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CHIMNEY HOLLOW RESERVOIR CONSTRUCTION RISK MANAGEMENT

BOOK REVIEW: CREDIBILITY CRISIS— BRUMADINHO AND THE POLITICS OF MINING INDUSTRY REFORM

USSD VIRTUAL CONFERENCE RECAP

CHIMNEY HOLLOW RESERVOIR
CONSTRUCTION RISK MANAGEMENT

Figure 1. Chimney Hollow Reservoir Rendering.
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The risks inherent in dam construction necessitate risk management for effective control of project costs and schedule. Now an industry standard, risk management has long been used on large construction projects with susceptibility to differing site conditions or for projects with long, linear critical-path schedules. Construction risk management is broadly recognized by the dam community as an important practice that aims to identify, evaluate, control, and monitor risks. Risk management also protects the reputations of organizations and projects and keeps project teams focused on achieving the objectives of all project stakeholders – owners, engineers, contractors, regulatory agencies, and the public. These acknowledged benefits notwithstanding, construction risk management is inconsistently used to address project risks related to the design and construction of dams. The slow adoption and advancement of risk management methods by the dam community is unfortunate given the recognized complexity in planning, designing, and building dams and reservoirs.

This article shares experiences with construction risk management and risk informed contingency budget allocation for new dam construction. The example and lessons presented are for Chimney Hollow Reservoir, which features a new hydraulic asphalt concrete (HAC) core rockfill dam. The dam type is relatively new in the United States, warranting special attention on construction risk and its potential to affect project cost. The risk management process undertaken by the project owner, construction management team, engineer, and contractor followed simple and robust guidelines focused on risk identification, evaluation, and control. As an extension of the risk management process, the engineer and construction manager independently computed cost-risk to inform contingency budget allocation. The engineer used cost driver, experience-based contingency approximations. The construction manager's cost-risk estimation involved developing model parameters and probabilistic modeling using *binomial simulation* and *expected monetary value* (EMV) methods. Owner and contractor perspectives on risk management and contingency budget allocation for a large dam construction project accompany the objective risk assessment.

CHIMNEY HOLLOW RESERVOIR PROJECT

The Northern Colorado Water Conservancy District's Municipal Subdistrict is executing the Windy Gap Firming Project (WGFP), or Chimney Hollow Reservoir, under a government-owned business known as the Windy Gap Firming Project Water Activity Enterprise (Enterprise). WGFP is a collaboration between 12 Front Range water and power providers to improve the reliability of water supplies from the Windy Gap Project, which started delivering water in 1985 and is operated by the Municipal Subdistrict. Chimney Hollow Reservoir is a proposed 90,000 acre-foot water supply reservoir occupying the valley west of Carter Lake near Loveland, Colorado. The reservoir provides storage for water diverted from the Colorado River during wet years, thereby increasing yield and improving the reliability of water delivery to participating water providers. The project will provide up to 30,000 acre-feet of firm yield to the project participants. Stantec is the design engineer, Black & Veatch is the construction manager, and Barnard Construction is the general contractor.

Chimney Hollow Reservoir features a 355-foot tall HAC core rockfill dam. At completion, the dam will be the second and the tallest HAC core rockfill dam in the United States. As depicted in Figure 1, the project also includes a 40-foot tall, 1,000-foot long zoned embankment saddle dam, concrete chute spillway at the left abutment, 1,700-foot long combined inlet/outlet conduit in a tunnel below the right abutment, and miscellaneous appurtenances related to the project interconnections to U.S. Department of the Interior, Bureau of Reclamation (Reclamation) facilities. The commercial value of the Chimney Hollow Reservoir construction project is approximately $485 million (M).

