

Lifecycle Engineering - Thinking Beyond Construction for Critical Infrastructure

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International Tunneling Symposium - Seattle

Rainier Room • Seattle WA
Friday, December 14, 2007 11:30 AM – 2:30 PM

Presentation will discuss:

1. International Tunnelling Association / Examples
2. Making the decision, above-ground or underground?
 - Difficulties in correctly estimating & controlling costs
 - Difficulties in obtaining funding and approval for underground projects
 - Justifying the generally higher initial capital costs of underground projects
 - Identifying and quantifying all the benefits for underground projects (present worth basis)
 - How to capture increased value such that additional capital cost can be funded (and approved by voters)
 - Social & political implications - long range planning
 - Examples, considerations & recommendations



ITA-AITES
INTERNATIONAL TUNNELLING AND UNDERGROUND SPACE ASSOCIATION
ASSOCIATION INTERNATIONALE DES TUNNELS ET DE L'ESPACE SOUTERRAIN

Sensible Underground Solutions
for Urban Problems

Prof. André P. Assis, PhD
(ITA & Univ. of Brasilia)

China Tunnel & Underground Space
Development Seminar
17 June 2004 – Shanghai, China

The Basic Alternative (2)




Gibraltar Straight Tunnel

Dr. Harvey Parker,
Past-President,
International
Tunnelling
Association








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why GO UNDERGROUND ?


CONTRIBUTION OF THE USE OF UNDERGROUND SPACE TO SUSTAINABLE DEVELOPMENT



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International Tunneling Association - Studies & discussion relevant to this topic

- ITA WG13 “Direct and Indirect Benefits of Underground Structures”
- *Godard, Sterling, Reilly*
- ITA WG20
“Urban Problems –
Underground Solutions”
- *Reilly, Thewes*
- Presentation to the ITA World Tunnel Conference, Prague, May 2007
- *Reilly, Parker*

UNDERGROUND OR ABOVEGROUND?

Making the Choice for Urban Mass Transit Systems

A REPORT BY THE
INTERNATIONAL TUNNELLING ASSOCIATION (ITA)

PREPARED BY

WORKING GROUP NUMBER 13 (WG13)

DIRECT AND INDIRECT ADVANTAGES
OF UNDERGROUND STRUCTURES



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Relevant papers - US Committee, ITA WG20

US Perspective: Challenges for Constructing Underground Facilities in Urban Areas

Eur. Ing. Christopher Laughton, Ph.D., P.E., C.Eng.
Fermi Research Alliance, USA

Amanda Elioff, P.E.
Senior Professional Associate, PB, Los Angeles, USA

ABSTRACT: A number of major underground projects are currently underway in the United States of America (US) and more are planned for a construction start within the next five years. This paper provides a brief overview of some of the more significant challenges that the US civil underground industry is currently facing as cities make increasing use of underground space to address issues of urban infrastructure renewal and development.

To be presented at the ThinkDeep International Conference
“Enlightened Underground” January 2008,
Center for Underground Construction, Netherlands



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Funding & Life-Cycle, Benefits + Costs

- In many parts of the world it is very difficult to obtain funding and approval for underground projects
- Even if the long-term benefits are positive
- Because the higher initial capital cost of underground projects means that a cheaper elevated or above-ground project is frequently chosen.
- Selection of an alternative only on the basis of initial capital cost is misleading and in many cases precludes the realization of very substantial long-term benefits. Therefore:
- Long-term/Life Cycle value (benefits + costs) need to be considered



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Life Cycle Value - Benefits & Costs

- Long-term benefits for underground projects are, in many cases, greater than those for above-ground projects.
- Tunnels often last twice as long as surface alternatives.
- These and other benefits mean that the underground alternative can return more benefits if long-term benefits and costs are considered = “Life Cycle”
- We define “Life Cycle” as the present value of all benefits + capital and operational costs of the facility



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Factors that affect “The Decision”

- There are many complex political & technical decisions in project planning and financing to determine the type of project – above-ground or underground
- Perceived high cost for underground is an assumption that prematurely eliminates consideration of tunnels
- These decisions are usually made only on the basis of initial capital costs
- Life Cycle analysis may show benefits that outweigh a higher initial capital cost for the underground alternative
- Many examples of tunnels being “in the competitive range”.



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Relative costs of above-ground and underground projects

- See ITA WG 13 Report “Underground or Aboveground, Making the Choice for Urban Mass Transit Systems” (*ITA, 2004*)
- WG13 reported cost factors for underground = 4.5 times that of surface, 2.25 times for elevated structures.
- But some projects underground initial capital cost only +25% - in one study the underground alternative was cheaper (LA Metro)
- These are significant cost factors in determining the choice for an underground or an above-ground facility.
- Generally, it is very difficult to argue for an underground structure on the basis of the initial capital costs!



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Compiling real costs for true infrastructure construction comparison

Is tunneling really the most expensive option of providing public transportation infrastructure? These research data compiled by a consulting engineering firm in the US suggest not. They bust the long-held axiom by considering more than construction cost alone.

What is the true cost of constructing transportation infrastructure? What is included in 'true cost'? How do the different transportation structures compare? Answering these questions has consumed many feasibility-study man-hours over the decades and often with unsatisfactory results. Once compiled, the difficulty of expressing the data in a readily appreciated manner is often the task that renders the information

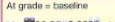
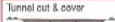

indigestible, too difficult to fathom, and the whole exercise somewhat futile.

In an effort to address this deficiency, a consulting engineering practice in the US has compiled these three tables that present a different take on cost comparison. Without publishing the name of the firm for the moment, what is your opinion of the data presented? How does your experience conflict or comply with these suggestions?

As part of this comprehensive tabular and graphic comparison, the researchers not only compare 'soft' as well as 'hard' construction costs, as a percentage of the at-grade baseline, but include also the impact each method of procurement has on property values within the traffic corridor, an aspect that is often ignored in project planning and estimating, or considered in only a cursory fashion.

With such data in hand, how to

Table 1: Project cost

	Weighted % Average Range	Soft cost				Construction cost				Total project cost (%)
		EIS/ER 3 - 6	Design fee 12 - 15	Right of way 8 - 15	Productivity loss 2 - 5	Construction management 12 - 15	Traffic relocation & maintenance 8 - 25	Utility relocation & support 6 - 15	Structures 15 - 35	
At grade = baseline 	1	1	1	1	1	1	1	1	1	1.0
Elevated structure/viaduct bridge 	1.4	1.4	1.8	1	2	1	1.2	7	2.8	
Tunnel cut & cover 	1.4	1.6	1	1.5	1.6	1.5	2	10	3.7	
Tunnel mined 	0.3	1.4	0.3	0.3	0.7	0.3	0.3	11	3.2	

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Table 2: Annual cost

Life span in years	Project cost per annum (%)			Weighted %	Average Range	Annual costs				Total
	Life span relation	Total project cost	Total			Environmental pollution	Loss of property taxes	Social divide	Maintenance cost	
-	-	-	100	-	25	25	15	35	100	
100	1	1	1	1	20 - 30	20 - 30	10 - 20	30 - 40	1	
50	2	2.8	5.7	1.2	1	1	0.8	2	1.4	
100	1	3.7	3.7	0.05	0.2	0	1.3	0.5		
150	0.66	3.2	2.1	0.05	0.2	0	1.1	0.4		

Notes: (1) Refer to Table 1 (2) Interest not included

Based on international experience in urban areas.

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T&T North America DECEMBER 2005

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Life: underground compared to above-ground

- Tunnels and underground structures last a significantly longer time than above-ground structures.
- About 50 years for above-ground, over 100 years for tunnels - many still in useful service today – e.g the 104 year old railroad tunnel under Seattle.
- Longer service life means that the present value of a tunnel, including or excluding other benefits, is probably more than an elevated structure, which has a shorter life - even though the initial capital cost of the elevated is less than the tunnel.



