Quantifying Uncertainty of Construction Material Price Volatility Using Monte Carlo

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ABSTRACT: This study uses Monte Carlo simulation to derive a quantitative measure of construction price volatility for two case study projects in Oklahoma. In the past four years, the impact of events like Hurricane Katrina and the economic growth in China have induced unprecedented volatility in US construction prices. This has caused a huge number of public construction project bids to exceed the owners’ estimates, making it difficult for public construction agencies to be able to predict construction budgets. Construction prices are a function of many factors beyond pure material costs. This study broke down the pay items from a typical transportation project down into five associated commodities costs. It then modeled the price volatility in each of the fundamental commodities as a stochastic function and used that output to develop a probabilistic cost model for the project. Monte Carlo simulations were run and the relative sensitivity to volatility for each commodity group was measured. The study finds that diesel is the most volatile commodity group for an equipment-intensive highway paving project. But when the same volatility model was applied to a specific bridge project, volatility in Portland cement prices became the commodity with the greatest potential impact on the project’s bid price. Finally, this study furnishes a methodology with which a public agency can test the validity of its estimates using commodity price data that is available in the public domain.

KEY WORDS: Bidding, costs, material pricing, price volatility, and Monte Carlo simulations

At a 2006 meeting of the Public Works Officers Institute, a speaker predicted that the impact of the Hurricane Katrina reconstruction effort, combined with strong demand for construction materials overseas (especially in China) would cause 2006 construction budgets to increase to 10 to 30 percent over the past year [5].

The same author stated that for the past 25 years, construction prices have predictability escalated in the range of 3 to 4 percent per year and that the members of the construction material supply chain were able to successfully manage their forward-pricing strategy based on this rule of thumb.

In 2003, construction costs increased 10 to 20 percent over the previous year [10]. This was followed by the next year by a jump of an unexpected 30 percent with another 10 to 20 percent climb in 2005 [5]. Typical cost increases in 2005 for California were as follows:

- building steel up 127 percent;
- copper up 235 percent; and,
- diesel up 91 percent [4].

Diesel alone caused costs for equipment-intensive construction tasks like earthmoving to escalate by over 30 percent. The 2005 spike caused, “92 percent of public and private owners [to] suffer budget busts on their new construction projects,” during that year [5].

Subcontractors and material suppliers are struggling to keep pace with the volatility and as a result trying a number of risk management techniques to be able to deal with the impact of commodity volatility on their pricing structures. One popular measure is the use of a fuel price surcharge on materials where such surcharges were unheard of three years ago. Concrete, sand, gravel, and steel are all materials that have seen diesel fuel surcharges imposed on them.

Figure 1 is taken from an article presented at the 2006 AACE International Annual Meeting [9]. The figure dramatically illustrates the difficulty for public cost engineers to be able to estimate public project costs using a combination of conventional historic cost data and predictions for the future of the construction market. One can see the extreme divergence of the Construction Inputs Index relative to the two more common measures of inflation that starts in 2004 and continues to the present.

J. Moss indicates that the problem with using historic data is that “historic costs do not change when market conditions have changed [10].” He cites the same unprecedented demand for construction services and materials as the previous authors reviewed by this study. He states: “Although this escalation is being experienced across the board, it is the impact on publicly funded schemes that is being trumpeted in the press, and it is here that the worst horror stories are found.”

P. Morris and W.F. Willson detail the genesis of these horror stories when they say: “Volatility ... makes contractors more likely to build risk premiums into their bids to cover potential increases in material prices, and suppliers more likely to wrap material quotes with an additional premium, to ensure that they will still be able to make a profit in a case of spikes in material cost. These premiums are usually much higher than the expected increase in overall material cost, making volatility a far greater cost inflator [9].”

This new level of uncertainty compounds the existing estimating problem in the public sector where there already exists a bias toward underestimating projects at early stages to ensure that funding is approved [2, 8].

