Integration of Financial and Construction Risks: A Simulation Approach

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A general approach for quantifying construction and financial risks of a major capital transit project was developed. The methodology relies on Monte Carlo simulation. The technique was used to estimate the probability of time and cost overruns in construction projects. The value of integrating both financial and construction risks into such an analysis was emphasized because these risks are interrelated and, in many cases, cannot be separated. When the two sources of risk are examined in isolation, there is the possibility that some risks at the intersection may be omitted or double counted. With an integrated approach, however, the potential impact of project cost overruns can be assessed consistently and completely. The proposed methodology can be used by the planners and owners of capital transit projects to help them decide on the levels of funding needed to meet construction and design costs, given various uncertainties. Rather than providing a safety factor to guard against unfavorable scenarios, the simulation approach allows the planner to define a consistent confidence level in regard to achieving project objectives. The approach is illustrated with an example involving a hypothetical capital transit project.

Cost and schedule overruns are common in large construction projects. Thompson and Perry report that out of 1,778 projects financed by the World Bank between 1974 and 1988, 63 percent experienced cost overruns (*1*). In the United States, cost overruns have been common in large, complex projects such as power plants. Major capital transit projects are not an exception in this regard. For example, Pickrell studied 10 large transit projects and found that 9 out of 10 of these projects suffered from budget overruns. The amount of overrun ranged from 11 to 106 percent (*2*).

Several parameters are responsible for such huge overruns. Scope changes, optimistic scenarios yielding low estimates of costs and high estimates of benefits, estimation error, incomplete information about project objectives, faulty design, and delay of the construction start date are some of the more important factors contributing to overruns. Whereas some of these parameters are strictly technical in nature, others depend on the political atmosphere surrounding the decision makers and the condition of the economy. Although these political and social factors sometimes prove to be the most important, we do not deal with them in this paper. Instead, we focus on developing guidelines to incorporate technical difficulties and economic uncertainties into project budget estimating.

On the basis of research and discussion with FTA experts, we believe that project uncertainties can be divided into two main categories: design and construction and financial. Hence, risks associated with either of these broad categories are either design and construction risks or financial risks. Design and construction risks relate to the process of construction and to the parameters that affect the construction budget or schedule. Financial risks tend to affect the project at a more macro level; they may include unfavorable changes in interest rate, the state of the economy and its impact on project financing, or uncertainty regarding a project's cash flows. An example of a risk checklist tailored to transit projects can be found elsewhere (*3*).

The traditional approach in calculating the impact of cost uncertainties has been to add a contingency of between 5 and 15 percent of the estimated cost of the project to the budget (*2*). Most of the time, the calculation of this contingency is based on incomplete data or on the intuition of experts. In some cases, an overall contingency rate is calculated and added without due analysis of project details. The accuracy of cost estimates is directly related to the clarity of the project's scope and the amount of information available at the time of the estimate. Figure 1 shows this situation. Horizontal bars show the steps required in FTA planning and engineering phases and their average duration (*3*). Distributions are used to show that a lack of knowledge of project details in the early phases of a project, leads to larger uncertainty in the budget estimates (*1*). Therefore, it makes sense that, in the earlier phases of a project, the contingency sum tends to be larger than the contingency estimate in later phases. The larger contingency estimate is needed to provide the same level of confidence.

In more recent projects probabilistic risk analysis has been applied. In such cases, the expected range for each major parameter contributing to the project's uncertainty is input into a computer program. A Monte Carlo simulation analysis is conducted for several hundred to several thousand iterations, and a cumulative distribution function (CDF) is calculated for the total project cost. Using the CDF, the planner can choose a probability of cost overrun with which he or she is comfortable. In other words, the planner may choose a budget for which the probability of actual cost exceeding that level would only be, say, 20 percent (*4*).

INTERRELATIONSHIP BETWEEN FINANCIAL AND CONSTRUCTION RISKS

A contractor of a transit system is interested in construction risks. The owner or the sponsor is interested in financial risks, design and construction risks, and the combined effect of these risks on the project. Financial and construction risks are interrelated. If the construction phase suffers schedule overrun (quite common for large public projects), that adversely affects the project budget. An increase in project cost will influence the level and cost of financing. The owner develops a financial plan by considering a reasonable construction budget. If the budget's financial contingency is not sufficient, the owner faces the uncertainty of lining up additional financing at a potentially unfavorable rate and time.