CONSTRUCTION RISK MANAGEMENT

As Chimney Hollow Reservoir approached its construction phase, risk informed decision-making and constructability reviews undertaken by the engineer as part of the design phase transitioned to the construction risk management process established by the construction manager. The construction risk management plan for Chimney Hollow Reservoir defines the process for proactively identifying, evaluating, controlling, monitoring, and reporting risks from completion of final design through construction and startup. Figure 2 illustrates the fundamental process employed for risk management. For risks that cannot be assuredly mitigated, the plan provides a method for understanding the potential cost and schedule consequences, such that a defensible basis for construction contingencies can be developed. This risk management plan primarily addresses construction and startup risks but also considers programmatic risks internal to the Enterprise. To maintain its effectiveness and relevance, risk management is a continuous practice involving all project team organizations. The risk review team meets periodically to identify new risks and to update previously identified risks.

The Chimney Hollow Reservoir risk register was developed within a database platform to document construction risks and the implementation of the risk management process. To effectively compare risks as they relate to project impact, the risk register incorporates a simplified risk evaluation to quantify the risks. Risk quantification is the process of estimating the probability of an event occurring and the magnitude of the consequence associated with its occurrence. In the risk register, all risks are assigned a risk probability score, a cost consequence score, and a schedule consequence score.

The risk probability score, related to the probability of occurrence, is selected for each identified risk using the scale presented in Table 1. Cost and schedule consequence scores for each risk are selected using the scales presented in Table 2. Cost and schedule consequences are scaled relative to the estimated commercial value and schedule drivers of the project.

On the basis of risk scores, a prioritized list of risks are maintained, for which response plans are subsequently developed and implemented. Typical pre-NTP action items to mitigate risks included supplemental geotechnical investigations, review and modification of the design details, environmental studies, or implementation of a best value procurement method to provide a mechanism for selecting

Figure 2. Generalized Risk Management Process. COPYRIGHT CREDIT: UNITED STATES SOCIETY ON DAMS

Risk Probability Score	Probability of Occurrence
1 – Rare	Less than 5%
2 – Unlikely	5% to 20%
3 – Possible	20% to 40%
4 – Likely	40% to 60%
5 – Frequent	Greater than 60%

Table 1. Risk Probability Score Definition.

Risk Consequence Score	Approx. Cost Consequence	Approx. Schedule Consequence
5 – Severe	Greater than $15M	Greater than 320 days
4 – Serious	$8M to $15M	190 to 320 days
3 – Significant	$4M to $8M	90 to 190 days
2 – Moderate	$2M to $4M	25 to 90 days
1 – Low	Less than $2M	Less than 25 days

Table 2. Consequence Score Definitions.

a technically proficient and quality-focused contractor aligning with the project goals.

PROBABILISTIC COST-RISK ANALYSIS METHODS

The Enterprise and construction manager extended the risk management process to include establishing and managing a *risk informed* contingency budget for funding construction. The monetized risk was developed by quantifying the cost consequences of identified risks. Probabilistic methods incorporated parameter uncertainties and variability into a model, such that the outcome of the probabilistic analysis was an estimate distribution rather than a single-point estimate. The analysis indicates a wider range of potential cost growth, and it further allows for contingency budget selection with corresponding confidence (i.e., probability of non-exceedance).

For each method, risk probability and cost consequence scores are represented by probability distribution functions established in general accordance with Association of Advancement of Cost Engineering International (AACEI) (2012b). The distribution functions are subjectively selected and bounded by rational limits, such as 0 and 100 percent probabilities of occurrence and non-negative cost consequences. The distribution function types and parameters represent "standard" ranges for risk probability and cost consequence, making this approach straightforward and easy to implement. Additional details around the probabilistic analysis methods are provided in Thompson et al. (2020).

