Risk Planning and Management for the Panama Canal Expansion Program

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Abstract: In April 2006, the Panama Canal Authority formally proposed a major expansion of the canal to increase its capacity and make it more productive, safe, and efficient. This proposal included cost and schedule estimates for completing the expansion and was supported overwhelmingly by the citizens of Panama in an October 2006 public referendum. Given the conceptual level of design at the time of the proposal and the inherent uncertainty in a project of this magnitude at the early stages of engineering, a comprehensive risk analysis was performed to develop a contingency model for the total expansion program cost and schedule. This contingency model is based on a Monte Carlo simulation of the cost and schedule estimates, taking into account the most significant risks identified for the project. The resulting model provides contingency assessments for duration and total cost and sensitivity analysis of the risks; it also allows for multiple scenario planning and ultimately supports overall risk management. This paper presents a project case study that focuses on the contingency model development and the resulting risk management and contingency resolution processes. **DOI:** 10.1061/(ASCE)CO.1943-7862.0000317.

CE Database subject headings: Construction costs; Risk management; Uncertainty principles; Panama Canal; Scheduling.

Author keywords: Construction costs; Cost estimates; Risk analysis; Uncertainty analysis; Risk management; Canals; Scheduling.

Introduction

One full century after its initial opening, the Panama Canal will celebrate a major expansion that approximately doubles its capacity and ensures greater efficiency and safety. The 1914 original completion of the Panama Canal is considered by many as one of the greatest civil engineering and construction achievements of modern times. Logistics management tools and information management technologies have appreciably improved canal operations and throughput since its opening. The physical configuration of the canal, however, has remained basically unchanged. Thus, the combination of high use rates and lock dimension limits that will not accommodate post-Panamax vessels has caused the canal to approach its full capacity (see Fig. 1). The expected, continued growth in global market demand has led the Panama Canal Authority to prepare a formal proposal for expansion via a third, larger lane at an estimated cost of $5.25 billion and a completion date of 2015. The Third-Lane Locks and Access Channel Expansion Program (Canal Expansion Program) was formally approved by the citizens of Panama in an October 2006 public referendum and is currently under way.

This paper offers a case study of the cost and duration contingency model developed for the Canal Expansion Program; these contingencies were especially important components of the proposal and referendum processes. A project description is provided to present the scale and complexities of the project. The Panama Canal Authority's approach to comprehensive risk management is outlined prior to the presentation of the contingency model itself. The case study concludes with a discussion of model results interpretation and model use in decision making, as well as the ongoing management of contingencies.

Canal Expansion Description

The Canal Expansion Program is expanding the canal's capacity in three integrated components: (1) the construction of two new lock facilities—one on the Atlantic side and another on the Pacific side—each with three chambers and three water reutilization basins; (2) the excavation of new access channels to these new locks and the widening of existing navigational channels; and (3) the deepening of the navigation channels and the elevation of Gatun Lake's maximum operating level (ACP 2006).

The Panama Canal was built to span from the Atlantic Ocean to the Pacific Ocean through the center of Panama by excavating channels and building locks to create Gatun Lake at 26.7 m (87 ft) above sea level. Vessels pass through the channels and are raised through three-step locks that lift them to the lake and back down to sea level (see Fig. 2). Since its inception, the canal has operated with two lock lanes on each end of the canal. The Canal Expansion Program is adding a third lane and locks at each end of the canal. Each of the three lock chambers will have three lateral water reutilization basins, for nine basins per lock and 18 basins in total (see Fig. 3). By alternating the direction of the

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Note. This manuscript was submitted on June 7, 2010; approved on November 1, 2010; published online on November 3, 2010. Discussion period open until March 1, 2012; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Construction Engineering and Management***, Vol. 137, No. 10, October 1, 2011. ©ASCE, ISSN 0733-9364/2011/10-762–771/$25.00.