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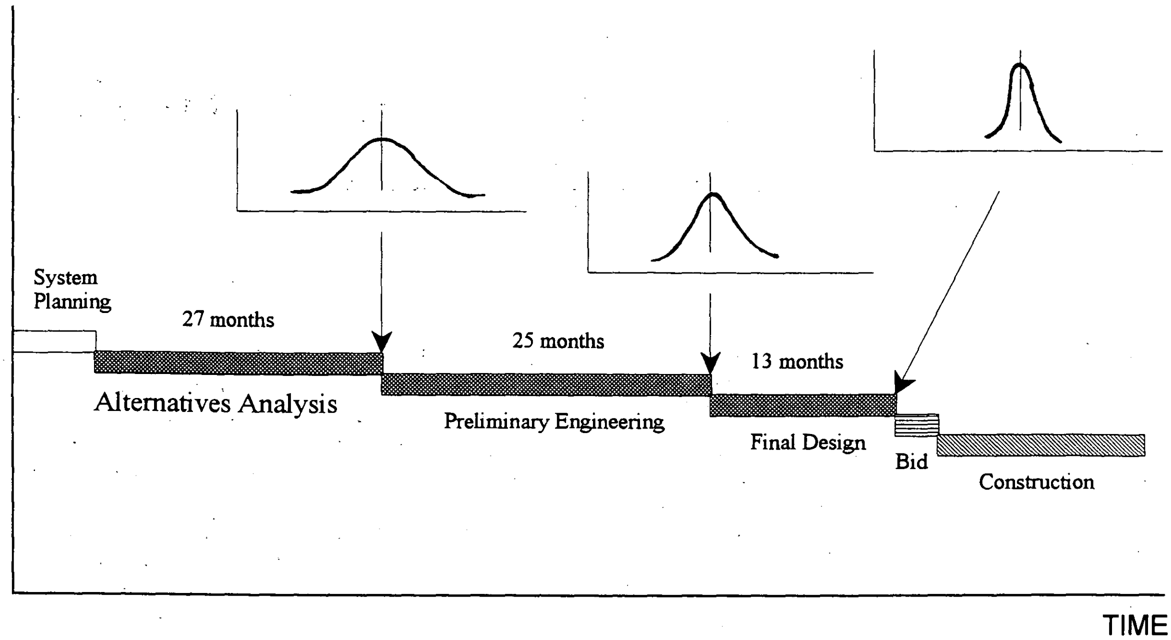

FIGURE 1 Change of project uncertainty with level of information.

Hence, an owner or sponsor of a project must consider the impact of design and construction risks on a project's financing picture as well as uncertainties related to the cost of project financing. Availability of financing will be directly influenced by expectations of future sources of revenues, interest rates, and financial markets. The authors emphasize an integrated approach to dealing with these risks and provide a simple approach for evaluating a project's financial plan and budget.

INTEGRATION OF FINANCIAL AND CONSTRUCTION RISKS

A better understanding of a project's overall risks can be gained by incorporating financial and construction risks into a single analysis. Whereas separate analyses of financial and construction risks can pinpoint specific problem areas, an integrated analysis shows the project's overall chance of success. The approach is especially useful from a project sponsor's or owner's point of view because it evaluates the adequacy of funding and the impact of a potential shortage of local funds and increases in construction costs on the project. The use of a probabilistic risk assessment approach in contingency calculation is advocated because it allows a planner to define a consistent confidence level in regard to achieving project objectives.