Binomial Simulation

The probabilistic model parameters representing risk probability and cost consequence scores were inputs for Monte Carlo simulations of construction costs above the bid award amount. In this first analysis approach, each simulation involved many iterations for which the probability of occurrence and cost consequence were sampled from the assigned distribution functions using the Latin Hypercube statistical sampling method. Each iteration of this model represents a separate instance of project construction in which some risk events occur, and others do not, with variable cost consequences per the assigned probability and consequence distributions. The occurrence of each risk is computed as a Bernoulli trial (i.e., a single success/failure experiment with a risk probability equal to the sampled risk probability). The statistical feature is also called a binomial trial. Individual risk occurrence/non-occurrence is computed with the binomial discrete probability function with parameters $n = 1$ (one trial) and p = the sampled probability of occurrence. The cost-risk for a particular risk was computed as the product of the cost consequence and the binomial function output. The overall cost-risk was the sum of cost-risk values for each risk. Simulation results – tabulated values of computed cost-risk from 100,000 iterations – indicated the cumulative distribution function of cost-risk. The results also indicate those parameters which contribute most significantly to overall cost-risk.

Expected Monetary Value

Contingency determination using EMV is a standard practice in project management (see AACEI, 2012a and 2012c). Monte Carlo simulations of an EMV model of construction risks were performed to develop a distribution of the mean value reflecting the uncertainties in assigned risk probabilities and consequences. The monetized value of project cost-risk, or expected value, is computed by summing the products of probability of occurrence and cost consequence for each individual risk. The overall mean EMV is obtained when mean probabilities of occurrence and cost consequence are assigned to each of the risks. EMV distribution represents the uncertainty in the mean value. However, this EMV model does not capture the full range of potential outcomes.

Integrated Sensitivity Analysis

During the design phase, risk scoring was performed using expert elicitation, wherein project team members from owner, construction manager, and engineer organizations, as well as independent consultants, developed consensus scoring based on experience and project understanding. To investigate the effect of alternate scoring on overall project cost-risk, the contingency calculation included a sensitivity analysis. The goal of this analysis was to capture the potential effect of scoring uncertainty on the evaluation of cost-risk.

Rather than conducting the sensitivity analysis with certain top-ranked risks having scores different than the assigned score, the sensitivity analysis used an approach that recognized some uncertainty in all risk scoring. This approach was important given total number of risks identified and the cumulative effect of uncertainty on a large number of risks. The risk probability scores and cost consequence scores were treated as uncertain parameters. Based on the assigned scores for each risk, the risk probability score and cost consequence score were simulated in accordance with the matrix in Table 3. The scoring simulation was implemented through a discrete distribution function that varies with the assigned score and the corresponding set of discrete distribution probabilities. The EMV and binomial simulation cost models were then performed using the simulated scoring.

The obvious effect of this scoring simulation approach was to broaden the range probability and consequence scores, thus producing a wider distribution of overall cost-risk. Once the contractor provided input on cost consequences, the cost-risk estimations using integrated sensitivity analysis were considered less important.

Assigned Score	Simulated Score Probability						Total
	0	1	2	3	4	5	
1	0.25	0.50	0.20	0.05	0.00	0.00	1.00
2	0.05	0.20	0.50	0.20	0.05	0.00	1.00
3	0.00	0.05	0.20	0.50	0.20	0.05	1.00
4	0.00	0.00	0.05	0.20	0.50	0.25	1.00
5	0.00	0.00	0.00	0.10	0.30	0.60	1.00

Table 3. Scoring Simulation Discrete Distribution Probabilities.

COST-RISK RESULTS AND DISCUSSION

The initial distribution of overall construction cost-risk with original risk scoring is shown in Figure 3. For binomial simulation, the mean value is about \$46M. Minimum and maximum values are \$7.6M and \$128.1M. Monetary values corresponding to various percentiles can be obtained from the cumulative probability density function. For example, 5th and 95th percentiles are \$26.5M and \$68.3M.

EMV distribution is also shown in Figure 3. The mean value is essentially the same as the mean value from the binomial simulation cost distribution. However, the EMV distribution is much narrower than the other cost distribution. Probabilistic EMV analysis using input parameter variability is an estimate of the mean value of cost-risk, inclusive of parameter uncertainty. However, the method does not capture the full range of cost-risk possibly incurred over the course of project construction. Therefore, EMV was calculated but not used to establish or to communicate risk informed contingency budgets.