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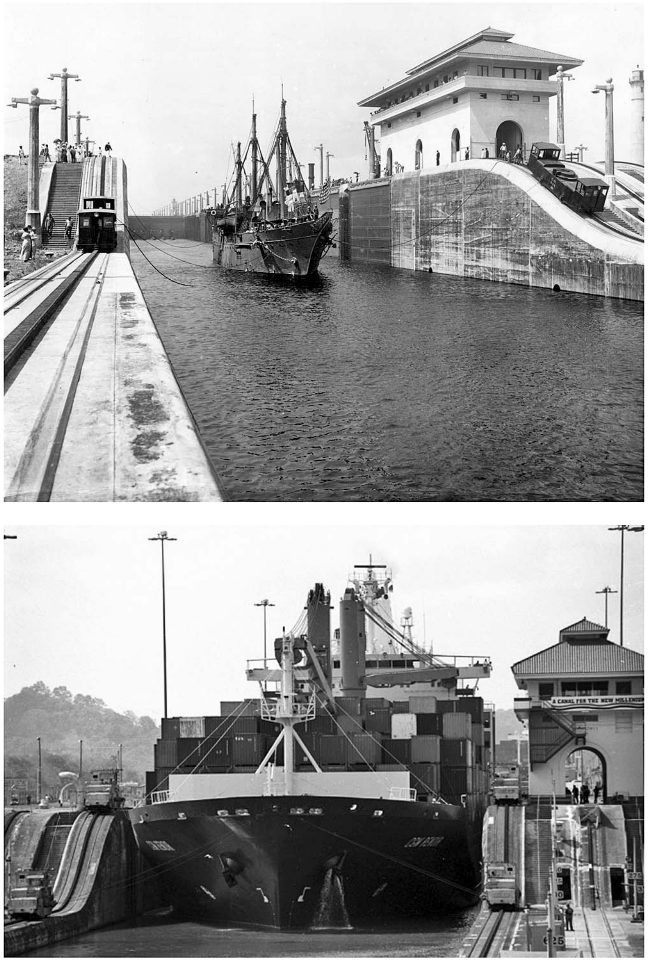

Fig. 1. A century of Panama Canal operations [Reprinted with permission from Autoridad del Canal de Panamá (ACP) 2006]

vessels passing through the locks, the water reutilization basins will help save lake water by reusing it to raise vessels from sea level to lake level. Similar to the original locks, the new locks will be filled and emptied by gravity, without the use of pumps.

One of the new lock facilities will be adjacent to the existing Gatun Locks on the Atlantic side of the canal. The other new lock facility will be adjacent to the Miraflores Locks on the Pacific end. These locks are located to take advantage of the existing excavation of a canal excavation begun in 1939 but suspended in 1942 owing to World War II.

The new lock's chambers will be 427 m (1,400 ft) long, by 55 m (180 ft) wide, and 18.3 m (60 ft) deep (ACP 2006). The existing locks use a hinged miter gate, and the ships are moved though the locks with a cog locomotive. However, Panama Canal Authority studies determined that rolling gates and tug vessels would create a more efficient passage through the new locks. Tugs have proved effective for locks of similar dimensions.

The Canal Expansion Program includes the construction of new navigational channels to connect the new locks with the existing channels. It is also deepening and widening the existing channels. The original canal excavation moved approximately 205 million cubic meters of earth. The expansion is estimated to move approximately 130 million cubic meters. A 3.2-km-long access channel will be excavated in order to connect the new Atlantic-side locks with the existing sea entrance of the canal. To connect the new Pacific-side locks with the existing channels, two new access

