USING THE PAST TO PLAN FUTURE TUNNELS

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ABSTRACT

For over a century and one-half tunnel planners and designers have had great visions and excellent ideas on how to construct and operate tunnels. Unfortunately, during the last half of the 19th Century and the early part of the 20th Century, the available technology lagged so far behind that these exceptional visions could not be realized. However, that has all changed and many projects exercising great vision can now be constructed and operated because of the advances in technology. It will be shown in this paper that the technology needed to build tunnels was very slow to develop especially before, say 1950. The author shows that technology is now developing at such a fast rate that there are greater challenges to planners and decision makers to be sure their tunnels are at or exceeding the State of the Art. However, new technology will develop during the planning stages that will affect the feasibility of the project. These and other planning issues are discussed.

Keywords: tunnel, planning, technology, development history, innovations, risk management

INTRODUCTION

Big infrastructure projects such as the Hsuehshan Tunnel and other long tunnels are always planned decades ahead. Since these huge projects are planed several decades ahead, it creates a great challenge to planners and decision makers. Moreover, the serviceable life of many tunnels is measured in centuries. That puts the significance of this important conference into perspective. Thus a planner must consider not only lessons learned from the past but also what new concepts and innovations may develop over a extremely long time.

POTENTIAL IMPEDIMENTS TO PLANNING

The English Language has two definitions for the phrase, "Tunnel Vision." In medicine, it is visual problem which is the loss of peripheral vision. One sees clearly only in the center of one's vision but the rest of one's vision around the periphery is dim and blurred. There is another definition for Tunnel Vision; that of "Narrow Mindedness." That means an extremely narrow point of view which results in sometimes one thinking they know the answer to a question before they study the question. This could be either consciously or sub-consciously. Fortunately, our tunnel planners do not experience this trait or tunnels such as the Hsuehshan Tunnel would not have been planned or built.

Rather, we should congratulate our tunnel planners for being so innovative and re-define what the author will call "Tunneller's Vision" which embodies many excellent traits needed to be visionary including: Imagination, Perception, Foresight, Awareness, and Common Sense while using Lessons Learned as a guide.

Another aspect of planning that has been overcome by our tunneling industry is that of reluctance to innovate. In the past, innovative thought has been curtailed because of legal pitfalls and the unwise emotion felt by some of not wanting to be the first to use untried techniques, even though they may be excellent solutions. Again, fortunately, our industry, including our planners and decision makers, especially on the Hsuehshan Tunnel must be congratulated on using innovations both in planning and in order to get the job done. We should be proud of the innovations implemented by our industry routinely.

CHALLENGES TO PLANNERS AND DECISION MAKERS

What are the challenges to Planners and Decision

Makers? They are not only numerous but they also change in significance with time as the process of planning develops over time. These include:

* Population & Demographics
  - How many people use the tunnel and where the tunnel is needed
* Social Trends
  - Changing Economic & Social Values
* Changes in transportation modes with economic development
* Change in transportation mode such as personal auto vs. transit values
* Increased interest for water and wastewater improvements; sanitation and quality of life
  - Changing Environmental Values
* Likely to be one of the biggest factors in the demand for future tunnels
* Increasing interest in preserving the environment
* Acceptance that preserving the environment is a worthwhile goal even if it costs a little more
* Tunnel Technology likely to be available
  - Tools and Methods
* Technical & Contractual
  - Innovative tunnel concepts
* Future Non-Tunnelling Technology
  - Improvements in technology outside of our industry will dramatically affect the type of tunnels and their design criteria
  - Especially true in Transport
* Dwindling oil supplies, higher oil prices may accelerate Fuel Cell and Hybrid development whose use eventually may reduce emissions and ventilation requirements especially in long tunnels
* Should consider concepts such as Maglev, or other breakthrough propulsion systems
* Need for Systematic Consideration of Both Risks and Opportunities in Tunnel Planning
  - Most importantly, begin a formal systematic program as soon as a tunnel is considered to identify and characterize risks but also to identify opportunities that should be considered.

WORLD POPULATION EFFECTS ON PLANNING

It is a fact that the world population is increasing at a staggering pace. In October, 1999, the world population passed the 6 Billion mark. A major factor in world demographics that is important to tunnel planning, is that, in the future, most of the world's population will live, not in rural areas, but in urban cities. In 1950, only about 1/3 of the world's population lived in urban areas. By October, 1999, about ½ of the 6 Billion people lived in urban areas.

