Cost Estimating For Underground Transit: Too Dangerous To "Guesstimate"

Victor S. Romero and John M. Stolz
Jacobs Associates
San Francisco, CA

ABSTRACT

Traditional construction cost estimating methods that rely on historical cost data are not well suited for underground transit feasibility studies, because not only do construction costs vary widely because of subsurface, geographic, and other project-specific parameters, but also because such construction costs are not generally available in cost databases. Furthermore, the inherently expensive and unknown nature of underground construction often leads to inaccurate cost estimates, which in turn can lead to a significant budget shortfall as the project moves from planning and design to construction. What does this mean for the planner producing an EIS/EIR or the engineer involved in conceptual design? It means that tunnels and other associated underground work cannot be estimated on a "per foot basis" as is customarily done during the early stages of an above-ground transportation project. Labor factors and geologic conditions will often dictate tunnel construction costs; tunnels in Boston have different labor factors than tunnels in Los Angeles, and tunnels in downtown San Francisco through soft-ground will have very different costs than tunnels through weak rock on the west side of San Francisco. This paper summarizes the unique aspects of underground construction relating to cost and concludes that while production-type estimates are crucial for developing realistic project budgets, such estimates do not require a high degree of project definition.

INTRODUCTION

Cost estimates are used for different purposes at different stages of a transit project. During the planning stage, cost estimates are used to determine project feasibility and to compare alternate transit modes or alignments during the environmental process (i.e., the "screening" process). During the preliminary engineering phase, cost estimates are used to refine alignment configurations and establish construction budgets. During final engineering, cost estimates are used to refine budgets and evaluate the responsiveness of construction contract bids.

Tunnel construction, and in particular transit tunnel construction, is by its very nature complex, risky, and often fraught with geologic unknowns. In urban areas, tunnel transit has a distinct advantage of minimizing surface disruptions compared to surface or cut-and-cover transit configurations. However, tunnel construction is an expensive endeavor. While social, political and environmental forces have favored tunnel alignments for many transit systems, the costs of construction have often exceeded budgets, preventing the development of new transit lines or the extension of existing systems, and eroding the public's confidence in the ability of tunneling projects to be accurately forecasted. It is therefore in transit agencies' best interests to get the most realistic and accurate cost estimate possible, particularly during the planning stages of a project. An estimate of construction cost for a tunnel alignment on a per foot or per mile basis is nothing more than a "guesstimate" that will likely prove to be grossly inaccurate in hindsight because it ignores the geography, geology, allocation of risk, and market conditions associated with a particular project.

APPLICABILITY OF AACE GUIDELINES

In 1997 the Association for the Advancement of Cost Engineering(1) (AACE) published recommended Practice No. 17R-97, which gives guidelines to identify the expected accuracy for an estimate commensurate with the level of project definition. Although the guideline recognizes that "extensions and additional detail for specific industries" are required, such refinements have not yet been published.

In general, AACE recognizes that stochastic methods are used for low levels of project definition (10 to 40 percent definition level), or what AACE calls a "Budget" or "Authorization" estimate (see Table 1). Deterministic methods are recommended at higher levels of project definition.

Unfortunately, there are no reliable stochastic estimating algorithms for underground projects for the simple reason that stochastic methods rely on historical costs, and historical tunnel construction costs vary to such extremes as to render a statistical mean useless. Similarly, so-called unit costs, also based on historical costs, are no better for estimating tunnel costs. This premise is best justified by examining the tunnel construction process itself.

	Primary Characteristic	Secondary Characteristic		
AACE Estimate Class	Level of Project Definition (% of Completion)	Purpose of Estimate	Estimating Methodology	Expected Accuracy Range[1]
Class 5	0% to 2%	Screening or Feasibility	Stochastic or Judgment	40 to 20
Class 4	1% o 15%	Concept Study or Feasibility	Primarily Stochastic	3 to 12
Class 3	10% to 40%	Budget, Authorization, or Control	Mixed, but Primarily Stochastic	2 to 6
Class 2	30% to 70%	Control or Bid/Tender	Primarily Deterministic	1 to 3
Class 1	50% to 100%	Check Estimate or Bid/Tender	Deterministic	1

Note: [1] If the range index value of "1" represents +10/-5%, then an index of value of 10 represents +100/-50%.