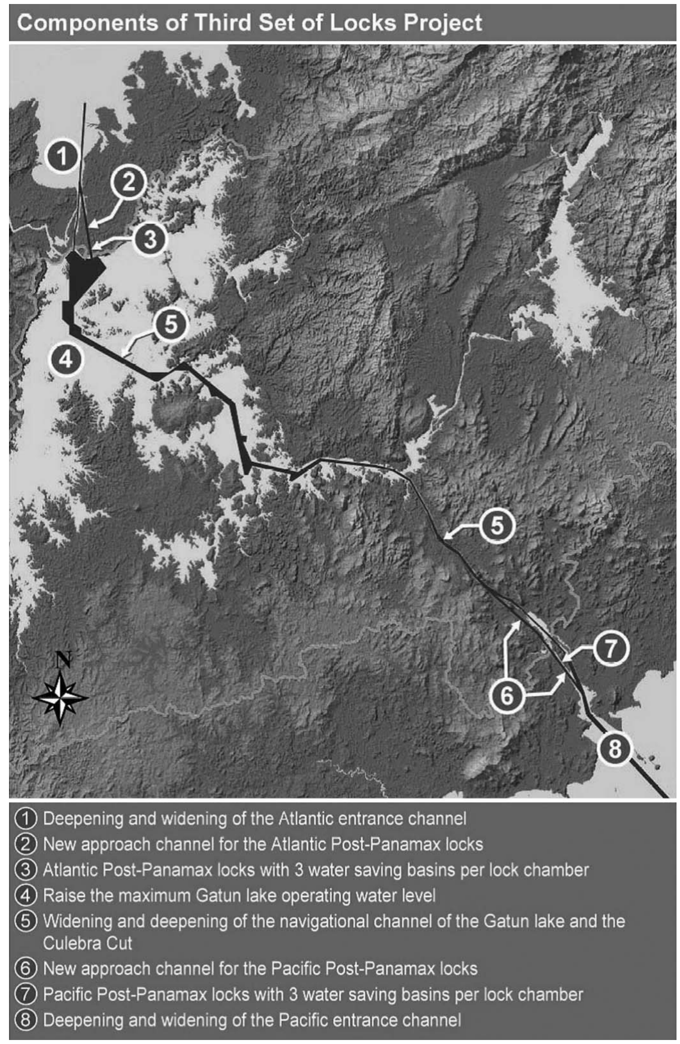

Fig. 2. Panama Canal Expansion Program [Reprinted with permission from Autoridad del Canal de Panamá (ACP) 2006]

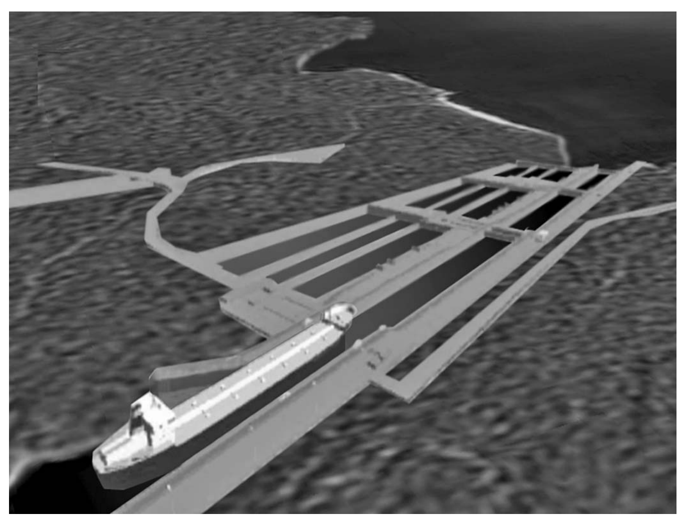

Fig. 3. Third locks design with water-saving basins and rolling gates [Reprinted with permission from Autoridad del Canal de Panamá (ACP) 2006]

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channels will be built: (1) the north access channel, which will connect the new Pacific-side lock with the Gaillard Cut, circumventing Miraflores Lake, and which will be 6.2 km long; and (2) the south access channel, which will connect the new lock with the existing sea entrance on the Pacific Ocean, and which will be 1.8 km long. The new channels will be at least 218 m (715 ft) wide, both on the Atlantic and Pacific sides, which will permit post-Panamax vessels to navigate through these channels in a single direction at any time (ACP 2006).

Additionally, to accommodate post-Panamax vessels, the expansion will deepen the existing channel. The Gaillard Cut and Gatun Lake navigation channels will be deepened by 1.2 m (4 ft). The channel will then be able to accept vessel drafts of up to 15.2 m (50 ft). Gatun Lake's channels will also be widened to no less than 280 m (920 ft) in their straight sections and 366 m (1,200 ft) in the turns. These dimensions will permit post-Panamax encounters or cross navigation in opposite directions in Gatun Lake. Additionally, the canal's sea entrance navigation channels on the Atlantic and Pacific sides will be widened to no less than 225 m (740 ft) and deepened to 15.5 m (51 ft) below the level of the lowest tides. Widening and deepening the canal entrances will allow post-Panamax vessels to navigate these channels and meet vessels of Panamax dimensions (ACP 2006).