Because of this, cities are becoming very large. So large, that the United Nations and other world bodies are giving special attention to those cities where more than 10 Million people live, the so-called Megacities. In 2001, there were only 19 Megacities. By 2015 it is estimated that there will be about 60 Megacities and most of these cities will be in the Developing World. The trend will continue. By 2030, it is estimated that 4.9 Billion people will live in cities which is 60% of the estimated 8.1 Billion world population. Infrastructure must be constructed not just for these cities to be sustainable, but just for them to survive.

Fortunately for the underground industry, if the environment and sustainable development are considered, the underground is often the construction method of choice for much of the infrastructure. It will require those of us in the industry to be pro-active to inform the city officials and planners, at very early stages of a city's growth, of the importance of the underground to sustainable development and to quality of life.

Moreover, more long tunnels will be needed to maintain the efficiency of the transportation networks between these Megacities. In fact, there may not be enough tunnellers to safely construct and operate such a large number of tunnels in such a short time.

TUNNELLING TECHNOLOGY DEVELOPMENT

Tunnelling Technology Development: General Comments

Mining and civil works schemes during ancient times and throughout the middle ages were, in their own right, great feats in their own time. Our most relevant history, however, is in the last 1 ½ Centuries. Our forefathers in the tunneling industry back then had great visions of technological goals that we have only been able to achieve in the last few decades.

The development of tunneling technology was very slow from 1850 to almost 1950. The Channel Tunnel took over a Century to realize the dream, not only for political reasons but also for technical reasons. Since technological changes were slow to develop, tunnel planners knew there was not much chance of significant innovations that might make a project feasible. Now (2005), just the opposite is true; innovations are becoming the norm and this rapid development in technology and innovations must be taken into account by planners. This opens a whole new set of visionary requirements for tunnel planners.

The author was fortunate to have been involved in pioneering work on innovative tunnel support systems in the late 1960's at the University of Illinois in Champaign-Urbana for a project for the U.S. Federal Railroad Administration (Parker, 1972). The impetus for this work was the ambitious concept of a tunnel or series of rail tunnels from Washington DC to Boston, a distance of some 750 km. The concept was bold but was never constructed for many reasons including cost. The project team found that very few ideas were truly new; almost everything had been tried before.

Our forefathers not only had great visions when they planned tunnels but, as will be seen later, they actually tried some of these great ideas. Subsequently, progress in technology made their ideas feasible; however, usually those ideas were put into practice decades or sometimes a century later (Parker, 1999).

Tunnelling Technology Development: Pre 1950

Prior to 1900, practicing tunnel planners, designers, and contractors had great vision and developed some extraordinary concepts for tunnel construction and operation. Unfortunately, more frequently than not, they were unsuccessful, mainly because technology had not progressed far enough to support their ideas and visions. Let's look at a few examples.

It is general knowledge that modern tunnel boring machines (TBMs) are a relatively recent development in our industry, say since the 1950's.

However, the first mechanized tunnel machine was created and tried a century earlier! It was a percussion-type machine that was tried unsuccessfully on the 12 km long Mt. Cenis Tunnel (also known as the Frejus Tunnel) from Italy to France (Stack, 1982). Interesting to the theme of this conference on Long Tunnels is the fact that this innovation (as well as the first use of the compressed air drill) took place in this tunnel which was the first of the long alpine tunnels. The second mechanized tunnel machine, also unsuccessful, was built for the 8-km-long Hoosac Tunnel in Massachusetts, USA in 1853. There were numerous attempts over the next century to build and use a form of mechanized tunneling machine. A few were fairly successful, including machines which successfully bored a couple of km for an earlier attempt at constructing the Channel Tunnel. But, whatever the reason, technology was insufficient to permit technically and cost effective machine excavation and there was a time-span of over a century before TBMs began to become practical.

Pressurized-face machines also took a long time to develop to a practical method of excavation. In 1874, Greathead patented a tunneling concept that consisted of a shield with water under pressure at the face, excavation using water jets, and muck being pumped out as a slurry. There was even a chamber for breaking up cobbles and boulders. For almost a century there were a few attempts to develop machines with pressure on the face but technology was again insufficient to permit technically and cost-effective machine excavation.

