Report on Underground Solutions for Urban Problems

ITA Working Group
Urban Problems - Underground Solutions

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>> Foreword

In 2007, our planet became predominantly urban as for the first time, more than half of the world's population was living in cities. In the second half of the last century the number of people living in urban areas increased from 750 million to 2.86 billion. By 2030, this proportion is estimated to rise to 61%, or nearly 5 billion people. While cities of the global North face challenges of physical expansion and urban sprawl, those in the South are experiencing rapid and uncontrolled urbanisation, competing demands for land and other increasingly scarce natural resources, and air, water and surface pollution. Unsustainable urban development is a common challenge, especially in metropolises and megacities, whether in developed or the developing world.

In this context, the International Society of City and Regional Planners (ISOCARP) is working towards producing knowledge for better cities. A global association of professional planners, ISOCARP was founded in 1965 and today its network brings together individual and institutional members from more than 80 countries worldwide. The Society has a formal consultative status with UNESCO and is recognized as an NGO/professional partner by UN-HABITAT and the Council of Europe.

Underground space is an area of special interest to ISOCARP, as we recognise that many cities, both in the developed and developing world, have no choice but to go higher and dig deeper in order to become sustainable. Underground spaces can be used for a variety of purposes, including not only the mundane and necessary such as infrastructure, services and transport, but also for recreation, entertainment and commercial uses. The key, however, is a broad understanding of how underground space can be planned and utilised most effectively, and ensuring that any negative impacts of underground development are properly mitigated. Whereas there are well-established planning instruments and procedures for the surface and going high, till now underground space is not planned in a holistic manner, but mostly tackled from the point of view of a technical solution from one specific discipline. At the same time, it is important to recognise that underground space is an essential part of our cities and has to be integrated part of holistic spatial planning.

There are many examples of successful use of underground spaces (e.g. underground shopping linked with the metro system in Singapore), but at the same time, many experiments have also failed due to lack of foresight and proper planning (e.g. pedestrian subways in Delhi). Urban planners need greater knowledge and insight into how underground spaces can be used to make cities more productive as well as sustainable.

For all these reasons and more, ISOCARP welcomes this extremely timely and interesting report from ITA-WG20 on "Urban Problems, Underground Solutions." It is a very valuable resource for urban planners and all those working on urban problems and potential solutions, and will give them ample food for thought. ISOCARP is keen to develop these ideas further, in collaboration with ITA/ITACUS, and this report is certainly an important step in the right direction.

Shipra Narang Suri, Ph.D. Vice-President, ISOCARP
Manfred Schrenk, Vice-President and Treasurer, ISOCARP

>> SUMMARY

World wide, we see developing nations building new infrastructure as well as developed cities rehabilitating and expanding their infrastructure to meet the demands of increased population, energy efficiency, and environmental awareness of the public. Ten years ago ITA issued its special edition of the Tribune entitled "Why Go Underground, Contribution of the use of Underground space to Sustainable Development." Working Group N° 20 of the ITA, focused on Urban Problems and Underground Solutions, has continued examining the use of underground space in the urban environment as it evolves with expanding cities and urban densification. This report present examples of the uses of underground space in cities, trends in Metro and roadway planning, and gives an overview of aspects to be considered during the decision making process, in order to optimally include underground solutions.

Common planning goals in dense urban environments include improvements in infrastructure: transit, distribution of resources, goods and service, while becoming environmentally sustainable. Placement of infrastructure and other facilities underground presents an opportunity for long-term improvements in the environment, and more efficient use of resources. Investment in these infrastructure projects creates opportunities for innovation in construction methods – important in reducing the impacts of infrastructure on the environment as well as the creation of jobs and commerce for the urban workforce and businesses.

Leaders see investment in infrastructure as a key to success … Cities such as Los Angeles – long seen as the leader in personal automobile travel – are now investing in urban rail and supporting intercity rail. The mayor, Anthony Villaraigosa has made promoting and expanding public transit options a top priority in his transportation agenda.
As part of this effort, he has encouraged LA residents to use the metro and bus systems throughout the City and has worked diligently to secure funding, including the passage of a ½ cent sales tax for local financing. The plan envisions expanding the regional urban rail transit network, including a "subway to the sea" among many other rail and transportation projects.

In London, Mayor Boris Johnson said of the Crossrail project that will connect isolated Railway stations constructed in the 1800s: "This amazing project will create and support thousands of jobs, relieve congestion and provide a high speed link between the east and west of London… When the first of Crossrail's chariots glide smoothly along its lines in 2017, it will change the face of transport in London and the south east forever."

More and more, city planners and decision makers are realizing that going underground is the only solution. Most recently, the highway tunnel in Seattle, the Alaskan Way Viaduct Replacement project, was awarded for construction. The tunnel will be one of the largest in diameter (17.6 m) to date. Other solutions – replacement of the existing at-grade structure or cut and cover construction, while feasible, would be as costly in terms of capital cost and loss of business during construction.

In Atlanta, Mayor Shirley Franklin has said, "no city can be successful unless it is safe, has clean water, clean air and a good educational system[(1)]. Clean water was one of her priorities, and she addressed the City's aging sewer system by initiating a $4 billion upgrade for the infrastructure, that includes the unpopular move of raising user fees. Today the city is well on its way to clean water and improved stormwater control".

Use of the underground is not restricted to mega projects. This paper presents innovative uses of space for storage, local transport, water conveyance and treatment, and commercial space. Underground solutions to urban problems were in the recent past only considered if all other (above ground) solutions had been exhausted. If the underground options are considered at an earlier project stage, more optimal solutions will become possible.

Therefore Working Group N°20 of the ITA hopes that this overview of existing underground solutions for urban problems and the way they can help in the decision making process can boost the consideration of the underground option for future projects.

(1) Epoch Times, February 2009, Mary Sliver

Figure 1, Metro entrance, Paris, France

Figure 2, Underground swimming pool, Helsinki, Finland

1 >> Introduction

For centuries, mankind has used underground space. The International Tunneling and Underground Space Association (ITA) was created in 1974 with a mission to encourage the use of the subsurface for the benefit of the public, environment and sustainable development, and to promote advances in the planning, design, construction, maintenance and safety of tunnels and underground space. Working groups within ITA provide special studies and publications to address the use and construction of underground space. Working Group N°20 was formed to provide an overview of the typical challenges of urban city planning and the solutions which are offered by the use of underground space. In this report we provide an overview of typical urban issues and an appendix of examples where the use of the underground and modern technology has been taken advantage of to provide overall benefits to the urban environment. Given increasing population growth world-wide, and continued aging of existing infrastructure, this publication elaborates on previous ITA work such as “Why Go Underground”(ITA, Godard, 2002), and provides new project examples to illustrate both traditional and creative uses of the underground to assist with beneficial urban space planning and preserving surface land for future use.

To understand why we use underground space, one must analyze the use of underground space versus the surface area above. The underground may provide a setting that is difficult to build in, environmentally undesirable, and more costly to construct in than surface facilities. On the other hand, it may offers better natural protection against environmental elements, including destructive weather, noise, and seismic events. At the same time, the space created for underground structures has the advantage of allowing use of the surface for other functions.

Over time, the uses for underground structures have developed from primarily shelter to space for infrastructure and a wide range of functional facilities.
The uses may be categorized into several primary uses: Infrastructure for transit and utilities, storage, and protection of the environment. Increasingly, the public, especially in larger cities, demands a higher quality environment with respect to:

- Reliable and safe transport of people and goods,
- Water distribution and sewerage systems,
- Sustainability of the environment and containing sprawl,
- More green spaces and recreational areas,
- Reduced use of fuel, and fuel emissions,
- Noise control,
- Aesthetics,
- Efficient use of real-estate.

All of these demands call for continuous improvement of sustainable and resource efficient urban planning and development, and is and can be facilitated by the use of underground structures.

Advanced underground construction technologies can provide solutions for reducing congestion and other environmental problems while contributing to energy efficiency. However one of the greater aims of underground use in an urban environment may be to free surface space for other human needs and to improve the living conditions of cities.

This paper is divided into three sections to present beneficial uses of the underground.

- The first section reviews typical urban problems for which use of underground space may offer a better alternative than use of the surface. Subject areas include architectural quality, safety and security, traffic congestion, noise, air quality, water distribution, flood control, and synergy effects.
- The second section describes typical solutions the underground can offer such as subway systems, road tunnels, underground manufacturing space, water and sewerage transport systems and storm water relief systems.
- The final section illustrates the

Figure 3, Mt. Baker Ridge Tunnel, Seattle, Washington, USA

Figure 4, Traffic Congestion, Los Angeles decision making progress for identifying and creating underground solutions. The appendix of the report includes referenced projects in a collection of worldwide case history examples to provide illustrations of significant underground solutions to urban problems.

The report is directed toward planners, developers, urban policy and other decision makers, and is intended to assist them by providing creative ideas for the solution of urban problems. The focus of this product is somewhat less on technical details and more on strategic aspects of urban planning, may they be of social, economical, ecological or aesthetical background.

1.1 TYPICAL URBAN PROBLEMS

Throughout the 20th century, urbanization has been occurring globally. The urban environment, however, cannot fully absorb the influx of people without substantial infrastructure improvements.
Rapid urbanization has produced many urban problems such as the need for more housing, roadways, water and power distribution systems, sewerage systems, reduction of air and noise pollution and other population growth issues.
In addition, it has been documented late in the 20th century that the related problem of sprawl away from the urban core strains the environment by creating more traffic congestion and travel time, loss of valuable farm land, and inequitable allocation of resources (Longman, 1998, Chen 2000).

Urban issues such as traffic and air pollution are typically associated with developed nations. But the pressing phenomenon of "Mega Cities" in developing nations also poses extreme infrastructure needs – which are compounded by inadequate water and power distribution systems, sewerage and treatment systems, and flood control measures.

Although there are many problems in urban areas, there are variations depending on the country's level of development. Japan's experience is used as a typical example. After the World War II, the economic conditions in Japan progressed greatly, but the infrastructure to support growth lagged behind. Table 1 summarizes the major urbanization issues in Japan from World War II to the present.

Around 1955, urban problems such as traffic control, pollution, noise, and slum expansion became obvious. Between the 1950s and 70s, significant urban problems developed, including lack of green space, aging infrastructure, development of use policies, traffic congestion conditions, water and sewer capacity, trash disposal, and energy consumption.

Table 1, Summary of Urban Development, Example of Japan (Nishi et. al., 2005, 2007, NLPI, 1997)

Timeframe	Urban Developments
After World War II (1945~1954)	The Lack of a number of public facilities (Railway, Highway, Housing, etc,)
1955	Traffic congestion
	Pollution and noise
	Slum development land use
1975	Integrated traffic system (Share between rail and road)
	Urban natural environment (Green and Open space)
	Urban space and landscape policy
1990	Revival of light rail (Revival of public transportation)
	New urban transportation such as a plan of great deep underground railway
2000 - present	The advanced age problem (Facilities for handicapped and aged)
	Safety and Security
	Shortage of Resources

Figure 5, Aging Surface Infrastructure, New York

Figure 6, Photos other Urban problems e.g., crowding, overhead wires

Figure 7, Urban Congestion, Japan

All of these continue to the present, and population related expansion continues - compounded with issues related to an aging population and demands for additional social services such as accessibility for the disabled.

Around 1985 to 1995, urban tree planting, urban planning, amusement centers and private sector vitality, safety and an interest in urban space and landscape policy were envisioned. New urban transportation systems such as a plan for a deep underground railway emerged. Since 1995, many phases of the transportation systems have been developed. Future urban planning is based on the landscape, the environment and other concerns such as disaster prevention, safety and security. All of this must be seen in the context of decreasing tax revenues, increasing national debt, decreasing birth rate and an aging population.

At the beginning of the 21st century, Japan sees continued population growth with additional pressures to find and conserve natural resources as energy becomes scarce and expensive (Newman, 2009). At the same time the democratic consensus building process and the need to weigh in the quality of the urban environment in any development, makes finding solutions for urban problems slower and more difficult.

1.1.1 Quality of the Urban Environment

In addition to basic necessities, "Quality of life" is one of the standards of the urban environment addressed by the World Health Organization (WHO). In 1961, 40 years ago, the WHO proposed four measures related to the quality of life: safety, health, convenience, and comfort (UN, 1961).


THURSDAY, DECEMBER 19, 2002

The Asahi Shimbun

Japan's Leading National Newspaper | English Edition

ニュースで英語が解る!

ASAHI WEEKLY

Court orders developer to lop a building in half

A Tokyo developer is told its apartments mar the view in Kunitachi and must be cut down to size.

違法部分の取り壊し命令

Figure 8, Illustration of Planning Regulations for Community Preferences

Architecture gives the order and the beauty to urban space and has a role which unites the community.

Urban plans and codes are developed to direct buildings to comply with agreed upon standards and guidelines. Standards for quality of life may be subjective, however, and in a democracy are difficult to come to agreement on. Over the same 40 year period, urban areas have seen a swing from approval of elevated freeways and transit systems to move traffic across downtown areas to removal of these structures for beneficial use of the surface land. Similarly, flood control projects undertaken in the early part of the 20th century are being re-considered for use of the waterfront for recreational use.

The urban "problems" are well documented and those that may be solved through use of the underground space include:

- Crowding and lack of space (for work and recreation),
- Traffic congestion,
- Aging infrastructure and distribution of resources,
- Environmental conditions such as noise and air pollution,
- Esthetic qualities and image of our urban environment quality,
- Safety, security, and protection against natural disasters,
- Flooding,
- Sewage conveyance and treatment,
- Synergy effects of the above.