A final component of the expansion will raise the maximum operational level of Gatun Lake by approximately 0.45 m (1.5 ft), from the present 26.7 m to 27.1 m (89 ft). Combined with the widening and deepening of the navigational channels, this component will increase Gatun Lake's usable water reserve capacity and will allow the canal's water system to supply a daily average of 625 million liters (165 million gallons) of additional water. This increased water volume is enough to provide an annual average of approximately 1,100 additional lockages without affecting the water supply for human use that is provided from Gatun and Alhajuela lakes (ACP 2006).

Project Schedule and Cost Estimates

The Canal Expansion construction will take between 7 and 8 years. The variability in this estimate is explained in subsequent sections of this paper. The new locks could begin operation between fiscal years 2014 and 2015. The construction plan, which was used as a basis for the cost estimate, includes an appropriate period for commissioning, personnel training, inspections, testing of operations, and commencement of transit operations.

The schedule analysis for this project included preconstruction and construction phases. Preconstruction elements include designs, physical models, specifications, and contracts. The program involves a series of projects and construction contracts. The locks are design-build contracts, while the dry excavation, dredging, and minor contracts are design-bid-build contracts. Dry excavation and the dredging of channels commenced in 2007, subsequent to project approval and before the lock preconstruction phase was completed. The construction phase includes the simultaneous construction of both lock facilities with their water reutilization basins, dry excavation of the new access channels, and dredging of both new lock access channels and Gatun Lake navigational channels, as well as of the sea entrances. Building the locks will take between five and six years. Dry excavation and dredging work will require approximately seven or eight years. The raising of Gatun Lake's maximum operational level will begin 4 years prior to the completion of the program.

The project cost estimate was developed through a detailed estimate of the conceptual design available at the time of the referendum (the "base estimate") and then supplemented with a risk-based contingency for those anticipated items for which no or very little information was available. The project's estimated cost considers potential increases in personnel, equipment, operating supplies, and materials costs in the base estimate. Possible price and quantity fluctuations for key operating supplies and materials, such as cement, steel, aggregates, fuels, and lubricants, among others were accounted for in the contingency model, as explained in subsequent sections of this paper. The design of navigational channels and the pertinent dredging works were compared with international productivity standards and with yields obtained by the Canal Authority for similar dredging works.

The construction cost of the third set of locks was estimated at the time that the cost and schedule model were completed and totaled approximately \$5,250 million. This estimate included design, administrative, construction, testing, environmental mitigation, and commissioning costs. This cost also included contingencies to cover risks and unforeseen events as well as the effect of inflation during the construction period. The complete estimate with associated contingencies and the explanation of the risks and uncertainties upon which the contingencies were based is explained subsequently.

Approach to Avoid Cost Escalation

The Panama Canal Authority was aware of the endemic problem of cost escalation on large infrastructure projects. Historically, large projects have experienced significant cost overruns when costs are compared between early conceptual planning estimates and final costs. A study of 258 infrastructure projects spanning a time period of more than 70 years found that project costs were underestimated in approximately 90% of the projects, and the actual costs averaged 28% higher than estimated on this sample (Flyvbjerg et al. 2002). Additionally, Flyvbjerg, et al. argue that construction cost estimating on major infrastructure projects has not been increasing in accuracy over the past 70 years. New ideas and techniques need to be developed to improve this area where no learning seems to have taken place.