Gunite, the forerunner to shotcrete was first developed in the USA around the turn of the century when Carl Akeley invented the Cement Gun to apply mortar over skeletal frameworks of prehistoric animals for Chicago 's Field Museum. Although tried in an experimental mine in Pittsburgh in 1914, it wasn't until 1952 on the Swiss Maggia Hydroelectric project before tunnels were solely supported by shotcrete (Parker, 2001). Again, there was a ½ century span between vision and practical application.

Technology Development: 1950 to Present

After about 1950, technology started to catch up with the vision and many of our forefather's ideas became reality. James S. Robins built an 8-m-diameter rotary TBM which successfully excavated Pierre Shale at Oahe Dam in the USA and then pioneered the use of solely using disc cutters on a TBM cutterhead on a small diameter tunnel in Toronto. Although there was a long, difficult period for hard-rock TBMs, ultimately technology permitted TBMs to overcome hard rock to where they are now routinely used to excavate most tunnels, even long tunnels. Technology is still developing for these TBMs at a rapid pace in attempts to make TBMs capable of controlling the more difficult ground conditions.

After more than a Century delay since Greathead 's patent, pressurized-face TBMs were also the benefactor of the rapid development of technology in the latter half of the 20th Century. In the 1960s, several developments took place all over the world that made these machines more feasible technically. These took place in Japan, Germany, England, Mexico, USA, Canada and elsewhere. Earth Pressure Balance and Slurry machines now are commonplace in many projects. Now, there are various concepts for handling mixed-face conditions to make machines more feasible for rock tunnels that will also pass through fault zones with differing ground conditions. Such machines are now designed to be able to be converted with some, but acceptable, effort from hard rock mode to a pressurized-face mode, becoming increasingly adaptable and are even being used on longer tunnels.

Steel fiber reinforced shotcrete (SFRS) was developed in the USA around 1970. The author worked on the practical development of SFRS at the University of Illinois in the early 1970's and published his results in his Ph.D. thesis in 1976 (Parker, 2001). Despite its great promise, it took another decade before SFRS became common in tunnel construction but SFRS is now routinely used.

These examples illustrate that technology has started to catch up with the vision of the planners and designers. The message to the planners and designers is that our industry is very creative and can overcome any challenge. Thus, planners should be bold and daring in the planning of projects.

TOOLS FOR PLANNERS

In the 1950s and 1960s, planners did not have many of the advances that we now enjoy (2005). These are too numerous to cover adequately in this paper but they include the following:

* TBMs
* Earth Pressure Balance Machine(EPB)
* Slurry Face Machine (SFM)
* Shotcrete
* SEM/NATM
* Microtunnels
* Single Pass Lining
  - Concrete Segments
* Waterproof Membrane
* Advanced Geotechnical Investigation Techniques
* Numerous Ground Improvement Techniques
  - Jet Grouting
  - Soil Mixing
  - Compaction/Compensation Grouting
  - Efficient and effective grouting in front of TBM

Even rock bolts were just being accepted by civil engineering projects in the 1950s although they had been used successfully in the mining industry.

Each of these (and the many others not listed) make tunnels and underground construction more technically and financially feasible. Accordingly, had planners been bold and daring back in the 1950's, more tunnel projects would have been proposed and built. Again, this is proof of the strength and creativity of our tunneling industry. If a planner can dream it up, our industry can get it done.

PAST AND CURRENT SUCCESSES FOR PLANNER 'S CONSIDERATION

General

Some of the past and current successful techniques that planners can use to assure themselves that they can be bold in their planning include the following:

* Tunnel Construction & Operation Techniques
  - Large & Adaptable TBMs
  - SEM/NATM
  - Microtunnels & HDD
  - Jet Fan Ventilation
* Innovative Tunnel Concepts (Use and Configuration)
  - A86 Paris (6 vs 2 lanes)
  - SMART Kuala Lumpur (Highway and Flood Control)

  - CSO Wastewater Storage Tunnels
  - Submerged Floating Tunnels
  - Long & Deep Tunnels
* Concepts from other Industries
  - MagLev (Or other Propulsion Systems)
  - Fuel Cells or Hybrid Vehicles
* Contractual, Financial, and Managerial Concepts
  - Risk Management Principles
  - Identification of Opportunities
  - Life-Cycle Cost Concepts
  - Advanced Cost Estimating concepts

These are just a few of a large number of techniques and tools that Planners and Decision Makers now have to look more boldly into the future to propose and to successfully implement more tunnel and underground projects.