The cost-risk distribution using the integrated sensitivity analysis of risk probability and cost consequence scoring is shown in Figure 4. The general trend of this scoring sensitivity simulation is for the cost-risk distribution variance and mean value to increase. This observation is predominantly attributed to the pseudo-logarithmic definition of cost consequence score ranges. Whereas the simulated score probability (see Table 3) is roughly normal about the assigned score, the effect of a higher cost consequence score (producing higher cost-risk) is much more significant than a lower cost consequence score (producing lower cost-risk). When accumulated over many iterations, the effect of the higher cost

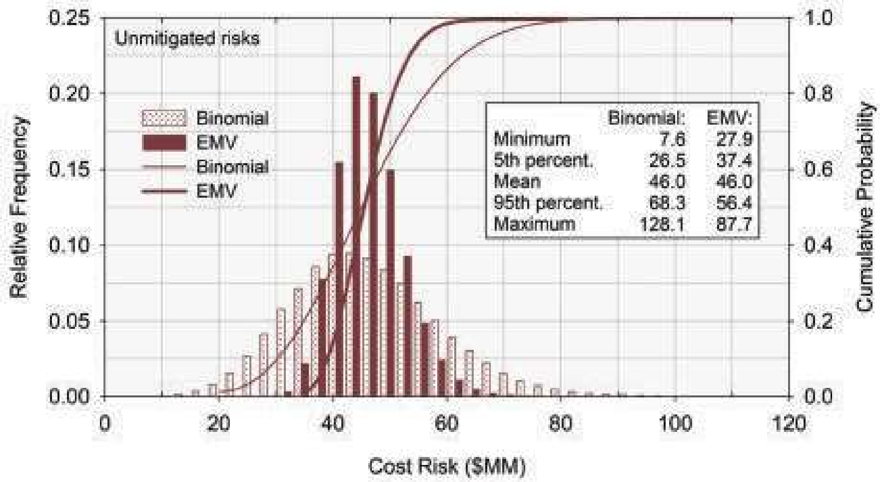

Figure 3. Comparison of Binomial Simulation and Expected Monetary Value for Unmitigated Risks.

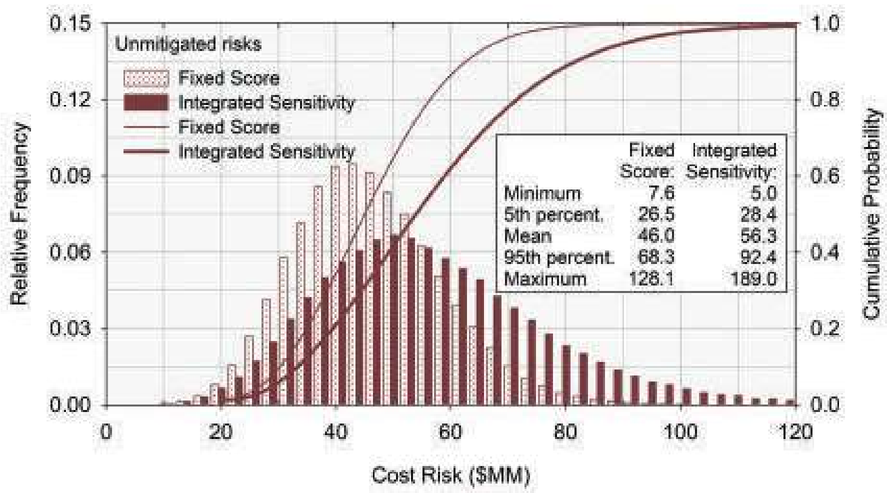

Figure 4. Effect of Integrated Sensitivity Analysis with Binomial Simulation on Unmitigated Risk Monetization.

consequence is a distribution noticeably higher than without the integrated sensitivity analysis.