1.1.2 Traffic Congestion and Travel Time

Since they are well understood, little effort needs to be devoted to documenting travel time issues and need for congestion relieve in automobile congested streets. Time savings during rush hours by using grade separated rail systems saves hundreds of hours per year per worker. The cost of road congestion in OECD(2) countries is estimated to be equivalent to about 2 per cent of the GDP (Godard, 2008).

Figure 9, Los Angeles River today

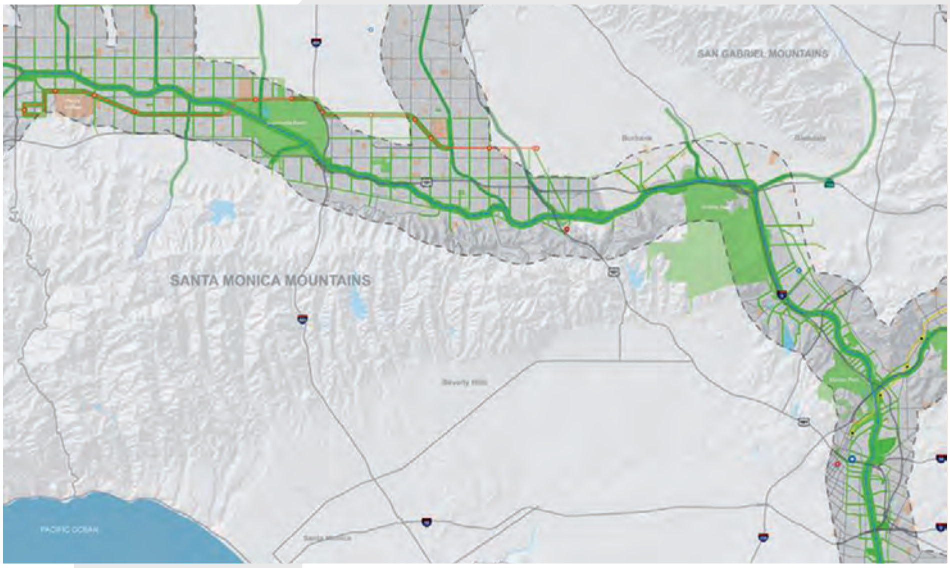


Figure 10, Los Angeles River plan for Green Spaces

(2) Organization for Economic Cooperation and Development, an international economic organisation of 34 countries founded in 1961 to stimulate economic progress and world trade.

1.1.3 Space Consumption

Surface space becomes scarce in the urban environment. It is interesting to compare to the use of a metro for passenger transport with typical surface transportation options such as bus and private cars. In this respect, the Paris Transportation Board, (RATP) reports for the city of Paris that: "… in order to transport 50,000 passengers per hour and direction, a metro needs a right-of-way measuring 9 m in width whereas a bus would require 35 m and cars 175 m." Table 2 shows the results of a study carried out in the Paris region regarding space consumption of the various transport means. This study used a new concept: the consumption of space and time of occupancy expressed using an appropriate unit of measurement, the m² x hour. The results obtained demonstrate clearly the performance levels of urban public transport of the Metro type, with the summary conclusions being:

- the car takes up from 30 to 90 times more space depending on the reasons for use: work, leisure or shopping,
- public road transport (buses) takes up 3 to 12 times more space, depending on the nature of the service provided and the driving conditions (ordinary roadway or bus lane).

Table 2, Space Consumption for Types of Transport in Paris, France

	SPACE CONSUMPTION		
	Parking	Circulation	Total
Pedestrians	0	2	2
Two wheeled vehicles			
work (9 hours)	13.5	7.5	21
leisure (3 hours)	4.5	7.5	12
shopping (1.5 hours)	2.5	7.5	10
Private car (1.25 persons / car)			
work (9 hours)	72	18	90
leisure (3 hours)	24	18	42
shopping (1.5 hours)	12	18	30
Buses (50 persons / bus)			
without traffic separation	0	3	3
with separated lanes			
(60 bus/direction//hour)	0	6	6
(30 bus/direction/hour)	0	12	12
Metros			
(>30,000 pers./direction/hour)	0	1	1
(for a 5 km long journey on an infrastructure used at its optimum capacity) Source: Paris Transportation Authority (RATP)			

Figure 11, Comparison of the space consumption of private cars and public transport busses (N.N., 2012)

1.1.4 Pollution and Noise

Freeway noise and emissions from vehicles are recognized as pressing problems in urban areas. Reduction of the social costs and costs related to the "external effects" (nuisances) associated with private means of transports (private cars and two-wheeled vehicles) can be reduced substantially with public transport. In Paris, it has been estimated that private transport is responsible for about 92 percent of the external costs associated with transportation of people in the Paris region.

The need for noise barriers and sound walls may not always be met by the transportation authorities and the visual impacts are major. It is widely accepted that residential property values near freeways are reduced due to high noise levels from automobiles and exhaust emissions. With respect to energy savings, RATP concluded that for Paris, "…one kEP (kg equivalent petrol) will allow a single person to travel more than 48 km by metro or 38 km by bus, but no more than 19 km by car." This means not only savings in cost but also in pollution due to exhausts and a reduction of noise levels can obtained by increasing the use of metro systems.

Table 3, Cost of Vehicle Noise and Pollution Nuisances

Costs (millions of Euros)	Noise	Pollution	Greenhouse Effect	Accidents
Private means of transport	380	751	256	1355
Public transports	125	37	10	81
Source: Syndicat des Transports d'Île-de-France (STIF), (2003)				

Figure 12, Sound Wall adjacent to Housing

1.1.5 Protection against Natural Disasters

With concentration of population, urban areas are particularly vulnerable to failures in infrastructure due to aging of the systems or those caused by other natural forces. Growth of population not only means more are reliant on the infrastructure, but that the man-made facilities may impact the severity of the impacts. For example, urbanization means more paved area leading to more severe flooding, as well as loss of water resources recharging groundwater.

1.2 SUMMARY

All cities have some or many of the problems described above. The common issues in every city have to do with housing and public transportation. Providing adequate living conditions and urban transportation to reduce noise, congestion and pollution is a common goal.

The role of underground space in solving urban problems is to provide space below the surface such that the above ground can be used for other needs – including green space.

Placing certain infrastructure below grade not only provides this objective but also protects the infrastructure from many environmental impacts. To see the benefits of the underground, we can look to examples of typical underground space use, innovations, and instances where structures placed on or above the surface are being replaced by new ones underneath. The following sections describe many of these uses and planning considerations. The Appendix to this report presents noted projects world-wide to highlight both typical and innovative use of the underground in urban areas.

2 >> Typical underground solutions

For centuries, underground structures, either natural or man-made, have been used for shelter and to produce raw materials. Today, underground structures help in the use of the limited and valuable space in urban areas more efficiently by replacing traditionally surface facilities with tunnels, caverns and other underground spaces. Today, underground infrastructure is a diverse field and can be categorized in several ways. A study in the Netherlands suggested five main uses (Admiraal, 2007):

- Transport Use (with emphasis on infrastructure): Provides for transportation tunnels and underground utilities,
- Production Use: Extraction of underground resources,
- Urban Structure Use: Structure foundations and underground facilities such as shopping malls, recreational facilities, car parks and working space,
- Storage Use: Space for materials best placed underground such as hazardous materials and energy storage,
- Archive Use: Underground resources – archaeological and earth science resources and subsurface bio-diversity.

Some of the uses involve access by the general public; others involve storage or are for protection of the materials from exposure or access.
The following sections present some representative examples of underground solutions for urban problems. The appendix of this report provides more detailed example projects selected for either for their typical or innovative use of the underground.

2.1 TRANSPORTATION AND INFRASTRUCTURE

Tunnels have been used since the 19th century to provide a grade-separated space to make individual (vehicular) and public transportation faster and independent from local traffic and natural barriers. The success of subways and vehicular tunnels continues to be seen in the expansion of existing systems world-wide and creation of new metros as the urban populations demand more rapid transportation. Road tunnels are increasingly seen as a way to reduce the surface impacts while maintaining a vehicular traffic lifestyle.

2.1.1 Rail Tunnels

The availability of subway (metro) systems in many cities in the world has become standard since the opening of the first steam-powered underground railway in London in the 1860s. European cities as a “rule-of thumb” provide underground transportation when the number of residents exceeds about 500,000 people. Worldwide over 48 metro systems currently exist, for over 9,000 km of underground rail.

The advantages of a metro system are well known. These include reduction of traffic congestion, faster travel times, less energy consumption, and other environmental benefits such as reduced noise and visual impacts. Metro systems are designed for public mass transportation and often link with other means of transportation such as surface rail, bus services and aviation. A complex subway system like that in London or Paris (shown in Figure 13) attracts many passengers and, therefore, represents a real alternative to the automobile. Travel time savings, combined with energy savings in terms of cost per passenger per km, contribute to the success of metro systems which are now a typical solution to urban transportation.

Continually improving tunneling and excavation support technology adds to the success of urban rail systems. Advances in Tunnel Boring Machine (TBM) Technology (refer to section 3.7) now allows tunneling in more difficult ground conditions – even below the ground water table – with little disturbance to the surface.

Rail System Technologies

Urban underground rail systems use various technologies for power and vehicle type. Light rail is a form of urban rail that generally has a lower capacity and lower speed than heavy rail systems.
The «term light» rail refers to modern streetcar and tram systems with rapid transit-style features that usually use electric rail cars operating underground in the vicinity of downtown districts. Light rail systems are powered with overhead catenaries, and may operate within city streets as well as underground. Heavy rail systems obtain power from an electrified

Figure 13, Paris Metro

Figure 14, Paris Metro Map

Figure 15, High Speed Rail Line from Nuremberg to Ingolstadt, Germany third rail, and must be grade separated – either in a tunnel or through an elevated system.

Inter-city rail transport is the conveyance of passengers and goods between cities along railways that facilitates national and international trade and economic growth. Due to geographic circumstances or spatial necessities, certain line sections run in tunnels. Especially in mountainous areas, certain types of tunnels, like helical tunnels or base tunnels have been developed over the last century. Numerous train tunnels, which are more than 100 years old, are still in operation today.

Since the 1980s, the development of high speed trains, like the French TGV, the German ICE (Figure 15), the Spanish HSL and the Japanese Shinkansen called for the construction of new railway lines over long distances. In order to reduce the time of travel and to improve the riding comfort, those stretches require little curvature and an extremely flat gradient. These boundary conditions resulted in the construction of new railway tunnels of sometimes considerable length. As rail systems are on a fixed guideway, and are increasingly automatically operated, safety - when compared to road travel is greatly increased.

2.1.2 Road Tunnels

Over the last few decades, many cities have constructed roadway tunnels to improve their traffic conditions and to adapt the road network to the predicted demand. At the same time the impact of traffic on the surrounding residents has been reduced.

Some cities have built tunnels in "ring roads" in order to avoid vehicles traversing the downtown area. A ring road in Munich with its long tunnel entrance is shown in Figure 16. Other recently completed tunnels near Paris and Madrid offer multiple traffic Lanes – and, in the case of Paris A86 tunnel, a double deck to allow two directions of travel in a single tunnel. The list of large ring road tunnels and direct access tunnels increases annually, with large road tunnels completed, under construction or planned in: Prague, Melbourne, Shanghai, Tokyo, Zurich, and other cities.

Tunnels on roads leading directly to the city centre are often dropped from consideration because of high direct costs, safety and security concerns for the operation of the tunnel as well as the need for ventilation structures and rescue routes. Also, the extensive construction process may cause major inconvenience for residents and local business. Never-the-less, the long-term and overall benefits are seen to outweigh the negative and temporary impacts. For example, the Melbourne City Link tunnel "celebrates" its existence with a modern vent shaft tower. Other locations may choose to move the shafts to less obvious locations or even camouflage them to be less noticeable.

In addition to the grade separation allowed by tunneling, the placement of the roadway – often over 50m wide for urban expressways, creates an opportunity for use of the surface for pedestrians, cyclists and local transport. The community especially benefits from greatly reduced noise and less air pollution combined with new spaces, and the overall environmental quality is improved. The tunnel users benefit from reduced travel times.

The decision to build a tunnel in an urban area is dependent on a number of considerations, including the existence of natural or man-made obstacles or conflicting usage, like existing subway tunnels or foundations of neighboring structures.

Aerial vs. Tunnel Decisions

In a number of US cities, for example, Boston, Seattle, and San Francisco, the communities have been extremely disappointed by the non-sustainability of the chosen surface solutions, mainly constructed in the 1950s and 60s. Giant elevated structures through downtown areas are now seen as unsightly, noisy, possibly unsafe, and provide only limited access to areas adjacent to the freeway. After a relatively short period of operation, the decision makers have in many cases realized the negative impacts of elevated structures and decided to favor road tunnel solutions. Earlier decisions only focused on direct construction costs. In order to avoid such unfavorable situations again, decision

Figure 16, Ring Road Tunnel, Petuelring, Munich, Germany

Figure 17, North and South tunnels, Caille 30, Madrid

Figure 18, Road Tunnel, Caille 30, Madrid makers should include real-estate impacts, structural life span, and long-term sustainability when making such choices.

In addition to the capital costs for a proposed tunnel project, the decision making process should also take the following aspects into consideration:

- Advantages of underground with respect to from health, less exposure to noise and pollution,
- Safety measures vs risk analyses and safety plans to be included from project conception,
- Enhanced property values without major blocking of views, visual blight and intense noise intrusion,
- Allows more opportunity for other uses of the at-grade space – including green areas,
- Increased revenue for commercial interests when public access is not impeded by the elevated structure,
- Increased tax revenue when public property is underground, allowing development of the surface,
- Life-cycle cost of underground structures are typically less than for those exposed. The service life of underground structures is typically longer. A number of aerial structures built in the 1950s in the US have now been replaced. Meanwhile older tunnels performing similar functions are still in service,
- Safety benefits from tunnels in seismically active environments perform better than elevated structures.