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Life Cycle benefit- cost analysis

- Benefit-cost analysis should include capital, operating and maintenance costs + direct and indirect benefits such as:
 - Road user time savings, public transport user time savings, travel time variability, pedestrian time savings, vehicle operating cost savings, accident reduction etc. & longer facility life.
 - Plus, the less tangible environmental and sustainability benefits such as improvements in social benefits, increased land value, increased amenities (parks etc.), less noise & pollution, energy savings, reductions in greenhouse gas emissions
- An equivalent value should be credited for the above (Parker, 2004, Hess, 2001).



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Examples – benefits of urban underground transportation projects

- The following examples outline major transportation projects in dense urban environments where an underground facility has been chosen over a surface or elevated one.
- These are road projects, but the same considerations would apply to rail or transit projects.
- In a few cases the cost-benefit of the underground solution has been quantified – some are reported here.



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Cross-City Tunnel, Sydney, Australia

- Sydney examined the costs and benefits of construction of the Cross-City Tunnel
- A critical location for flow of traffic in the inner metropolitan area.
- Crossing point for major road and public transport flows for north–south and east–west directions.



- Initial Capital cost estimate \$AU330m
- Total benefits estimated \$AU1,175m as shown following.
- Equivalent net present value of the benefits \$AU448m.
- *Delivered capital cost \$AU680*



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Projected Benefits - Cross-Sydney

Element	Benefit (\$AU m)
Time savings (road)	738
Time Savings (public)	83
Time Savings (Pedestrian)	67
Vehicle cost savings	211
Accident reduction	10
Noise reduction	11
Pollution reduction	.1
Greenhouse gas reduction	51
Increased property value	3
Totals	1,175



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Rheinufertunnel - Benefits

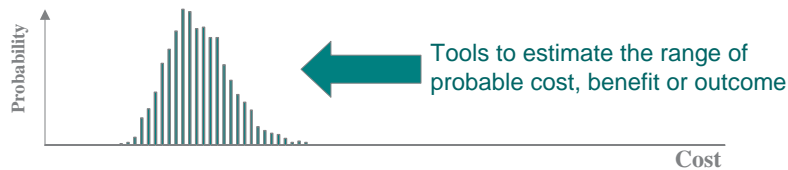
- Valuable surface space reclaimed
- Additional traffic capacity
- Relief from traffic congestion
= time savings
- Reduced noise and pollution
- Quality of environment improved
- Safety and security improved
- The project was completed on time
and within the original 300 million
Euro budget.



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Tools to quantify range of probable costs + benefits

- New tools can better address cost, probable cost, risk identification, risk management, value engineering, life-cycle costs and benefits and probable funding.
- Example - Washington State Department of Transportation's Cost Estimate Validation Process (CEVP®)
- Identifies ranges of probable costs by combining "base costs" with risks + opportunities
- Can be extended to include life-cycle process w. present value



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Summary

- To make a more equitable case for selection of underground alternatives we need to make the case to the public, agencies and political decision-makers that :
 - Planning and public policy must consider long-term life-cycle costs and benefits
 - The long-term life-cycle costs and benefits need to be quantified through an accepted methodology
 - Benefits need to be communicated to the public and political decision-makers
 - The political process should recognize that this is an appropriate planning and selection process
 - A funding mechanism that will support the higher initial capital cost must be found – this means we need longer-range public financing and policies
 - Revenue to support the financing mechanism needs to be able to be collected and applied to the project(s)
 - The credibility of this process must be demonstrated



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BENEFITS AND LIFE-CYCLE COSTS OF UNDERGROUND FACILITIES

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ABSTRACT

Up until 2002, ITA Working Group 13 addressed the “Direct and Indirect Benefits of Underground Structures. In 2002, WG20 continued this theme with the topic “Urban Problems – Underground Solutions” (the principal author was an Animateur of both groups). Much progress has been made in understanding the issues - however in many parts of the world it is very difficult to obtain funding and approval for underground projects, even if the benefits are positive, because the higher initial capital cost of underground projects means that the cheaper elevated or above ground project is frequently chosen.

Selection of an alternative only on the basis of initial capital cost is misleading and in many cases precludes the realization of very substantial long-term benefits. Underground projects have long-term (life cycle) benefits that are, in many cases, much greater than those for above ground projects. Tunnels often last twice as long as surface alternatives. This and other benefits, described in this paper, mean that the tunnel alternative can return more benefits.

This paper addresses these issues, gives example of underground transportation projects and their key benefits and suggests a process to better quantify the long-term life-cycle benefits and costs.

INTRODUCTION

There are many very complex and emotional issues and decisions in the planning and financing of any infrastructure project. Perceived high cost is an assumption that prematurely eliminates consideration of tunnels in many planning sessions. These premature decisions are usually made only on the basis of initial capital cost since there is a general misconception that tunnels cost too much and therefore need not be considered at all. In fact the true long-term cost of a tunnel may or may not be more expensive than surface or elevated schemes. When evaluated from the standpoint of Life Cycle Cost and Benefits there are examples of tunnels having benefits that outweigh their higher initial capital cost and many examples of tunnels being “in the competitive range.”

Therefore, the true cost of a tunnel should be evaluated, not in terms of initial capital cost, which is often the only factor considered, but in terms of life cycle costs and benefits considering the generally much longer useful service life of tunnels and their contribution to the environment and sustainability.

The underground industry has been remiss not to have developed methodology and databases that can easily evaluate projects from the standpoint of life cycle costs and benefits. In 2001, the authors organized an AUA Regional conference highlighting these issues in Seattle, USA but the industry has been slow to respond. Life cycle cost methodology is used routinely by the highway pavement industry and private business, but is seldom used for a complete evaluation of major infrastructure projects.

Fortunately, techniques and tools have and are being developed to better identify cost, risk and value. These can be extended to include life-cycle costs and benefits as well as funding/revenue projections. An outline of this is presented later in this paper.

OVERVIEW - THE DECISION TO BUILD UNDERGROUND

More cities are deciding to construct urban transportation projects underground for several reasons.

- They are often the shortest route between two points.
- Tunnels are a way to maintain mobility, using space that is not in conflict with surface functions
- Tunnels allow multiple use of real estate, essentially doubling the potential use of any parcel of land
- They provide significant environmental benefits (reduction of noise and visual impacts) and social opportunities (better public use for the surface space)
- They allow movement of people, goods and services, without having to change modes of conveyance
- Tunnels operate in, and can provide shelter from, adverse weather conditions - safety is improved by the absence of glare, distractions, rain and snow.
- They allow movement under or through obstacles (preserving the obstacles if necessary).
- They allow grade separation without going higher overhead.
- They conserve energy or are inherently energy efficient.
- They are ideal for preservation of the environment and sustainability

Examples of international cities building transportation tunnels include: Amsterdam, Hamburg, Stuttgart, Melbourne, Moscow, Oslo, Paris, Shanghai, Stockholm, Sydney and Tokyo. In these cities, there is a relationship between sustainable development and tunnel demand. Tunnels have environmental and social benefits that are recognized by decision makers and voters - in the Netherlands (where many tunnels must cross beneath rivers or through highly valued rural areas) they have put a rail tunnel beneath farmland at a significant extra cost to preserve the environment (High-speed rail project).

New York is planning the Gowanus tunnel to replace the elevated Gowanus Expressway – the tunnel has been shown to be technically feasible and aesthetically desirable to surrounding communities. The increased space provided by the demolition of the elevated expressway would be used to develop a tree-lined boulevard along Third Avenue. Eventually, esplanades and parks will be created along the waterfronts in the corridor.

Population, and urban concentration are major factors to consider. In Japan, the lack of available land for infrastructure is driving demand for tunnel construction, and the country builds more tunnels than any country with over 700 miles of tunnels. Switzerland builds mostly through mountains in rock tunnels. Sweden has a policy to first consider underground solutions.

COST OF UNDERGROUND PROJECTS & LIFE-CYCLE BENEFITS/COSTS

It is generally true that the initial capital cost of underground construction is significantly greater than elevated or surface facilities. This was documented in the ITA Working Group (WG) 13 Report “Underground or Aboveground”, Making the Choice for Urban Mass Transit Systems. (ITA Working Group 13 2003). The cost factor for underground was reported around 4.5 times that of surface and 2.25 times elevated. These are very significant cost factors.

