TECHNICAL ARTICLE

Integration of Schedule and Cost Risk Models

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ABSTRACT:
These authors discuss techniques for integrating schedule and cost risk analysis using current software. Their recommendation is to prepare cost and schedule risk analyses simultaneously with different software, and then combine the results. This article discusses techniques for integrating the uncertainties associated with time and monetary resources when using the Monte Carlo simulation tool for risk analysis on capital projects.

Key Words: risk, scheduling, scheduling software, Monte Carlo analysis

Prior to making a strategic capital investment decision in anticipation of achieving a potential business objective and/or return, three essential questions need to be addressed.

- What is going to be accomplished (scope)?
- How much is it going to cost (cost estimate)?
- How long is it going to take (schedule)?

The components of time and cost are both very important for capital investment decisions, and are closely interrelated. Corporate strategic decisions are usually centered on new product introductions, increased capacity for existing products, vertical business integration, or other decisions that generally affect the balance sheet of a company. These decisions have high visibility and are complex; several factors affect the ultimate decision.

The traditional approach to developing the cost and schedule components has been to create single-point estimates and schedules with single-point completion dates. These components often are developed in relative isolation, with little or no effort given toward ensuring consistency between the components. The need to assess capital investment alternatives and make significant business decisions with a limited amount of information has caused many companies to address strategic capital decisions with probabilistic approaches and processes. Management now seeks more information than single-point cost and time estimates can provide. These processes require inputs to be generated from several areas within the company when building mathematical models, and require the development of probabilities for the assumptions in the model that are based upon the uncertainty of each input.

This article discusses techniques for integrating the uncertainties associated with time and monetary resources when using the Monte Carlo simulation tool for risk analysis on capital projects.

INTEGRATED RISK ANALYSIS SOFTWARE FEATURES

Commercially-available schedule risk analysis packages have the capability to integrate the cost and schedule, but to do so requires that the schedule is fully resource loaded. These features provide meaningful and very useful results when the level of project definition allows for a class 2 or class 1 estimate (see figure 1). In fact, estimating software packages that perform detailed activity-based costing estimates have the capability to move the resources over to the schedule. With a fully resource-loaded schedule, the integration of cost and schedule risk analysis using existing Monte Carlo software is possible. Integrating cost and schedule simulations is useful for tracking the project and monitoring contingency.

However, strategic capital investment decisions are usually made much earlier in the development sequence, with a much lower level of project definition. Therefore, for the majority of projects, the Monte Carlo risk analysis that is used to estimate contingency for both cost and schedule will be based on much less project definition than is available to integrate the cost and schedule into a fully resource-loaded simulation model. Our experience has been to run the cost and schedule simulations separately, using different software, and then use other techniques to ensure consistency between the separate analyses.

Software packages that integrate the cost and schedule contain some very powerful features. The inputs (probability distributions) can influence the duration of the activities, the unit rates used to calculate the costs, the amount of resources required to perform the activity, and the lags and logic of the schedule. Software packages offer correlation features that allow two or more activities to be tied together to act congruently, or with negative congruency.

Scheduling simulation software packages do not offer the same flexibility found in cost simulation software packages that use spreadsheets. A single variable is not easily assigned to multiple terms (inputs)—total project labor productivity or construction season effects. Schedule simulation software packages do offer some short cuts, such as applying the same probability distribution to all resources or to all lag factors.

However, identifying specific cost items requires inputting a distribution for each resource that is used for each activity involved. This can lead to a very complex model and may result in few people understanding the inputs. Because of the complexity, analyzing the outputs of a truly integrated cost and schedule simulation becomes a function of the confidence management has in the estimators and schedulers.

	Preliminary Characteristic	Secondary Characteristic			
ESTIMATE CLASS	LEVEL OF PROJECT DEFINITION Expressed as % of complete definition	END USAGE Typical purpose of estimate	METHODOLOGY Typical estimating method	EXPECTED ACCURACY RANGE Typical variation in low and high ranges [a]	PREPARATION EFFORT Typical degree of effort relative to least costs index of 1 (b)
Class 5	0% to 2%	Concept Screening	Capacity Factored, Parametric Models, Judgment, or Analogy	L: -20% to - 50% H: +30% to +100%	1
Class 4	1% to 15%	Study or Feasibility	Equipment Factored or Parametric Models	L: -15% to -30% H: +20% to +50%	2 to 4
Class 3	10% to 40%	Budget, Authorization, or Control	Semi-Detailed Unit Costs with Assembly Level Line Items	L: -10% to -20% H: +10% to +30%	3 to 10
Class 2	30% to 70%	Control or Bid / Tender	Detailed Unit Cost with Forced Detailed Take-off	L: -5% to -15% H +5% to +20%	4 to 20
Class 1	50% to 100%	Check Estimate or Bid / Tender	Detailed Unit Cost with Detailed Take-Off	L: -3% to -10% H: +3% to +15%	5 to 100