Systematic Risk Management Techniques

Very important among these is the recommendation that tunnel owners and planners begin to use systematic risk management principles to identify any risks in a way that directs the rest of the planning process to minimize those risks. This systematic procedure is done as early as possible in the stages of a project (pre-conceptual or idea stage). The development of Risk Registers is often done in meetings of experienced experts who identify the risks and solutions. This systematic risk management work then is carried on and updated all the way through design and construction. The risks to be considered should be broad and also include risks of cost, schedule, environment, public acceptance, etc in addition to the technical risks that always immediately come to mind. The same concepts can be used to identify value engineering ideas, as well as to identify broad ideas and opportunities (including “thinking out of the box”).

Tunnels often remain in service for over a century. Accordingly, decisions about whether a certain infrastructure should be a tunnel, or not, should be made on considerations of Life-Cycle Cost, not Initial Capital Cost. This is a difficult concept to implement but it is important for planners and decision makers to avoid the pitfall of decisions based on initial capital cost. Finally, using principles similar to those used in Risk Management, the likely range of the cost of the tunnel should be developed as a range, not as a single number.

Construction Technology

There are many tunnel construction and operation techniques that planners should consider for all projects, including long tunnels. These include the large and adaptable TBMs that have evolved over the years to cope with mixed-face conditions. Naturally, Sequential Excavation Methods (SEM/NATM) are always available when even the TBMs are not appropriate, including those openings with irregular geometry. Microtunnels and Horizontal Directional Drilling methods (HDD) are now being considered as methods to supplement the construction of larger tunnels, to include pipe-roof techniques etc.

There are new concepts being developed all the time for safe ventilation of tunnels (including long tunnels) during construction. The development of jet fans now makes it possible to build longer road tunnels (within limits) without having to build and maintain a large fixed fan for permanent works.

Bold and Daring Tunnel Concepts

There are many innovative tunnel concepts that have evolved because the project planners were highly creative and “thought out of the box.” These include the A86 road tunnel project in Paris. By changing the rules and requiring all vehicles that use one of their tunnels be less than 2-m-high, the owner is able to fit 4 lanes of traffic (in a double-deck configuration) in a 11.6 m outside diameter tunnel. There are even plans for future expansion to have 3 lanes on each deck for a total of 6 lanes in a tunnel that, at least in the USA, can only fit 2 lanes of traffic. That makes the cost of those tunnels per km per lane on the order of ½ to 1/3 of the cost elsewhere.

Another innovative concept is the SMART tunnel project in Kuala Lumpur. This double-deck tunnel is specially configured to handle both auto traffic and floodwater. During low and medium flows, water flows beneath the lower deck while cars are still traveling through the tunnel. However, when a very big flood occurs, cars are removed and the flood waters are passed through the entire tunnel including the roadway. This way, the public gets two end uses for the tunnel for a price and construction disruption that is less than that of two separate tunnels. Moreover, the cost of the tunnel is shared by two groups making each easier to afford. The concept of using tunnels to store wastewater during a storm, such as the Chicago TARP project, is another dual use of tunnels.

In Seattle, a 50-year-old viaduct which follows the waterfront was damaged by an earthquake and needs replacing. Also, the seawall just beneath the viaduct also needs replacing. Planners and decision makers are considering a double-deck cut and cover roadway whose outboard wall will be designed to be the new seawall. This new structure will replace both the viaduct and the seawall with one structure again with cost, schedule, and disruption savings to the public and increases the potential sources of funding.

Finally, a Submerged Floating Tunnel (SFT) has been proposed several times around the world but never built. Conceptually, the SFT can be a lot shorter tunnel which gives much greater flexibility in locating tunnel portals. Though SFT may not have much to do with Long Tunnels, the concept of thinking outside of the box, which such a concept represents, is important.

Impact of Issues and Events Outside of the Tunnelling Industry

Finally, there are many issues and events outside of our industry that will have a significant impact on our planning for tunnels. One of these is the price and availability of oil. There have been numerous claims over the past decades that the world would run out of oil, or otherwise cost too much, and that other fuels will be necessary. This has not happened yet but may happen, if nothing else, because of greatly increased demand for oil by developing countries. So there is a greater chance that the world will need other fuels, possibly to include hydrogen fuel cells or a hybrid.