In summary, early planning stage studies should include proposals for road tunnels. Those underground solutions must not only be judged by their initial costs, but also by their overall long-term advantages.

In the meantime, a number of cities have realized the need for a sustainable approach with regard to their overall traffic planning. Cities like Sydney, Brisbane, Amsterdam and Shanghai have shown that there is a need for action. Figure 23 shows the Alaska Way Viaduct in Seattle, USA, today and a proposal for a suitable

Figure 19, A86, Paris Region, Upper Deck (Photo: Cofiroute)

Figure 20, Schematic Operation A86 (Photo: Cofiroute)

Figure 21, Melbourne City Link vent shaft

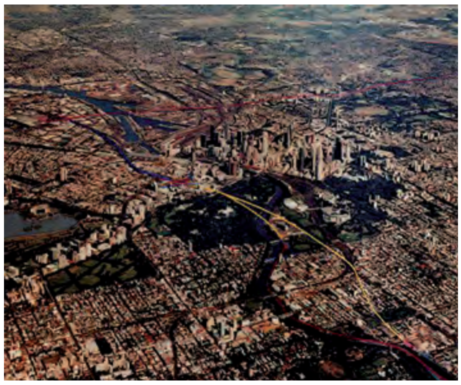


Figure 22, Melbourne City Link

a) **b)**

Figure 23, Alaska Way Viaduct Today (a) and Proposed Tunnel Option (b) tunnel solution in the future. After seven years of studying options for replacing the existing viaduct (aerial structure), a large bored tunnel is now funded and in intensive planning.

2.1.3 Pedestrian and Bicycle Tunnels
Pedestrian tunnels may be used where the demand of pedestrians to cross another traffic route is high. If limiting disruption to highway or train traffic is the priority, pedestrian tunnels represent a suitable solution. Foot tunnels have been used to cross rivers as well as roadways, such as in Greenwich, East London (see Figure 24).

Often, pedestrian tunnels are being combined with other underground structures. For example, they serve as connecting ducts between subway platforms or even in-between neighboring stations or to help to provide barrier-free access from one building to another. The Koopgoot in Rotterdam, The Netherlands (Figure 25), is an underground passage below a busy city road that has incorporates shops and connects the existing shopping centers on both sides of the road with each other.

In road or train tunnels, pedestrian tunnels may support the self-rescue of the tunnel users in the event of an emergency and also provide access for relief units. The large Mt. Baker Ridge highway tunnel in Seattle Washington, US, contains space for a pedestrian and bicycle tunnel in the upper portion of the tunnel.

2.2 DRINKING WATER STORAGE AND DISTRIBUTION

Access to unpolluted freshwater is a critical issue for human survival. Only three percent of the water on earth is fresh, and about two-thirds of this is frozen in glaciers and polar ice caps. Most of the remaining water is underground and only 0.3 percent is surface water. Freshwater lakes, most notably Lake Baikal in Russia and the Great Lakes in North America, contain the majority of this fresh surface water.

Several methods to deliver and to process drinking water are used today.
Stored freshwater from dams is distributed both by open channel or through pressure pipelines. Water from lakes and barrages, or water from deep lying aquifers, is also used for the production of drinking water. What these systems have in common, is that the water needs to be stored, treated, and distributed, which requires a large network of basins, pipelines and pumping stations.

Storage
For over 2,000 years, cisterns – underground caverns or accessible tanks – have been used in areas where water is scarce. Present day cisterns are often only used for irrigation due to concerns over water quality. Cisterns today can also be outfitted with filters or other water purification methods when the water is

Figure 24, Greenwich Foot Tunnel, East London

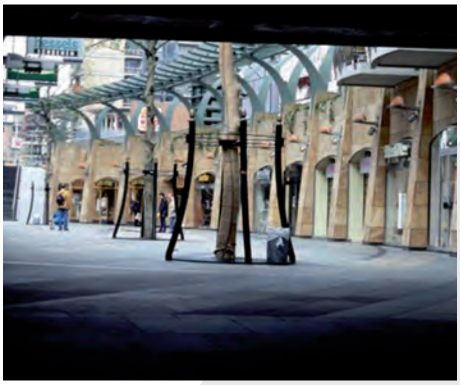


Figure 25, Koopgoot Pedestrian Tunnel and Shopping Center, Rotterdam, The Netherlands

Figure 26, Mt. Baker Ridge Pedestrian and Bicycle tunnel

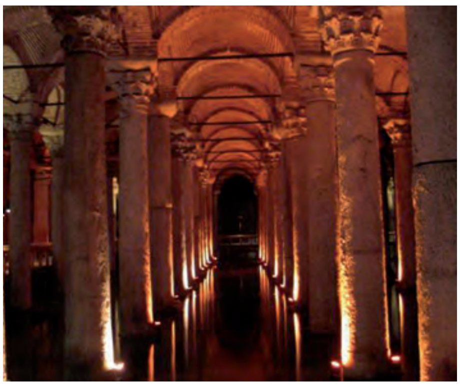


Figure 27, Basilica Cistern, Istanbul, Turkey

Figure 28, Hollywood Reservoir Project, Los Angeles, US

Figure 29, CSO Storage Cavern, Atlanta, Georgia,US meant for consumption. The Basilica Cistern (see Figure 27) is the largest of several hundred ancient cisterns that still lie beneath the city of Istanbul, Turkey. The cistern, located in the historical peninsula of Istanbul next to the Hagia Sophia, was built during the reign of emperor Justinian I. in the 6th century.

Modern reservoirs are now being placed underground for protection of the water against air pollution and to make the water supply more secure.

2.3 STORM WATER RELIEF AND CSO SYSTEMS

Handling the effects of storm floods is proving to be an increasing problem for cities as, along with development, paved areas increase and infiltration into the ground is reduced. Other reasons for this increasing problem are:

- former retention areas adjacent to stream courses have been converted into populated or economically used land,
- more intense storms attributed to climate change are occurring.

To cope with the unfavorable effects of flooding, the options include:

- recreating natural storage areas,
- improvement of the drainage capacity using pipelines or tunnels,
- creation of temporary storage capacities (above and below ground), such that storm and sewer water may be treated before being discharged into natural waterways,
- combinations of the above utilizing underground space multi purpose systems.

Numerous recent examples of combined sewer outfalls (CSOs) can be found in US cities.

In Chicago, the Tunnel and Reservoir Plan (TARP) is a large project that aims to reduce flooding in the metropolitan area, and to reduce the harmful effects of flushing raw sewage into Lake

Figure 30, Deep Pump Station, Portland, Oregon, US

Figure 31, Tunnel Reservoir of the TARPProject Chicago, USA

Michigan, by diverting storm water and sewage into temporary holding reservoirs (see Figure 31). Full completion of the system is not anticipated until 2019, but substantial portions of the system have already opened and are currently operational. Similar projects in the United States include the East and Westside CSO (Combinded Sewer Overflow) projects in Portland Oregon, the Custer Avenue CSO in Atlanta, Georgia, and the North Dorchester CSO in Boston, Massachusetts.

Figure 32, Water Storage and Traffic Tunnel Kuala Lumpur, Malaysia

One of the most interesting projects with respect to multiple purpose systems is the SMART Tunnel project, (Stormwater Management and Road Tunnel).
The objectives of this tunnel, which is situated in Kuala Lumpur, Malaysia, is to solve both the problem of flash floods and traffic jams during rush hour. The 9.7 km long SMART Tunnel, put into operation in May 2007, consists of three separate sections. During normal conditions, a 3 km long section of the upper two decks is used for vehicular traffic, wheras the base section of the tunnel is used for the transportation of water from a basin in the northeast to a reservoir in the southeast. In case of an increase in storm water due to a major storm incident, all three sections of the tunnel with a diameter of 13.2 m can be used for water storage and transport.

The necessity for closure of the tunnel for traffic is expected to happen once or twice a year. By combining these two functions, Kuala Lumpur saves money and space compared to building two separate systems (Tunnels and Tunneling, 2008).

2.4 ENERGY STORAGE AND DISTRIBUTION IN UNDERGROUND NETWORKS

The distribution of fossil fuels and electric energy requires a sophisticated network of infrastructure. The availability of these resources must be guaranteed at all times for urban areas. With urbanization, there is an increasing need for undergrounding power transmission – for safety and land use considerations.

2.4.1 Production, Storage and Distribution of Energy

In the following section, energy production, its storage and distribution, are discussed in terms of district heating, geothermal energy, thermal heating, hydropower, and fossil fuel distribtion. All of these may be associated with underground solutions. The feasibility of an underground solution depends largely on local conditions and its purpose in combination with commercial and financial considerations. Depending on local boundaries such as water resources, appropriate geological characteristics or the existence of other forms of energy, most of the following solutions can be applied for urban areas.

a) District heating is a system for distributing heat using steam (vapor) or water – via a thermally isolated network of underground pipes in densely populated areas. The heat is generated in a centralized location and is predominantly used for residential heating.
The heat is often obtained from a cogeneration plant burning fossil fuels or increasingly from biomass. Geothermal heating and central solar heating also may be used. Simultaneous production of electricity and heat is highly efficient and offers a couple of advantages:

- Opportunity to use waste heat from industry,
- Large plants instead of many small units increase efficiency,
- Use of multi-fuel boilers minimizes effects from fluctuating fuel prices.

Instead of individual earth-covered pipelines, some communities use tunnels (see Figure 34) to bundle pipelines for district heating to allow easy access for maintenance.

b) Geothermal energy results from the use of the underground as a heat or cold source or as a thermal reservoir. It is well suited for many applications due to the available large volume and the constant natural temperature level.
Geothermal energy from the underground is obtained via underground heat exchangers or by pumping groundwater. Apart from heating, heat pump systems can also be used for space cooling.
Often, ground probes, to be inserted in designated bore-holes, are used to extract heat or cold from the ground.
Recently, a precast tunnel segment to be used as a heat exchanger in tunnels or ducts has been developed and patented. In deep mountainous tunnels for example, heat in the vicinity of a tunnel tube could then be used to defrost nearby road sections during the winter period.

The usage of geothermal energy within the first 400 m below the ground surface is often referred to as near-surface geothermal energy, whereas all activities below that point are called deep-seated geothermal energy. In recent years, a great effort has made to extract hot water from great depth, i.e., 5,000 m below the ground surface in order to produce electricity or to feed it into local district heating systems.

c) The underground can also be used as a **thermal reservoir** for heating and cooling. Heat from other sources, which would otherwise be lost can be stored and used later. By the same principle, environmental cold can also be stored for later cooling applications. Underground thermal energy storage is especially suitable for storing larger quantities of heat or cold over longer periods of time. Foundations elements such as cast-in-place piles can be made to be very efficient in exchanging heat into the ground or extracting it. Many major new office blocks are making economical use of these new developments, thereby

Figure 33, SMART Entrance

Figure 34, District Heat Tunnel in Cologne, Germany

Figure 35, Geothermal pile with heat exchanger tubes attached to the reinforcement to be incorporated in the concrete (Parriaux, 2009) minimizing the use of underground pipe systems for long distance energy transport.

The Minewater Project in Heerlen, The Netherlands, aims to demonstrate how the geothermal energy, stored in the form of water in flooded mines can be used as a safe and ecological way to heat buildings. Amongst others, the goals of this pilot project are:

- To supply new, «green» energy from old mines,
- To economically regenerate an abandoned area,
- To develop an environmental solution instead of an environmental problem.

Cooling systems. Underground placement of cooling plants is now used. These large facilities prepare cooling water for distribution while the underground setting allows placement in convenient locations – for example adjacent to the Seine River in Paris, while protecting the character of the locations. The Appendix features the Cooling Plant at Place du Canada, Paris, France.

d) Gas Storage: Underground reservoirs are an important method of storing various gases. Three principal types are used: depleted gas reservoirs, aquifer reservoirs and salt cavern reservoirs. Depleted gas reservoirs are formations from natural gas fields that have produced all their economically recoverable gas. The depleted reservoir formation is readily capable of holding injected natural gas. Aquifers are underground, porous and permeable rock formations that act as natural water reservoirs. In some cases they can be used for natural gas storage. Underground salt formations are well suited to natural gas storage. Salt caverns allow very little of the injected natural gas to escape from storage unless specifically extracted. The walls of a salt cavern are strong and impervious to gas over the lifespan of the storage facility.

e) An oil depot – sometimes called a tank farm or an oil terminal – is an industrial facility for the storage of oil and/or petrochemical products and from which these products are usually transported to end users or further storage/refining facilities. An oil depot typically has tankage, either above ground or underground, and gantries for the discharge of products into road tankers or pipelines.

In Singapore the Jurong Rock Caverns project is underway to create a series of underground caverns, at a depth of 120 m and a storage capacity of about 9 million barrels. Set for completion by 2014, this project will significantly increase Singapore's storage capacity for oil without using expensive surface areas.

Figure 36, Underground Coal Storage, Helsinki, Finland (Photo: Jorma Vilkman)

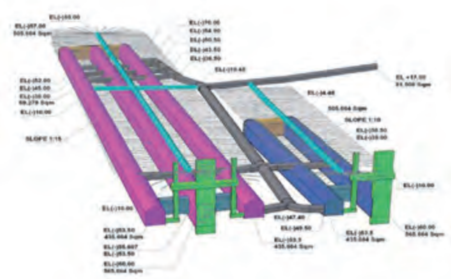


Figure 37, Underground Oil Storage (Wallis, 2011)

Along similar lines, Helsinki, Finland, moved the storage of coal from surface to underground caverns. This move freed up valuable space at the surface for other uses and allowed a nearby residential development to proceed without the hindrance that in the past the surface storage of coal caused.

f) Hydropower

Hydropower is the generation of energy from the force or fall of moving water. Most hydroelectric power comes from the potential energy of water held in dammed reservoirs. The water under pressure is used to drive a turbine. In many areas, the turbines are situated in large underground caverns. To obtain a very high head, i.e., the height difference between the upstream and the downstream water level, water for the hydraulic turbine may pass through a steel-plated tunnel, also called a penstock. Other forms of hydropower, like tidal power or pumped storage power exist in suitable regions. All of these solutions comprise specific underground structures.