Table 1. AACE Cost Estimate Classifications.

Tunnel construction is often regarded as a special subset of heavy-civil construction because construction at the tunnel heading must be performed under highly congested work conditions while maintaining a supply line through a long, narrow work area that is highly susceptible to bottlenecks. As a result, tunnel construction costs cannot be estimated in the same manner as above ground structures. A tunnel is analogous to a high-rise building that must be built on its side, with access only through the freight elevator, that allows only one trade to perform structural, electrical, mechanical, and architectural finish work, and which requires these activities to be performed virtually simultaneously.

Tunnel construction progress is also highly dependent on how well the tunneling equipment has been matched to the physical constraints within the tunnel and the subsurface conditions. Oftentimes, major tunneling equipment is specially fabricated for a specific project. Consequently, since tunnels are linear features requiring linear construction sequencing, small variances in production produce large variations in construction costs as those small production variances are applied against the relatively high hourly costs of labor and equipment. Nearly any variance in equipment performance will affect productivity.

Tunnel construction is therefore highly dependent on production of the tunnel crew in addition to the capability of the equipment used, and costs in turn are highly dependent on the physical subsurface conditions encountered. It is precisely for these reasons that cost estimates for projects at the screening or conceptual phase should be founded on experience-based deterministic methods rather than stochastic or other methods that rely on variable historical costs. In other words, unit costs for tunnel construction on a per foot basis are not off-the-shelf values than can used for a project without taking into account various critical factors, as discussed below.

CRITICAL FACTORS AFFECTING UNDERGROUND CONSTRUCTION COSTS

The most important measure of success for cost estimates is usually the range of accuracy compared to actual cost. In fact, many owners set standards for cost estimating accuracy based on the level of project definition, e.g., +15/-5 percent of actual cost for a Class 1 estimate, as AACE suggests may be reasonable in its guidelines. However, many owners and engineers disagree on the definition of "actual cost," variously defined as low bid, cost after all change orders have been paid, or cost after all claims have been settled, with the latter often difficult to measure since legal disputes may be settled long after construction is completed.

Regardless of whether a cost estimate is measured against bid price or some other final cost, most estimators and the AACE agree that the quality of reference cost estimating data greatly affects the accuracy of a cost estimate. However, estimates for underground construction are greatly influenced by factors other than published reference data. The most important factors affecting underground transit construction costs are:

Geography – the location of a project has a great influence over the available labor pool for underground work, which requires specialized skills. In addition, underground and related labor unions have varying amounts of influence in different parts of the U.S. and in different countries. For example, east coast union manning requirements differ from west coast requirements. In addition, regional labor forces are likely more accustomed to performing work using means and methods that are cost effective locally, but not in other regions. Also, transit projects built in heavily congested urban locations are penalized with higher costs than those for projects built in outlying areas due to available construction staging areas and environmental impacts like noise, vibration, work hours, and transportation restrictions. These constraints are the primary reason why transit tunnels in an urban setting are much more costly than water tunnels in mountainous locale – and why historic cost data for water tunnels should not necessarily be applied to a transit tunnel estimate.

Geology – common sense dictates that difficult geologic conditions translate into higher construction costs, and conversely favorable geologic conditions can reduce construction costs. Consider that tunnel advance rates in competent rock can easily exceed those in weak soils under the groundwater table by a factor of 4:1. In addition, some geologic conditions are fairly unique to a locale, such as the marine clays of the San Francisco Bay Area ("Bay Mud") or the glacial clays in Boston ("Boston Blue Clay"). In these special geologic conditions, the construction engineering and contracting industries have developed specific, long-established approaches to addressing these geotechnical challenges, sometimes with no correlation to cost. In addition, tunnel construction is largely a function of excavation considerations and ground support requirements. In general, rock tunnels are harder to excavate, but easier to support, whereas the reverse is true for tunnels in soil.

