Relating Cost Growth from the Initial Estimate to Design Fee for Transportation Projects

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Abstract: Intuitively, there should be a relationship between the size of the design fee for a transportation project and the quality of the resulting design. This study sought that relationship by looking at the fee expressed as a percentage of the construction cost and the final construction cost growth from the engineer's initial estimate of the construction cost at the time the design contract was awarded. The research team analyzed 31 projects from the Oklahoma Turnpike Authority with a total construction value of $90 million. The projects were divided into road and bridge projects. Based on the results of the analysis, it seems that as the design fee decreases, the absolute percentage of construction cost growth from the engineer's early estimate increases. The relationship is strongest for bridge projects, which tend to be more technically complex to design than roadway projects. This confirms for U.S. projects the result of an earlier study in Saudi Arabia. This paper concludes that the design fee should be viewed as an investment at a point in time where the ability to impact the project is the highest and can accrue the benefit of reduced cost growth.

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Introduction

This purpose of this research was to explore the relationship between the amount paid to produce construction documents (i.e., the design fee) and the change in cost from the engineer's initial estimate at the time the design contract was awarded to the actual cost of final construction. This change in cost will be called the "cost growth from the initial estimate" (CGIE). This metric differs from the classic construction cost growth metric found in the literature, which only measures the change in cost from the original construction contract award amount to the final contract amount (Konchar and Sanvido 1998; Gransberg and Villarreal 2002). This study tests the hypothesis that if an engineer is given more resources to complete the design then the design should be less likely to contain errors, omissions, or major quantity discrepancies which would in turn cause the project's construction cost to vary. Thus, this study attempts to relate the "quality" of the design to the change in the project's budgeted cost from the time the design contract is awarded to the final completion of construction.

It should be noted that in this definition CGIE could be either positive or negative. Positive CGIE indicates that the final cost of construction exceeded the initial estimate, presumably as a result of scope changes and/or quantity inaccuracies. Negative CGIE indicates that the final cost of construction was less than the initial estimate for much the same reasons. While negative cost growth may seem to be a desirable result, in fact, it is a good indicator of the inefficient use of available capital in public works (Gransberg and Villarreal 2002). This is because a project that finishes under budget has unintentionally tied up available capital that could have been used to award additional projects in the given agency's fiscal year. So, the use of CGIE as a project performance metric in fact also measures the public owner's ability to control the ultimate cost of the project through "investing" in the design phase and then fully utilizing the available project funding.

Finally, a short discussion of early estimate quality is in order. The issue of early estimate quality is not a new one. A study by Molenaar (2005) indicates that "construction cost estimating on major infrastructure projects has not increased in accuracy over the past 70 years. The underestimation of cost today is in the same order of magnitude that it was then." Another study of 258 infrastructure projects found that costs were underestimated 90% of the time (Flyvbjerg et al. 2002). Trost and Oberlender (2003) state the issues succinctly when they say: "Early estimates are typically plagued by limited scope definition (and thus high potential for scope change) and are often prepared under stiff time constraints." On top of the technical challenge of estimating the cost of a project that has not been designed, the issue of political pressures adds another level of complexity to the early estimating process and creates a bias toward underestimating project costs to obtain project approval and funding (Molenaar 2005). In spite of these issues, early estimates are nevertheless the most current estimate available to a project's owner on which to base the magnitude of the design fee. Thus, it is important to understand the impact of design fee and ultimate design quality.

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Relationship between Design Quality and Design Fees

A recent study by Carr and Beyor (2005) reported that design fees have not kept pace with inflation for the past three decades. This creates a situation where "the high-quality professional services rightfully expected by the public will become increasingly difficult [to attain] if the erosion in fees continues unabated into the future" (Carr and Beyor 2005). In essence, this pricing pressure forces engineers to literally furnish the requisite level of design services with a steadily decreasing amount of resources. This could unintentionally induce a bias toward minimizing design activities to maintain necessary project profitability, which in turn would manifest itself in the form of declining quality of construction documents. This environment is further exacerbated by the recent demand by owners to compress project delivery periods. A survey by the Construction Management Association of America (CMAA 2003) found that the "demand for increasing speed of project delivery is the top reason for decline in construction document quality." The survey also reported that: "In their responses to questions about the quality of construction documents, more than half of the owners surveyed responded that these documents often have significant amounts of missing information. Specifically, 45% of respondents indicated that construction documents, although sufficient, still had significant information needed, whereas an additional 12% found that documents were typically inadequate because of major information gaps" (CMAA 2003).