The conclusions of the WG13 report are significant. The following list gives relevant findings:

1. The decision on whether to place an urban mass transit system underground or aboveground is a complex planning, engineering, construction, urban design, economic and political decision.
2. In many cases - for example in the center areas of older cities - for functional, social, historic environmental and economic reasons there is no alternative to the choice of an underground alignment for new mass transit systems.
3. For many developing countries, the investment cost of a fixed guideway urban mass transit system is significant compared to the national or city economies. For urban mass transit systems developed or operated by private companies, return on investment is a critical issue.

4. For newer cities, cities without extensive historical districts, and cities with wide streets, elevated alignments can offer full grade separation typically at substantially lower initial construction cost than underground alignments, with certain exceptions usually related to right-of-way costs.
5. The initial capital cost is only a part of the total long-term financial commitment. Costs include capital (including financing), operating, maintenance, security and rehabilitation.
6. Consideration of all costs – including capital, operating, maintenance, security and rehabilitation costs are necessary.
7. Consideration of all benefits - direct and indirect, short and long term - are necessary.
8. Long-term benefits such as increased economic activity and urban development potential are frequently not calculated in making the choice of whether to place an urban mass transit system underground or aboveground.
9. For the choice to be made well, both short and long term costs and short and long term benefits need to be objectively and comparatively considered.
10. Many aspects of the cost-benefit relationships are hard to quantify. Reference analyses and reports with the experience of other cities are very useful – particularly in the early stages of planning and design – however such quantification must be considered.
11. A cost ratio typically assumed for surface versus elevated and versus underground systems has been reported to be 1:3:6. Analysis of the data received from this questionnaire showed very large variations in cost ratios according to the particular circumstances of each city and existing infrastructure – which means that such ratios are not very useful in practice. The median ratios from the data received for this report were approximately 1:2:4.5.
12. Underground construction costs are tending to fall with time, as technologies and productivity improve. However, the costs of underground transit systems may not reflect this due to the fact that higher standards of amenity and safety are being built into new underground systems, e.g. large volume public spaces, air conditioning systems, better surface finishes etc.

Long-range cost-benefit analysis

Cost-benefit analysis should include capital and operating and maintenance costs, road user time savings, public transport user time savings, travel time variability, pedestrian time savings, vehicle operating cost savings, accident reduction, etc. The benefits accrued to underground projects should include the time value of the use of the surface over the tunnel (a value can be assigned even if it is a park), right of way advantages, increased property values and employment in the general vicinity, and overall energy savings that might result from shorter travel times, flatter grades, etc. Moreover, an equivalent accrued value should be applied for the less tangible environmental and sustainability benefits such as noise impacts, air quality impacts, and greenhouse gases which are significant over the life cycle (Parker, 2004, Hess, 2001). The following examples include many of these elements and this issue is developed further later in this paper.

Maintenance and operating costs - underground vs. above-ground

Increased maintenance and operational costs for underground facilities may or may not be greater than surface or elevated facilities. Operating costs for light, ventilation, communications and safety systems will cost more for a tunnel. Maintenance costs however may be the same or could be less than for an elevated structure. For example a study for the Newfoundland and Labrador Fixed-Link project, 18 km long, which compared the estimated capital, maintenance and operating costs for several alternatives including bridges compared to immersed tube, drill and blast and TBM tunnels, found significantly lower maintenance and operational costs for the tunnel configurations - \$CA16.9 million/year for the bridge and between \$CA 6.8 and \$CA7.6 million for the tunnel (*Newfoundland and Labrador Fixed-Link project*).

In Sydney (see following) the projected Net Present Value (NPV) of operating and maintenance costs were projected at about 8% of the cost of construction. These costs were included in the cost-benefit analysis which showed a positive investment return. Hess (2001) reported a similar very comprehensive life-cycle evaluation

of the Prague Metro in which he concluded that over the life cycle, a subway project brings a profit to public budgets in spite of increased operational costs compared with the surface transport.

EXAMPLES – BENEFITS OF URBAN UNDERGROUND TRANSPORTION PROJECTS

The following examples outline major transportation projects in dense urban environments where an underground solution has been chosen over a surface or elevated one. These are road projects, but the same considerations would apply to rail or transit projects. In a few cases the cost-benefit of the underground solution has been quantified and is reported here.

Cross-City Tunnel, Sydney, Australia

Sydney, Australia examined the costs and benefits of the construction of the Cross-City Tunnel which occupies a critical location in relation to the flow of traffic in the inner metropolitan area. It is the crossing point for major road and public transport flows in both north–south and east–west directions. The economic assessment of the Cross-City Tunnel (*NSW Roads and Traffic Authority Working Paper 2000*) found an expected gross benefit of over \$A1 billion and a substantial net benefit of over \$A400 million - after including the actual (completed) cost of construction. The aim of the study was to provide a detailed account of the economic and financial costs and benefits from the construction and use of the proposed tunnel.



The Sydney Cross-City Tunnel had an estimated a capital cost of \$A330m and a delivered capital cost of \$A680 - see other papers for cost growth of major infrastructure projects (*Reilly, 2005a*) but was estimated to deliver total benefits of some \$A1,175m - a good benefit/cost ratio with an equivalent net present value of \$A448m. The listing of benefits was :

Table 1 – Benefits of Sydney’s Cross-City Tunnel

Element	Estimated benefit
Time savings - road	738.15
Time savings, public	83.48
Time savings, pedestrian	67.15
Vehicle cost savings	211.27
Accident reduction	10.17
Reduction in noise	10.94
Reduction in pollution	0.13
Greenhouse gases	50.58
Increased property	3.41
Total	1175.28

Rheinufertunnel (Rhine embankment tunnel), Düsseldorf, Germany

As in many old cities, which are situated along rivers, the road along the embankment of the Rhine in Düsseldorf was frequented by 55,000 cars per day until the early 90s. This road separated Düsseldorf's "Altstadt", the famous historic part of the town, which is also frequented by many tourists, from the river Rhine, preventing the public from enjoying the special urban quality of living next to a river. In 1993 a 4-lane

road tunnel under the previous embankment road was opened, also opening the chance for an immense improvement of the urban quality in this part of Düsseldorf. The tunnel partly is under the water line of the Rhine and therefore was built using compressed air under a lid with the help of diaphragm walls. The area today has proved to be one of the most beautiful parts of the city and its recreational value, esp. on weekends, is inviting thousands of citizens. The case history is being evaluated by ITA Working Group 20, Urban Problems, Underground Solutions.

The tunnel provided the following benefits:

- Valuable surface space was made available again
- Additional traffic capacities were provided for individual transport
- Relief from traffic congestion was achieved
- Time savings in transport were achieved
- Noise levels were brought to acceptable levels
- Pollution (esp. air pollution) was reduced
- Architectural quality of urban environment was improved
- Service quality of the urban environment was improved
- Safety and security in urban environment was improved
- The project was completed on time and within the original 300 million Euro budget.



Rhine embankment road in the 70s,



Today's Rhine embankment

Alaska Way Viaduct and Seawall Replacement, Seattle, USA

The Washington State Department of Transportation (WSDOT), the U.S. Federal Highway Administration and City of Seattle are working to replace the Alaskan Way Viaduct and Seawall, considering two basic alternatives – a tunnel along the waterfront or an elevated highway structure. These two alternatives were carried forward in 2004, following three years of environmental and engineering review, 76 initial concepts, over 200 community meetings and over 4,500 public comments.

The viaduct plays a major role in sustaining the regional and city economy and maintaining mobility throughout



Seattle. One quarter of all north-south traffic through Seattle (103,000 vehicles) use the viaduct every day. When the project was closed temporarily after the 2001 Nisqually Earthquake there was extreme congestion on adjacent freeways and the downtown city grid. The earthquake also damaged the seawall and subsequent investigations revealed that the seawall also needs to be replaced. Options considered for the Alaska Way Viaduct replacement are given in the Table following.