2.4.2 Pipeline Systems

The transport of fossil fuels, freshwater, sewage and electric energy through underground pipelines and cables was strongly developed in the 19th century. Pipeline transport has proved to be an economical way to move pressurized liquids and gasses over long distances, and typically has lower cost per unit and higher capacity than other means of transport. The potential for damage to the facilities due to natural causes – or interference by humans – is greatly mitigated by placing these pipelines below the ground surface. On the other hand, lack of visual accessibility means that underground pipelines need more extensive remote monitoring, for instance by monitoring pressure variations. Pipeline operators employ qualified surveyors and inspectors to continuously control the performance of critical pipelines.

Figure 38, Pipeline in Trench Excavation

Figure 39, Utilidor in Amsterdam under the Mahlerlaan (Photo: H. Admiraal)

Figure 41, Underground Trash Collection, Netherlands

2.4.3 Utilidors

To guarantee consumers the distribution of fresh water, gas, district heating as well as electricity and telecommunication in cities, pipeline and cable systems may use more complex underground solutions, for example, bundling all components in service ducts or tunnels.

Cable tunnels carry high voltage cables accross bodies of water, consolidate conduits, and reduce the disruption of cut and cover methods for individually installed conduits and the consequent impact on city streets.

In Ashgabat, Turkmensistan, a cable tunnel has been combined with a large scale drainage system. The drainage system discharges excess subsurface water into the nearby desert for use in an irrigation project. At the same time the tunnel functions as a sewage main and cable tunnel for the city centre and major government buildings.

a) Other Underground Transport

The idea of using pipelines for more applications than just liquid and gas transport is not new. Pneumatic tubes, for example, are systems in which cylindrical containers are propelled through a network of tubes by compressed air or by vacuum. They can be used for transporting physical objects. Pneumatic capsule transportation was originally invented in 1806. The Victorians were the first to use capsule pipelines to transmit telegraph messages, or telegrams, to nearby buildings from telegraph stations. For example, both, Paris and Berlin had a functioning pneumatic tube network of more than 400 km in length until the 1960s. Further development was then stopped due to the establishment of the fax machine. To the present day, many studies have investigated the possibilities of using pipelines to transport consumer and manufactured goods.

Another interesting example can be found in Almere, the Netherlands.
Garbage disposal problems sparked interest in pipeline transport systems.
An extensive network of pipelines, with a total length of about 8 kilometers now transports the garbage out of the city.
Next to offices, shops and apartments, intakes for three types of garbage (paper, biological and other garbage), as shown in Figure 41, have been constructed.
Using a suction method, the garbage is transported at a speed of 70 kilometers per hour to a collection terminal, where it is divided into different containers.
Filled containers are automatically replaced

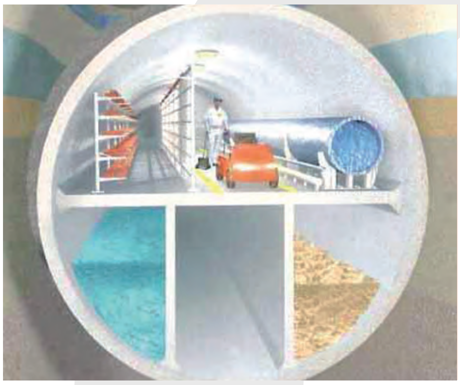


Figure 40, Utilidor, Ashgabat,Turkmenistan and a signal is sent to garbage trucks to take the full containers to the incinerator. Similar transport systems have also been used in Tokyo, Stockholm and Barcelona. The use of this system has reduced pollution throughout the city, and the absence of garbage trucks has reduced sound and smell nuisance.

b) Future Concepts

«CargoCap» is a safe and economical way to carry goods quickly and on time in congested urban areas by underground transportation pipelines.
This innovative concept, which is currently under development, is the outcome of the interdisciplinary collaboration in research and development at the Ruhr University of Bochum, Germany. The system is independent from aboveground traffic congestion and weather conditions.
A model is displayed in Figure 42. Each vehicle, the so called «cap», is designed for the transportation of two euro-pallets. Euro-pallets represent the majority of the general inner-European cargo transport, and can thus be directed through pipelines with a diameter of about 1.6 m.

Since urban areas are becoming more crowded and polluted, it seems only a matter of time before more new ideas will be transferred into reality. When shops and offices could be supplied with goods via the underground, pollution and traffic congestion in cities can be greatly reduced, resulting in a better quality of life and an improvement of the work environment.

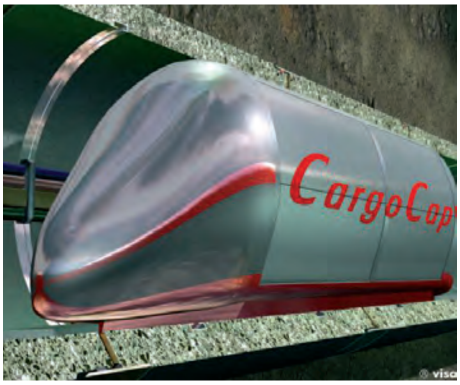


Figure 42, «CargoCap» Concept

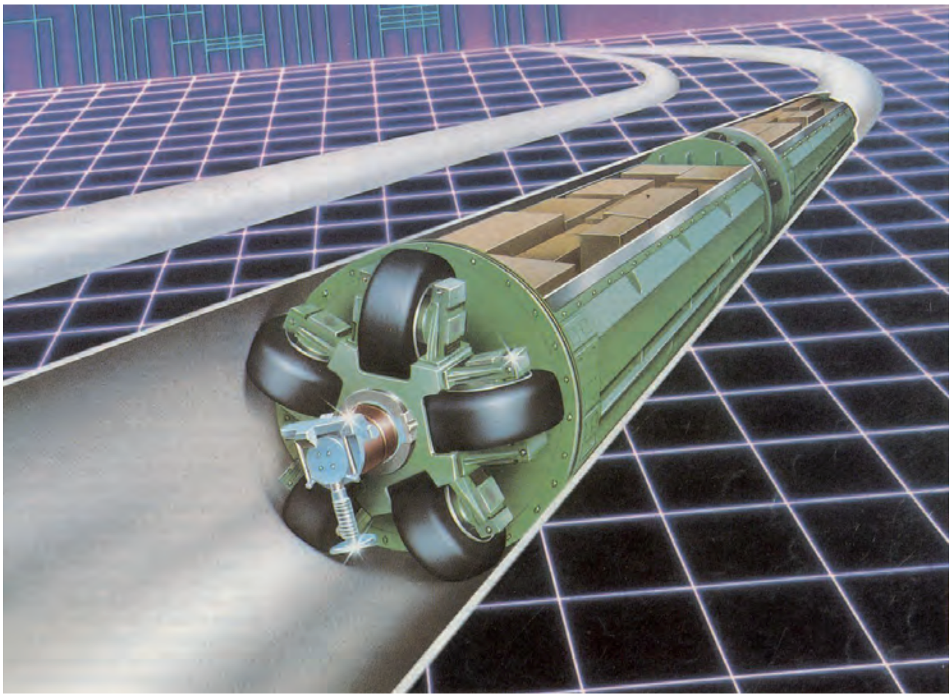
2.4.4 Deep Geological Repository

In several locations world-wide nuclear power plants are located in or close to urban areas. At these locations spent fuel rods are temporary stored in above ground fuel ponds. These storage locations could also be located below ground, reducing the possible environmental impact.

For more permanent storage of spent fuel, the deep geological repository concept has been developed. This involves the placement of long-lived radioactive waste in rooms excavated deep within stable, low-permeability bedrock. The combination of waste package, engineered seals and bedrock would provide a high level of long-term safety, without relying on on-going future maintenance. Common elements of potential repository systems include the radioactive waste, the containers enclosing the waste, the tunnels housing the containers, and the geologic makeup, or type of rock, of the surrounding area.

The process of selecting appropriate deep final repositories is under way in several countries. In Germany, there is a political debate about the search for a final repository for radioactive waste, accompanied by loud protests – especially in the Wendland area, which was seen ideal for the final repository until 1990. This location is currently used for the temporary storage of nuclear waste.
There is also a proposal for an international repository in optimum geology – Australia or Russia are possible locations.

Figure 43, Waste Isolation Pilot Project Caverns, US



2.5 COMMUNITY DEVELOPMENT AND IMPROVEMENT

The charm of a city centre is closely related with the existence of leisure time facilities and public green spaces. Urban centers for shopping, entertainment, dining and social events are seen as key for "quality of life" in urban areas. These factors attract people to stay and live in the city centre areas.

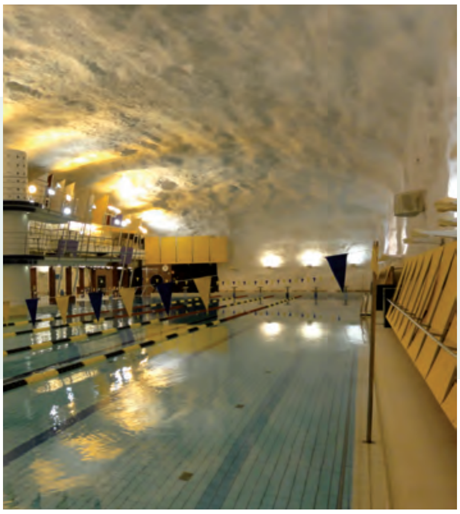
2.5.1 Underground Cultural and Amusement Facilities

Due to limited space in downtown areas, some cities have expanded their cultural facilities into the underground. Since no eye-catching historic or challenging exhibition building is apparent from street level at first glance, these places may need additional promotion or benefit from ongoing word-of-mouth or active advertising. Cultural facilities revitalize downtown areas and improve the quality of life.

Some remarkable examples include the Philharmonics in Cologne, Germany, where performances are below the earth's surface right next to the world-heritage site of the Gothic Cathedral. Graz, the capital of the federal state of Stryria in Austria accommodates an event hall chiseled into a mountain below the castle («Dom im Berg», Figure 44). The facility is used for multiple events and offers a volume of 6,700 m³. The world's largest arena excavated in rock can be found in Gjøvik, Norway. The Gjøvik Olympic Hall was one of the sites of the Lillehammer Winter Olympics Games in 1994 and houses up to 6,000 visitors. The hall is today used for sport and cultural events. The Louvre in Paris, France, and the extension of the Rijksmuseum in Amsterdam, The Netherlands, both possess underground exhibition space.

Caverns, tunnels, subway facilities and others that were originally built for one single designated purpose have occasionally been converted into cultural facilities. The so called «Kunstraum» in Munich, Germany, is an art-gallery which revitalizes an unused section of Munich's subway next to a principal subway station. The music club «Substage» in Karlsruhe, Germany, uses a former pedestrian underpass for rock concerts, parties and other cultural events. In Düsseldorf, Germany, an art-gallery, named «KIT», has opened its doors in a dormant space between the bores of a road tunnel.

Throughout the world, many major underground shopping malls in combination with restaurants, cafés, and cinemas open their doors daily. The first large center, the so called «Underground City», was constructed in Montreal, Canada (Figure 45). Later, cities like Seoul, Beijing, Moscow, Toronto, Tokyo, Singapore and others adopted this concept. Especially where unfavorable climate conditions exist, planners have chosen to go underground. In Toronto, Canada, the underground system of tunnels and shops is credited with allowing both the surface and underground public and commercial spaces to thrive (Belanger, 2007). Architectural design, focusing on human psychological needs like sufficient light, air, and social safety has created underground worlds in metropolitan areas.



Environmental Control

In Bailly village (North of Burgundy, Yonne department), a previous stone quarry comprising 4 hectares of galleries, 50 m below ground level, was first reused as a mushroom bed (1927-1972) and then as cellars, thanks to its very good location in a vineyard region, its natural humidity and constant temperature.

Figure 44, "Dom im Berg", Graz, Austria

Figure 45, Underground City, Montreal

Figure 46, Bailly village Cellars, France (Photo: Gilles Puech)

2.5.2 Underground Parking

An underground parking garage is a building or part of a building, which is designed specifically for automobile parking situated below the ground surface. It is usually accessed via a ramp on the street floor level and consists of one or more parking levels. In many cities in the world, it is now standard to use the underground space in central areas for parking garages instead of a high rise car park. Figure 47 illustrates the Post Office Square in Boston, USA, demonstrating an obvious improvement of the downtown quality. A similar example in Marseilles illustrates the beautification of the public space by placing the parking structures underground, Figure 48.

Further reduction in underground space needs may be realized by automatic multi-storey car parking garages. These provide lower building costs per parking slot, as they typically require less building volume and less ground area than a conventional facility with the same capacity. However, the cost of the mechanical equipment within the building that is needed to transport cars internally needs to be added to the lower building cost to determine the total costs. Other costs are usually lower, too, for example there is no need for as much energy intensive ventilating systems, since cars are not driven inside and human cashiers or security personnel may not be needed. The driver leaves the car in an entrance module. It is then transported to a parking slot by a robot trolley. For the driver, the process of parking is reduced to leaving the car inside an entrance module.

a) before

b) after

Figure 47, Post Office Square Parking, Boston, USA – 1960s (a) and Post Office Square Today (b)

2.6 LIVING AND WORKING

Humans generally prefer to live and work under the influence of sunlight and fresh air. Nevertheless, due to extreme climatic conditions, and limited resources for heating and cooling, some places require underground housing solutions.
In other instances, lack of surface space has meant looking for additional space to be placed underground – especially when the existing building may have historic designations or significant appearance.