A number of studies have looked at the relationship between design quality and subsequent construction contract modifications. Studies by Morgen (1986) and Kirby et al. (1988) found that design deficiencies are the major cause of construction contract modifications and that 56% of all modifications are aimed at correcting design deficiencies. Additionally, a study by Burati et al. (1992) found that deviations due to design errors discovered during construction account for 79% of all modification costs and average 9.5% of the total project cost. An Australian study found that "design firms have eschewed implementing quality assurance and other subsequent aspects of quality such as continuous improvement" (Love et al. 2000). This study found that the lack of a formal design quality program led to poor contract documentation and was the "major source of rework," which in turn created cost growth during construction. Thus, past research is showing that improving design quality has the potential to accrue benefits through reducing construction cost growth.

In order to quantify the impact of a poorly prepared design on a construction project, one must first define the reasons that the construction contract cost changes as a result of errors and omissions in the construction documents. Intuitively, the costs of producing quality documents at the design stage are usually lower than the cost of correcting the errors during the construction project (Venters 2004). According to Brown (2002), owners and designers spend large amounts of time and money correcting problems caused by design errors and omissions in the construction documents. In the transportation sector where unit price contracts are the norm, final construction costs are further impacted by inaccurate quantities of work computed by the designer.

As stated earlier, the quality of the ultimate constructed project is a direct function of the quality of its design. McGeorge (1988) related design quality to project cost after construction completion using the cost of contract modifications as a metric. Another research team stated: "[final] project cost is a good indicator of project [design] quality…" (Bubshait et al. 1998). This research team went on to show that design quality is directly related to the size of the fee paid to the design consultant. The same research also showed that there is a point above which an increase in design fee no longer produces a commensurate increase in design quality. In traditional design-bid-build project delivery, poor design quality leads to increased construction cost as the project's owner warrants the quality of the construction documents upon which the construction bids were predicated and errors, omissions, and quantity inaccuracies discovered during construction must be paid for by the issuance of contract modifications (Beemer 2005). Moreover, the design articulated in the construction documents literally defines the level of required construction quality and, as such, is extremely important to a transportation project's ultimate success.

Bubshait et al. (1998) completed a study of Saudi Arabian construction projects in 1998 that effectively proved that there was a strong statistical relationship between the amount of design fee and the cost of design deficiencies discovered during construction. The team used regression analysis and was able to achieve a coefficient of determination (R^2) value of 85% for the fifth-order polynomial equation shown in

$$y = -0.003 + 0.0991(1/x) - 0.0016(1/x)^3 + 0.0013(1/x)^5 \quad (1)$$

where x=design fee per project cost (in thousands of U.S. dollars); and y=corresponding design deficiency cost per project cost (in thousands of U.S. dollars). This model yields a graph where the cost of design deficiencies decreases as the design fee increases to a point where the curve intersects the x axis around 20%. This study confirms the hypothesis that paying more for design ostensibly reduces design deficiencies for the engineering/construction industry in Saudi Arabia, the country in which the projects were delivered.

The gist of the paper by Bubshait et al. (1998) was an argument against the concept of awarding design contracts on a basis of low price. The authors conclude by saying: "The selection of the design professional is critical in achieving quality in the constructed project. The final selection should not be based on the design fee only." In the United States, most public transportation agencies are required by law to award design contracts on a qualifications basis. The Brooks Architect/Engineer Act (Public Law 92-582, enacted in 1972) forbids price-based selection of design professionals on federal projects and requires that selection be based on professional qualifications alone (qualifications-based selection or QBS). Thirty-four states and other public entities have adopted laws modeled after the federal statute requiring states and localities to utilize QBS procedures for procuring design services (NSPE 1999). Thus, while the Bubshait study's statistical correlation is good, the Saudi model may not apply in the United States.

McSkimming et al. (2005) posits that most owners establish a change order contingency within their overall budget to avoid the "prohibitive cost of perfect [design] documents" and that most owners are willing to accept a "reasonable" percentage of change order costs. Thus they argue, given the inherently imperfect nature of the design process, an allowance for correcting design quality issues should be expected. This tracks with Beemer's assertion that a common misconception is that "contract documents are 100% complete, free of any defects, and contain everything needed for the construction contractor to do the job" (Beemer 2005). McSkimming (2005) also found that "owners cut [design] fees from the 10% of the project they control (soft costs) which has the greatest impact on the 90% or construction (hard costs) of the project." Finally, a presentation made by Janacek at the 2006 Public Works Officer Institute captures the idea of why an owner should invest in quality design: "Don't try to squeeze that extra quarter point from their [design] fee. For every dollar you spend up front on design and planning, you will save 10 to 20 fold down the line" (Janacek 2006). Combining the results from the aforementioned literature brings one to the conclusion that although construction documents can never be "perfect," public owners should strive to ensure that the designer has adequate resources to furnish quality construction documents. Thus, the idea that paying an adequate fee for design accrues benefits in reduced construction cost growth is confirmed in the literature

