Gotthard Base Tunnel : World's Longest Railway Mountain Tunnel

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Abstract

Switzerland was suffering from serious traffic problem and so it proposed a gigantic project. Over 35 miles long tunnel would cut through the heart of the Swiss Alps. Redirecting the rush and traffic of Europe not over the Alps but under the Alps. To do this, miners had to punch their way through the hardest rock on this planet. For this a TBM was required, each 3 stories high and larger than 4 football fields, working continuously for 6 years. This project was very dangerous and outrageously expensive at a price tag of $10 billion.

Keywords : **Longest railway mountain tunnel, Mega projects, TBM, $10 billion**

I. INTRODUCTION

Switzerland seems to be beautiful country. It was dealing with a serious problem for many years. Being in central Europe and land locked, Switzerland had as many as 14 million cars and trucks from all over Europe passing by to their destinations. This led to serious traffic jams in the country making these the worst jams in the world. An obvious solution was to put the trucks and cars onto trains to reduce their numbers on the roads but unfortunately the existing railway network was running at full capacity.

In 1992, Swiss voters agreed on a common problem in the country and united to find a solution to this problem. So they decided that $10 billion was to be put in for a project which was a high speed flat-straight railway line to cross the trans-Alps barrier not going over it but through it. The Swiss voters were very much in need of this solution but at the same time they were worried about the environmental damage to the beautiful country.

This staggering project would require 2 separate tunnels, each 3 times larger than any existing mountain tunnel in the world. Since it would run directly under the mountain named Gotthard, the project was named **Gotthard Base Tunnel.** Another reason was that this project bypasses the existing Gotthard railway line.

The tunnel would be straight, low lying right through the base of the mountain. This route would let high speed trains run through the mountain at a maximum of 100 mph and even faster passenger trains traveling at 150 mph.

The project approved by 64% Swiss voters put enormous pressure on the project engineers and contractors. The approved project demanded two conditions, first was the guarantee that the project would last at least 100 years, which meant that every material used had to be tested to be the most rigorous in history. Second, and the worst of all was that the project had to be delivered fast and if engineers made mistakes and put the project behind schedule or lead it to bankruptcy, the engineers would pay stiff penalties.

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II. CONSTRUCTION

A. Survey and Sampling

In 1993, after the approval of the Swiss voters, sampling and surveying started. A team of geologist entered the tunnel at five different access points to sample the mountain structure and rocks over there. This was necessary as they were already short on time, so no faults and wrong decisions could be afforded. The engineers found it fit to first decide the course of the tunnel and then begin a full scale invasion on the mountain. During the surveys in 1996, the geologists discovered that this mountain had different rock and structural zones, and one of the most dangerous was the loose rocks holding water. They were hit by an explosion of water and dust while taking core samples which destabilized the entire area. This factor increased the risks and dangers exponentially. The engineers estimated that the entire area would cost $ 600 million to continue which was simply out of budget. After 6 month of exploring, geologists found a much safer area below that danger zone. Deep down they found a totally different rock, which was marble. It was easy to go on with a TBM here. Fig. 1 shows marble.

Fig. 1. Encountered Marble [1]

After sampling and surveying they were aware of the type of geological mountain they were dealing with but they still didn't know how to be precise, and this was a serious concern. If they had missed the direction just by 6 inches, the workers would have to move back and dig many tons of rock to get back on track. So, to make sure they had the exact coordinates, they moved to the global positioning system (GPS). GPS locators were placed at the North and South entrances along with 3 midway points along with the proposed path. The GPS satellite in the geo-orbit position above the earth beamed signals to the receivers which gave them precise signals such as longitude, latitude, and altitude. Once engineers had these coordinates, all they had to do was connect the dots.