[a] The state of process technology and availability of applicable reference cost data affect the range markedly.
The +/- value represents typical percentage variation of actual costs from the cost estimate after application contingency (typically at a 50 percent level of confidence) for given scope.
[b] If the range index value of 1 represents 0.005 percent of project costs, then an index value of 100 represents 0.5 percent. Estimate preparation efforts are highly dependent upon the size of the project and the quality of estimating data tools.

Figure 1—Cost Estimate Classification for the Process Industries [1]

THE QUALITY OF COST AND SCHEDULE MODELS

AACE International has published a *Recommended Practice No. 18R-97, Cost Estimate Classification System—As Applied in Engineering, Procurement, and Construction for the Process Industries* [1], which establishes the expected accuracy ranges for five estimate classes (see figure 1). The recommended practice does not mention Monte Carlo simulation, although it is a particularly useful technique for determining contingency. It also can be used to validate that an estimate's quality, as measured by the accuracy range, meets expectations that are based upon the level of project definition. The same technique should be used for schedules. For each estimate class, both the estimate and schedule are, or should be, developed with the same level of project definition, purpose, and preparation effort. Therefore, the expected accuracy range for the schedule and estimate should at least be similar, if not identical.

A graphic view of the typical project sequence of activities required to prepare estimates for different end uses is shown in figure 2. This sequence demonstrates the way one oil company makes important capital investment decisions, and how it segmented the execution process by specific activities into a series of phases. This company requires every large capital investment to go through three phases before the final investment decision is made. In order to complete a given phase, certain predefined activities must be complete to achieve a specific quality level (expected accuracy range). The quality of the estimates produced throughout the project sequence is checked for concurrence to the expected accuracy range using the Monte Carlo risk analysis technique.

For this particular company, the screening phase was done in-house, and all of the work was expensed. Once the screening phase estimate and schedule products achieve the required accuracy range, an analysis should be performed to determine if the investment passed the corporate investment criteria. If so, the next phase is funded. An independent engineering company usually is hired to perform the activities of the next (conceptual) phase. As more activities are accomplished during the conceptual phase, the level of risk is reduced and the quality of the conceptual phase estimate and schedule improves (as illustrated in figure 2 by the current estimate range below the logic-linked activities).

The second decision point for the capital investment determination occurs at the conclusion of the conceptual phase. Note that at this point the risk has been significantly reduced (expected accuracy range) while the company has only invested between 1 and 5 percent of the total project cost (if the estimate and schedule products have achieved the required accuracy range). If approved, the next (preliminary) phase is funded and additional activities are accomplished that ultimately further increase the quality of the estimate and schedule products produced at the conclusion of the preliminary phase.

The third decision point for a capital investment decision occurs at the conclusion of the preliminary phase. This point roughly corresponds with a class 3 level of project definition that is not sufficient to provide the required data for an integrated cost and schedule simulation.

The process continues through subsequent phases (design and construction), with more work (accomplished activities) increasing the quality of the cost and schedule products. At this point, however, the level of project definition has increased sufficiently to provide the required data and accuracy necessary to develop and run an integrated cost and schedule simulation (class 2 and 1).

THE SEQUENCE OF BUILDING RISK ANALYSIS MODELS

The development of the cost and schedule simulation models should begin very early in each phase, with inputs from essential subject matter experts. Each subsequent simulation model should use the basic elements from the previous phase's model to determine and refine the significant terms in the new model. During the development or enhancement of the simulation models, experts can provide increasingly accurate input. The skeleton for the models should be developed before the team is asked to work together to develop/enhance the inputs and probability distributions. Schedulers should seek inputs for the models about the sequence of work and the schedule for completing the deliverables, while estimators should get team inputs for the models on ranges,