Option	Capacity at Completion	Environmental Impacts	Other Opportunities
Boulevard Along Alaskan Way: Multi-Modal Transportation Options	Road capacity reduced; Portion can be replaced by Transit and trip reduction	Minimal	Opens views and provides potential open space
Elevated Roadway Along Alaskan Way	3-4 lanes each direction; Potential to increase current capacity if redesign Battery St Tunnel	Noise continues (reductions); Stormwater treatment; Visual remains; Seawall - ESA, shoreline issues	Limited change from existing; some opportunities under replaced viaduct
Cut & Cover Tunnel Along Alaskan Way	3 lanes each direction; probably 2 lanes each direction north to SR 99	Noise reduced; Stormwater treatment; Hazardous soils; Visual improved; Seawall - ESA, shoreline issues	Opens views and provides potential open space
Deep Bored Tunnels: Along Alaskan Way	2 lanes each direction; extra lane difficult	Noise reduced; Visual improved; Seawall - ESA, shoreline issues	Opens views and provides potential open space
Along 1 st & 2 nd Aves.	2 lanes each direction; 2 nd Ave extra width potential	Noise reduced; Visual improved;	Opens views and provides potential open space
Along 5 th Avenue	2 lanes each direction; extra lane difficult	Noise reduced; Visual improved;	Opens views and provides potential open space
Under I-5	2 lanes each direction; extra lane difficult	Noise reduced; Visual improved	Opens views and provides potential open space
Sunken Tube Under Elliott Bay	2 lanes each direction; extra lane difficult	Noise reduced; Visual improved; In-water work would involve ESA, shoreline issues; substantial permit concerns	Opens views and provides potential open space
Deep Bored Tunnel Under Elliott Bay	2 lanes each direction; extra lane difficult	Noise reduced; Visual improved; Limited In-water work would involve ESA, shoreline issues	Opens views and provides potential open space
Submerged Floating Tube Under Elliott Bay	2 lanes each direction; extra lane difficult	Noise reduced; Visual improved; In-water work would involve ESA, shoreline issues; substantial permit concerns	Opens views and provides potential open space
Cable-stayed bridge	3 lanes each direction	Noise continues (reductions); Stormwater treatment; Visual remains	Raises deck, opens waterfront, less surface involvement, less involvement with utilities,
Elliot Bay Signature Bridge	3-4 lanes each direction; design to meet demand	Noise reduced; Visual improved along waterfront, but new visual barrier created; In-water work would involve shoreline issues; permit concerns	Opens waterfront views and provides potential open space; new signature bridge

BENEFITS OF UNDERGROUND FACILITIES – WITH REFERENCE TO SEATTLE

One of the primary findings from the review is that relevant tunnels and underground structures last a significantly longer time than the equivalent above-ground structures. Tunnels constructed over one hundred years ago in the U.S. and elsewhere are still in useful service today.

For example, the Seattle Alaskan Way (elevated) Viaduct is 52 years old and needs to be urgently replaced. The West Side Highway in New York City was taken out of service after 42 years. The Embarcadero Freeway in San Francisco was demolished after approximately 30 years.

A review of data describing transportation corridors shows that underground structures last much longer, often over a century and more. The Burlington Northern (BN) Rail Tunnel beneath Seattle is over 100 years old – it was opened in November 1904 and is now on its second century of low-maintenance service. The Seattle Battery Street Tunnel, now 53 years old, will continue to take traffic well into the future.

A significantly longer service life means that the present (discounted) value of that structure (the tunnel) can be less than a shorter-life structure (elevated viaduct) although the initial capital cost of the viaduct is usually less than that of the tunnel.

Economic Studies

Several economic benefit studies have been made. An economic case for the tunnel was outlined recently by the Downtown Seattle Association (*Pascall, 2006*) reporting that, by funding the tunnel option (at an additional cost of \$1 billion plus over the elevated highway replacement), property values would increase by \$450 million, as much as \$2 billion in additional property development would occur and \$325 million a year would be generated by tourism.

A previous review indicated the following benefits for the tunnel might be realized in addition to the environmental improvements, compared to the approximately \$US1 billion extra capital cost of the tunnel:

Increased values associated with the waterfront:	\$0.7 - 1 billion over 25 years
New visitor spending:	\$1 billion for each 1% increase in visitors
Increased property values:	\$280 – 960 million.

In total these numbers indicate that the value of the tunnel could exceed the extra initial capital cost by a factor of between 1 and 3. However, it is hard to quantify these numbers sufficiently or accurately in the context of current practice. This is an area for further study by ITA.

NEW TOOLS TO QUANTIFY COSTS AND BENEFITS

There are new tools that can better address cost, probable cost, risk identification, risk management, value engineering, life-cycle costs and benefits and probable funding. An example of one of these is the U.S. Washington State Department of Transportation's Cost Estimate Validation Process CEVP® which is a process to identify ranges of probable costs by identifying and combining "base costs" and risks plus opportunities to produce a "range of probable cost and schedule" for the explicit and implicit conditions of the evaluation. The process has been described previously (*Reilly, 2005a, 2004b & c, 2003c*)

Current thought is to extend this process to include a life-cycle and value-engineering components. An outline has been drafted for the value engineering process and one could be readily developed for life-cycle costs. This Life Cycle Cost Estimation Process (LCCEP) would allow us to tie together cost validation, ranges of probable costs and benefits and value-added returns in order to better assist determination of alternatives considering long-range costs and benefits.

CONCLUSIONS

1. There is rising skepticism toward the underground design and construction industry, particularly for large expensive projects in cities. This is due to many major cost over-runs and sometimes mismanagement - which need to be addressed. We also need to improve design standards for safety, security, environmental soundness and user friendly tunnels and to and communicate this effectively to the public and political decision makers.
2. We cannot do this unless we develop reliable methodologies to systematically estimate and manage costs and risk, and to use those methodologies to reduce the costs of tunnels and underground space. Adding value engineering and life-cycle costs and benefits will enable better total cost comparisons for alternatives if the environmental and political decision processes are also aligned.
3. The concepts outlined in this paper, including the proposed Life Cycle Cost Estimation Process (LCCEP) if developed and applied, would allow, for the first time, practical and more reliable comparisons on the basis of cost and benefits to select a preferred project alternative from significantly different alternatives such as elevated, surface, cut-and-cover, various bored tunnel and other underground schemes and alignments.
4. This can be done because of the comprehensive nature of the proposed process, which could fully take into account relevant factors and could provide the equivalent monetary value of all the environmental benefits the proposed project provides. It is anticipated that underground projects would become more economically attractive as a result.
5. The referenced CEVP process (*Reilly, 2005*) has improved our ability to predict a project's probable cost and schedule in ways that incorporate the effects of risks, technical and non-technical. The same concepts and attitudes necessary to be successful with CEVP are also those that are needed to quantify for life cycle costs and benefits.
6. When fully developed, LCCEP will allow engineers, planners, decision makers, politicians, the general public, and the media to better understand the compromises and tradeoff choices that are made in planning a given infrastructure project.
7. When this methodology becomes mature, the authors believe that tunnels and underground space will be found to be more competitive with other alternatives and many decisions regarding alternates can be made on the basis of issues such as the environment and quality of life. It is likely that the underground alternative will be selected much more often.
8. The concept of life cycle costs is not new as it has been applied to pavement replacement for decades. The approach regards cost as an investment to be managed prudently. The same is true for major transportation projects, but the methodology has not been applied similarly and, as a result, engineers and planners are not used to apply it to major infrastructure projects.
9. The underground industry should have already developed this acutely needed methodology. We must be proactive to develop these concepts and to get them to be understood and accepted by the decision makers. We must continue to explain that tunnels and underground space are investments and NOT Costs. The decision makers will justifiably be reluctant to embrace such issues but, with proper training during early education.
10. Much needs to be done to develop and simplify practical methodology to accomplish the goals of LCCEP. If we are successful, there will be abundant opportunities to build challenging tunnels and underground space.