B. Design

Since the tunnel channel was safe they could move on with their next big decision, which was the designing of the tunnel. The cheapest was to make a single tunnel with double tracks. This design had a fatal flaw. If a train

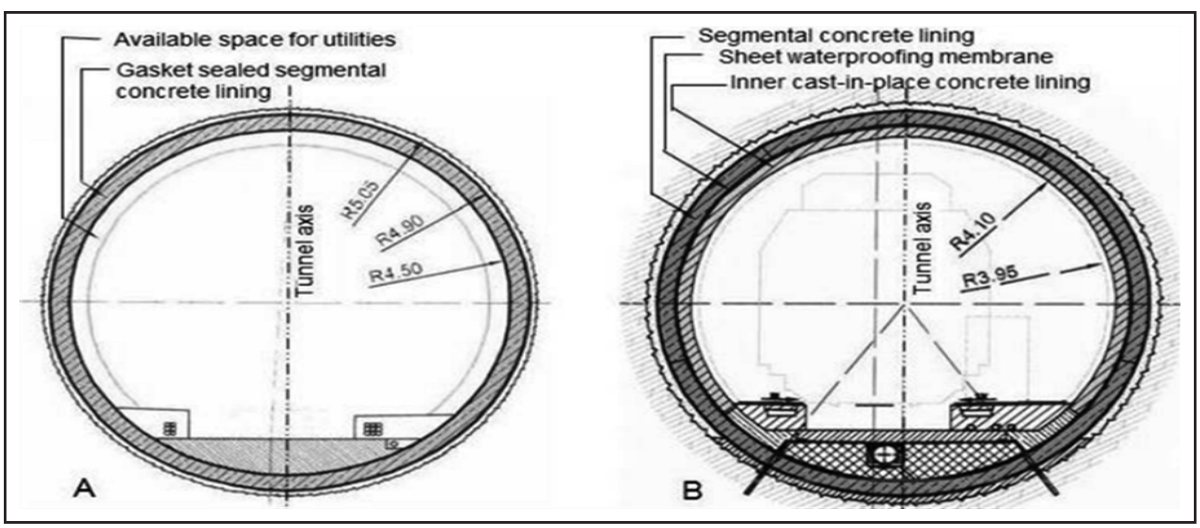

Fig. 2. Double Tube Single Track Design [2]

derailed inside the tunnel, it could hit a train passing by or could block the tunnel for days causing financial stress. A safer way was a three tunnel channel, but it was way out of budget. From the past events, the engineers had learnt that tunnels would always be risky and disaster could happen any moment. This could be avoided or handled with a near perfect and safe design. Thus, safety was considered very important. The Swiss engineers considered pros and cons of every design and finally came up with the best design possible.

They came up with a twin tube single track design reducing the risk of head on collision (Fig. 2). To enhance safety, passage ways connecting the two tubes were placed at every 1000 ft. allowing passengers and rescue teams to move between the tunnels in emergency cases. Two crossover points with rail tracks were there to allow trains to interchange tracks in case of emergency. The designers also added an important feature, a series of escape routes that could crossover to the other side. Each tube had two of these emergency stations. In case of emergency, computers would direct the train to the emergency stations and would allow passengers to escape via these tubes. Massive air turbines would bring in fresh air to these tubes and exhaust the thick smoke out of the tunnel.

C. Digging and Mining

Now the real work could begin. Base camps were setup to attack these mountains, this was because the job was so enormous that the engineers decided to make five entrances reducing the project time by 6 to 10 years. Each entrance had a base camp which consisted of separate concrete plants, water treatment plant, rooms to stay, cafeteria, and even a transit system. This could perform a crucial role in saving the environment. The major problem was the water siting in these mountains, trapped for millions of years which was flowing continuously out of the mountain contaminated by drilling. So, they decided at each base camp to clean this water, removing the contaminants from it and channelling the water to nearby flowing rivers.

Five points where construction started together to speed up the project :

- Erstfeld (the 7.7 km (4.8 mi) section from Erstfeld to Amsteg), with two tunnel boring machines (TBM) boring the two tubes. The break-through of the east tube between Erstfeld and Amsteg took place on June 15, 2009. The portal area was surface-mined.