The Monte Carlo technique for arriving at the statistical distributions of objective functions was used. Whereas an analytical solution to the problem of calculating the cost distribution is attractive, the complexity of its derivation under general conditions remains a major obstacle. Widespread use of the Monte Carlo technique in similar applications has increased users' familiarity with the method. Also, a former obstacle to performing Monte Carlo analysis, lack of access to expensive hardware and software, has been removed. Several powerful software packages, designed as add-ins to popular microcomputer spreadsheets, have facilitated the use of Monte Carlo, especially in cost estimating and financial applications—areas in which spreadsheets have long been used. In the following example, we have used @RISK by Palisade, which works with a Lotus 1-2-3 spreadsheet and allows the user to generate random numbers from a host of different statistical distributions (*5*). A detailed discussion of the benefits and the shortcomings of the Monte Carlo approach, along with the typical cost models used in construction, is presented elsewhere (*4*).

HYPOTHETICAL EXAMPLE

To illustrate the probabilistic approach to evaluating project financial and construction risks a hypothetical transit project was used. It was assumed that feasibility studies and alternatives analysis phases were complete and that a sponsor had decided to go forward with construction of a fixed guideway transit project consisting of 19.3 km (12 mi) of elevated tracks and related stations and equipment (*3*).

Construction Costs

Total project cost is modeled as the sum of several cost items, some of them random variables. Obviously, if one wants to consider cost variations in every small cost component that goes into a detailed estimate, the approach would be impractical. Because of this, only cost items that have a significant impact on the total project uncertainty are modeled as random variables. In a large project, most of the total cost variation is due to the variability of a limited number of components.

Monte Carlo simulation can be used for modeling cost items with a high potential for variability as random variables and for generating random numbers according to their assumed cost distributions. These items are added up, the fixed costs are added to these, and the total project cost is computed. The procedure is repeated at least several hundred times, and every time a value for the total cost is computed. A histogram and, later, a CDF can be constructed for the total cost. The CDF can then be used to estimate the probability of completing a project at or below a certain budget and to arrive at a reasonable contingency sum for the project.

The process of identifying major risk items in a transit project, choosing a proper statistical distribution for modeling the data, and developing an appropriate cost function for the total costs is the subject of another research project by the authors (*3*). There is considerable literature on the choice of distribution for various cost components. It appears that most cost variables may be modeled using a unimodal, unsymmetrical distribution, preferably with confined positive limits (*6,7*). Another mathematical complexity involves modeling of correlations that exist between cost variables. It has been shown that many construction cost items are correlated (*7*). Correlations between economic factors, such as interest rates and inflation, have been established. An analyst cannot disregard correlations, because in general they tend to affect the variance of the total cost and this, in many cases, underestimates the risk of cost overrun. Generating correlated random numbers is possible, but the analyst has to be aware of mathematical constraints. Developing joint density functions is generally difficult, and if data are not normally distributed, it is not always feasible. Many Monte Carlo simulation software packages use rank correlations. This allows generation of correlated random variables, even when marginal distributions are not normal (*8*). It should be noted that each of these issues deserves extensive discussion in its own right. This paper emphasizes the interaction and integration of financial and construction risks.

Assume that, in the present example, the project's budget (or target estimate), including escalation factors, is estimated at $1,205 million. Further assume that the project's critical cost components with potential for large variation have been identified, their distributions and parameters specified, and a Monte Carlo simulation conducted to compute the total cost. A CDF for the project was developed and is presented in Figure 2. It shows that there is almost a 50 percent chance that the project cost will exceed the target estimate of $1,205 million. If the owner is not comfortable with that confidence level and prefers one of 80 percent, for example, then the budget required would be approximately $1,300 million. In other words, a $95 million contingency reserve is needed to assure, with a level of confidence of 80 percent, that the project will not suffer cost overrun.

The project spans a 5-year period, and the overall cost has been distributed over these years using the project schedule (see spreadsheet provided in Table 1). It was assumed that each of the annual budgets follows a lognormal distribution and that for every year a contingency budget would be calculated, such that the probability of cost overrun would be kept to less than one-third (33 percent). The total project contingency is $97.5 million (8.1 percent of target estimate), providing a confidence level of 81.7 percent against cost overrun. In other words, there is one chance in six that a cost overrun will occur if the total budget considered is $1,205 million + $97.5 million, or $1,302.5 million.