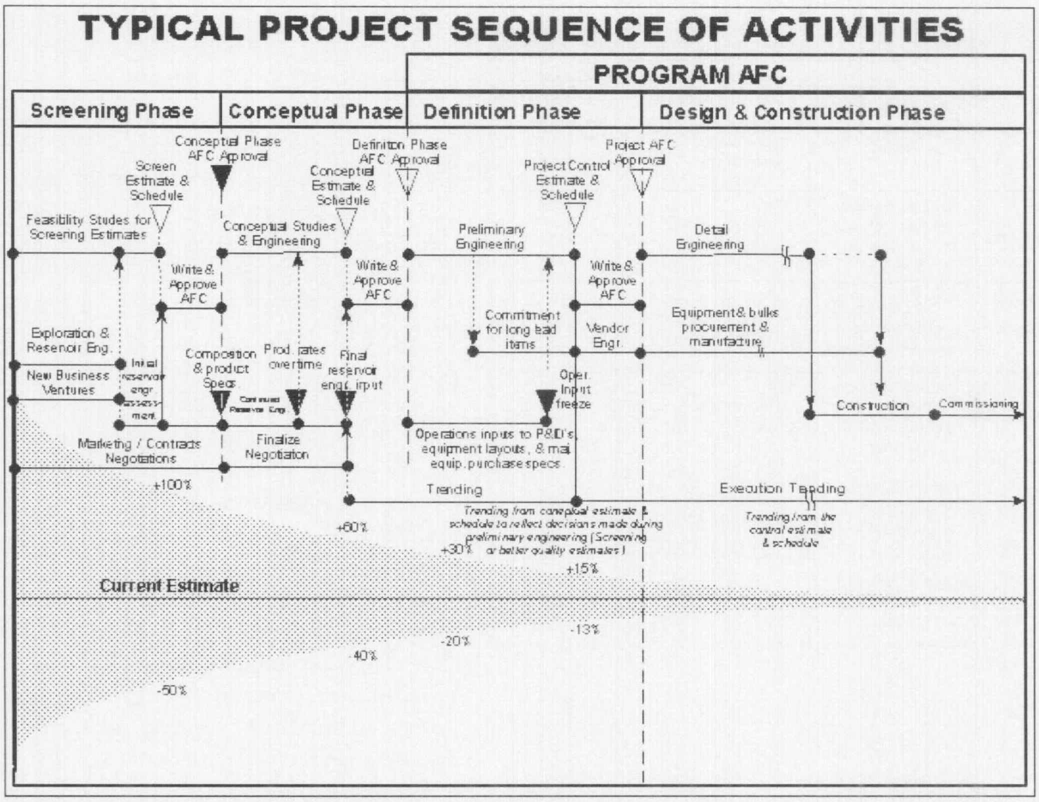

Figure 2—Typical Project Sequence of Activities

terms, and variables that pertain to the various required resources.

The development of range estimates early in the process, during each phase, avoids a common problem of human nature known as anchoring. Anchoring, as defined here, is the tendency for people to attribute more confidence in a result, after they have put effort into developing that result, than they would have if they had not participated in its development. For example, to produce a class 3 estimate it may be necessary for structural drawings to be 60 percent complete. Using the team approach, the structural engineers are asked to provide an 80 percent confidence interval range (expressed in percentages) for the estimated quantities of structural steel required. Their assessment of the range of values for structural steel material take-off (MTO) volumes made prior to their actual take-off of the material will be different (usually wider) than their assessment of the range of values for these same materials after they have completed the MTO, even though the drawings are still only 60 percent complete.

Our experience indicates that the range of values given before the work is started provides a more accurate subjective estimate of the expected final quantity than a range provided after, or in the middle of, the work. Variables and logic that affect both time and quantities should be analyzed for their potential effects on both the schedule and estimate, and input into the models appropriately.

The deterministic (for classes 3, 4, and 5) estimate and schedule products are prepared and completed near the end of each phase. As additional work (activities) is accomplished during each phase, the resulting schedule and estimate product quality should be higher. The structure of the models should capture this characteristic. The analysis of the simulation results for the estimate and schedule occurs during the review meeting(s) near the end of each phase. At this time, all of the team members who participated in the preparation of the schedule and estimate products are asked to assess whether they achieved their anticipated level of completion of their inputs, compared to where they planned to be when they attended the first meeting. Based on the participants' responses, the ranges to both the cost and schedule simulation models are adjusted accordingly. The simulations are then rerun and are ready for final analysis.

ANALYSIS OF THE RESULTS

Prior to integrating and presenting the results of the cost and schedule simulation, the results must be thoroughly analyzed from the perspective that the simulations must be consistent. If the sensitivities of the cost simulation indicate that the volume of a specific category of work (say piping) is influencing the results significantly, the schedule results also should indicate that this is the case. Likewise, accelerated equipment delivery durations and the acceleration cost assumptions should be consistent between the two models. For example, the cost of rework should be included in the cost model if the schedule logic has acceptance rework logic built into the model.