2.6.1 Underground Housing

A life of comfort and safety is the perpetual desire of humanity. To achieve this desire, suitable space is required for dwellings. However, fulfilling this need for suitable space is becoming more and more difficult in many areas of the world due to a growing shortage of urban land. Underground housing offers an energy conserving, low environmental impact form of shelter that can be appropriate in some climates and environmentally sensitive areas. This being said, it is well known that many people have negative feelings about spending extended periods underground due to lack of sunlight, poor ventilation and air quality, a high level of humidity, lack of orientation, or an association with darkness, coldness and dampness. Technical solutions for these problems do exist, however, such as air conditioning, ventilation, light shafts, glass floors and proper lighting conditions.

a) before

b) after

Figure 48, Parking Garage Marseilles, France

Figure 49, Terraced Earth Sheltered Housing on Steeply Sloping Hillside, France

The advantages of underground living offers additional benefits when compared to living in traditional buildings, including a nearly constant comfortable temperature without the need for additional insulation, quiet, resistance to hurricanes, tornadoes and most weapon systems and the unobtrusiveness of such buildings on the landscape. One of the greatest advantages is energy efficiency. The stable subsurface temperature of the earth saves energy costs. Additionally, the noise insulation of the surrounding earth makes underground homes exceptionally quiet, and with a smaller surface area, fewer facing materials are used. However, underground living in flat areas can be easily affected by flooding and waterproofing and moisture control are key design and operations issues in underground buildings.

2.6.2 Office and Public Facilities

A number of international facilities have been placed underground to allow access to and additional space under the important building while allowing un-obscured views of the building. Well known examples include the expansion of the Louvre museum in Paris, France, the Smithsonian Museum in Washington, DC, US, and the US Capitol Visitor Center (CVC). In the case of the CVC, it is seen as an extension of the Capitol Building that welcomes over 1,000,000 visitors per year to the seat of American government.
At nearly 54,000 m^2, the CVC is the largest project in the Capitol's 215-year history and is approximately three quarters the size of the Capitol itself. The entire facility is located underground on the east side of the Capitol so as not to detract from the appearance of the Capitol and of the grounds designed by Frederick Law Olmsted in 1874.

2.6.3 Underground Manufacturing and Special Facilities

Many human activities or consequences of such activities are best placed underground for the protection of the environment and specialized equipment.

The underground may be suitable for manufacturing, laboratories or scientific facilities. Such facilities can be constructed in the underground for obvious standard reasons like safety, fire protection, protection from severe weather, reduced noise and vibration, energy savings, and other special reasons such as shielding of the surface from radiation.

Worldwide, a number of nuclear research facilities, operate large underground structures like particle accelerators.
For example, the Large Hadron Collider (Figure 52) which is run by the European Organization for Nuclear Reseach is contained in a circular tunnel with a circumference of 27 kilometres at a depth ranging from 50 to 175 metres below the ground surface. The 3.8 metre diameter, concrete-lined tunnel crosses the border between Switzerland and France four times. Surface buildings hold ancillary equipment such as compressors, ventilation equipment, control electronics and refrigeration plants.

The decision making process involved in the planning, funding and construction of major infrastructure across the globe is dependent on many factors, most importantly:

- Financing and funding aspects,
- Designated function of the facility,
- Type and jurisdiction of owner,
- Market sector (transportation, water, utilities, other),
- Legal and administrative process,
- Authority granted to the lead agency,
- Number and role of every stakeholder,
- Owner status: public or private.

How the process and factors are managed within individual countries, as well as within localities, varies markedly, but the principal steps involved in remain:

- Recognition of the purpose and need for the infrastructure for concept justification and development,
- Planning and preliminary engineering: to define scope, feasibility, and preliminary budget definition,
- Implementation: including strategies for project delivery, procurement, packaging, engineering, cost estimate, financing strategies,
- Implementation and Construction: including contract terms and definitions of roles, risk allocation and sharing strategies, and construction approaches.

Figure 50, Earth Sheltered Housing in a National Park District, UK (architect Arthur Quarnby)

Figure 51, US Capital Visitors Center

Figure 52, Section of the Large Hadron Collider Tunnel

Decision- making is involved throughout the process at key milestones and may be as simple as a review and comment of a draft planning or engineering document, to the assessment of project risks and their allocation among project partners, to the ultimate project funding and approval. Projects and managers must evolve with the project over time to satisfy the constraints and apply adaptive management strategies to assist in progressing the program and helping the decision makers.

It is important at the outset of a project that the program requirements are clearly defined, the constraints identified to facilitate the early planning and preliminary engineering stages and that the information is provided to justify or disqualify the project to the managers and ultimately the political leaders. Distribution, discussion, and transparency of project information to all stakeholders throughout the life of the project is key to unfettered implementation.
In the absence of information, stakeholders are left to speculate and frequently this can result in inadvertent dissemination of misinformation.

It is also important at the outset of the project for the managers to have a clear sense of the entire organisational network including the constituent stakeholders to understand the communications network and information needs to assist each of the decision makers.

History shows that the best information and the best prices are not often what is used in the public discourse leading up to public decisions about infrastructure alternatives. In an urban environment the answers are should be clear but the transitional edge cities and suburban areas are gray areas where the debate to go underground is often waged, loudly by stakeholders. Voices of the proponents and opponents may not be those of the designers or the estimators, but of the stakeholders representatives, who frequently present information that is unclear, confusing or misleading while the industry stands frustrated on the sidelines.

Even in the absence of misinformation, the decision about whether to solve urban problems with underground solutions is usually complex. It depends on a large number of aspects which should all be taken into account including:

- Social - aspects concerning people and their preferences,
- Safety and security issues,
- Aesthetic needs – visual and architectural impacts of the solution,
- Ecological impacts –those aspects concerning the environment,
- Legal issues – including regulatory and zoning aspects,
- Economic and cost considerations,
- Technical – related to the possible construction techniques and risks involved.

The focus during the decision making process may be somewhat less concerned with technical details and more on strategic aspects of urban planning, may they be of social, economical, ecological or aesthetic background. Nevertheless, the technical aspects cannot be discounted from any discussion of underground construction. A general perception exists that the risks in underground construction are higher than those of other construction methods and that, partly through the higher risk and uncertainty involved, the direct building costs of any underground solution will be substantially higher.
This Chapter addresses the various aspects of underground construction and considerations in the decision making and evaluation of underground solutions.

The decision making process may take several to many years to complete – as illustrated in Figure 53 below. Identification of the need – faster travel time, capacity of sewerage system, etc. – is followed by the evaluation of alternatives and their relative costs, evaluation of environmental impacts and benefits. In the decision making process, a combination of factors drive the decision to go underground – or not – and depending on the weight that various factors are given, different solutions can be reached. Examples of the various factors are given in the following sections.

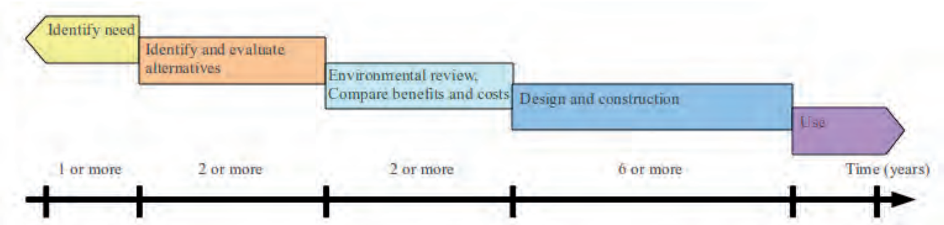


Figure 53, Flow Chart – Typical Transit Project

3.1 SOCIAL ASPECTS

Underground solutions may play an important role in social aspects of project development. The achievement of an environmentally-friendly development should be considered during the decision making process. This can encompass a reduction of pollution or noise nuisance, the efficient use of space, economic development, the preservation of the living environment, public health or safety, amongst others. Some of the social factors addressed in this chapter that have a direct impact on the choice for underground solutions are:

- Construction impacts and other temporary conditions affecting the community,
- Structures dividing a community;
- Development potential of the area;
- Other uses of the space, for example recreation,
- Noise, vibration and other impact on the environment.

Barriers to movement: An example of a structure that negatively impacts the community is any elevated transportation system – roadway, rail line, pipeline, etc. These structures can significantly impact a community by impeding access to residences and businesses.
These impacts can result from the combination of a constrained corridor, chronic traffic congestion, and land ownership patterns that constrain property redevelopment. The result can be a degradation of the physical environment, with passage across the transit corridor permitted perhaps only at intervals along the right-of-way or at stations.
This can also cause businesses or residents to relocate, perhaps “down-market”, with the structure creating a physical barrier to movement of people and vehicles between communities on either side, with economic impacts to the adjacent communities. Noise and pollution from combustion engines also reduces property values around the structure. Elevated structures in the wrong corridor or location can create physical as well as visual separation and may blight frontage properties (ITA WG N°13, 2003).

Figure 54, Toronto Metro

Figure 55, ‘Alaskan Way Viaduct between downtown and waterfront

Figure 56, ‘Alaskan Way Viaduct – impact on adjacent properties

3.1.1 Land Use

Underground solutions often offer better development options. Well planned subway systems, road tunnels, underground parking, and underground cultural facilities, for example, allow more effective use of the area above ground. This maximizes the prospects for intensification of land use where accessibility is at a premium and it offers the prospect of development gain. These potential benefits depend upon effective planning to be realized in practice.

Parks and Open Space: A related aspect is that underground solutions can help to create or retain local recreation possibilities, such as parks and other open spaces. These can be a determining factor in the decision making process, as the social implications are considerable. Figure 57 illustrates the public use of the Rhine Embankment Boulevard, Dusseldorf, Germany, an inner-city area that was previously devoted to automobile traffic, and is now used for public space and enjoyment of the waterfront.

These elements are clearly illustrated when elevated systems (freeways and parking garages) are removed and replaced as in the cases of the Boston Central Artery, Boston; the Post office square, Marseille, France; the Embarcadero Freeways, San Francisco or the Madrid Ring Road.

The increased land values that result from an underground solution, freeing up the surface area, is conceptually a straightforward analysis. Similarly, as the benefits of removing physical barriers from the community and increasing the development potential of that area are self evident. However, clear financial examples are difficult to access.
It is even harder to put a monetary value on the reduction in noise and vibrations that an underground solution can provide (see Section 3.6 for more details).
These analyses are becoming more common and have successfully been conducted for most subway projects that might have considered at-grade or aerial systems, and are also more commonly applied for roadways including the Alaskan Way Viaduct, described above, and a number of roadways in Europe and Asia including the Madrid Ring Road and the A86, Paris.

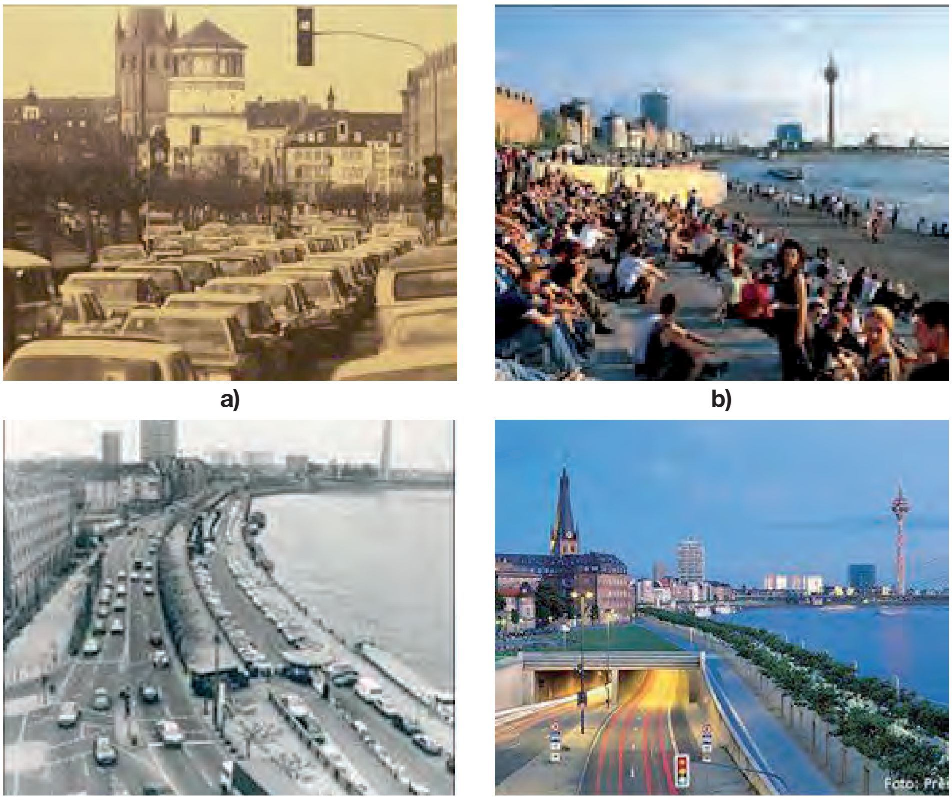


Figure 57, Rhine Embankment, Dusseldorf, Germany, 1970s (a) and Rhine Embankment Today (b)

3.1.2 Noise Impact
Certainly, the amount of noise generated by traffic or industry can be an important issue in the decision making process. The noise associated with elevated structures in urban environments is problematic and the social acceptance of noise in urban environments is decreasing. It is clear that the impact of noise to the environment is substantially reduced with underground construction.