A 2002 study that included 258 infrastructure projects that spanned over 70 years reported project costs were underestimated in approximately 90 percent of the projects, and the actual costs averaged 28 percent higher than originally estimated [2]. Thus, adding an unexpected level of volatility to a system that is already resource constrained creates an untenable situation for many public agencies. Morris and Willson indicate that, “In order to minimize the risks associated with this market volatility, project owners must move away from the traditional way of thinking about projects [9].” Thus, costs engineers working on public projects must modify their current deterministic method by using a different approach for all levels of estimates that allows them to incorporate some factor to model the probable volatility of the costs that they are estimating.
Fortunately, with some preparation and research, the Monte Carlo simulation allows the cost engineer to do exactly that [14]. The purpose of this article is not only to illustrate the impact of price volatility on a case study construction project, but also to demonstrate the use of this powerful analytical tool in assisting the cost engineer in modeling the condition of the market in a stochastic rather than deterministic way.

**Methodology**

This research's primary objective was to use actual historical pricing data from various industries in construction to quantify the uncertainty associated with volatility in construction material prices.

The researchers chose to follow the methodology proposed by A. Touran and elaborated on in a second article by the same author [13, 14]. In his article, Touran indicated that, "It is common practice to use a Monte Carlo simulation approach for calculating the cumulative distribution function (CDF) of the total project costs."

"This is because direct analytical approaches tend to be difficult and are sometimes infeasible... There is no point in modeling every cost component in the project as a random variable; in most projects, costs for many items can be estimated with relative accuracy, are relatively fixed, and do not have the potential to affect the bottom line in a significant way."

This prior research confirms the fact that not every cost variable has to be modeled as a stochastic function and validates the cost modeling approach that will be detailed later in this article.

As such, the team chose to associate each bid form pay item in the case study project with an appropriate commodity. Five commodities that are common to typical transportation projects were selected: asphalt, aggregates, Portland cement, steel, and diesel. Pricing data from the past 10 years was collected in order to capture the fluctuations seen in each commodity over an appropriate period. The timeframe of the data researched was from January 1996 to May 2006. This period also permitted the researchers to look at varying period lengths within the sample to develop a deeper understanding of the volatility mechanism.

Some of the items contained more than one commodity group and some items did not contain any of the commodities that were being researched. The next step was to isolate the percentage of the total estimated item cost that included these specific commodity costs.

A national cost estimating manual was used to determine the percentage of the total costs was made up exclusively by material costs for asphalt, aggregates, cement and steel products [7]. Diesel was estimated as 15 percent of the equipment costs for activities that used diesel-consuming equipment [3]. Labor cost was not modeled as a stochastic function and was added to the appropriate pay item as a constant on the stochastic function for the material and equipment costs. The equation for each commodity group can be generalized as shown in equation 1.

\[ C_X = M_X + E_X + L_X \]

Where:

- \( C_X \) = Stochastic cost of pay item associated with commodity X
- \( M_X \) = Stochastic cost of material commodity X
- \( E_X \) = Stochastic cost of equipment component X tied to diesel commodity
- \( L_X \) = Deterministic cost of labor for pay item (a constant)

The sum of each of the five commodity groups is added to remaining costs in the case study project which were input to the model as deterministic functions, based on the engineer's estimate for the project. The complete cost model is shown in equation 2.

\[ TC = C_A + C_B + C_C + C_D + C_S + D_V \]

Where:

- \( C_A \) = Stochastic cost of aggregate pay items
- \( C_B \) = Stochastic cost of bituminous material pay items
- \( C_C \) = Stochastic cost of Portland cement pay items
- \( C_D \) = Stochastic cost of diesel pay items
- \( C_S \) = Stochastic cost of steel pay items
- \( D_V \) = Deterministic value of remaining project costs that are not associated with the five commodities under analysis.

To enhance the value of this study, the researchers used a commodity cost data source that was available in the public domain. Engineering News Record (ENR) magazine's Quarterly Cost Reports satisfied that requirement [1]. This continued to follow A. Touran's model [14]. He and his coauthor stated that ENR's "cost indices are one of the most important, oldest, and commonly used in..."
the construction industry [14].” This study will be consistent with previous studies and can be compared in that context.

ENR collects and publishes data called, “Construction Materials Price Movement” tables, which are derived from the US Bureau of Labor Statistics. These furnish monthly readings of the percentage of change in price for 19 commodity groups, including the five commodities of interest in this study. Additionally, using a single data source that provides the required data for these five commodities is important because its output is derived from a process that maintained the same standards, assumptions, and statistical processes for each of the commodities under study, ensuring consistency in the data set.