Relationship between Cost Growth and Design Fees

There are a number of ways to define and hence to calculate "construction cost growth" in the context of design fee amount. The literature shows two standard metrics called "award growth" and "cost growth" (Gransberg and Villarreal 2002). A short discussion of these is in order to ensure the reader understands the difference between them and the new metric used in this study. Cost growth is a performance metric that measures the change in a project's cost from the original cost to the final cost. As cost growth is expressed as a percentage, the analyst can compare the projects in the database regardless of their size. If the cost growth is positive, the project increased in cost due to modifications, or it was initially underestimated. If the cost growth is negative the cost of the project decreased due to changes in the scope or the project was overestimated. Construction cost growth is classically expressed by the following equation:

$$\text{Construction cost growth} = \frac{\text{Final construction cost} - \text{original contract cost}}{\text{Original contract cost}} \quad (2)$$

where original contract cost=construction contract value at award and final construction cost=construction contract value after construction completion.

Award growth is the change in the estimated construction cost after design is completed (often called the "engineer's estimate") to the amount at which the construction contract is awarded. It can go up or down depending on whether the engineer over or under estimated the construction cost after design (Gransberg and Villarreal 2002)

$$\text{Construction award growth} = \frac{\text{Original construction cost} - \text{engineer's estimate}}{\text{Engineer's estimate}} \quad (3)$$

where original contract cost=construction contract value at award and engineer's estimate=estimated cost of construction after design is complete.

By definition, the design fee is established <u>before</u> the design is complete. When a public agency negotiates a design fee, the only number they have available regarding the construction cost is the engineer's estimate before design. Thus, this paper introduces a new metric that will be called "cost growth from the initial estimate" or CGIE. CGIE is the change in construction costs from the estimate the owner used to negotiate and award the design contract to the final construction contract value. This change will faithfully model the impact that the agreed design fee has on the quality of the construction documents by measuring the change in value of those documents as expressed by the original scope and final scopes of work. The research will use the following formula to compute CGIE:

$$\text{CGIE} = \frac{\text{Final construction cost} - \text{initial estimate}}{\text{Initial estimate}} \quad (4)$$

where initial estimate=estimated cost of construction before design and final construction cost=construction contract value after completion.

Research Methodology

The Oklahoma Turnpike Authority (OTA) originally provided the research team with 72 projects worth $235 million, which essentially constituted its entire design-bid-build construction program for the period 1998–2003. Of that group, 31 projects worth $90 million had the required data to calculate the design fee expressed as a percentage of construction cost and the CGIE expressed as a percentage of the construction contract amount. After the design fee and the CGIE were calculated, the research team followed the methodology of Bubshait et al. (1998) methodology by using linear regression analysis to determine if there was a statistical correlation between the design fee and the CGIE. Linear, polynomial and logarithmic functions were used to fit a curve to the data points in each set. A second order polynomial expression gave the best results and was applied first to the entire data set without regard to project type. This confirms the Bubshait study in that it also found the strongest correlation with a polynomial regression equation. The data was then divided into two types of projects, roads and bridges, to determine if the relationship was stronger when grouping the projects by type. The coefficient of determination (R^2) was used as the decision criterion for identifying a statistical correlation between two parameters (Newbold 1988).

Thus, three statistical analyses were completed:

1. Analysis of average design fee expressed as a percentage of construction cost for all projects in each data set, for all road projects in each data set, and all bridge projects in each data set.
2. Analysis of average CGIE for all projects in each data set, for all road projects in each data set, and for all bridge projects in each data set.
3. Linear regression analysis of CGIE versus design fee for all projects in each data set, for all road projects in each data set, and all bridge projects in each data set.

The projects where next divided up into two categories:

- Road projects: The majority of the construction was related to pavement and roadway construction, reconstruction, upgrade, or rehabilitation.
- Bridge projects: The majority of the construction was related to bridge construction, reconstruction, upgrade, or rehabilitation.

Projects that did not fit into any of the above categories, such as toll stations, were not included in this analysis. There were 13 road projects with a total construction value of $63.6 million and 18 bridge projects with a total construction value of $26.4 million. Road projects ranged from $585,000 to $27.4 million, whereas bridge projects ranged from $490,000 to $5.4 million.