PRACTICAL USE OF RISK MANAGEMENT AND COST-RISK ESTIMATES

Owner's Use and Perspective

Throughout the planning and preliminary design phases of the project, the Enterprise carried contingencies within the project budget aligning with AACEI contingency percentages for the estimate class. During final design, the contingency was also evaluated as part of the engineer's estimate by identifying the major project cost drivers and applying an experience-based cost variance, or contingency, to each. The engineer considered the top 32 cost drivers (bid items) – those items having a value greater than $2M – and assigned discrete contingency values (ranging from 2 to 30 percent) and then selected a blanket 5 percent contingency for the remaining (i.e., non-cost driver) 233 bid items. Cost drivers accounted for 80 percent of the contingency value. The overall contingency estimate was 11 percent.

The cost-risk distribution based on the risk register was first estimated prior to finalizing the design. The mean value was approximately 12 percent of the construction value ($56.3M on $485M). The two independent methods provided contingencies within 1 percent. As with the engineer's approach, the probabilistic analysis provided further insight into specific risks that were driving the contingency budget. Discussion on key risks also made clearer the timing of potential risks and how such cost-growth could be handled administratively. The Enterprise, engineer, and construction manager executed an action plan to mitigate construction risks to the extent practical. By the bid phase, the cost risk had been reduced to a mean of approximately 8 percent of the construction value ($37.2M on $485M), demonstrating significant post-award risk reduction. The Enterprise ultimately elected to budget 10 percent contingency for the construction project with greater confidence in the established program budget.

Contractor's Use and Perspective

The general contractor joined the risk management process following an administrative notice to proceed (ANTP). The initial benefit to the contractor was the open and transparent communication about risk afforded by the process. As with the formal partnering by the project team, each team member organization was able to identify and convey the vulnerabilities and concerns it considered most significant. In some instances, concerns were alleviated by improved understanding of the issue and of the approach to the work, as expressed by the diverse risk review team. The shared concern over other risks naturally produced a list of key risks. Detailed mitigation plans and action items for these significant risks were developed collaboratively and assigned to responsible individuals, providing some assurance that the project team would work together to address construction risk.

Population of the risk register also included discussion about risk ownership. For each risk identified, the risk ownership was assigned to either the owner or the contractor; few risks were presumed to be shared. For many identified risk outcomes, the risk was duplicated and assigned to the owner and to the contractor with differentiation around the risk cause. For example, instability of the steep right abutment due to a differing site condition was assigned to the owner, whereas abutment instability caused by means and methods implemented to achieve the foundation criteria was assigned to the contractor. This exercise set clear expectations around responsibilities and risk ownership, such that a team member organization is always well informed about its own risk profile.

Construction-Phase Monitoring

Risk management activities and periodic cost-risk updates are continuing through construction. The risk review team expects significant updates to risk probability values (higher or lower) based on observed site and subsurface conditions, and more modest updates to consequence scores. The overall cost-risk update early in construction, when initiating conditions may first be encountered, will bring about lower variation and greater certainty in the assessed monetary value, regardless of how the value compares to the preconstruction estimate. Trends in cost-risk estimates over the four-year construction period, evaluated alongside other project cost control data, will guide the owner and construction manager in forecasting project cost and making decisions about project funding.

CONCLUSIONS

The benefits of adopting construction risk management and risk informed contingency budget estimation are particularly valuable for large dam and reservoir projects due to inherently uncertain conditions and relatively large cost consequences for changes to construction scope. As demonstrated, simple probabilistic cost-risk analysis methods can be applied to construction risk management to address the limitations of addressing contingency budget allocation based solely on deterministic methods that rely heavily on experience and judgment. The calculations are independent of the project cost model and treat the cost-risk amount as the total of post-award construction cost increases above the construction contract bid award amount. The simplified calculations represent an improved basis for informing the project team on risk and provide a linkage to discrete risks identified by the team. This approach, complemented by other traditional simpler methods, can improve the owner's confidence in making decisions regarding project financing and contingencies. The method also provides an expanded basis for managing risk and contingency throughout project construction.

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FOOTNOTES

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