Similarly, vibration can be a significant issue in the case of underground solutions, particularly where the alignment is under a historic center with important, old buildings or is located near sensitive facilities such as hospitals, research centers or universities. Measures to reduce vibration to acceptable levels are available, at some incremental cost (usually small) (ITA, WG N°13, 2003). Even without additional measures, the impact of vibration of an underground solution is often less than that of an above-ground solution.

3.2 SAFETY AND SECURITY

Although underground facilities can be seen in a negative light when safety and security are considered, in most cases they are better protected from external threats and natural hazards than surface facilities. On the other hand they do need more attention with regard to fires and other internal risks during their design and operation. If properly managed, however, these risks can remain comparable to that of surface and elevated structures.

3.2.1 Smoke and Fires
In particular, the threat of fires has been highlighted in the recent past by a number of well publicized incidents, such as the Feb. 2003 incident in the Taegu metro station in Seoul, South Korea. An arson attempt led to a fire in a metro carriage, which produced great amounts of smoke in the metro station. The smoke hindered escape attempts of passengers from the station platforms, prevented fire fighters from quickly entering the station and also prevented a second train from entering the station where the fire occurred.

The fact that the second train remained in the running tunnel, and that the metro carriages contained large amounts of combustible material contributed greatly to the 192 casualties.
The fire risk can be mitigated to a large extent during the design phase. Design criteria can be developed to purge smoke from the system in a number of scenarios, depending on the location of the fire: Tunnel, station, platform or concourse levels. Train operations also can be controlled to ensure that there is adequate separation between oncoming trains and fires. For example, the Amsterdam North South Line has a "safe haven" concept, whereby a train can only enter the running tunnels if sufficient platform space is available at the next station or emergency exit, preventing trains getting stuck in the running tunnels. This is combined with an absence of easily combustible materials in the carriages.

Development of metro carriage interiors in the Paris and other metros world wide has led to the use materials that do not ignite at gasoline combustion temperatures, thereby not contributing to the fire load (smoke and heat) in case of fires. Success of the new materials in use is demonstrated in that in 1975 a Paris metro fire led to the loss of several carriages, but a similar fire load in 2002 did not spread outside a 1m^2 area and self-extinguished (Marchais, 2009).

3.2.2 Earthquakes
When natural hazards such as earthquakes are considered, underground facilities are most often better protected without additional measures than their surface counterparts. The lower levels of ground motion away from the ground surface and the constraining effect from the surrounding soil contributes to the safety and stability in this case.
With the development of seismic codes, subways are now considered very safe in earthquakes. Examples are listed in Table 4 below. Most recently, in 2010 in the 8.8 magnitude earthquake in Chile, surface roads and public transport suffered extensive damage, but the Santiago metro system was virtually undamaged.

3.2.3 Terrorist Attacks
Since the sarin gas attack in Tokyo's subway system in 1995, the safety and security of tunnels and underground facilities against malicious attacks have been serious concerns.
Subsequent attacks heightened this concern and made it of critical importance to transportation facility owners, law enforcement agencies, and the public. Countermeasures for the protection of underground structures include many of those being undertaken for all public facilities, but also are including new designs to protect the facilities against excessive loads, including explosions (Munfah, 2009). Understanding the impact of a blast on the tunnel structure and its systems enables the development of countermeasures that can be implemented on existing tunnels to strengthen them or can be implemented as part of the design of a new tunnel or underground facility. Specific Design concepts are reported elsewhere, such as (Munfah, 2009) and (TRB 2006).

Figure 58, Earthquake Damage surface Structure, Chile (Wallis, 2010)

Table 4, Summary of Recent Earthquakes and Impact on Metros

Earthquake	Date	Magnitude	Impact on Subway
Mexico City	1985	8,1	No damage to tunnels. Some power disruption. Patrons evacuated safely
Loma Prieta (SF)	1989	6,9	No damage to tunnels. Subway served as lifeline structure.
Northridge	1994	6,7	No damage
Kobe, Japan	1995	7,2	No damage to tunnels, damage to station and sewer pipes. Attributed to 1962 design with moderate seismic provision
Taipei	2002	6,8	No damage
Chile	2010	8,8	Running next day. Some damage at entrance to station

3.3 AESTHETICS

The visual and aesthetic impact is often the major quoted reason for deciding to relocate infrastructure to the underground. Compared to above ground solutions, like elevated structures, an underground structure would not impact on the visual image and character of the environment. This may be important to hide unattractive technical facilities in sensitive locations or when industrial facilities must be sited adjacent to residential areas.
This might also be important for the preservation of natural landscapes.
The increasing requirement for all utility services to be placed underground stems essentially from visual impact considerations and concerns about protection against the elements.
Underground solutions can also fulfill architectural requirements as shown in Figure 61. The Canary Wharf Station is a good example how underground structures and architectural features can meet. With proper design an underground solution can be an aesthetic highlight in itself.

Figure 59, Wine Caves for Storage at controlled temperature

3.4 ECOLOGICAL AND ENVIRONMENTAL ASPECTS

Underground space utilization can help solve environmental and resource dilemmas in several ways.
Underground facilities are typically energy efficient in their own right. The natural insulation provided by the soil regulates the temperature within the construction and thereby reduces the need for heating or cooling, lowering the energy consumption when compared to surface constructions. Over time the higher cost of construction may be compensated for by savings in power and the alternative use of the surface.

More importantly, by using underground space, higher urban densities can be supported with less impact on the local environment. In addition to the obvious benefit of preserving green space and agricultural land, higher urban density can lower fuel resource consumption by containing sprawl. Underground development will be an important tool in reshaping our urban areas to meet the challenges of the future without destroying their heritage or worsening their surface environment. (Esaki, 2005)

During the construction phase, however, underground construction can have an influence on the environment, including effects on soil, water, air, climate, fauna, flora and their living space, cultural assets as well as on human beings. In the decision making process, the stakeholders need information on the environmental consequences of their decisions.
It is therefore necessary to assess environmental effects of underground structures in the decision making process and observe them during the construction and operation phases.

Some of the environmental impacts of underground structures are:

- Air pollution due to construction equipment,
- Effects on the groundwater level,
- Pollution and treatment of groundwater,
- Excavation of polluted material;
- Waste water originating from the construction,
- Pollution of surface water,
- Use and displacement of (natural) resources.

Of these effects, only air pollution and effects on the groundwater are discussed in detail, as these are of ongoing importance. The other effects are mostly limited to the construction phase and differ little for above-ground or underground construction techniques. A brief discussion of cut-and-cover methods is mentioned further below as this method may be particularly disruptive.

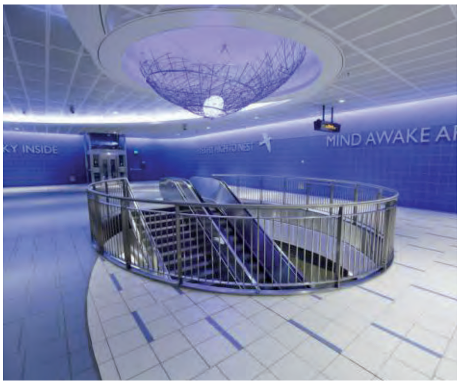


Figure 60, Underground Architecture

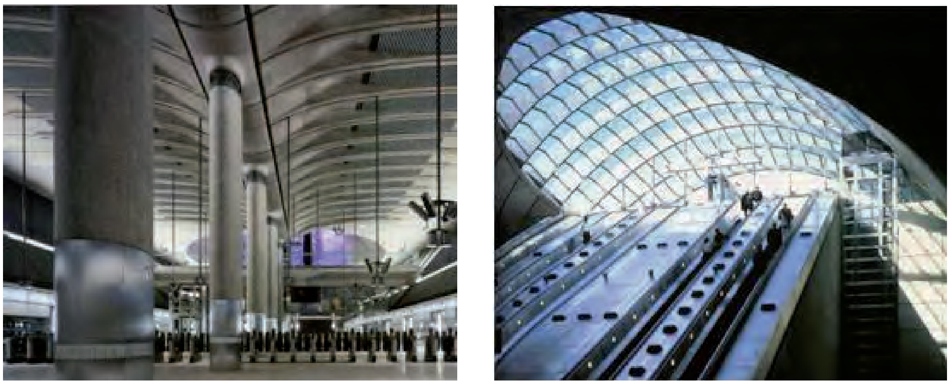


Figure 61, Canary Wharf Station, London

3.4.1 Air Quality

Air pollution in the vicinity of underground solutions can be generated, during the construction phase, by emissions coming from machines to build the structure and, during the operation phase, by the engine exhaust of traffic using the underground structure.
During tunnel construction the air pollution around the tunnel exit portals is mainly caused by exhaust gas from combustion of fuel for electric power generators, tunnel boring machines and other equipment.
In addition, excavation of dry tunnels can generate dust. Several measures may be applied to minimize concentrations on vulnerable construction sites.
For instance electric powered equipment can be used, that at least moves the emissions from the construction site to the power station. Also, low emission engines, exhaust purification catalysts and particle filters can be used to lower the air pollution, and improved logistics, work and route planning can lower the overall fuel consumption on site. Dust mitigation measures include sectioned off work areas, plastic strip doors and water mist curtains.

During the operations phase air pollution is mainly caused by the engine exhaust from traffic. Although the actual concentrations will depend on the background concentrations, the air pollution from road tunnels will be concentrated around the tunnel exit portals. Models are available that can predict emissions and concentrations based on traffic intensity, type of traffic, average speed, etc, so that emission concentrations can be predicted and arrangements to reduce the concentration can be made. In Norway, the Laerdal Tunnel, high air quality in the tunnel is achieved by ventilation and purification. As with all long road tunnels, fans draw air along the tunnel.
This tunnel is equipped with an air treatment plant, located in a 100 meters wide cavern that removes both dust and nitrogen dioxide from the tunnel air. Dust and soot are removed by electrostatic filters and a large carbon filter can remove excess nitrogen dioxide (Brekke, 2001).

In the operating phase an underground structure is often a better solution to prevent air pollution caused by traffic than a surface structure since the pollution is (in case of tunnel structures) restricted to the immediate vicinity of the tunnel ventilation outlets and the tunnel exit portals.
Here, it is possible to install purification facilities to remove exhaust gases and dust particles from the air before it is released to the environment. The pollution of the tunnel exit portals will also be diminished when a transverse ventilation system is installed with a separate ventilation shaft. The cost of these systems must be weighed against a system without the tunnel, and the dispersion of the contaminants, along with the energy use of the scrubbers and disposal of the filtered material.

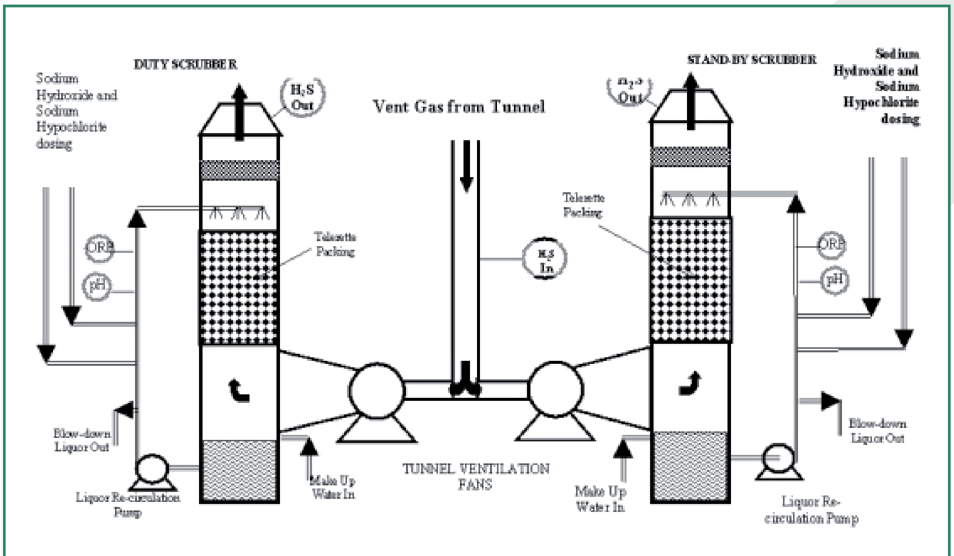


Figure 62, 'Ventilation shaft carbon scrubbers (Picture: Sydney Water)

3.4.2 Water

Effects on the groundwater level can occur when an underground structure is built in groundwater bearing layers or groundwater lowering is used during construction. Above-ground constructions will interact with groundwater levels to a lesser degree during operation, although the influence during the construction phase might be the same as an underground solution, depending on the construction method used.
Geology and groundwater regime are of course key factors in the considerations about the construction options for underground solutions. The construction of a tunnel, for example, can induce changes in the groundwater level depending on the local geology and groundwater regime, the choice of construction methods and the design of the tunnel. Such changes in groundwater levels can affect:

- soil stability, causing subsidence of soil and settlements of buildings and other man made structures,
- water supplies, by drying of wells or removal of potential resources for water supplies,
- habitats, by desiccation of wetlands;
- agriculture and forestry, as desiccation of land can cause changes in productivity. The effect can both be negative or positive depending on drainage of agricultural land.

Pollution of the groundwater can occur during underground construction if a spill or loss of chemical compounds to surrounding groundwater occurs, if such chemical agents are used in the construction work. Similarly, fuels and other substances from the machinery could leak into the groundwater. Spills can also happen when existing installations in the soil are damaged by accident. This includes leakage from sewers or of coating oil from heavy power supply cables. The problems arising from these types of spill are not different from other kind of construction works, but it should be stressed that deep excavation and underground work in many cases makes the groundwater more vulnerable, because the covering soil is removed. That is especially the case in areas where groundwater is a resource for water supply.

During the operational phase, spills, for example from fuels transports, can occur, but these accidents are not expected to pollute the groundwater but primarily the drain water system.
In this respect, they may be even better contained when compared to similar accidents above-ground.