- Amsteg (the 11.3 km (7.0 mi) section from Amsteg to north of Sedrun), ARGE AGN (Strabag and Züblin Murer) received the contract for work in this sector. On December 9, 2009, the Amsteg section was officially delivered to the owner for fitting-out, with civil engineering, construction, concrete, and lining work completed in early 2010.

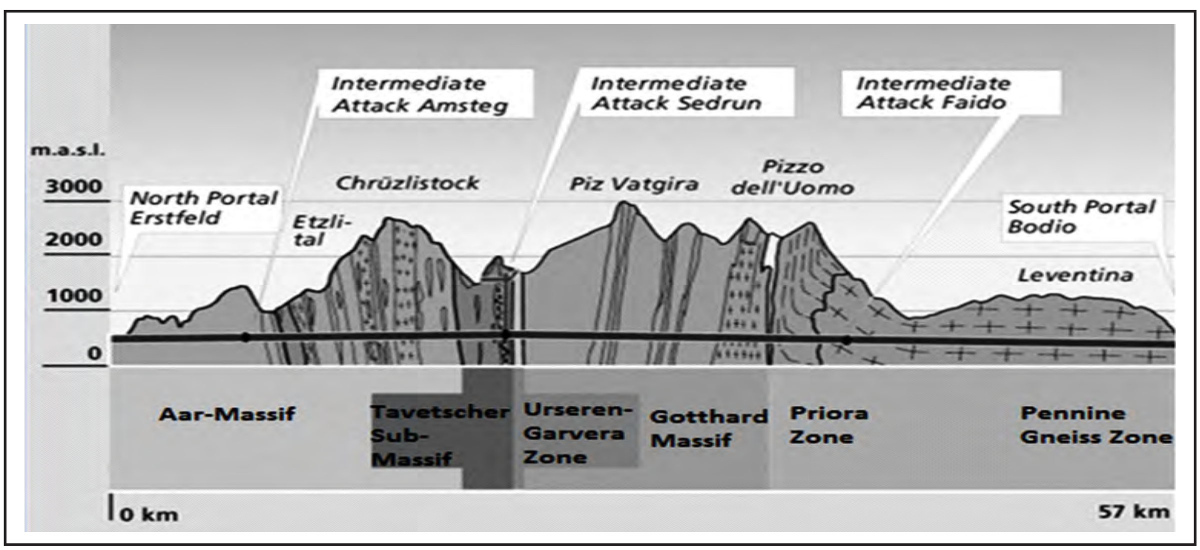

Fig. 3. Schematic Representing the five Initial Entrance Points of the Gotthard Base Tunnel and the way used [3]

Fig. 4. Dark Working Conditions Inside a Tunnel [4]

↳ Sedrun (the 8.6 km (5.3 mi) East tube and 8.7 km (5.4 mi) West tube in the section immediately north and south of Sedrun), along with work performed by Transco (Bilfinger SE, Implenia, Frutiger, and Impresa Pizzarotti). The final breakthrough in the west tube occurred in March 2011. The northbound tubes from Amsteg to the Sedrun multifunction station (north) were handed over to the railway systems contractor Transtec Gotthard on September 15, 2011, the date specified in the construction schedule.

↳ Faido (13.4 km (8.3 mi) East tube and 13.6 km (8.5 mi) West tube in the section from south of Sedrun to Faido), with Consorzio TAT (Alpine Mayreder Bau, CSC Impresa costruzioni, Hochtief and Implenia, and Impregilo).

↳ Bodio (15.9 km (9.9 mi) East tube and 15.6 km (9.7 mi) West tube in the section from Faido to Bodio), with work performed by Consorzio TAT (Alpine Mayreder Bau, CSC Impresa costruzioni, Hochtief, Implenia and Impregilo). Civil engineering construction, concrete, and lining works were completed in early 2010 [10].