Allocation of Risk – many owners now recognize the good business sense of allocating risk to the party best suited to manage that risk. On underground projects, risk allocation measures such as Disputes Review Boards, Geotechnical Baseline Reports, and the use of a Differing Site Conditions clause are often used(2,3). The efficacy of other risk allocation measures such as Owner Controlled Insurance Programs and Escrow Bid Documentation have yet to be determined. Regardless, the types of risk allocation measures, or the lack thereof, have a profound influence on a contractor's decision whether to bid a project and the amount of contingency placed in a bid for risk.

Market Conditions – the size and complexity of a project has a large influence on the number of prospective contractors that have the financial capacity and technical experience needed to pursue the work. Large bonding and other financial requirements can be met by either a handful of large contractors or by smaller contractors that form a joint venture. Technical capability comes from personnel experience or by specialty contractors that do certain types of work, e.g., jet grouting, soil-cement walls, etc. In either case, financial and technical hurdles can reduce competition, and thus increase bid prices.

Transit projects by nature are usually large and complex, with many third parties involved. This, coupled with the unknowns inherent in underground construction, makes cost estimating for underground transit projects more than just an exercise in obtaining quality reference data for costs. Geography, geology, allocation of risk, and market conditions must also be factored into the estimate of construction costs and ultimately, price.

DIFFERENCE BETWEEN "COST" AND "PRICE"

Contractors often joke that Engineer's Estimates represent the cost of construction in heaven. It is the authors' opinion that this perception is the result of estimates that either do not account for constructability issues, or pay short shrift to risk and competition. This highlights the difference between "cost" and "price" of a project. The cost of a project is what cost estimators are normally familiar with; production-type estimates that build the project on paper. Contractors estimate costs in a similar fashion, but add other contingencies to settle on an overall price. Such contingencies, whether they are defined as such or not, are related to the factors described above, namely geography, geology, allocation of risk, and market conditions (and hence number of bidders). In fact, recent highway bridge and transit tunnel projects have been plagued with bids that greatly exceeded the Engineer's Estimate, primarily due to the risk, financial expenditures, and reduced competition associated with very large construction contracts. However, the dollar spread of these bids also serves to indicate the lack of agreement between contractors themselves on what the price should be. The preparation of cost estimates must therefore recognize that price can be driven by other factors than estimated construction costs.

COST ESTIMATING METHODS

As discussed above, heavy-civil construction costs can be based on a number of unit rates such as a contractor might submit on schedule of bid values, by production-based efforts that essentially build the project on paper, or by a combination of the two. However, since these two methods require substantially different levels of effort in their preparation, it is imperative that planners and engineers understand that unit price-based estimating is only appropriate for pricing work that is independent of and unlikely to be impacted by other concurrent tasks, and for which reliable historic records exist. Unfortunately, tunnel construction is extremely dependent on concurrent work tasks, and historic records of tunnel costs vary so greatly that it is ill advised to use stochastic methods on this data.

It is the authors' experience and recommendation that deterministic methods be applied to transit tunnel cost estimates early on in project development (in fact, as early as the AACE Class 5 level of project definition, as described in Table 1). The deterministic method used should be a production-type estimate that develops each task with labor, equipment, and material requirements. Contrary to other types of construction, tunnel costs can be estimated in this manner with minimal project definition. Only basic project elements require definition, such as the length of the tunnel, approximate size, and construction access points. Geologic conditions can be defined to various degrees, with appropriate contingencies applied to the estimate depending on the level of confidence in the geologic conditions. For example, a project at the screening or feasibility stage may utilize geologic mapping and case histories from tunnels in the area to characterize geologic conditions and "excavatability," with an appropriate contingency applied based on the estimator's experience. As the project moves from feasibility to the preliminary design stage and site-specific geotechnical exploration is conducted, the contingency applied to geologic conditions may be reduced. Similarly, a production estimate must be refined with increasing levels of project definition.