Considering that above-ground solutions have nearly similar impacts on the environment (although the character and the intensity of impacts may differ), these aspects must be kept in mind during the decision making process and at the end a comparison between underground and above-ground solutions has to be made.

3.4.3 Disruption during Construction

As noted above, the focus during the decision making process may be less concerned with technical aspects, such as the construction techniques used. For many underground construction techniques, the only impact at surface level are the portals, access shafts or entrances, where significant space may be needed during construction. Such solutions do not generally disrupt or influence the quality of life to the extent that other (above-ground) solutions would. An exception is tunnels built from the surface in open trenches, which are only closed after the entire construction is finished (so-called cut-and-cover constructions). However, even in the case of cut-and-cover, temporary decking can be placed to allow traffic to pass while work goes on below.

According to ITA WG N°13, when making the choice for urban mass transit systems it is safe to say (in case of mass transit systems like a metro) that the most disruptive construction method is cut-and-cover construction, which is often used for underground subway stations and sometimes for the line structures which connect the stations (ITA WG N°13, 2003). Significantly less disruption is caused by elevated or above-ground constructions, since construction is primarily at the column locations of given routes. However, above-ground station structures have a significant impact during construction (and the final structure has long-term visual and noise impact).
The least disruptive method is tunneling for line structures and mining techniques for stations. The major disadvantage of these techniques is an increase of construction costs, although when the costs of economic disruption to adjacent business and other indirect costs are considered, cost may be reduced overall. Such indirect costs include loss of profit for nearby businesses, increased travel cost due to road disruptions, but also rise or fall of property values due to extended construction works.

Figure 63, 'Precast concrete decking with excavation ongoing below

Figure 64, Cut and Cover Construction within Street, New York City

Figure 65, Maintaining trees during the construction of an underground car park, Champs Elysees Avenue, Paris

Progress has been made in cut-and-cover construction methods, especially in the area of ground support (slurry or precast walls, grouting, and anchors).
But the efficiency of these construction methods is significantly reduced by the constraints resulting from underground congestion due to the presence of numerous utility networks and the more and more severe environmental requirements.
In addition, cut-and-cover methods are encountering growing resistance from local inhabitants, because of the disturbances and nuisances caused by major excavations undertaken in such congested areas. This illustrates that the construction technique used to realize an underground solution can have a significant influence on its social impact and should not be overlooked.

Figure 66, Sytwende Ring Road and City Extension, The Netherlands

3.5 DECISION MAKING PROCESS AND LEGAL ASPECTS

Various legal aspects can influence the decision making process for underground solutions. Underground solutions will leave the surface area open for other uses, allowing for multiple use of land in densely developed areas. This intensive use of land can ease the decision making process, as it allows multiple functions to be combined in the same area. In this way, it is often possible to conform to zoning plans and solve urban problems at the same time and in the same location.
Restrictive zoning plans or other regulations may not allow mixed use of land in all cases, which would hinder underground solutions from developing their full potential.

An example is the Sytwende land tunnel in the Netherlands, where a long-term conflict between city extension and ring road development has been solved by completely enclosing a new road and building houses almost on top of the road (see Figure 66). Local regulations actually prohibited building the houses above the road, a solution that would have further increased the number of houses that could be realized in the area.
This example shows that underground solutions can solve zoning problems, and at the same time can be hindered by local regulations.

Apart from zoning, laws and legal restrictions do exist in many legalities that prohibit building under existing structures that are not publicly owned.
Such laws can severely limit the possibilities for underground solutions and will need to be considered during the decision making phase. Although in many cases buildings or lands can be expropriated, this will add additional cost to the underground solution, which has to be weighed against the benefits of mixed land use, for example.

On the other hand, when expropriation is impossible or severely restricted, both above ground and underground solutions are limited, and extending public transport and services will soon become next to impossible. In Japan for instance the uncontrolled rapid expansion of underground space use combined with limited expropriation possibilities led to a situation where metro extensions below publicly owned land had become too restrictive due to extensive urban growth. To open up future expansion possibilities government passed the Deep Underground Utilization Act in 2001 that basically expropriates all ground 40 m below the surface (MLIT, 2008).

It is not only that underground solutions can help and influence the decision making process in offering alternative solutions for urban problems, it can also be that the political process drives which underground constructions are possible. An example is the extension of the Madrid metro system, where the extension phases of the metro are timed to coincide with the 4 year terms of the city council.

The planning period for a new metro extension directly proceeds the elections, such that directly after elections the necessary political decisions can be taken. Building can start directly after and (part of) the lines can be taken into operation during the term.

As this example shows in Figure 67, underground solutions can be included in the decision making process easily, if the underground is considered at an early stage. Unfortunately, this is still not a common scenario. When the underground space is taken into consideration only on an ad-hoc basis, the risk exists that users use the underground on a first come – first served basis, and thereby block future possibilities and an optimal use of both above ground and underground space (ITACUS, 2010). An early view of the value of underground space, combined with reservations for future use, such as the City of Helsinki makes, facilitates the future decision making process and keeps future options open.

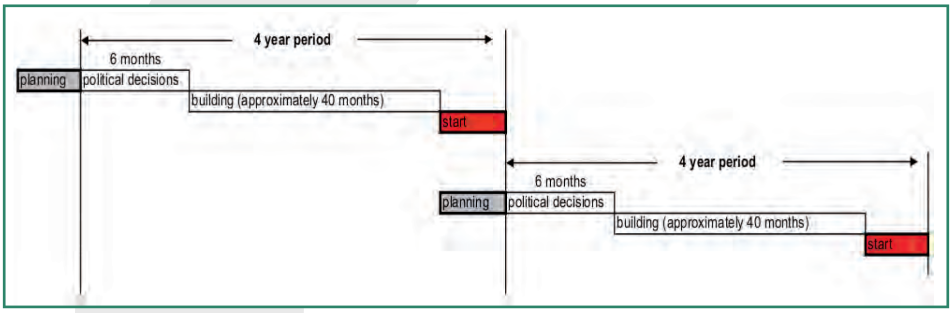


Figure 67, Decision Making Process

3.6 ECONOMICS

The fact that the initial capital cost of underground projects is often significantly higher than for elevated or above-ground solutions in most cases ultimately leads to the less expensive option. However, selection of an alternative only on the basis of initial capital cost may be misleading and in many cases precludes the realization of very substantial long-term benefits.

Considering that underground solutions have long-term benefits like lower life cycle costs due to longer durability when compared to above-ground projects, the underground alternative can return more benefits during its life time. Therefore, the true cost of an underground solution should be evaluated, not in terms of initial capital cost, but in terms of life cycle costs, benefits considering the longer service life underground solutions as well as their contribution to the environment and sustainability. In order to achieve this goal, a long-range cost-benefit analysis, where the initial capital is only a part of the total financial commitment, has to be performed (Parker and Reilly, 2008). In such an analysis, a consideration of all direct and indirect costs is necessary. The cost-benefit analysis should include the life cycle cost analysis, considering the following:

- Construction costs,
- Costs of operation,
- Maintenance costs,
- Disposal costs,
- Surface use and land cost.

As well as an analysis of benefits. An example of the influence of surface use and land cost is the underground sewage treatment plant «Dokhaven» in the centre of Rotterdam, the Netherlands.
The original plans of the water board called for three separate sewage treatment plants above ground at different locations, which would also involve a costly restructuring of the entire sewer network in the city.
By constructing a single treatment plant underground in an old harbor dock, substantial savings in direct cost were possible and a restructuring of the sewer network was not necessary. At the same time this opened up the former brownfield location and surrounding areas.
Since 1987 the area has been redeveloped into a modern and vibrant living quarter, distinctly increasing the property values for a large neighbourhood.

3.6.1 Life Cycle Costs Analysis

Life-cycle cost analysis (LCCA) is a method for assessing the total cost of a construction project. It takes into account all costs of construction, operating, maintenance and disposal of a building or building system. LCCA is especially useful when project alternatives that fulfill the same performance requirements, but differ with respect to initial costs, operating costs and maintenance costs, have to be compared in order to select the one that maximizes savings. The LCCA should be performed early in the design process while there is still a chance to refine the design to ensure a reduction in life-cycle costs (LCC). Figure 69 shows possible life cycle costs.

It is generally true that the construction costs of underground solutions are greater than elevated or surface facilities.
This was already documented in (ITA WG N°13). The cost of an underground mass transit system was reported around 4.5 times higher than a surface construction and 2.25 times higher than an elevated construction (in case of an urban mass transit system). As shown before the bare initial cost comparison is not reasonable as it should include costs during operation and replacement costs. In most cases operating costs for lighting, ventilation,

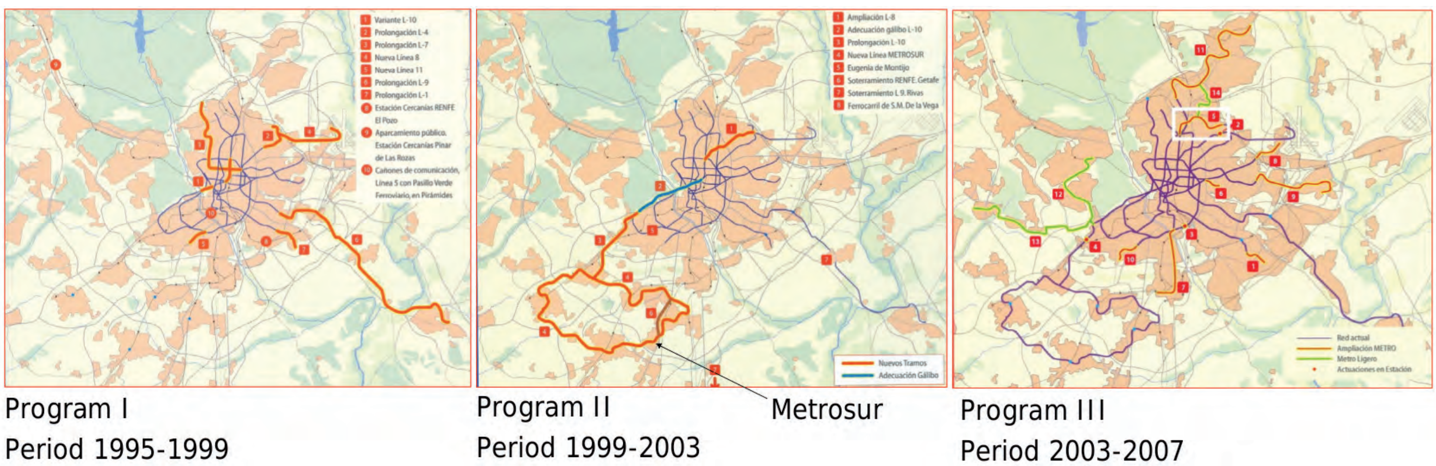


Figure 68, Madrid Metro Planning and Expansion

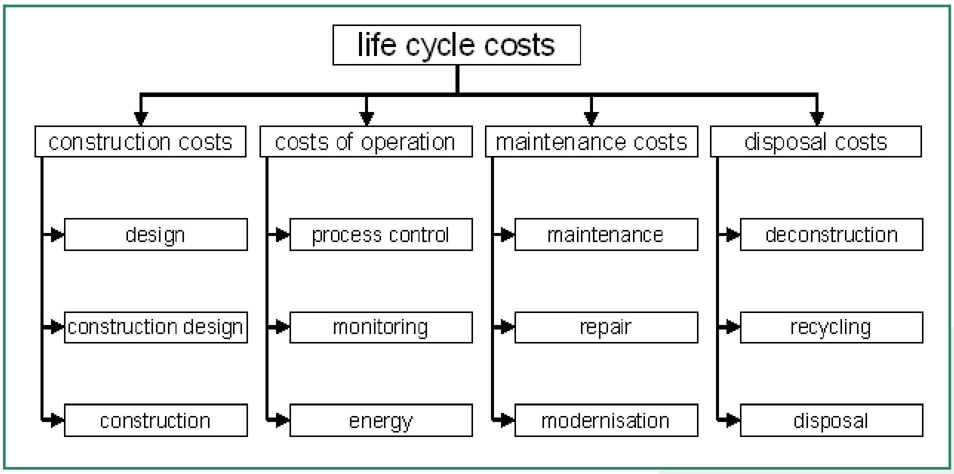


Figure 69, Life Cycle Cost Considerations

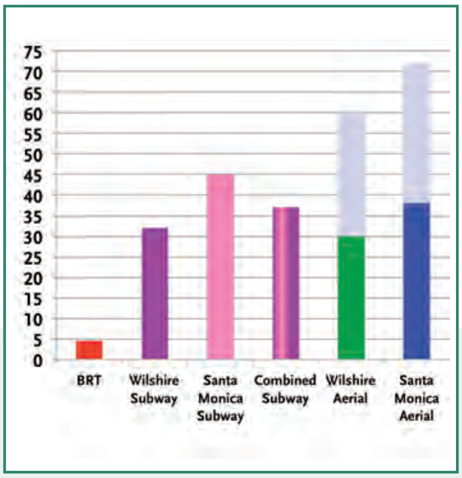


Figure 70, Planning estimates for Subway vs. Aerial Structures, Los Angeles Subway

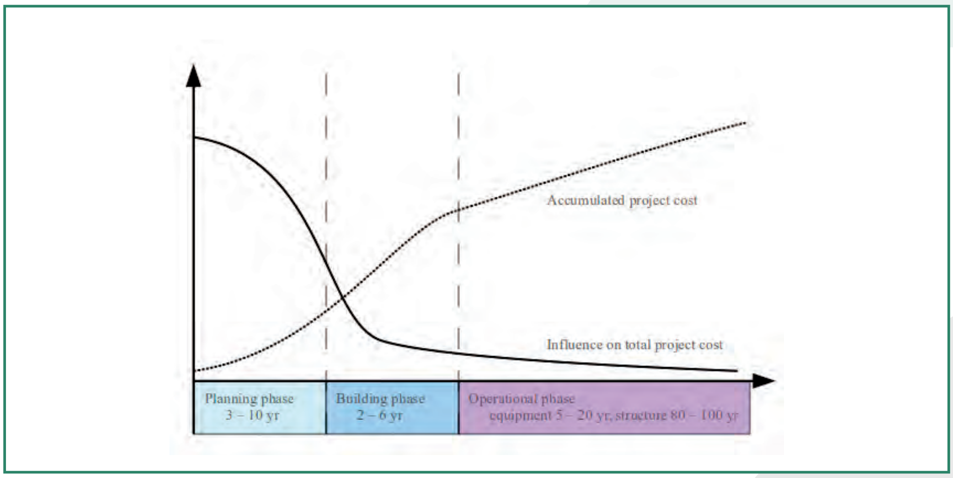


Figure 71, Tunnel Project Phases:
Accumulated Cost and Corresponding Influence on Cost (PIARC)

communications and safety systems will be higher for underground solutions. Maintenance costs could be the same or even less than for an elevated structure. However, considering the generally much longer useful service life of underground constructions, the overall life time costs might be lower.