Cost estimating and cost management on large projects is complex. Managing the capital construction of these projects requires the coordination of a multitude of human, organizational, technical, and natural resources. Factors driving cost escalation can include, among others, engineering and construction complexities, schedule changes, scope changes, effects of inflation, unforeseen events, unforeseen conditions, and market conditions (Akinci and Fischer 1998; Arditi et al. 1985; Board on Infrastructure and the Constructed Environment 2003; Booz Allen 1995; Callahan 1998; Chang 2002; Federal Aid 2003; Harbuck 2004; Hufschmidt and Gerin 1970; Mackie and Preston 1998; Merrow 1988; Pickrell 1992; Semple et al. 1994; Touran and Bolster 1994; Transportation Infrastructure 1997; Transportation Infrastructure 1997; Woodrow 2002). Quite often, however, the engineering and construction complexities of such projects are overshadowed by economic, societal, and political challenges. In addition to these challenges, a number of observers have suggested that project estimates have purposely been misrepresented in an effort to secure project approval (Bruzelius et al. 1998; Flyvbjerg et al. 2002; Pickrell 1992).

Being cognizant of these potential cost escalation issues, the Panama Canal Authority sought to develop the most accurate and transparent cost and schedule estimates possible for the Canal Expansion Program. The Authority consulted with numerous international experts to develop the estimate. The accuracy of their estimate is based on three fundamental components of accurate

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scope definition, detailed base estimating techniques, and robust contingency modeling based on detailed risk and uncertainty analysis.

First, the cost and schedule estimates were based on detailed, but conceptual, lock and navigational channels designs. The Canal Authority contracted two separate consulting teams to individually design project concepts. It then evaluated the concepts proposed and configured a standardized design with appropriate elements from each concept. Second, the conceptual design was thoroughly analyzed in terms of construction feasibility to determine the sequence and interdependency of activities and to accurately estimate the requirement for personnel, equipment, operating supplies, energy, administration, and tests and materials, among other considerations. Third, the cost estimate was supplemented with a detailed risk analysis modeling process. The risk analysis was subsequently integrated into the ACP's risk-based management philosophy.

Comprehensive Risk Management

Risk management is the art and science of anticipating and planning for future uncertain events. It is concerned with identifying and analyzing a range of possible outcomes, and then with controlling and mitigating their negative impacts. The objective is to understand and mitigate or control risks. Understanding the risks inherent with each potential project alternative is important to controlling cost and developing estimates that reflect the cost of accepted risks.

The Canal Authority developed its risk management process around industry standard processes used by other agencies around the world that build large projects (Caltrans 2003; Federal Transit Authority 2004; Highways Agency 2001; Molenaar 2005; Molenaar et al. 2006; Project Management Institute 2004a; Project Management Institute 2004b; U.S. Department of Energy 2003; Wideman 1992). The Canal Authority has adopted a comprehensive and continuous project risk management process that includes the following:

- Identification: Pinpoints potential project risks and documents their characteristics. Risk identification is best done in a group setting with representation from all project disciplines.
- Analysis: Involves qualitative and quantitative methods to evaluate each of the identified risks. It includes risk rating and prioritization in which risk events are defined in terms of their probability of occurrence, severity of consequence/impact, risk modeling, and precedence analysis.
- Planning: Develops an organized, comprehensive, and interactive strategy and methods for tracking risk areas and developing risk management plans.
- Implementation: Executes the recommended risk management strategies and follows specific instructions on what should be done, when it should be accomplished, who is responsible, and what are the associated cost and schedule.
- Monitoring: Systematically tracks and evaluates the performance of risk managing actions against established metrics throughout the project and develops further options, as appropriate.
- Control: Performs continuous risk assessments to determine how risks change and assigns adequate resources.
- Documentation and communication: Records, maintains, and reports assessments, handles analysis and plans, and monitors results. It includes all plans and reports for the project management and decision authorities.

Fig. 4 provides a comprehensive overview of the Panama Canal Authority's risk management approach. The process cycle of risk management includes different processes, steps within each process, tasks, and the outputs.

In the context of cost estimating, risk management and an understanding of project uncertainty assisted the Panama Canal Authority in setting an appropriate contingency for the project. It also will assist project management in understanding and controlling contingency as the project progresses through its development. The development of a risk-based contingency value for a baseline project budget estimate is the outcome of a rigorous quantitative risk analysis process. In the broader context of project risk management, and specifically the Panama Canal Authority's risk management approach, risk analysis is the second step in a comprehensive and continuous risk management process (see Fig. 4).