Interestingly, the fuel cell is another concept that was invented in 1839 but did not gain any real practical use until used by NASA for space travel. The concept is being worked on by many countries and, in the USA; there are several local and regional agencies which have fuel cell or hybrid technology as a test. When hydrogen is the fuel, the only emission is water. It may be preposterous to think that the internal combustion engine may be replaced by something better, but stranger things have happened even within the author 's lifetime such as the development of jet engines, space travel, television, computers, and cell phones, etc. The author is not predicting such a transformation in transportation may take place but one should think of what effect it would have on the design of the ventilation system and the operation of the tunnels if it were to take place. More likely, in the foreseeable future, some hybrids will become popular and the gasses our tunnel ventilation systems must deal with may decrease or may not increase as fast as predicted.

Anther concept that may affect future tunnel planning is related to propulsion technology such as MagLev or other future propulsion breakthrough. There are Maglev systems in operation now but not in tunnels. There is a lot of development, and reduction in cost, necessary to make Maglev, or any other new propulsion system worth considering for tunnels. However, there are some promising aspects if the concept becomes viable. For instance, the system is capable of being faster and it is environmentally friendly. Moreover, it can negotiate tighter curves and steeper grades both of which may allow tunnels to be shorter and therefore less costly. Whether such a concept will be technically feasible or cost effective is yet to be seen, but consideration of such a concept for bold and daring planning of future tunnels may not be unreasonable

Long Tunnels

Finally, the theme of this conference, design and operation of long tunnels has its innovative concepts in itself and they fall in the category of bold and daring. Long tunnels, especially long transportation tunnels, will be needed more and more as the Megacities develop around the world to connect the inner city with the outer suburbs and to interconnect the Megacities. They afford great reductions in travel time but also important reductions in fuel consumption and emissions. They also avoid the visual blight and they provide great environmental and sustainable development advantages over that of surface transportation that goes up and over the topography. In order to make these long tunnels more financially feasible and to make them more acceptable to the public, planners should definitely convert the strong environmental advantages to an equivalent cost savings to society.

Thus, the initial cost should be mitigated and offset by significant savings attributed to the environment over the years of operation. It is imperative for planners to consider the financial aspects of tunnels from a Life-Cycle Cost standpoint that also takes into account the accumulative equivalent financial benefits from saving the environment. Planners and decision makers must be courageous and convincing as they present a clear message of the overall advantages of tunnels to the media, public, politicians, and fellow decision makers.

CONCLUSIONS

We should be very proud of our forefathers who had great vision and whose ideas were not achieved until our lifetime. Technology development was so slow from about 1850 to 1950 that their ideas did not materialize until technology made their schemes feasible.

Now, technology is keeping up with our ideas and vision which can be implemented relatively quickly. Accordingly, planners should be aggressive and bold in their plans for tunnels.

Owners and planners should use risk management principles from the very first time a tunnel solution is considered and carry out systematic risk management evaluations throughout planning, design and construction. These same principles should be used to systematically develop and implement value engineering and new opportunities, especially those thinking out of the box. This is particularly true for long tunnels that have abundant uncertainties.

It should always be remembered that tunnels, particularly long tunnels, are an investment, not a cost. Owners should develop ways to account for a financial credit resulting from environmental advantages especially for long transportation tunnels that accrue enormous environmental benefits to society. These environmental cost advantages should be incorporated into cost ranges that take into account the long service life of the tunnels by making the decision on Life Cycle Cost concepts, not initial capital cost.

The tunnel and underground industry is very creative and their ability to innovate has been proven many times, including the successful completion of the Hsuehshan Tunnel. Owners and planners should have faith in the tunnel and underground industry. The industry will be up to any challenge so planners can plan boldly and with Tunneller's Vision.

REFERENCES

* Parker, H. W., and Semple, R. M., (1972), " Development and Large-Scale Testing of Innovative Tunnel Support Systems," Proceedings, North American Rapid Excavation and Tunneling Conference (RETC) The American Institute of Mining, Metallurgical and Petroleum Engineers, 469-497
* Parker, Harvey W. (1999),"The Development of Hard and Soft Ground Tunnels," Proceedings, Tenth Australian Tunnelling Conference, Keynote Addresses and Asia-Pacific Forum Volume, The Australasian Institute of Mining and Metallurgy Publication Series 1a/99, Victoria, Australia, 25-31
* Parker, Harvey W. (2001), "Early Developments of Shotcrete and Steel Fiber Shotcrete," Proceedings, Shotcrete for Underground Support VIII, ASCE, Reston, Virginia, 240-258
* Stack, B.(1982), Handbook of Mining and Tunnelling Machinery,John Wiley & Sons: Chichester, 742 pp