Once the variables for the model are identified and recorded, the next step is to develop the probability distributions that applied to each of the variables. This task is straightforward for the large historical database by using the BestFit® 4.5 software that was specifically made to fit data to the best distribution type [6]. With one data point entered for each month into the software, distributions were fit to the input data by commodity. The program output all potential data distributions and ranked them by their associated chi-squared statistics. The distribution with the lowest chi-squared value was selected as the best fit. Table 1 is the resulting distributions for each commodity and figure 2 is an example for Portland cement.

Once the data was collected and reduced, Monte Carlo simulation using @Risk® software was used to quantify the uncertainty that exists in estimating projects because of the volatility of these specific construction material prices [11]. Monte Carlo simulation selects variable values at random to simulate a model. For each uncertain variable (one that has a range of possible values), the possible values are defined with a probability distribution. Then, a simulation is run to calculate multiple scenarios for the model by repeatedly sampling values from the probability distributions for the uncertain variables.

### Table 1 — Best Fit Probable Distributions for the Five Commodities

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Best Fit Distribution Coordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregates</td>
<td>BetaGeneral (2.7509, 9.7019, -0.43456, 3.0519)</td>
</tr>
<tr>
<td>Bituminous materials (asphalt)</td>
<td>Log-Logistic (-1.8402, 2.2654, 4.5492)</td>
</tr>
<tr>
<td>Portland cement</td>
<td>Log-Logistic (-0.8078, 0.95654, 3.2968)</td>
</tr>
<tr>
<td>Diesel</td>
<td>Logistic (2.1199, 5.5636)</td>
</tr>
<tr>
<td>Steel</td>
<td>Extreme Value (-0.046603, 0.43999)</td>
</tr>
</tbody>
</table>

Case Study Project Simulations

Two case study projects that were awarded in 2006, were adopted for use in the study. The first one was a highway rehabilitation project (hereafter referred to as the “road project”) that consisted primarily of asphalt paving work, as well as a substantial amount of equipment-intensive demolition of existing concrete pavement. The second project was a bridge expansion project (hereafter referred to as the “bridge project”) that used both structural Portland cement concrete and structural steel members in the design.

The bridge project was the more complex of the two and as a result its cost model was more involved. Additionally, it used “A+B” bidding procedures (see [12] for details) where the contractors were asked to establish their own schedules and a cost of $2000 per day was added to each project’s bid price.

This introduces a mechanism where the construction contractor can reduce its exposure to price volatility by proposing a shortened schedule and makes this an ideal project to analyze within the context of this article. The procedures used for both projects will be discussed for the bridge project and not repeated for the road project.

The bridge project was estimated by the owner to cost about $5.1 million, including charge for a 420 day schedule that yielded an A+B estimate of $5.9 million. It had two bidders that bid as follows:

- $4.735 million and 180 days; A+B = $5.095 million. And,
- $4.334 million and 340 days; A+B = $5.014 million.

![Figure 2 — Example Best Fit Distribution for Portland Cement](image-url)
One can see that the owner's estimate was higher than the two bidders as was the owner's estimated schedule. This type of bidding allows the cost engineer to see the impact of time on the estimated cost of construction.

One other factor is not apparent in the bid prices. This is the potential impact of both front-loading and unit price unbalancing. Front-loading is the deliberate overpricing of pay items completed in the early phases of the project to enhance project cash flow projections [3]. Unbalancing is specific to unit prices and consists of quoting unit prices that are not uniformly marked up for overhead and profit [4].

Attempting to control these factors is beyond the scope of this study. The researchers decided to use the owner's estimate as the basis upon which to build the bridge and road projects' cost models for the Monte Carlo simulations. This provides the added advantage of being able to relate the impact of construction material price volatility to the owners estimate and compare the expected value generated by the simulation to the actual bids.

The bridge project's cost model contained a deterministic constant of about $2.6 million covering such items as signage, striping, traffic control and other costs that were not commodity associated. Roughly half the project's cost was influenced by the stochastic functions of the material commodity models. This amounted to 30 of 72 pay items, the largest of which was $175,000.

The largest single pay item was structural steel which was estimated at $1.379 million. When the Monte Carlo simulation was run for the bridge project, an expected mean value of $5.085 million was found with a 90 percent confidence interval of $5.066 million to $5.104 million, which agrees pretty closely with the original estimate.