Fig. 3. represents the schematic representing the five initial entrance points of the Gotthard Base Tunnel and the way used.

The workers had to work in near darkness and breathe in thin, dusty air as shown in Fig. 4. The working conditions were so hard that inside the tunnel temperature could reach 46 degree celsius. They risked their life every day in this project. In case of emergency like explosion or fire the first thing that runs out is the oxygen as it is consumed by the fire and they had limited oxygen to breath because they were underground. They had heavy machinery like dumpers, excavators, etc. working in near dark dusty tunnels and they might have hit someone during the work as they couldn't see anything. Tunnelling is after all a battle between man and the earth itself. Tunnelling is a risky job but to minimize the risk a team of geologists helped workers by sampling stones and directing the path before drilling. They encountered hard rocks like granite and more which they

Fig. 5. Transit Trains for Workers [5]

could dig with a TBM. A TBM could chew away hard rock but in case of soft or lose rock they used different methods such as drilling and blasting. In cases of tumbling rocks and high water pressure zones, the use of this method can increase dangers exponentially.

An even bigger problem was the 24 million tonnes of rock carved out during excavation. They came up with a brilliant idea to recycle the rocks back into the project. They processed the rocks and converted them into 7.5 million tonnes of concrete used to line up the walls of the tunnel. Once base camps were in place and work had taken pace, the project managers could bring in manpower, 1800 workers from all around the world. These included some of the finest technicians, explosive experts, and heavy machine operators. They began a full scale attack on the mountain. Their first task was to build access tunnel for transporting workers, machinery, and equipment to and from the tunnel. The workers used trains, busses, and even elevator to enter the worksite (Fig. 5).

This big project required the work to go on for 24 hours a day, 7 days a week non-stop for 12 years to be on schedule. This included drilling, digging, and blasting but even after all this, the project would have been impossible without the help of a Tunnel Boring Machine.

D. Tunnel Boring Machine (TBM)

The TBM with a 30 ft high grinding head was designed to cut through some of the hardest rocks in the world. This 400 meter long TBM at full speed can cut 100ft - 130ft of hard rock in a day and had to work for 6 non-stop years. This was only possible by the custom made TBM grinders custom made for this job. Each TBM required 58 of these custom made rollers, each 17 inch in diameter, all custom made by Herrenknecht, in Schwanau, Germany.

A TBM can have up to 90,000 parts with a 3,500 kW engine, generating 4,700 HP required to move the TBM head. This special TBM also had gripper pads used to hold the machine in direction on work and push it forward. These gripper pads were put in place with the help of hydraulic arms. Each TBM puts 26,000 ton of pressure towards the mountain. This machine was also equipped with drilled just behind the grinding head to drill bolts into the tunnel wall to prevent any lose rock from falling. 65 yards behind the drills was a robotic arm, spraying liquidised concrete called short Crete at every inch of the newly carved tunnel wall. In a matter of seconds this solution dries, solidify, and binds the tunnel walls which is also a preventive measure from falling of lose and falling rocks.

A **tunnel boring machine (TBM)** also known as a "**mole**", is a machine used to excavate tunnels with a circular cross section through a variety of soil and rock. It can bore through hard rock, sand, and almost anything in between. Tunnel diameters can range from a metre (done with micro TBMs) to almost 16 metres to date. Tunnel boring machines are used as an alternative to drilling and blasting (D&B) methods in rock and conventional 'hand mining' in soil. It is like an earthworm making its way

