BBT-SE*.

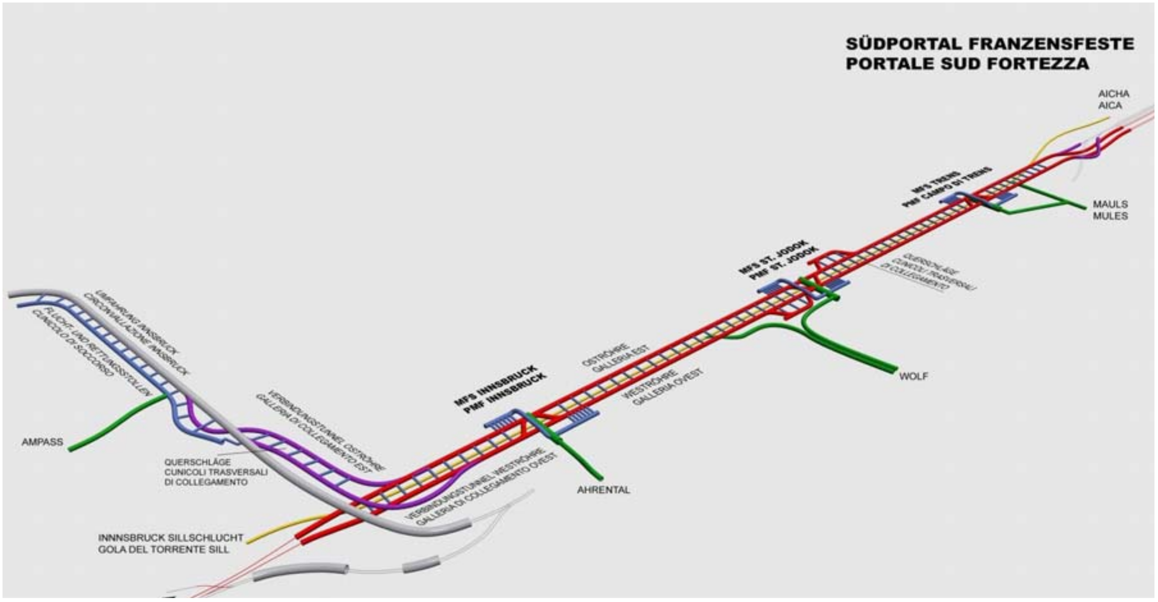


← NORTH

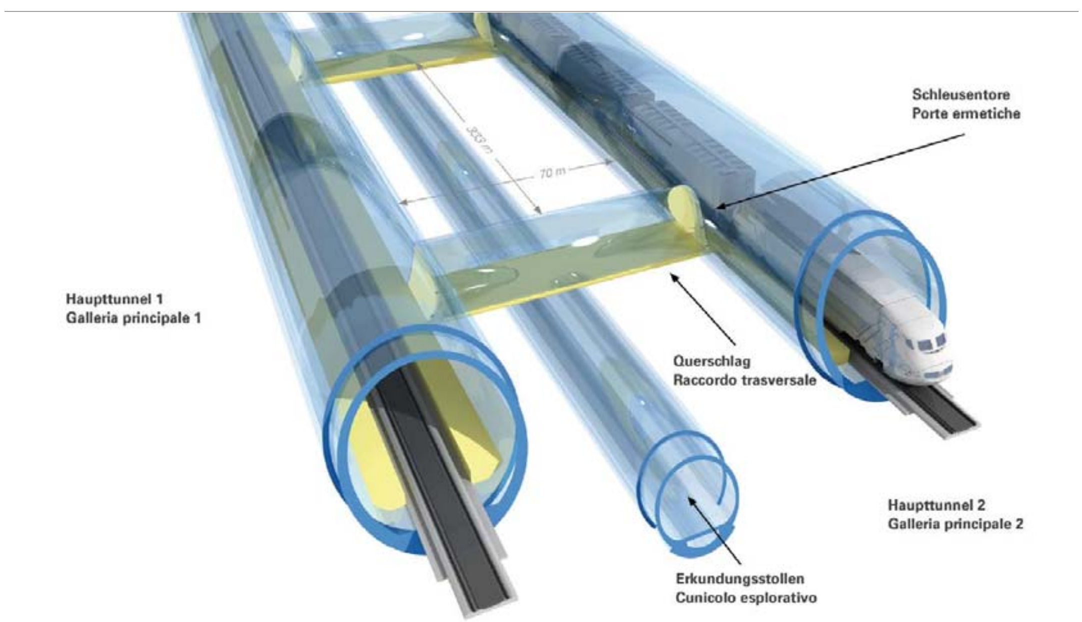
Berlin-Palermo Axis



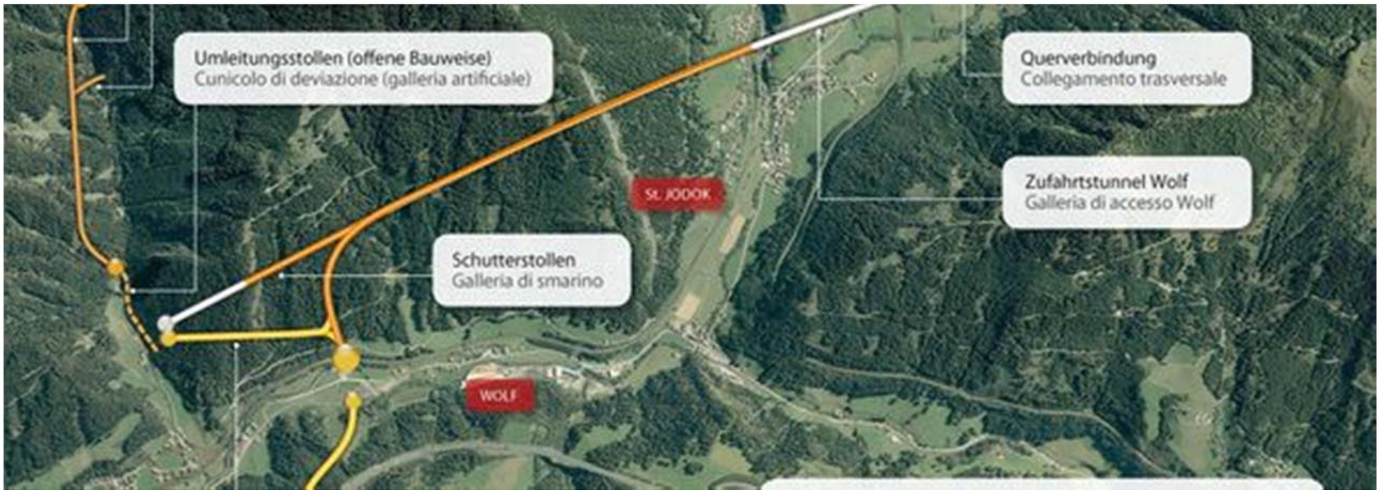
Schematic of BBT Railway System, with Access Tunnels. From *BBT-SE*



Rendering of Tunnel Cross-Section. From *BBT-SE.*



Wolf Construction Plan View. The big dot is the portal at the surface construction site. The access tunnel goes up and to the right. The Padastertal deposit is the dotted line on the left. Visible are the two tunnels for spoil transport between the access tunnel and the deposit. The longer tunnel straight out of the access tunnel is for the conveyor system. The autobahn exit with the Saxen tunnel is on the bottom left. **From *BBT-SE***



7.2 PHOTOS FROM WOLF

The Wolf Site, looking South, with Wolf River and State Road B182. The Wolf portal is on the left, the Saxon tunnel on the right. **From *BBT-SE.***

The Wolf Portal

The Wolf Construction Site, with Saxen Tunnel Off-Ramp and Concrete Materials Silos