To make a better, more equitable case for selection of underground alternatives, several things are needed:

- a. Planning and public policies must consider long-term life-cycle costs and benefits
- b. The long-term life-cycle costs and benefits need to be quantified
- c. Benefits must be communicated to the public and political decision-makers
- d. The political process must recognize that this is an appropriate planning and selection process
- e. A funding mechanism that will support the higher initial capital cost must be found
- f. Revenue to support the funding mechanism needs to be collected
- g. The credibility of this process must be demonstrated

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PROBABLE COST ESTIMATING AND RISK MANAGEMENT

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INTRODUCTION

Good project management requires, among other key elements, good cost and schedule estimates, as well as a process to identify and deal with uncertainty and management of risk. These elements are the focus of this paper.

THE COST ESTIMATION PROBLEM

Even when a project is well planned and managed, in a significant number of cases project conditions change and problems arise. Of these, political changes seem to have the most significant effect (Salvucci 2003). These changes and problems have resulted in significant undesirable consequences which include cost and schedule over-runs, resource competition between projects, negative media attention and, consequently, public mistrust.

Thus we find that the public is skeptical of our ability, as a profession, to accurately estimate the final costs of large, complex public projects and is also skeptical of our ability to manage these projects to established budgets. Questions they have asked include:

- o “Why do costs seem to always go up?”
- o “Why can’t the public be told exactly what a project will cost?” and,
- o “Why can’t projects be delivered at the cost you told us in the beginning?”

Our inability to answer these questions consistently is a consequence of many factors – including inadequate cost estimating procedures and our prior inability to correct these poor estimating practices (Flyvbjerg et. al. 2002). Additionally, the effects of poor project management and poor communication with the public has further added to the problem – resulting in unfortunate results, including negative votes for proposed transportation funding.

Many government agencies, including the Federal Highway Administration (FHWA) and some State Departments of Transportation have recognized this problem and in response are now requiring risk-based cost and schedule estimating, as well as formal risk management plans (FTA, 2003; FTA 2004, FHWA 2006).

EXAMPLES OF POOR COST INFORMATION AND ESTIMATION

One international survey (Reilly & Thompson, 2000) found that specific, relevant cost information was usually unobtainable. Little objective history could be found, including findings that would support recommendations for improvement. Because of the difficulty in obtaining hard data, firm conclusions could not be reliably drawn but the following findings were reported by the owners (note that this data is now 8 years old, conditions may have changed but the fundamental issue are still relevant:

- o There were significant cost and schedule overruns suggestive of poor management in at least 30%, and possibly more than 50%, of the projects.
- o It appears that the factors that most directly influence success or failure are a) expertise and policies of the owner and b) procurement procedures.

- o The professional teams engaged in projects were judged, by the owners, to be competent leading to the conclusion that problems in poorly performing projects may lie primarily with the ability of the owner to effectively lead and manage the project process.
- o Risk mitigation was not well-understood or applied, even in elemental ways. This was considered to be a promising area for development, in particular as it related to cost over-runs and unforeseen events.
- o Reported cost and performance data – especially for “good” results – should be treated very cautiously.
- o Consistent, complete and relevant data are very hard to get and almost impossible to validate after project completion.
- o Conclusions based on reported cost data, unless the conclusions are grossly evident (e.g. meta-findings), should also be treated with caution.

Other studies confirm the problem (Flyvbjerg et. al. 2002). Flyvbjerg surveyed 258 projects spanning 70 years and found that the problem of accurate cost forecasts has been chronic for that time period. Key findings were:

- o 9 out of 10 transportation projects underestimated costs with an average overrun of +28%
- o Road projects averaged +20% higher than estimated
- o Tunnel and Bridge averaged +34% higher
- o Rail projects averaged +45% higher than estimated

Specific examples include several of the FTA Demonstration projects such as Tren Urbano in Puerto Rico - \$1,285 million over initial budget (+133%), the Silver Line Transitway Project in Boston - \$286 million over budget (+90%), the London Jubilee Line Transit Project – 2 years late and £1.4 billion over budget (+67%), the Channel Tunnel Rail Project – £3.7 billion (+80%) over budget, Denmark’s Great Belt Link rail and road link (+54%), the 2003 Woodrow Wilson bridge tender in Virginia 72% over estimate and, Boston’s Central Artery Project – many billions over the initially published cost numbers (which were extremely unrealistic) and years late.

Note: the cost percentage number in parentheses in the above paragraph indicates the final cost of the project divided by the budget which was communicated at time of decision to proceed. This important because it is the “number” that the public tends to remember and the media reports. However, it does not include new scope and other changes, which might be quite legitimate. It does include poor initial cost estimates and/or poor estimation of risk and other factors – including poor management, the effects of external events and political changes or transitions (Salvucci, 2003).

Of major concern is that, as an industry, we have not corrected the “chronic cost underestimation” of such projects – if we had done so, there would have been a uniform number of results equally over budget as under budget. This problem has existed for over 70 years, as shown by Flyvbjerg, whose conclusion is that the problem is both an inability to estimate accurately, a bias to estimate on the optimistic side and political misrepresentation.

THE INFLUENCE OF VARIABLES

The final, definitive cost and schedule of a project cannot be predicted accurately because the project can, and will, be affected by a number of variables. These variables include nature (e.g., ground conditions, weather), technology (e.g., design, methods, equipment, materials) and human (e.g., labor, public, politics, regulatory agencies, funding/insurance/bonding agencies, market conditions). These variables cause uncertainty in cost and schedule through variations in those project conditions assumed for the estimates (e.g., average unit rates, progress rates, and escalation rates) and through uncertain impacts from unplanned events (deviations from those assumptions).

EARLY INFORMATION AND UNCERTAINTIES

Early in project development when project estimates are initially developed, information on these variables is typically limited, but a process for identifying and managing potential problems should be developed at this time, when the problems are easier to resolve, if identified.

If these uncertainties are not explicitly included in the estimating process, and if inevitable estimating biases are not corrected, project cost and schedule estimates are likely to be inaccurate, consensus will be difficult to achieve, and it will not be possible to answer critical questions such as: “Which project alternative is best?”; “What scope is actually affordable or will actually be built?”; “Is the current estimate high or low relative to what the actual cost and schedule will ultimately turn out to be, and by how much?”; “What should the funding/budget and milestone dates be for this project?”; “How can the project cost and schedule best be controlled?”

POTENTIAL SOLUTIONS

A variety of approaches have been developed to attempt to provide better cost and schedule estimates. These various approaches generally differ in the following areas:

- a) Traditional contingency-based deterministic (single value) approaches vs. probabilistic approaches – either combined uncertainty or itemized uncertainty, e.g., individual risks;
- b) Separate and unlinked cost and schedule models vs. integrated cost and schedule models;
- c) Varying levels of detail and approximation; and
- d) Input assessment methods (e.g., cost data base vs. project-specific judgment of technical experts).

The author, clients and colleagues (WSDOT 2007, Roberds & McGrath, 2005; Grasso, 2002;) believe that a flexible (depth and breadth of detail and degree of approximation), probabilistic, risk-based approach using an integrated cost and schedule model is the most appropriate way to quantify uncertainties for complex projects and to guide risk management in order to better define and control costs and schedules.

EXAMPLE OF ONE APPROACH

Such an approach forms the basis of the Washington State Department of Transportation’s (WSDOT) Cost Estimate Validation Process (WSDOT, 2007) which is used on all WSDOT projects over \$25 million has been used on a number of Federal Highway Administration and State Department of Transportation programs and other Agency projects (e.g. Alaska Railroad, Toronto Waterfront Revitalization). The approach has also been used to quantify uncertainty in programmatic measures such as program expenditure and cash flow and for programs consisting of a large number of individual projects, each of which are uncertain but often related to some degree. Specifics of the development of this approach follow.