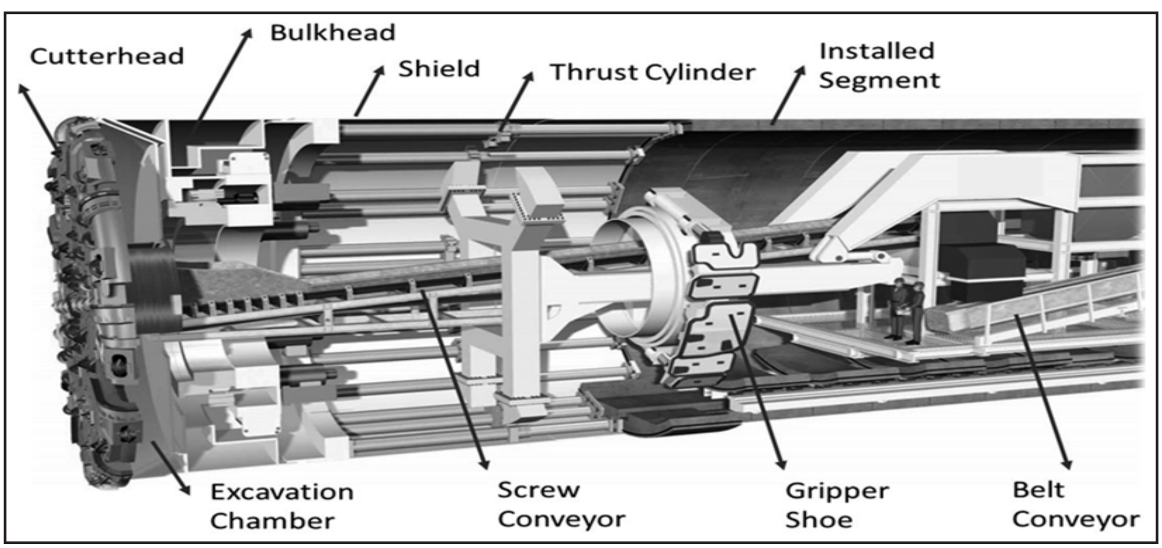

Fig. 6. Components of a TBM [6]

through soil. Fig. 6 shows components of a TBM. While digging the team came across many obstacles, one of them was the hardest rock on the planet, that is, granite.

After every 7ft the workers stopped to reposition the grippers to follow the correct path after which the process started all over again. The project was so big that it required 6 of these custom made TBM machines, each with a price tag of $ 21 million. First pair burrowed north from the southern entrance, a second pair dug south from a midway point and the third pair drilled from the north entrance to a midway towards south. The TBM is a very powerful machine but cannot work in all conditions. There were some slots in the mountain where the rock turned soft where the TBM could not work. Therefore, some old technology of drilling and blasting was used. A special purpose machine called the Rocket Bomber was used for this old technology. It could dig up to 19 ft of circular rock in a day, all because of mathematical tools and planning. First, the machine aligned drills with lasers and made a hole. Next, the Rocket Bomber's computer decided and calculated the blasting pattern which would deliver the most payload. It drilled 80 holes into the wall upto 19 ft high. Two different chemically engineered chemical mixtures were filled into these holes for blasting. Into this combination a detonator was added, and with this simple design, it provided a powerful blast. Blasts like this were set off back to back each day. Fig. 7 shows a heavy duty drilling and blasting machine. Fig. 8 shows a drilling and blasting method cycle.

Fig. 7. A Heavy Duty Drilling and Blasting Machine [7]