In order to decrease costs during the operation phase a long-term strategy should already exist during the design. As shown in Figure 71, the influence on costs is enormous during the planning phase but declines to a minimum in the operating phase. The other way around occurs with the accumulated costs: these costs are at a minimum in the planning phase and increase many times over during the operation phase.

Where urban property values are increasing, the capital cost of underground construction can be competitive with the above ground option – when mitigations for property impacts and replacement of traffic lanes and parking are taken into account. In a proper LCCA such costs, as well as future benefits must be considered. Such future benefits attributed to underground projects should include:

- Valuable surface space will be untouched or made available again (land cost savings),
- Road user time savings (in case of road tunnels),
- Public transport user time savings (in case of urban mass transit system),
- Pedestrian time savings,
- Accident reduction,
- Increased property values and tax revenues,
- Reduction of noise impacts,
- Improvement of air quality,
- Improvement of the architectural quality of urban environment,
- Improvement of safety and security in urban environment.

It is a fact that long term benefits such as increased economic activity and urban development potential are frequently not included in making the choice of whether to go underground or above ground.

3.7 TECHNICAL ASPECTS

As this paper focuses on the decision making process much more than the construction process, technical aspects of underground construction are not dealt with in great detail. Only a short overview of topics which could be interesting during the decision making process is given. In order to decide whether to build underground or above ground a feasibility study comprising all boundary conditions and all available construction methods should be made. In this feasibility study different construction methods would be considered. The fact that a large number of different underground construction methods are available, as well as a multitude of underground solutions, reveals the innovative aspect of underground construction. As shown in Chapter 3, a significant proportion of urban problems can be solved by underground solutions.

A good overview of underground construction methods is given in e.g., (Puller, 1996, Maidl et al. 1996). Here only a selected number of significant engineering developments in underground technology in recent years are given, based on the experience of major projects. Such developments are:

- A significant improvement of the sustainability and safety of underground urban road and rail systems, through improved (safety) installations and design guidelines,
- A lowering of the costs and improvement of safety and quality of underground construction and space, making it a competitive alternative to surface construction,
- The realization that underground space is a platform for new construction concepts and new business models, and is adopted by city planners and decision makers to foster the development of sustainable cities,
- The development of tunneling equipment that can operate in any type of ground,
- The development of new and innovative methods and equipment for geological exploration, monitoring and decision support systems, significantly lowering the risk of unknown geological conditions,
- The application of new cutting technologies in mechanized tunneling, increasing the excavation speed and lowering the costs,
- Continuous monitoring of the construction environment combined with active control to minimize the impact during the construction phase on the surroundings,
- The inclusion of renewable or geothermal energy systems in underground structures, lowering the energy footprint of these constructions,
- The combination of large underground construction projects with concurrent educational/outreach programmes, in order to make the underground construction business an attractive technology-driven, skills demanding industrial sector, whilst creating new job opportunities,
- The use of shallow small-diameter tunnels to create a novel underground transport system for supplies and goods, supplementary to existing infrastructures, which reduces the surface road traffic,
- Use of diaphragm walls to limit wall deflection during excavation and reduce impact to the environment of building activities.

Figure 72, Modern tunneling technology

3.8 “MEGA PROJECTS”

No paper on the benefits of underground space use would be complete without some discussion of Mega projects that have achieved notoriety due to the scale, cost and duration of construction.

Especially large scale projects costing millions to billions of Euros are open to public scrutiny and much attention in the news media. One in particular, Boston’s Central Artery/Tunnel project (affectionately known as the “big dig,”) gained special attention in the 1990s through 2007, when it was substantially completed. The project was originally planned to replace an existing six-lane elevated highway (Interstate 93) through downtown Boston with an eight to ten lane underground expressway - directly beneath the existing road, and extended the I-90 under Boston Harbor to Logan International Airport. The elevated road would then be demolished to provide open space and some modest development. To put these highway improvements in the ground in a city like Boston proved to be one of the largest, most technically difficult and environmentally challenging infrastructure projects ever undertaken in the United States. The project spans 13 km of highway, 260 km-lanes miles in all, about half in tunnels. The larger of two Charles River bridges, a ten-lane cable-stayed hybrid bridge, is the widest ever built and the first to use an asymmetrical design. However, cost projections for the initial scope of the project in the

Figure 73, Public Space over former at-grade freeway planning phases were in the on the order of $2.6 Billion (1982 estimate), while the final cost of construction in 2007 was over $14 billion. Schedule over-runs, construction claims and a public tiring of the construction related traffic diversions has given it the perception of mis-used funding.

Whether the project was justified will, need to be judged over time, but it now may be claimed that Boston is truly a city transformed. Where an ugly green elevated highway once stood - slicing through the heart of the city's downtown and restricting access to the waterfront and historic North End - there is now parkland and new commercial development over a tunnel that zips traffic through the city. Another tunnel speeds traffic to the city's airport, and a majestic cable-stayed bridge over the Charles River has become a new city icon.

All this, and more, was made possible by the Big Dig, a $14.8 billion transportation project that has produced a host of related benefits - $7 billion in projected private investment, the creation of more than 40,000 jobs, and a 12 percent reduction in carbon monoxide emissions. Before the project was completed, it prompted a real estate boom in downtown Boston and beyond
In addition to dramatically reduced driving time through Boston and to the airport, the project provided a new multimodal transportation center at South Station; an 11-hectare greenway over the I-93 tunnel; new bus rapid transit service (the Silver Line) that runs partially through tunnels built by the Big Dig; a new park on Spectacle Island in Boston Harbor created by capping a former landfill; and 16 hectares of parkland along the Charles River.

The technical challenges of construction were unprecedented, requiring feats of engineering breathtaking in their scope and complexity.

"Of all the project's engineering challenges, none was more daunting than the first -how to build a wider tunnel directly underneath a narrower existing elevated highway while preventing the overhead highway from collapsing," according to a December 2007 article on the Web site of Time magazine. To keep the old elevated highway in service while construction proceeded on the new Central Artery, engineers put temporary steel supports into place, transferred the load of the old elevated highway to the walls of the new underground expressway, and then cut away the legs of the viaduct.
Traffic continued on the old elevated highway, with drivers unaware of any change.

The main tunnel carrying I-93 through the city had to go under the century-old Red Line subway, climb nearly to the surface to go over the Blue Line subway, and then go under ramps to an existing highway tunnel before emerging to cross the Charles River on the widest cable-stayed bridge in the world - which was constructed over the Orange Line. Tunnels under working railroad tracks at South Station were pushed through soft fill by giant hydraulic jacks, but first the ground had to be "frozen" with injections of chilled brine to make it stable enough for the six giant tunnel segments - the largest structures ever "jacked" in this way.

In one of the project's greatest logistical challenges, a tunnel carrying I-90 under the Fort Point Channel was constructed with giant concrete (immersed) tubes built on site in a casting basin, floated into position and placed about 1 meter above the Red Line, supported by 110 concrete shafts drilled into bedrock.

Figure 74, Tunnel to Boston's Logan Airport and Charles River Bridge Boston

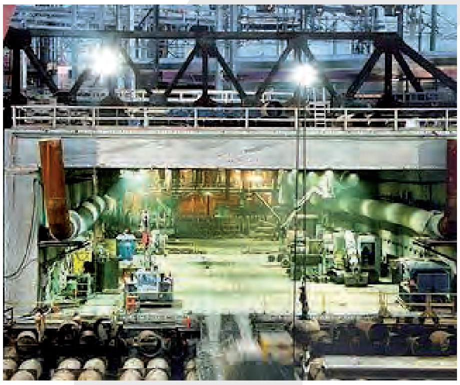


Figure 75, Ground Freezing for section under active Rail Road

Figure 76, Central Artery 1

The Cost of a Mega Project

How does a project end up costing $14.8 billion when it was originally projected to cost $2.6 billion?

In the case of the Big Dig, the answer includes the cost of more than two decades of planning, design and construction, plus the effects of inflation, major additions to the scope of the project, and extensive mitigation of the project's environmental impacts.

The initial cost estimate for the Central Artery/Tunnel project, prepared in 1982, was $2.6 billion. That estimate did not include inflation (per Federal Highway Administration guidelines) and was for a highway system considerably smaller in scope than the project ultimately completed in 2007 at a cost of $14.8 billion.

The project's initial schedule, which called for completion in 1998, was based on the assumption that the project would have all environmental approvals in place by 1986. In fact, the project did not receive full environmental approval until 1994, and the project was substantially completed 12 years later - virtually the same time frame as originally projected - but with a significantly expanded scope.

More than half of the increase in the project's cost can be attributed to inflation, which added $6.4 billion to the cost estimate prepared in the early 1980s. Major additions to the project's scope - including the reconstruction of the Dewey Square tunnels, new interchanges at Logan International Airport and Massachusetts Avenue, more complex methods for the Fort Point Channel crossing, roofs for open-air tunnels in South Boston and East Boston, and temporary ramps to maintain traffic during construction - increased the cost by an additional $2.7 billion. Efforts to mitigate the project's environmental, social and economic impacts added $3 billion, including $400 million to dispose of fill on Spectacle Island to create a park and $1 billion for a bridge over the Charles River that was extensively redesigned over a period of 11 years. “Mitigation eventually accounted for about one-third of the Big Dig's cost,” according to a 2007 article in City Journal magazine.

Over 21 years, the Big Dig was expanded, redefined and revised to meet a myriad of legitimate concerns and demands by the project's many stakeholders, resulting in the final $14.8 billion cost. In contrast, if the scope of such mega projects is clearly defined and all complexities and stakeholders are taken into consideration, the budget can be more realistically determined and kept from the start.

The Pioneer Institute for Public Policy Research, in a report produced in December 2008, concluded: «With the passage of time, the Big Dig should, and will be seen, as one of the most successful congestion relief projects ever built...the extraordinary improvements in transportation service that the completed Big Dig now brings to the city of Boston will hopefully become the legacy that lasts, not the decade and a half of construction.»

4 >> Solution Summary

Worldwide, there is an increasing need for new infrastructure as cities expand, redevelop and rehabilitate their existing infrastructure, in order to meet demands of increased population and an increased awareness of the general public for the quality of their surroundings. In many cases this leads cities to expand outwards, with lower urban density further away from the city centre, in order to find the required space.

If, however, underground space is included when looking for solutions to urban problems, higher urban densities can be supported, leading to more compact cities with a lower impact on the local environment. In addition to the obvious benefit of preserving green space and agricultural land, there is strong evidence that higher urban density can lower fuel and resource consumption.
Underground development will be an important tool in reshaping our urban areas to meet the challenges of the future without destroying their heritage or worsening their surface environment (Esaki, 2005).

In order to efficiently include underground solutions in the decision making process, it is important to realize the current possibilities of underground construction and the problems that can be solved in this way. In Chapter 1 the paper gives an overview of urban problems that may be solved through the use of underground space, such as:

- Crowding and lack of space (for work and recreation),
- Traffic congestion,
- Aging infrastructure and distribution of resources,
- Aesthetic qualities and image of the urban environment,
- Safety, security, and protection against natural disasters,
- Flooding,
- Environmental conditions such as noise and air pollution,
- Sewage conveyance and treatment,
- Synergy effects of the above.

For each of these topics, Chapter 2 gives an overview of underground solutions that address one or more of these topics. These include:

- Road and rail tunnels,
- Parking,
- Drinking water storage and production,
- Storm water relief,
- Energy and goods distribution,
- Short and long term storage,
- Recreational facilities, leisure and shopping,
- Office space and housing.

These solutions are further illustrated by several key projects around the world (see Appendix A), where the use of underground space is a major component. Chapter 3 finally focuses on the decision making process and lists points of attention when considering or comparing underground solutions, such as the impact on environmental quality, aesthetical issues, social and legal influences, reduction in travel times, energy saving and possible increase in property values. In an ideal situation all such aspects are considered when above ground and underground solutions are compared.

"Population growth and the advent of mega cities are increasing the pressure on sensitive areas. The underground has enormous potential for realizing spatial benefits. You could say that one of the greatest challenges facing mankind is to achieve higher density while at the same time improving urban existence."
Lord Norman Foster, British Architect

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APPENDIX A

Editors and Contributors to Working Group N°20: Animateurs, Vice Animateurs and Tutors 2008-2012)
This report has been edited by the Animateurs, Vice Animateurs and Tutors of Working Group N°20 over the period 2008-2012.

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6 >> Appendix

This report contains contributions by the various Working Group members over the period 2008-2012.

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