WSDOT’S COST ESTIMATE VALIDATION PROCESS - CEVP

In January 2002, the Washington State Secretary of Transportation was questioned by a State Senator about the poor reliability and history of increases of cost estimates for a large project. WSDOT managers and key consultants – “the core team” (Reilly et. al, 2002) – were asked to develop a better cost estimation process. As part of defining “the problem”, a review of relevant data led to the following findings:

1. There is a general failure to adequately recognize that an estimate of a future cost or schedule involves substantial uncertainty (risk),
2. Uncertainty must be included in cost estimating,
3. Cost estimates, must be validated by qualified professionals, including experienced construction personnel who understand “real-world” bidding and construction,

4. Large projects often experience large scope and schedule “changes” which affect the final cost. Provision for this must be made in the cost estimates and management must deal competently with these changes.

WSDOT decided to act on these findings by:

- o Developing an improved cost estimating methodology,
- o Incorporating cost validation, risk identification and management,
- o Openly and reliably communicating “ranges of probable cost” to public, media and political decision makers.

WSDOT’s strategy was to deal openly with the process of public infrastructure cost estimating so that the public would better understand, and be better informed, as project managers and elected officials make critical project funding decisions. The challenge was to develop a valid procedure to do this. WSDOT decided to open the “black box” of estimating and present a candid assessment of the range of potential project costs, including acknowledgement of the uncertainty of eventual project scope, the inevitable consequence of cost escalation due to inflation, and other major risks.

THE WSDOT PROCESS

The WSDOT team developed a specific management-cost-risk assessment tool which was called the “Cost Estimate Validation Process” or CEVP[®]. The draft procedure included:

1. A cost validation process adapted from the Boston Metrowest Water Supply Tunnel project,
2. Inclusion of the impacts of risk and opportunity events derived from procedures previously developed for infrastructure tunnel projects (Einstein 1974; Anderson, Reilly & Isaksson 1999; Grasso et. al. 2002),
3. Use of independent subject matter experts, particularly those who have been responsible for construction of these projects in a hard-money bid environment.

The basic approach requires a peer-level review, or “due diligence” analysis, of the scope, schedule and cost estimate for a project and then incorporation of uncertainty (uncertainty includes both risk and opportunity) to produce ranges of probable cost and schedule. Specific objectives of the method are to evaluate the quality and completeness of the “base costs” together with the inclusion of inherent uncertainty (risk and opportunity) in the estimate. Risk mitigation can also be included.

WSDOT launched the CEVP[®] program with a major commitment of its personnel, including functional and project staff, staff from project partners, members of the consultant teams already working on some of the larger projects and, the core CEVP development team. To this were added external specialized consultants including a group of very senior engineering, construction and cost estimating specialists drawn from around the country (see “Acknowledgements” at the end of this paper). The following Figure shows base cost and the range of probable cost histogram.

- ❑ In the beginning, there is a large potential range for “ultimate cost”
- ❑ The “ultimate cost” will depend on the outcome of many factors
- ❑ We can’t predict exactly - but we can develop probable ranges of cost which include all relevant risk and opportunity events we can identify

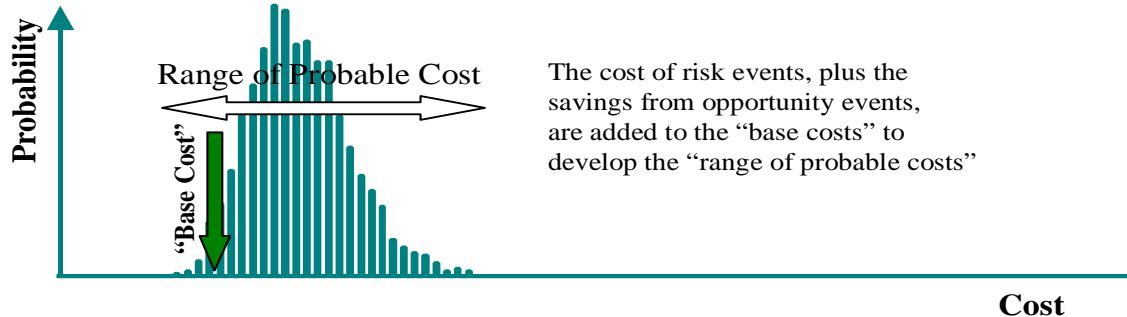


Figure 1 – Future costs are a “range of probable cost”

KEY CONCEPTS

As the CEVP methodology emerged, several key principles were identified. Among these were:

1. Avoid single number estimates. Recognize that at any point in the development of a project, from initial conceptualization through the end of construction, an estimate will require selecting a representative value to characterize many factors that are inherently variable. These variable factors will include issues that have been identified and quantified (the known/knowns), those that have been identified but not yet quantified (the known/unknowns) and those that have not yet been identified (the unknown/unknowns). Some factors will be controllable by design or by the owner, some will not. But all of these contributing factors are fundamentally uncertain and need to be treated as such.
2. Use a collaborative assessment environment that combines high levels of critical external peer review expertise, particularly in construction and estimating construction in a bidding environment, with appropriate roles and responsibilities for the Project Team. Project Teams and owners are (and should be expected to be) biased. They are generally too optimistic about the project and want to see it advanced, funded and built. Balance this bias with independent subject matter experts, peers and others with valued experience that is based on experiences separate from the specific project.
3. Acknowledge that both cost uncertainty and schedule uncertainty are major contributors to problems with project estimating, and incorporate both in the evaluation methodology. WSDOT foresaw the clear advantage, in fact the necessity, to integrate the effects of cost and schedule uncertainty. CEVP[®] was developed:
 - a. To incorporate quantified uncertainty for both risk and opportunity factors,
 - b. To identify these factors using an aggregated-component approach that separated components whose cost and/or duration could be considered separately and,
 - c. To integrate cost and schedule using appropriate analytical methods.
4. Be practical and use common sense notions of risk descriptions and quantification. The CEVP[®] method was to be completely rigorous and treat uncertainty in ways that acknowledged correlation, independence and other probability principles. However, the sources of information and definition of uncertainty were likely to encompass a range which might extend from highly

quantified issues to those where subjective opinion from the contributors was all that would be available. This range of uncertainty data needed to be captured objectively.

5. Produce project output that could be understood by the ultimate audience, the public. This led, ultimately, to a focused approach that presented the concepts of cost ranges, probability, risk and opportunity and risk management to the public, media and political decision makers in June of 2002. The public, media and political decision makers accepted these concepts surprisingly quickly and without major comments.

CEVP® – PROCESS AND RESULTS

CEVP® develops a probabilistic cost and schedule model to define the probable ranges of cost and schedule required to complete each project. The results of the assessment are expressed as a probable distribution of cost and schedule values for the project as shown in Figures 1 and 2. The CEVP process (Reilly & Brown, 2004):

1. Critically examines the Project estimate to validate all cost and quantity components using independent external professionals.
2. Removes all “contingency” and allowances for unknowns, then
3. Replaces the contingency and other approximating allowances with individually identified and explicitly quantified uncertainty events (risks and opportunities).
4. Builds a model of the project – normally in an Excel spreadsheet using a flow-chart of key planning, design, permitting and construction activities. Included are quantification of cost and critical path schedules. The model assigns the quantified uncertainty events to activities with the associated probabilities and impacts.
5. Runs a simulation to produce the projected “range of probable cost and schedule” and reports the results (Figure 2 - Model results – probability vs. probable cost).