Even with the best design and engineering, capital construction is a complex task that is fraught with risk and uncertainty. Traditional methods of cost estimating and project management often overlook risk and uncertainty or deal with it in an ad hoc manner. Using a formal risk management process that is integrated into the cost estimating and project management process has many advantages. Some of the most frequently cited advantages include the following:

- A better understanding of the project delivery process, including schedule, contact packaging, procedural requirements, and potential obstacles;
- More realistic and transparent estimates of individual project components, which lead to more realistic expectations of total project cost and duration;
- A better understanding of the project contingency requirements and a basis for tracking contingency resolution;
- More accurate information to support other project activities, such as value management and strategic planning; and
- The potential to improve the project budget and scheduling processes.

Risk Model Development

Modeling Approach and Strategy

Early in the expansion program proposal development, the Panama Canal Authority senior management recognized the importance of producing reasonable and reliable cost and schedule estimates. It simultaneously engaged international engineering experts and invested in training for the Authority's engineering staff in estimating methodologies. The resulting schedules and cost estimates were more detailed and refined than one would normally encounter at the level of engineering design completed. Consequently, there was concern that the level of perceived risk and related contingency might be artificially low. As one can see in Fig. 5 (left side), a typical or traditional way to assess contingency is to add factors onto the cost and schedule estimates. These factors are most often percentage-based and reflect inversely the level of estimate detail—more detail, less contingency. The model approach developed here is shown in Fig. 5 (right side). The cost estimate and schedule are integrated and combined with risk factors to create the risk model.

Risk Identification and Selection of Critical Risks

The crucial first step in generating the risk model was to determine the primary risks. Even in the earliest stages of proposal development, great attention was focused on factors that might adversely affect the Canal Expansion Program execution. The Authority's personnel from all areas and key consultants participated in several workshops to identify project risks and possible management or engineering responses. More than 200 potential risks were

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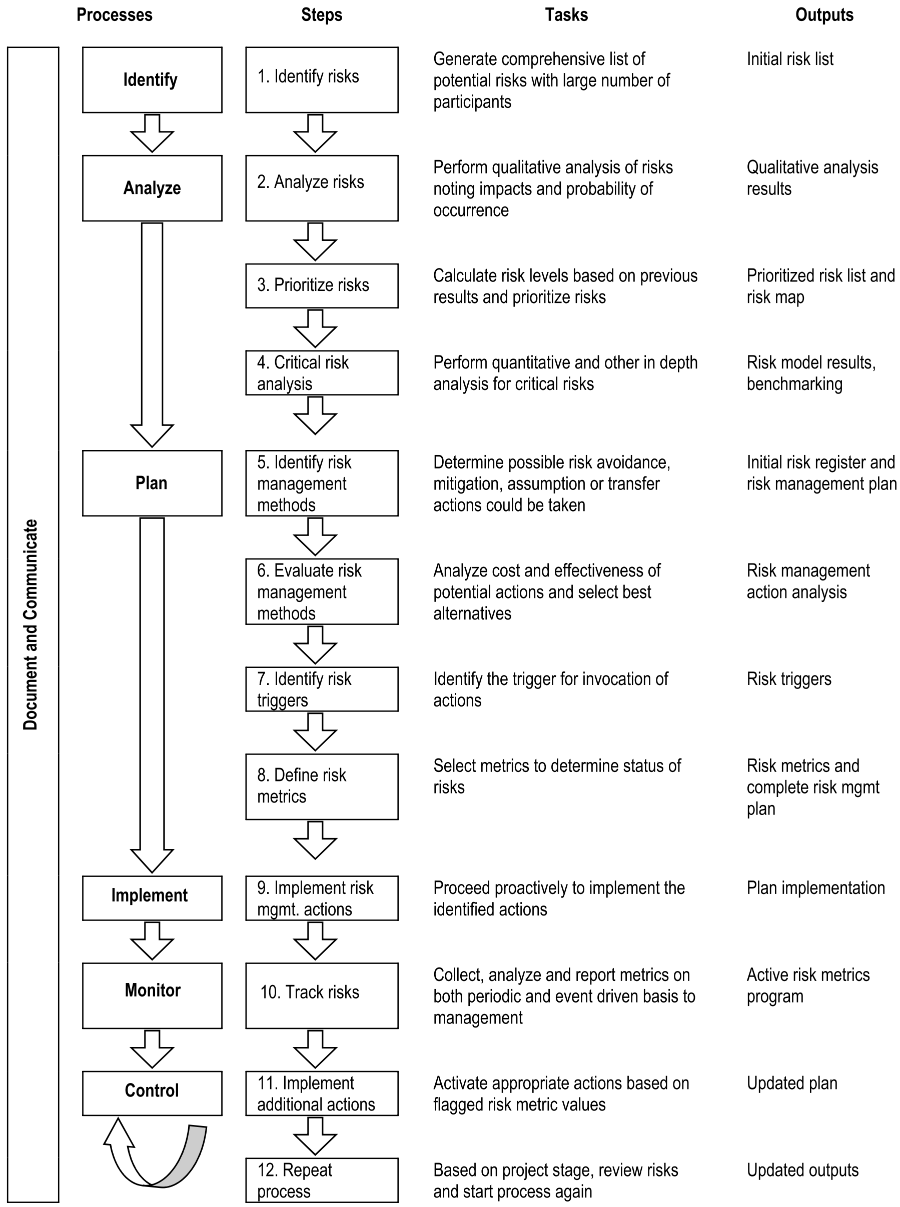