Remembering that this is an A+B project and that the owner's estimate was predicated on a 420 day schedule, one can then compare the simulation output to the contractors' bids. The bids are noticeably lower. However, as this is a unit price rather than a lump sum contract, the bid price does not become the final contract amount. The final cost is dependent upon the final actual quantities of work, as well as any scope changes that may have been encountered during construction. The real value of this simulation comes when one looks at the results of the sensitivity analysis.

With this being a bridge project whose largest single pay item is structural steel, intuitively one would expect that the final estimate would be most sensitive to volatility in that commodity price. This idea is doubly confirmed in light of the introductory discussion that cited one author as estimating steel to be up as much as 280 percent in 2006 [5]. Figure 3 is the tornado diagram of the regression sensitivity for the bridge project. Sensitivity is measured using the standardized beta weight (Std b) coefficients. These are shown on the X-axis indicate how much one standard deviation increase in the given commodity price will affect the total cost for the project [11]. Interestingly, the project's final estimate is most sensitive to the price of Portland cement. Steel ranks second with diesel ranking third.

With this type of analytical output the owner's cost engineer can adjust the original assumptions that went into the estimate if necessary to cover the potential for near-term volatility in the commodities that are most important to this particular project. Additionally, with the 90 percent confidence range delineated by the simulation, the cost engineer can compare this output with the contingency that was used for the estimate to determine if it is adequate. This exercise serves to quantify the uncertainty because of construction material price volatility and permits the cost engineer to make professional judgments as required by the analysis.

The same analysis was done for the road project and again the sensitivity analysis proved to be quite startling. Figure 4 shows the tornado diagram for the road project and once again furnishes a counterintuitive result which is nevertheless very instructive.

On the road project the major pay item consisted of asphalt paving. However,
the most sensitive commodity was diesel. When given some analysis, this eventually makes sense. The second largest pay item was the demolition of the existing concrete pavement which is a completely equipment-intensive activity.

While asphalt paving material can be quite expensive, it is also an equipment-intensive construction process that requires a large amount of diesel fuel in addition to the paving materials. This output again permits the cost engineer to use his/her professional judgment regarding the size of contingency that should be applied to this particular project. This analysis might also warrant the use of a fuel cost escalator clause as a risk management device on this project. That would allow the owner to share the risk of diesel fuel volatility, rather than forcing contractors to bid it. Bidding could potentially bid the drive bid price higher than the project’s approved funding.

This analysis leads to three major conclusions. First, the literature shows that construction material price volatility has been greater in the past three years than it has been in the previous two decades. As a result, cost engineers must seek new tools to deal with this phenomenon and use them to enhance the accuracy of their estimates.

Next, to be able to model construction material price volatility, the needed data is available in the public domain thorough industry sources like ENR. Given the appropriate cost models, owner’s cost engineers can easily transform their estimates form their traditional deterministic form to more robust stochastic models. The stochastic models can then be manipulated to generate the types of critical information demonstrated in this article’s case study projects.

This type of modeling permits professional judgments, regarding project contingencies and other items, to be made. These judgments can now be based on quantifying the uncertainty of material price volatility rather than the anecdotal information currently in use.

Finally, the results of the two case study projects clearly demonstrated that the intuitive determination of price sensitivity was not an accurate representation of the true relationships between commodity groups inherent to the cost model. In both cases, the highest cost pay item was not the most sensitive. Having this type of output is valuable in allowing the cost engineer to truly understand the dynamics of a given estimate and to quantify the impact of uncertainty resulting from construction price volatility on a given project.

Beyond the knowledge that was developed by this analysis, the methodology was proven to demonstrate its ability to generate valuable output. This methodology can be applied to any given construction project for which material volatility data can be gathered.

This methodology is not limited to using ENR cost data. A cost engineer could add a degree of accuracy by assembling a database of actual material pricing history for specific products in a specific geographic location. The use of Monte Carlo simulation no longer requires large amounts of academic knowledge on the subject. The software is available for a reasonable cost and it works in conjunction with most standard commercial spreadsheet packages.

No programming or special knowledge beyond the ability to knowledgeably use computer spreadsheets is required. Therefore, the model described in this study is recommended for a wide range of projects and has the potential to assist not only the owner, but other members of the industry in developing better estimates during a period of unprecedented volatility.

REFERENCES

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