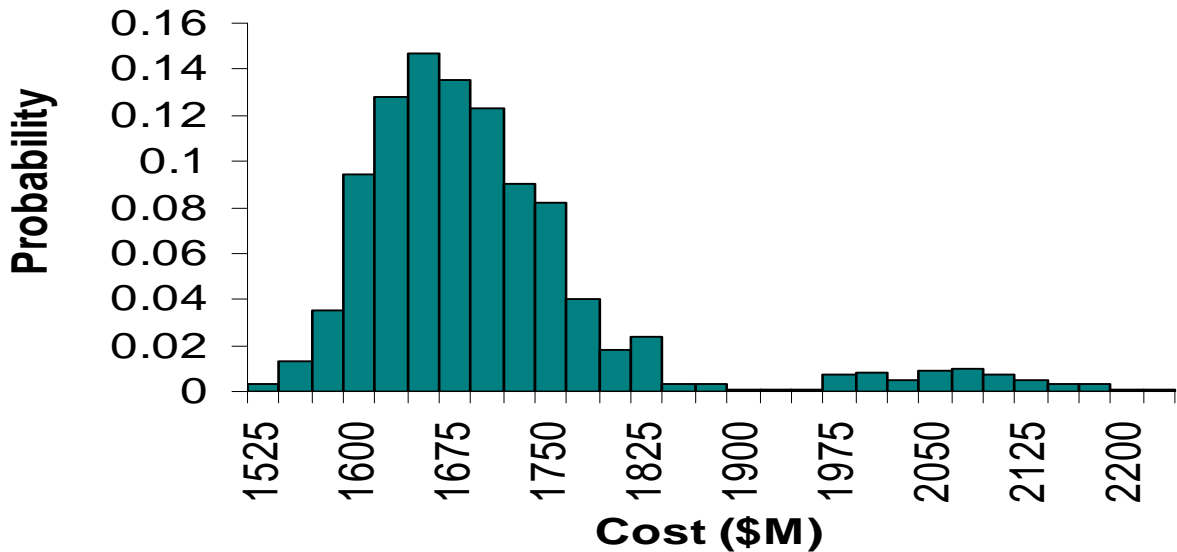


Figure 2 – Model results – probability vs. probable cost

CEVP® WORKSHOP ELEMENTS

Key elements of the CEVP® workshop are

- 1) Develop a model of significant project elements reflected in a “flow chart”,
- 2) Cost validation – determination of “base cost” and,
- 3) Risk elicitation – defining the probability and impacts of risk events.

The fourth element is the subsequent communication of results to the public, media and political decision-makers. The basic CEVP® process has been described previously in several papers (Reilly & Brown 2004, Reilly 2005) so the following text will describe the flow chart, cost validation and risk elicitation.

THE PROJECT FLOW CHART

The Project Team provides a detailed description of the expected project plan, with the major activities and their associated costs and durations. From this information, the team develops a project flow chart that represents the sequence of major activities to be performed in the project. Major decision points (e.g., funding decisions) and project milestones, as described by the Project Team, are explicitly represented in the flow chart. The base costs and durations, as well as any related major uncertainties or correlations for each activity are entered on the flow chart using values as confirmed or defined by the base cost review team.

COST VALIDATION

The cost part of the workshop is led by a manager with program delivery experience, supplemented by team members with both design and real-world construction experience. The use of personnel with experience in contractor's methods is necessary to bring that perspective into the cost review for a well-shaped determination of “base cost” – the cost if “all goes as planned and assumed” without contingency. The process consists of the following:

1. The project team first briefs the CEVP® specialists on the detailed scope of the project and identifies cost and schedule risks that have been included in the project estimate.
2. The CEVP® cost specialists discuss the cost estimate with the project team, reviewing what the estimate represents and the basis of its development. They discuss what metric has been used to calibrate the estimate and what contingencies have been included in the estimate.
3. A review of the scope of the project is completed with the project team on an element by element basis to assure that all elements and phases of the project have been accounted for.
4. The estimate is reviewed to assure that items such as: right of way, mobilization, permitting, mitigation, temporary facilities and utilities, construction phasing requirements, seasonal constraints, cuts/fills, hazardous material issues, archaeological issues, storage and disposal of material, haul distances, compaction and testing, protection of work, testing of mechanical and electrical systems, occupancy permits, de-mobilization, etc. have been recognized and addressed – from a cost standpoint.
5. The schedule for the project is also reviewed - is it realistic?, does it consider adequate time for mobilization?, set-up of temporary facilities and utilities?, construction permitting?, construction phasing?, dealing with differing site conditions?, traffic or operational issues?, seasonal constraints?, site access limitations?, testing of piping?, electrical and signals?, SCADA systems? etc..
6. Unit prices and production rates that have been assumed for the major items of work are reviewed, asking if the production numbers (the basis of the units costs) are reasonable and if there are any risks that those unit prices may not have taken into account – such as high ground water or the presence of organic material.

7. The contingency that is included in each unit price – or the entire estimate – is identified and removed from the cost estimate. This is done in order to develop the “base cost” of the project (the contingency is subsequently replaced by the probable cost of risk and opportunity events).
8. During the discussions, and upon completion of the above review, items of work that may be missing, over- or under-estimated are identified and recorded. Estimates for missing items are developed and recommendations for adjustments are made. Finally, an agreed “base cost” is determined. This becomes the base to which the cost of potential risk and opportunity events are added by the cost/schedule uncertainty model.

RISK IDENTIFICATION AND QUANTIFICATION

The risk identification and quantification is led by an experienced risk elicitor/analyst who is familiar with uncertainty theory, de-biasing techniques and the structure of a subsequent cost and risk model. Other workshop participants include representatives from the project team who have familiarity with the plans, strategies, assumptions and constraints on the project, plus the Subject Matter Experts (SME’s) who bring an independent perspective on important areas of project uncertainty.

The identification and quantification of uncertainties requires a balance of project knowledge, risk analysis expertise, cost estimating expertise, and objectivity. Project knowledge and the independent expertise of SME’s are essential to identify the uncertainties. Risk analysis expertise is required to capture balanced information on risk and model uncertainties. The goal of the risk workshop is to identify, quantify and model the uncertainty in project cost and schedule. The risk identification process - preparation and workshop - includes the following activities:

1. Introduction to the participants of principles of uncertainty (risk and opportunity) assessment
2. A preliminary list of risks and opportunities, generated by the project team
3. Workshop identification of potential risks and opportunities. This is done in an open brainstorming process that typically begins with a prior list of potential uncertainties from the project team, lists from similar projects and other sources. In the workshop, it is necessary to provide a critical environment that allows for this initial information to be combined with other suggested risks. As a practical matter, the team should identify a screening criteria to help produce a prioritized list of significant cost and schedule risks.
4. Characterization of potential risks and opportunities. This process combines subjective and objective information to identify the consequences to the project if each of the risks were to occur. Typically there are varying opinions on the range of consequences, such as increased cost or schedule delay. The risk elicitor is responsible for guiding the group to an appropriate agreement regarding the consequences of the risks – i.e. probability of occurrence and impact. Independence and correlation among risks is also defined, positively or negatively or conditionally.

The risk and opportunity events that are the output of the workshop should be defined to be independent as far as possible. When this is not possible, the dependencies among events must be defined and accounted for. In addition, each risk or opportunity event must be allocated to the project activities that are affected by it or, if a given event affects multiple project activities, significant correlations among occurrences need to be addressed. Significant uncertainties and correlations among event impacts also need to be defined. This information is incorporated in the cost and schedule to produce the model results.

Risk elicitation in the workshop is an iterative process that combines subjective and objective information. Uncertainty characterizations and probabilities are defined simultaneously to provide reasonable, practical descriptions of uncertainty.