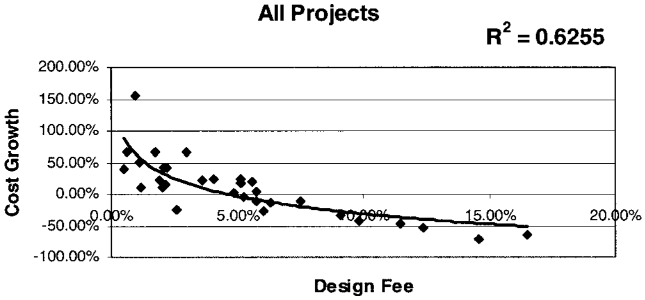

Fig. 1. OTA entire population, CGIE versus design fee

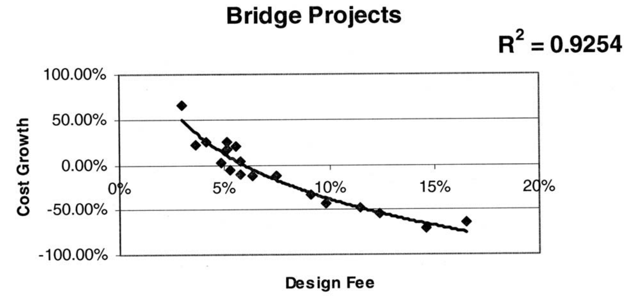

Fig. 3. OTA bridge projects, CGIE versus design fee

Comprehensive Analysis for OTA Projects

The projects provided by the OTA were first grouped together, which yielded an average design fee of 5.21% and an average CGIE of 9.65%. When the projects were divided by subgroups, road projects had an average design fee of only 1.96% but an average CGIE of 36.31%, which supports our hypothesis that the design fee is inversely proportional to the cost growth. The bridge projects had much higher design fee, 7.61%, and a CGIE of −9.60%, which leads the research team to believe that OTA is overestimating the amount of resources that would take to complete a bridge project.

The next analysis was to use second order polynomial regression to mathematically determine if there is a correlation between the design fee and the cost growth. The R^2 value after taking out the outliers by trial and error for the whole data set was 0.626 as shown in Fig. 1. When the projects were separated by type, the R^2 value for the road projects shown in Fig. 2 was 0.395. As it can be seen in Fig. 3, the bridge projects yield an R^2 of 0.925. Thus in bridge projects, which demand the most complex design, there is a very strong correlation between the design fee and the construction cost growth. The strong correlation within the bridge sample also demonstrates the potential to fine-tune the process of negotiating the design fee on these types of projects to gain a better set of controls on postdesign cost changes.

In other words, the regression analysis also supports the hypothesis that the design fee is inversely proportional to the cost growth from the engineer's estimate. A lower design fee negatively impacts the ultimate construction cost of a project, whereas a project with a higher design fee is more likely to have less CGIE. As with the design fee of Bushait et al. (1998) design fee versus quality analysis, there is a point where increasing design fee will not provide more control over CGIE to the agency awarding the project. That point appears to be a design fee of around 15% of construction costs for all projects.

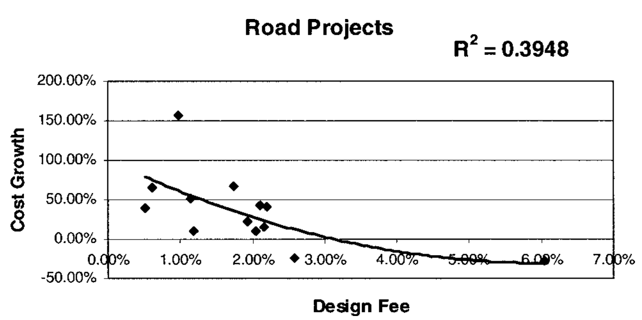

Fig. 2. OTA road projects, CGIE versus design fee

Conclusions

The consensus among designers is that design budgets cannot be cut without some negative effect on the overall quality of the project. The research by Carr and Beyor (2005) sounds a warning on the issue of under-funding the design phase of a project's life cycle. This research will prove itself useful when explaining the importance of the project cost implications at the design stage to public owners and the legislators that authorize the public funding. It is easy to say that emphasizing the quality of the design process can save money overall, but unless designers have the numbers to prove it, it is extremely difficult to substantiate the claim. Some design quality issues can be worked out in the field, but the probability of the best resolution being chosen on the fly during construction is low in most cases. This is not to say that higher fees necessarily guarantee superior design, but a well-planned budget allocates the necessary resources to achieve the best solution.

Given the previous discussion, this project generated a number of interesting findings. The conclusions deal with both the relative level of design fee that should be allowed on typical transportation projects and with the relationship between design fee and postdesign construction cost growth. The general conclusions found in the study are as follows:

1. As the estimated cost of a construction project increases, the design fee expressed as a percentage of the construction cost should decrease.
2. Bridge design projects should command a relatively higher design fee than roadway projects to due the increased complexity of design.
3. Both the OTA study and the Bubshait et al. study (1998) found that there is a point above which increasing the design fee no longer impacts the measure of design quality.
4. It seems that as the design fee decreases, the absolute percentage of construction cost growth from the initial estimate increases. Thus, owners should consider the design fee as an investment in future project budget control rather than merely a component of project life cycle cost.

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