Project Financing

The project would be financed through three primary sources: federal grants, excise tax revenues, and proceeds from bond issues. The amount derived from federal sources is assumed to be certain and is distributed as indicated in Table 1. It is assumed that FTA will provide $765 million distributed over a period of 5 years, or about 60 percent of the total construction estimate plus contingency. The ratio appears to be reasonable given current circumstances. The serial bonds issued are revenue bonds; $490 million is planned to be raised by issuing a series of them. The sales tax revenues are assumed to service the repayment of principal and interest of the bonds issued. These revenues are assumed to grow at a mean annual rate of 2.5 percent. Growth rates are drawn from a truncated normal distribution with a mean of 2.5 percent, standard deviation of 2.5 percent between −2.5 percent and 7.5 percent. The growth rate reflects assumptions regarding the income of the underlying regional economy, population trends, and expansion of the regional job base.

Interest Rates

Interest rates are modeled as the inflation rate plus a time premium that increases with the bond's maturity. The inflation rate itself is assumed to follow a truncated normal distribution with a mean of 3.25 percent and a standard deviation of 3.25 percent, truncated between 0 and 6.5 percent (*9*). Mean interest rates for the serial bond issues used in this example are given in Table 2. Another

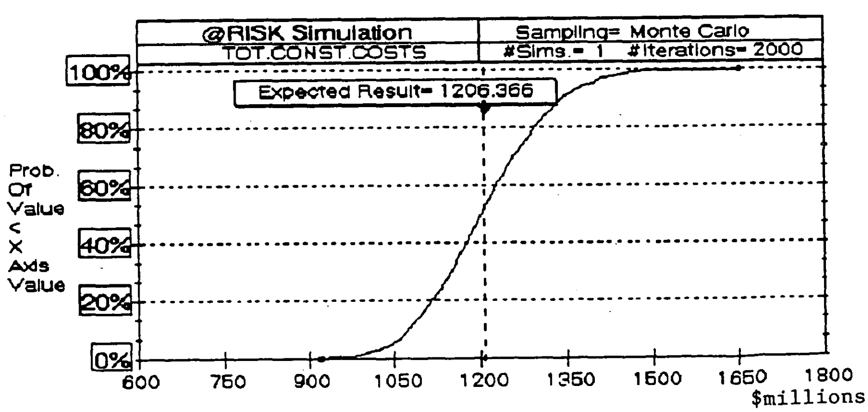

FIGURE 2 CDF for the total construction costs.

TABLE 1 Capital Financial Plan

YEAR	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	TOTAL
FUNDING:												
FTA	120.00	175.00	175.00	175.00	120.00							765.00
Sales tax	45.00	47.62	50.40	53.34	56.45	59.74	63.23	66.91	70.81	74.94	79.31	667.77
Interest Income	3.63	4.74	5.66	7.84	8.86	9.92	9.18	9.21	8.01	5.38	3.00	75.44
Bond Proceeds	100.00		200.00		190.00							490.00
TOTAL REVENUES	268.63	227.36	431.07	236.18	375.31	69.66	72.40	76.13	78.83	80.33	82.32	1998.21
COSTS:												
System Contract	90.00	325.00	230.00	255.00	225.00	80.00						1205.00
Contingency	2.50	16.00	23.00	26.00	22.00	8.00						97.50
Bonds Debt Service	5.26	5.26	15.43	15.43	20.05	40.05	49.10	97.60	113.80	169.18	105.50	636.65
TOTAL COSTS	97.76	346.26	268.43	296.43	267.05	128.05	49.10	97.60	113.80	169.18	105.50	
NET SURPLUS/DEFICIT	170.87	-118.90	162.64	-60.24	108.26	-58.39	23.30	-21.47	-34.97	-88.85	-23.18	
Beginning Cash Balance	0.00	170.87	51.97	216.61	154.36	262.62	204.24	227.54	206.06	171.09	82.25	
Additions to cash	170.87	-118.90	162.64	-60.24	108.26	-58.39	23.30	-21.47	-34.97	-88.85	-23.18	
Ending Cash Balance	170.87	51.97	214.61	154.36	262.62	204.24	227.54	206.06	171.09	82.25	59.06	
Debt Coverage Ratio	9.24	9.95	3.63	3.97	3.26	1.74	1.47	0.78	0.69	0.47	0.78	