COMPLETION OF THE CEVP® PROCESS

The “range of probable cost and schedule” is determined by combining base costs determined from the cost validation with the risks identified in the risk workshop in a Monte-Carlo model which:

1. Integrates base costs with risks and opportunities (uncertainties) in a probabilistic model
2. Reports the results as a “range of probable cost and schedule”

Results of the model analysis are presented as cost and schedule probability distributions, usually in a graphical form (Figures 2, 3) with supporting tabulations of characteristic statistics. First order descriptions and models are sufficiently accurate and are used for most projects. These distributions can describe a variety of situations of interest including:

1. Current dollar (time of assessment) cost and year of expenditure cost (\$YOE)
2. Fully funded or partially funded scenarios
3. Comparative design options
4. Probable date of completion for the project
5. Probable schedule to meet project milestones

The specific form of the reported results can vary depending upon need and the results can be used for a number of applications, including:

1. Project assessment / management re-direction
2. Risk management plans
3. Data input to value engineering workshops
4. Integrated management of multiple projects
5. Better internal and external communications
6. Financial management options and alternatives

CEVP® is iterative in nature and represents a “snapshot in time” for that project and under the conditions known at that point. Changes to optimize cost or reduce risk can be verified in a reassessment of the project and model update. The following example for a complex project in Seattle comparing 2003 results to 2002 shows a reduction in both probable cost and range of uncertainty by management of scope and risk:

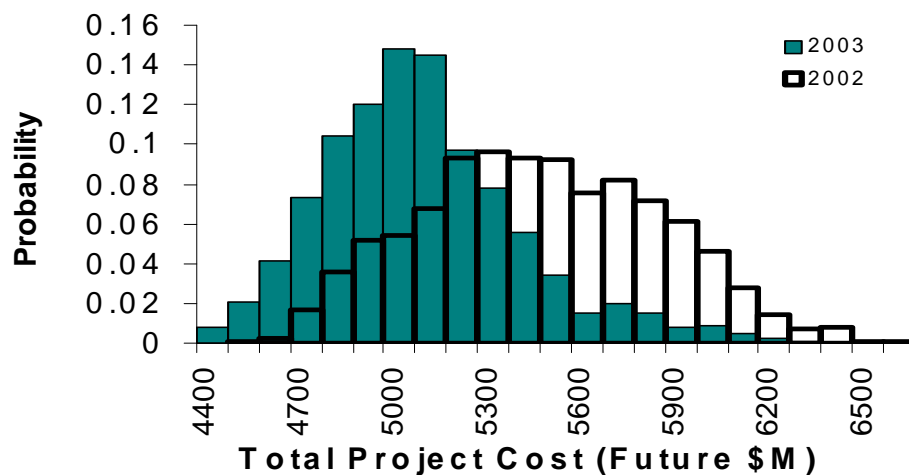


Figure 3 – Improvement in probable cost for successive CEVP® workshops.

RISK MANAGEMENT

Early, strategic risk management is one of the most important tools for managing cost and schedule. Referring to London’s Jubilee Line Transit Project with a cost overrun of +67% the Secretary of State’s Agent (oversight consultant) stated: “Time and cost overruns could have been minimized with a more established strategy at the very beginning of the project” (Arup, 2000).

But, how to determine the “more established strategy at the very beginning of the project”?

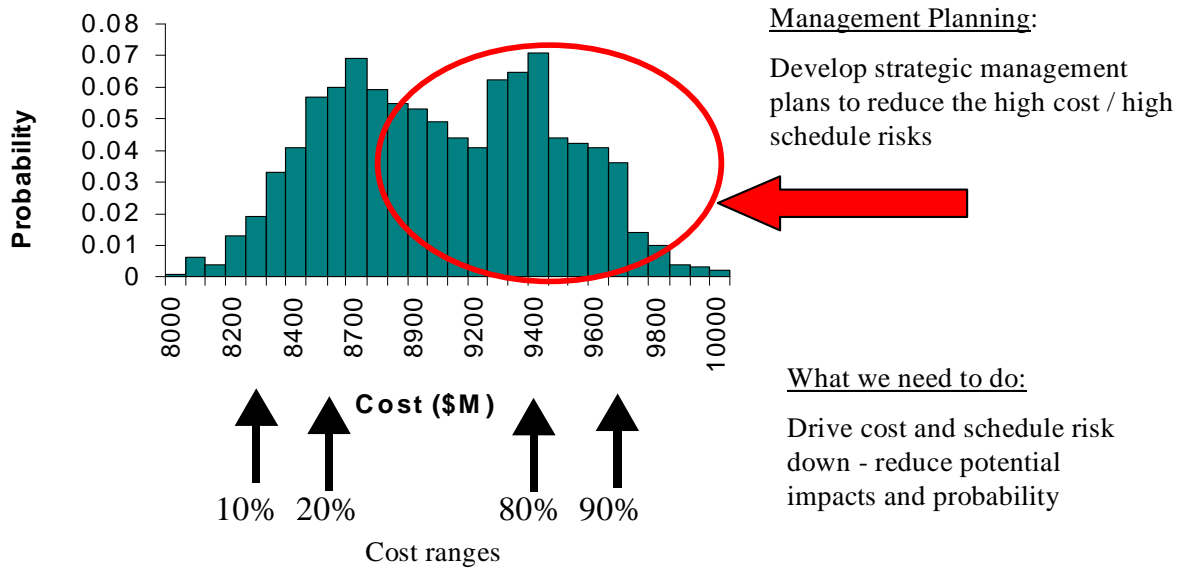


Figure 4 – General Risk Management Approach after CEVP®

A key output from the CEVP® assessment is a ranked listing of the risk and opportunity events contributing to the uncertainty in a particular estimate. The ranked risk table presents the most important risk issues, along with a measure of their contribution to the total uncertainty in the estimate. The variety of risks, including technical risks, policy risks, environmental risks, construction risks, etc. can be treated in a consistent way using this data.

One of the not-so-incidental benefits of CEVP® is that it provides an explicit quantification of potential risk and opportunity events that could impact the project’s cost and schedule. From this quantified risk profile, risk management plans can be developed earlier in the project life-cycle. Risk management procedures are well understood and many references are available (Einstein et. al., 1974; Roberds & McGrath 2005; Grasso et. al. 2002; Isaksson, 2002).

CURRENT DEVELOPMENTS

CEVP® is proving to be a useful process for estimating and communicating ranges of probable costs and schedules, as well as explicitly identifying and quantifying risks for large, complex projects early in the planning and design phases. This produces better information that the public and elected officials and can be used to make more informed decisions, while allowing engineers to better manage these projects.

WSDOT has internalized the CEVP® process and uses it, and a simpler, cheaper “Cost Risk Assessment” process, for many of its projects. The U.S. Federal Transit Administration (FTA) and the Federal Highway Administration (FHWA) have each investigated CEVP and similar processes and have run demonstration projects. They have concluded that a probabilistic cost-risk process, such as CEVP® or an alternative, should be used for most large, complex transportation projects.

As of this writing further demonstration projects and educational seminars are underway and several government Agencies are beginning to require the process in their upcoming projects (e.g. Florida, Toronto Waterfront) and international enquiries following presentations of the CEVP process have shown interest in its application.

FINDINGS

1. WSDOT recognized the value that cost validation and risk assessment yields in the determination of the “range of probable cost” including explicit potential risk events.
2. WSDOT found that the CEVP[®] results allowed a more intuitive communication with the public which better related to “...what people already know”.
3. WSDOT found that CEVP[®] focuses early attention on the significant cost and schedule risks for a project and increases the project team’s awareness of risk.
4. Use of experienced external subject matter experts, who have constructed similar projects, is good value and gives an independent check on key assumptions.
5. Because risks are explicitly defined, a risk management plan can be quantified earlier. This allows significant management and control of cost and schedule earlier in a project and allows a more explicit communication of cost and schedule (and changes thereto) with the public and key political decision makers.
6. WSDOT recognized that CEVP[®] is not a “magic bullet” or a “quick fix”. WSDOT therefore committed to improve its cost estimating process by implementing the CEVP[®] program on a state-wide, long-term basis and training staff in the technique.
7. Presentation of CEVP[®] to the industry, including FHWA representatives, resulted in a review, assessment and recommended use of probalistic cost estimating processes by that and related agencies.

RECOMMENDATIONS

1. Owners of complex infrastructure and underground projects should consider using a probalistic cost–risk type process for cost estimates and risk identification.
2. Periodic updates to the model should be used to assist with, and explain rationally, project changes. They can, additionally, evaluate and compare alternatives.
3. The process should be used to assist owners in determining a more realistic “range of probable cost” which can enable better communication about, and management of, these projects.
4. This is only possible if the owner truly wants to know the realistic “range of probable costs”, is prepared to communicate this to the public and decision makers and then will manage the projects to the subsequently established budgets.
5. It is recognized that significant concerns have been raised that, if we tell the public the more realistic probable costs, which tend to be greater than other estimates, those projects may not be funded and authorized. Such concerns imply that we cannot trust the public with the real cost information. If true, such a position has moral implications that the profession needs to address.
6. A risk management plan should be developed and implemented using the explicit, quantified definition of potential risk events.

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