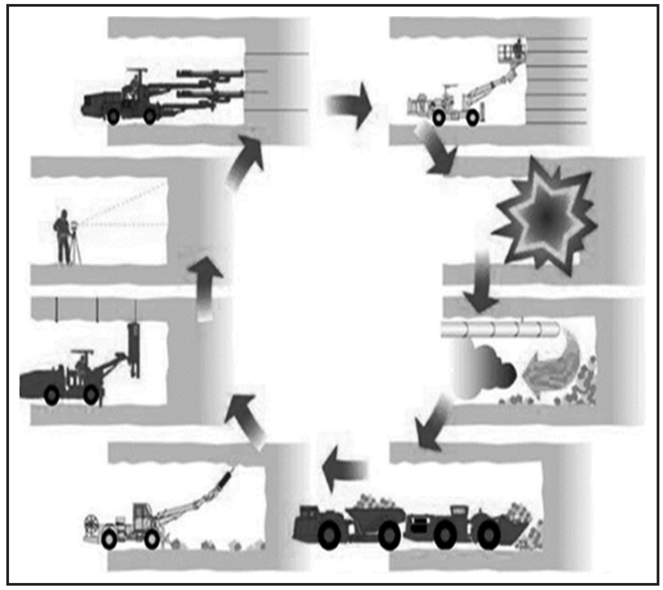

Fig. 8. Drilling and Blasting Method Cycle [8]

Another crucial job was to line concrete on the tunnel wall but the main problem was water continuously sipping out of tunnel walls. The only way was to remove this water because if blocked or sealed off, this could blast out of the tunnel wall and damage the project. The engineers had to apply layers of plastic to this. First layer was of plastic mesh by support of which the water would slip down to the bottom of the tunnel and the second layer was to seal off the inside of the tunnel and send the water at its back to the bottom of the tunnel further throwing it out of the tunnel. This made inside of the tunnel water proof. After the wall lining, metal frames were put across the tunnel to hold the lining in position. After drying, the frames were removed leaving a smooth wall surface.

After finishing the solid structure, engineers began to lay down tracks and modernize it. The main feature of the tunnel was safety of the passengers and freight load. No tunnel is perfect but design and efficiency make it less risky.

It was the safest tunnel ever built on paper, but no one knew until it was tested. Fig. 9. shows safety features in the Gotthard Base Tunnel.

E. Facts

- Diameter of each of the single-track tubes: 8.83–9.58 m (29.0–31.4ft)
- Distance between cross passage tube: ca. 325 m (1,066ft)

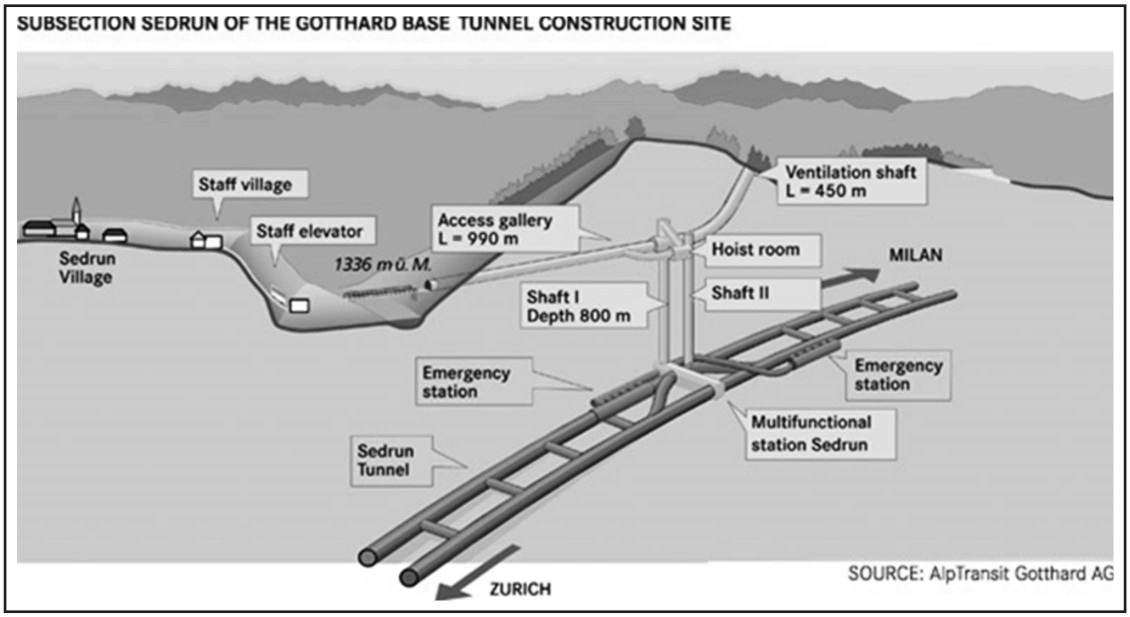

Fig. 9. Safety Features in the Gotthard Base Tunnel [9]