TABLE 2 Debt Service Schedule for Project Bonds

Bond Series	Bond Amount	Bond series	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	
	($millions)													
1(a)	20.00							20.00						
		4.75%	0.95	0.95	0.95	0.95	0.95	0.95						
1(b)	30.00								30.00					
		5.00%	1.50	1.50	1.50	1.50	1.50	1.50	1.50					
1(c)	50.00												50.00	
		5.63%	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	
2(a)	80.00									80.00				
		4.75%			3.80	3.80	3.80	3.80	3.80	3.80				
2(b)	70.00											70.00		
		5.25%			3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68		
2(c)	50.00												50.00	
		5.38%			2.69	2.69	2.69	2.69	2.69	2.69	2.69	2.69	2.69	
3(a)	100.00										100.00			
		4.63%					4.63	4.63	4.63	4.63	4.63			
3(b)	90.00											90.00		
		4.75%					4.28	4.28	4.28	4.28	4.28	4.28		Totals
		Principal						20.00	30.00	80.00	100.00	160.00	100.00	490.00
Total Issued	490.00	Interest	5.26	5.26	15.43	15.43	20.05	20.07	19.12	17.62	13.81	9.18	5.50	146.65
		Debt Service	5.26	5.26	15.43	15.43	20.05	40.05	49.10	97.60	113.80	169.18	105.50	636.65

relevant interest rate is the rate the owner can achieve from the surplus cash balances generated during the project's life. This rate is modeled as the inflation rate plus 1.0 percent.

Timing of Bond Issues

In this example, three serial bond issues are provided in 1995, 1997, and 1999. The issues are timed to provide positive cash flows during the construction phase of the project. Bonds are issued according to the schedule in Table 2 and have a total face value of $490 million. Interest rates for the bond issues are tied to their issue dates and to variations in inflation rates. The model assumes an upward-sloping yield curve, the prevailing structure in 11 of the past 16 years and one described by current interest rates (*10*). This means that longer-term bonds carry a higher interest rate than shorter-term bonds. However, the model is sufficiently flexible to allow an alternative yield curve definition (flat or inverted, for example). This flexibility is important, because the owner may choose to alter the timing of market financing on the basis of the prevailing term structure of interest rates. Tax revenues are not large enough to provide sufficient financing during construction. After construction, bond principal and interest are offset by sales tax revenues. The cash flows that result from this financing strategy are robust in early years and sufficient in later years. In practice, more complex bond issues would be used to minimize the surplus cash balances in early years. However, the simplified financing structure in this model captures the essence of cash-flow management reasonably well.

Simulation Analysis

Several items in Table 1 have potential for chance variations. Construction expenditures for every year are modeled according to lognormal distributions, as discussed earlier. Sales tax is a function of growth rate and inflation; interest income and debt service are modeled as functions of interest rate, which itself is a function of inflation. Because the inflation and growth rates are modeled probabilistically, sales tax, interest income, and debt service become probabilistic variables too.

A Monte Carlo simulation analysis was conducted on the spreadsheet. This was accomplished by generating random numbers according to specified probabilistic models for 2,000 iterations. The number of iterations chosen was sufficiently large to allow the simulation results to converge to their theoretical values.

Analysis of Results

There are several important issues that have to be studied in Table 1. First, planners have to make sure that the construction budget is sufficient and the contingency reserve is large enough to meet unexpected cost variations. Second, the ending cash balances should be positive throughout the spreadsheet. A negative value in any year means a cash shortfall that can create financial hardships and complications, either in the construction process or in meeting financial obligations to lenders. Simulation helps to assess the probability of having negative cash balances at any time in the project.