Materials Staging Near Portal

Inside the Wolf Access Tunnel April 2014

Water Treatment Settling at Wolf

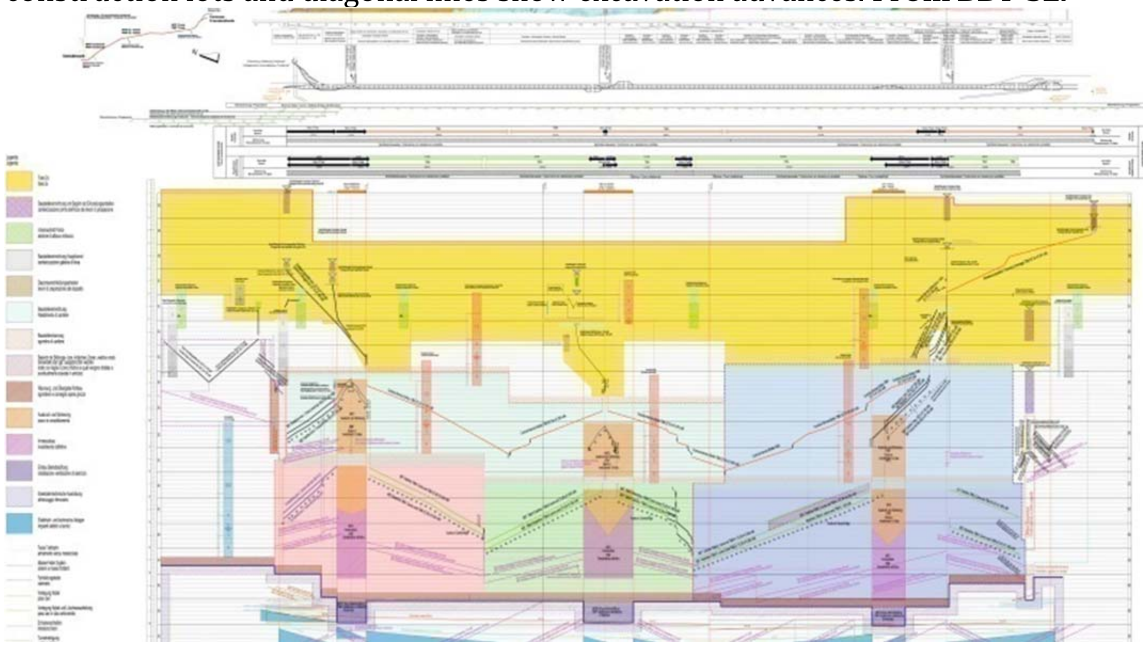
Swietelsky 3-Arm Drilling Jumbo

Shotcrete Machine

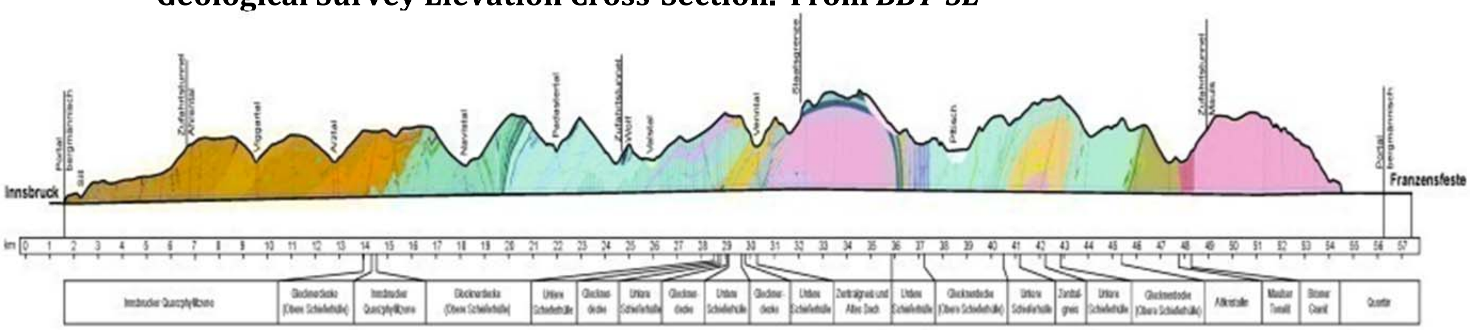
Padastertal Deposit, Looking West. The truck in the foreground has just exited the Padaster Tunnel. The Padaster Brook cover is visible below the crane. Beyond the brook cover the concrete walls of the debris screen are visible. The A22 Brenner autobahn is in the background. **From *BBT-SE***