- Numbers of cross passage tubes: 178
- Maximum overburden:2,450 m (8,040 ft) (at Piz Vatgira)
- Start of construction: 1993 (sounding drills), 1996 (preparations), November 4, 1999 (official start, first blasting), 2003 (mechanical excavation)
- Breakthrough: October 15, 2010 (Eastern tube), March 23, 2011 (Western tube)
- Commissioning: May 2016
- Inauguration/opening: June 1, 2016
- Start of daily passenger service: December 11, 2016
- Total cost: CHF 9.560 billion ($10.5 billion) (as of December 2015)
- Travel time: Passenger trains – 20 minutes
- Amount of excavated rock: 24,200,000 ton.

F. Sacrifices Made

Table I shows the sacrifices made.

TABLE I.

SACRIFICES MADE

Date	Nationality	Details
8 June 2000	German	Hit by a boring bar that fell 700 metres (2,300ft).
12 March 2002	South African	Buried by excavation material.
3 April 2003	German	Hit by a rock.
11 September 2003	Austrian	Crushed by a toppling cable drum.
21 January 2005	Italian (1) Italian (1)	Hit in a mine train collision.
23 November 2006	German	Crushed by a mine train.
24 June 2010	German	Catapulted from an inspection train.
16 July 2012	Italian	Fell from a scaffold.

III. POST DELIVERY

Post-delivery of this project is a huge success. There is no traffic on the country roads as expected by the engineers. This tunnel claims to keep everyone alive and bring back to safety even in the worst conditions. Once the New Transalpine Railway was completed in 2016, it was expected to provide many benefits for the region and its inhabitants :

- **Travel time saving :** The New Transalpine Railway would allow a reduction in journey time of one hour between Zurich and Milan for passengers and goods.
- **Additional revenues :** It was expected that this in combination with additional ticket sales of $ 80.54 million and the $ 78.47 million in revenue resulting from goods transportation would generate an annual return of

$ 414 million a year.

↳ **Environment preservation :** By switching to some of the passenger and freight transport from road to rail, Switzerland was implementing one of Europe's largest environmental protection projects. The conservation of the delicate alpine environment through reduced road traffic would reduce environmental costs by $ 134.23 million annually [11].

↳ **Traffic Free :** After the project was delivered, the country roads were as free as never before. The Swiss voters were completely satisfied with the outcome.

With help from all around the world, this project was finally successful. The voters who love their country united against a cause and agreed for a single plan, as they wanted their country to grow and save the environment at the same time. This is one of the best kind of developments known to man. The team worked hard day and night non-stop for 12 years to make the best outcome possible. Even after moving against geological challenges and working with a tight time line, they made everything possible. Fully utilizing their resources such as the best technology, custom made machinery, world class technician, explosive experts and skilled operators they carved the best out of a mountain. For the native people can enjoy their country roads and speed up the economy, Switzerland took risk but did a great job making the world's longest mountain railway tunnel. This project would retrieve the entire investment amount in about 15-20 years, making it a win-win situation.

IV. CONCLUSION

This project is suitable for countries and places that have a mountain barrier in the transportation system and which could make travel easy and hassle free. There are many places in Northern Asia and in North and South American regions where we can use this type of technique. Also, once such a kind of project was made possible other countries can take reference and idea from this project. This project provides ample inspiration for the rest of the world suffering from traffic or transportation issues. This project would prove a very safe alternative to 4, 6, or 8 lane highway where there is still a chance of road rage or accident causing the whole infrastructure to fail in its purpose. This inspirational model also is a very good choice to preserve the environment as it has nil carbon emissions.

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