The most obvious need is to ensure that the two simulation models react in the same manner and to the same degree in the area of time-dependent overhead. The two models need to be re-run a few times to make certain like items are consistent and react sensibly to the other. This iterative process is time consuming and often difficult, especially when there is an urgency to present the estimate and schedule results to justify approval for the next phase of a project. Time for a thorough contingency analysis, which is an important result of the simulation methodology, needs to be planned into the preparation process. Do not underestimate the time required to develop a thorough and accurate product. Time should be made available during the estimate and schedule review meeting(s) to develop the range for the contingency draw-down schedules (cost and schedule) for the detail engineering and construction phases.

A major advantage of integrating the cost and schedule simulation is the graphic depiction of the interrelationships between the cost and schedule components (see figure 3). Separate illustrations of the cost and schedule simulations do not convey the interrelationships nearly as well, and this type of graphic presentation is not available for nonintegrated simulations.

When it is not possible to integrate the cost and schedule simulations, the separate cost and schedule simulations should be presented simultaneously. The implica-

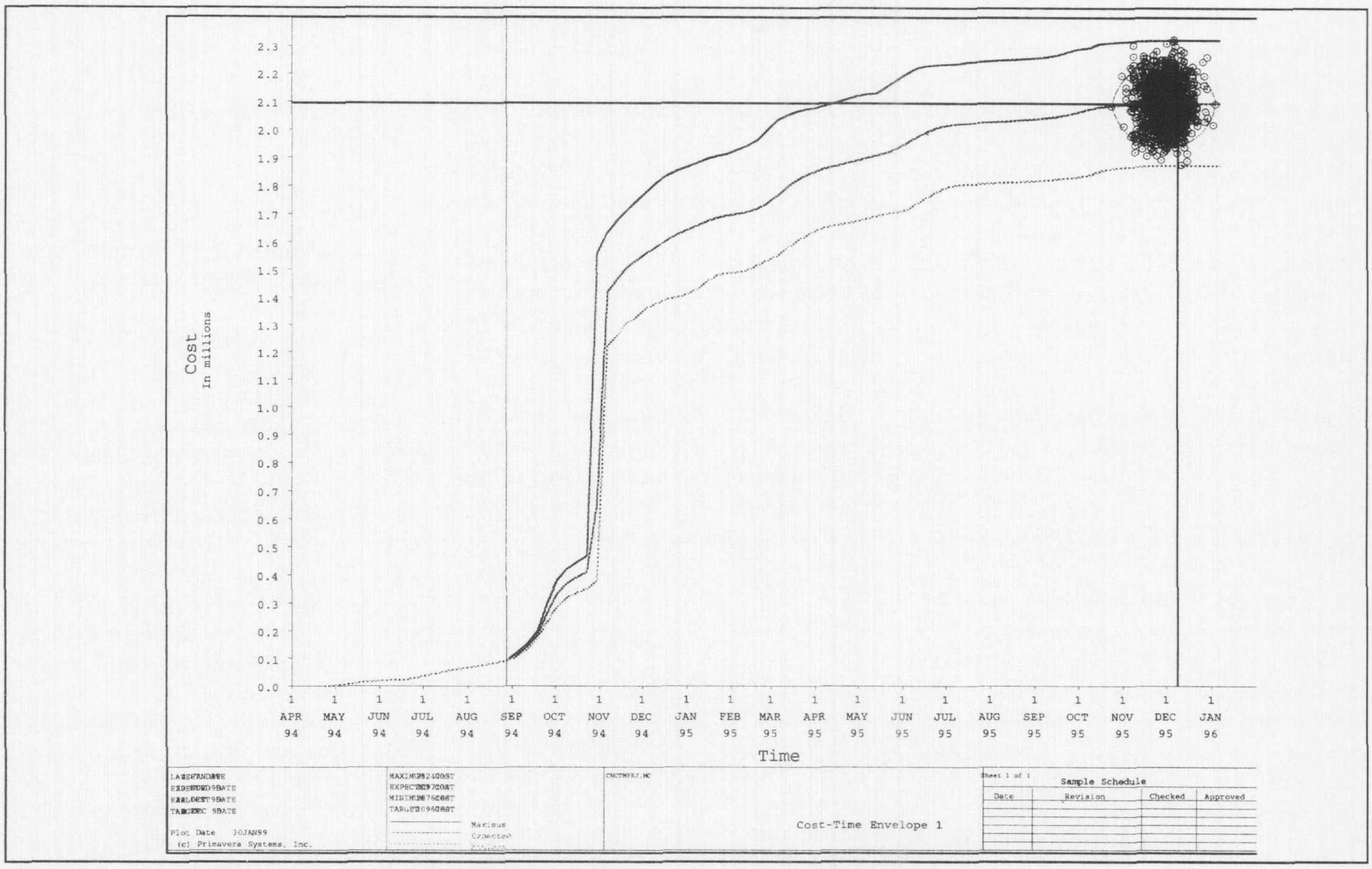

Figure 3—Results of an Integrated Cost and Schedule Risk Analysis Presented Graphically

tion is that contingency should be managed in a similar manner for both cost and schedule. Every company manages cost contingency differently, and very few apply the same methodology to schedule contingency. A preferred method is to distribute the overall cost contingency using the sensitivity analysis as a guide, and include contingency as part of the expected costs for each component in the work breakdown structure (WBS).