7.3 <u>Charts and Organograms</u>

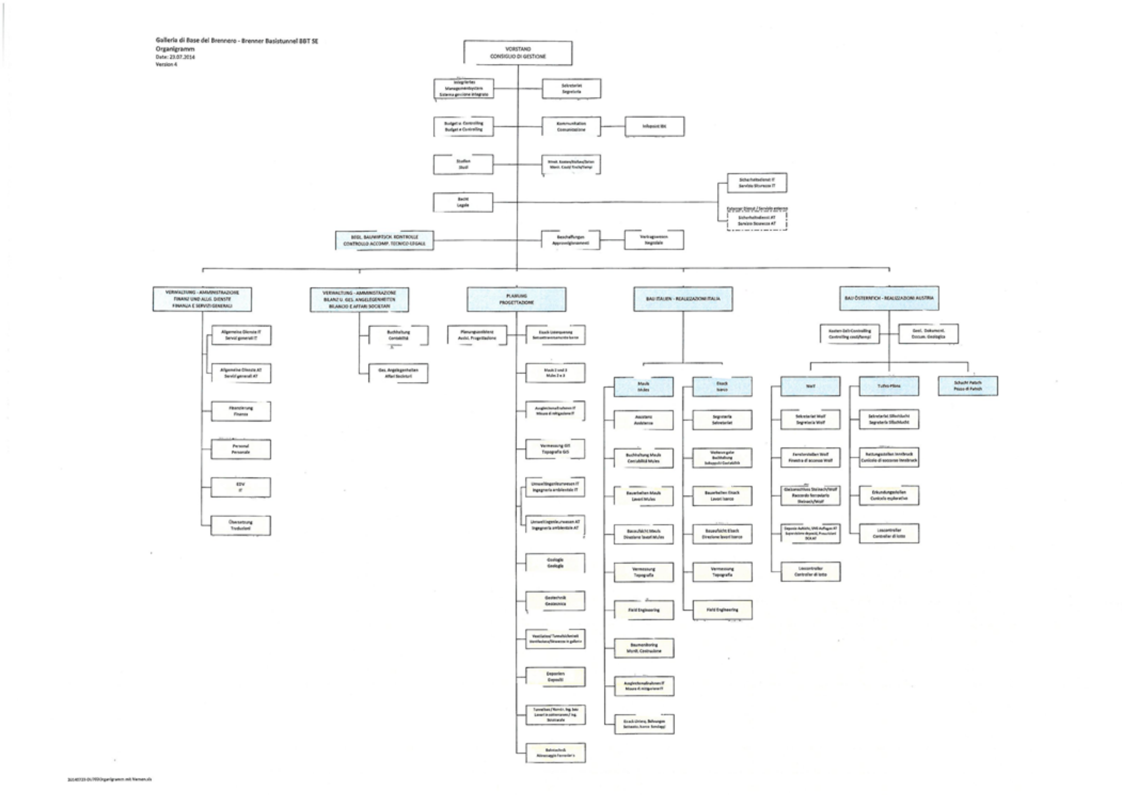
Bauprogram 2013. Time advances down the Y-axis. Tunnel position North to South out the X-axis. Although unreadable at this size, color blocks show construction lots and diagonal lines show excavation advances. **From *BBT-SE.***



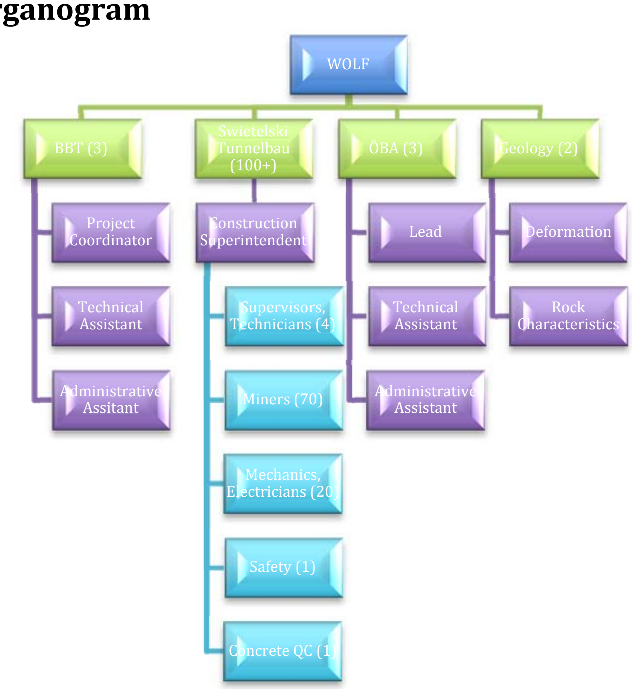
Geological Survey Elevation Cross-Section. From *BBT-SE*



BBT-SE* Organogram.** Names are erased for privacy. **From *BBT-SE



Wolf 2 On-Site Organogram



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