The effective application of production-type estimates for transit tunnels is dependant on an estimator's construction knowledge and experience. Even with an accurate cost database for equipment and labor, matching the equipment to the ground conditions and sizing crews to tunnel construction tasks requires an innate understanding of tunnel construction that invariably can only be gained from field experience, preferrably from a contractor's perspective.

TUNNEL COST ESTIMATING IN PRACTICE

Recent underground transit projects in the U.S. have run into budget difficulties, whether real or perceived. Sometimes these problems are related to politics and poor communication with the press and public. In other cases, however, budget problems have been the result of inaccurate cost estimates. Many of these problems can be grouped into one of five categories:

Scope creep – as a project develops, the scope can increase due to subsequent third party agreements that are required to keep the project moving forward. In addition, as a project moves into preliminary design and geotechnical explorations are conducted, unforeseen conditions may be revealed which change the scope of work.

Reduction of contingencies – cost contingencies related to project definition are typically reduced as the project becomes better defined. However there are some contingencies endemic to underground construction that remain relatively constant throughout the cost estimating process. Examples include the cost for rescuing a TBM on a project where anticipated ground conditions suggest that the TBM might get stuck, or the cost of repairing a structure damaged by tunnel settlement if a decision was made not to protect the structure prior to tunneling.

Project size – there has been a tendency in the past decade to combine smaller contracts into "mega" contracts, with the intention of reducing coordination efforts on the owner's part. But this coordination does not go away, it is merely shifted to the contractor, who will add contingency to his bid based on the complexity and risk inherent in the project.

Project delivery method – the Federal Transit Administration, along with several transit agencies, have begun to use design-build and other project delivery methods on new projects. Contractors' inexperience with alternate project delivery methods, or the perception that owners are not experienced with alternate delivery methods, also leads to higher contingencies in price.

Escalation and Year of Expenditure (YOE) – large, complex projects often take many years to get through the environmental approval process. As a result, aggressive project implementation schedules sometimes cannot be met, and completion dates are delayed. Cost estimates must be escalated if the YOE is delayed.

CONCLUSIONS

The following generalized conclusions are made based on the authors' experience with underground transit construction, and preparing cost estimates for such projects:

1. Constructability and estimator experience with underground construction methods is paramount to the development of a realistic cost estimate. Constructability cannot be overlooked.
2. Production-type estimates that account for geography and geology of a project must be used to establish accurate budgets.
3. On large, complex transit projects, contingencies that account for allocation of risk and market conditions must be incorporated into the cost estimate.
4. Construction cost estimates for underground project must incorporate higher contingencies to account for unknown conditions.
5. Cost estimates should always be reported in YOE dollars. Previous cost estimates must be escalated as YOE dates shift during project development.
6. Contingencies, escalation, YOE dates, and other cost estimating intricacies must be explained to the public. Project budgets that are transparent to the public are less likely to go awry or be criticized.

ENDNOTES

1. Association for the Advancement of Cost Engineering, "Cost Estimate Classification System," AACE International Recommended Practice No. 17R-97, August 1997.
2. P.E. Sperry, Chairman, "Avoiding and Resolving Disputes During Construction, Successful Practices and Guidelines," Technical Committee of Contracting Practices of the Underground Technology Research Council, American Society of Civil Engineers, 1991.
3. Randall J. Essex, Editor, "Geotechnical Baseline Reports for Underground Construction, Guidelines and Practices," Technical Committee on Geotechnical Reports of the Underground Technology Research Council, American Society of Civil Engineers, 1997.