Another preferred method is to use Monte Carlo simulation to establish a cost contingency draw-down procedure. This establishes a maximum draw-down schedule. If a company's established methodology would cause contingency to be drawn down at a substantially different rate, the final draw-down plan would have to reconcile the differences. Similarly, the overall schedule contingency should be allocated to the deterministic schedule activities (or group of activities consistent with the components of the WBS). This can be accomplished as a buffer period near the end of each grouping that was defined by the project WBS. In a manner similar to a cost draw-down schedule, the schedule buffer is reduced by periodically running the simulation as the project is executed. Another method of allocating overall schedule contingency to the deterministic schedule, which is more rigorous and provides a better execution schedule, is to adjust the schedule duration of each principal activity, on each major critical path, based on the sensitivity analysis and/or based on an analysis of each activity's duration variance.

CONTINGENCY AND CONFIDENCE INTERVALS

The results of Monte Carlo simulations can and should be used to calculate contingencies (cost and time) for a project. Many companies have policies for assigning contingency based upon guidelines that provide for an equal opportunity of overrunning or underrunning a project. This is done by assigning contingency to bring the estimate/schedule to the median (50/50) value. Some companies with many capital projects may prefer to use the mean value instead of the median value of the simulation distribution.

In addition, the 80 percent confidence interval is used by many companies as the overrun or underrun limit provided to the project team before additional resources and/or time are requested from the company's management. The range between the 10 percent and 90 percent points on the cumulative probability distribution (separately or on an integrated basis) is presented in funding documents. For example, on an integrated basis, this can be ascertained from figure 3. The 80 percent confidence interval in figure 3 is the outline of the shape (cost/time, or risk, envelope), which resembles a football (albeit a fat football in this case), around the majority of plotted cost/time pair outcomes (small circles). From the graph, the expected cost is between \$1.95 million and \$2.25 million. The expected completion date is between late October 1995 and early January 1996. The expected cost is \$2.1 million, and the expected completion date is December 1, 1995.

The planning or financial departments that are assigned with evaluating the profitability of each capital investment should evaluate the project using the high end of the cost and schedule range. If the project does not clear the economic hurdles at the high end of the cost and schedule range, additional analysis may be required. Management may need to re-evaluate the results and determine what steps are required. Either the estimate may need to improve (lowering the upper limit on the confidence interval) and/or the schedule may need to improve (lowering the upper limit on the confidence interval). An analysis of the sensitivities of the inputs will help with this analysis.

SENSITIVITIES OF INPUTS

Cost risk simulation tools provide good analysis on the sensitivities of the variables used in the simulation. Graphic illustrations that show the variables with the greatest effect on the results are not available for schedule risk simulations. Generally, the scheduling software reports only the number of times a specific activity is on the critical path (criticality index).

The schedule simulation analysis therefore needs to be run multiple times to determine what happened to the results as important activity durations are changed. The input ranges for an activity on the critical path, or near the critical path, are changed for each iteration. The results are recorded, and the process is repeated for the next activity. The results are presented as a Pareto chart or torpedo chart (like the cost software presentation of sensitivity), or by similar methods, to communicate which activities have the most influence on the schedule completion.

When the level of project definition is sufficient, the integration of schedule and cost Monte Carlo simulations is possible and very desirable. The software currently available supports this inclusive approach. However, integration is best suited for a class 2 or class 1 level of project definition that allows resources to be estimated with sufficient detail and accuracy, to be identified with specific activities, and to be loaded into the schedule. For estimate and schedule products prepared in the early project development phases, the simulations should be performed using different software, and the cost and schedule simulation results should be correlated by a series of multiple simulation iterations. After running multiple iterations of the simulations, the inputs to the separate cost and schedule models should be adjusted accordingly until the results are consistent. Time-dependent estimate variables must be consistent with the schedule; material volumes and productivity variables in the estimate must be reflected accurately in the schedule simulation.

Thus, time and monetary concerns are always going to contain some elements of risk—the techniques described in this article will help you to make more educated decisions about these risks.

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