Figure 3 shows a distribution summary graph for the ending cash balances. Table 3 provides summary statistics for this parameter. The probability of having a negative cash balance increases in the later years. This is expected because of the modeling approach used in the example. For every iteration, a random value for inflation and growth rate is generated for the first year. In subsequent years, the values generated for the previous year will serve as the mean of the normal distribution used to model growth rate and inflation rate. In other words, the value of the growth and inflation rates will depend on their values in the previous year and will show a variance around the previous year's value. Tax revenues, interest income, and bond proceeds are updated in every iteration on the basis of the generated growth and inflation rates. More complicated models based on probabilistic treatment of population trend, local income, and so forth also can be conceived.

As indicated in Table 3, there is a 33.6 percent chance that the project will sustain a cash shortfall in 2005. This probability is 26.4 percent for 2004. For earlier years, the probability is significantly lower and never exceeds 9.4 percent. The planners could respond to this problem in several ways, depending on their tolerance for risk. One option is to issue more bonds. That option should be considered only in conjunction with the local economy's ability to repay the debt. An alternative is to increase the sales tax rate. Either option could be pursued before the project is undertaken or as funds are needed.

The growth of sales tax and its variations is another item of interest. Because sales tax is the major funding source for servicing the debt in this example, the project's sensitivity to varia-

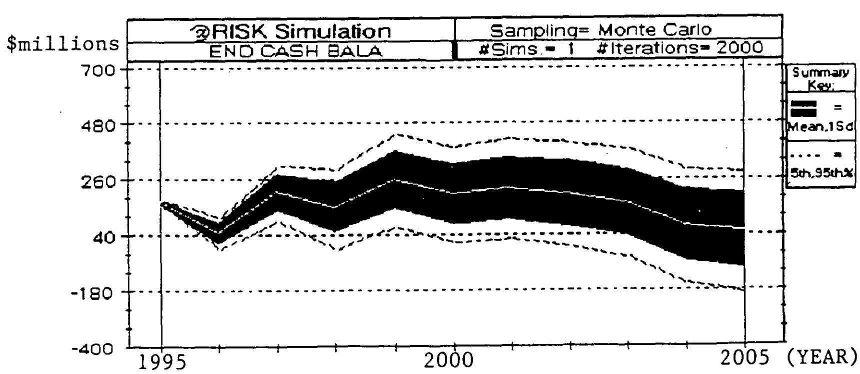

FIGURE 3 Distribution for ending cash balances, 1995 to 2005.

TABLE 3 Ending Cash Balances Statistics for Various Years

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Result of 2,000 Iterations											
Maximum Result	191.31	154.87	427.85	394.77	600.67	577.40	632.56	645.53	637.45	574.94	572.75
Minimum Result	150.27	-84.15	-117.76	-213.04	-147.05	-208.12	-197.37	-240.76	-296.60	-402.99	-443.93
Chance of Positive Result	100.0%	90.6%	99.6%	94.2%	98.7%	95.7%	96.8%	94.9%	90.8%	73.6%	66.4%
Chance of Negative Result	0.0%	9.4%	0.4%	5.8%	1.4%	4.3%	3.2%	5.1%	9.2%	26.4%	33.6%
Standard Deviation	6.28	38.20	67.05	93.69	109.01	114.08	118.00	122.90	128.64	135.13	142.74

NOTE: All figures except percentages are $ millions.

tions in cash inflows from this source should be studied. That can be done two ways. One method involves changing the values of growth rate and studying the impact on the project's viability. Another method involves a sensitivity analysis that can be conducted while assuming a probabilistic model for the growth rate. The second model, though a bit more complex, is more realistic because it provides a measure of uncertainty for every scenario studied.

SUMMARY

Cost and schedule overruns are common in large construction projects. In this paper, the process of measuring and analyzing construction and financial risks in construction were described. Probabilistic methods for estimating project contingency and for modeling financial factors affecting project budgets were reviewed. Emphasis was placed on the integration of financial and construction risks and on analysis of the impact of their interaction on a project's successful completion. The methodology used was based on Monte Carlo simulation. A hypothetical project was used to illustrate the modeling concepts and the process of risk quantification. It was shown that one can quantify the impact of variations in construction costs and financial fluctuations on the ending cash balances of project funds. Also, problem areas in the financial plan were pinpointed and the extent of their impact was quantified.

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