Fig. 4. Panama Canal Authority risk management process

identified through these meetings. Additional sessions, sensitivity analyses, and detailed studies reduced the number of the most important risks to 14. The final factors range from design changes and material quantities variations to management systems such as claims administration, controls availability, and planning efficiencies. The breadth of risks included allows for a much more comprehensive assessment of contingencies than would normally occur. The 14 most important risks, in alphabetical order, are as follows:

- Changes in design and quantities
- Extreme bad weather
- General inflation
- Inadequate claims administration
- Inefficient contracting process
- Inefficient planning
- Insufficient revenues
- Lack of controls
- Lack of skilled and local labor
- Local labor strikes
- Material, equipment, and labor cost
- Organization risks
- Owner driven changes
- Referendum delays

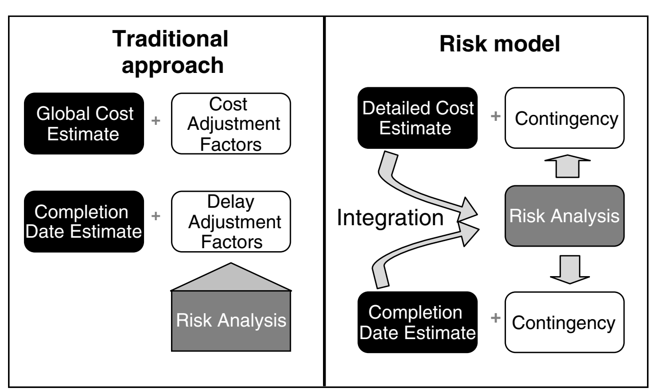

Fig. 5. Traditional/normal approach versus integrated risk model

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Model Structure

A spreadsheet representation of the cost estimate was employed in Microsoft Excel to serve as the basic model structure. A simplified schedule model that included all major program milestones was added to the base; care was taken to incorporate the activities that would be most affected by variations in quantities, productivity (labor and equipment), or singular events. Linkages between cost elements such as dredging materials quantity and the corresponding activity duration were built and tested. Special attention was taken to reflect productivities as drivers to both quantity variation and duration change. The integrated cost and schedule spreadsheet model was tested against the primary program cost estimate and schedule to verify accuracy and robustness.

The integrated cost and schedule was made into a Monte Carlo simulation model by the addition of the @Risk add-in for Excel. This same approach is used for other Authority financial/business models and is already well understood by the Authority's analysts and management.

The previously identified 14 risk factors were represented by stochastic variables in the integrated model. Again, appropriate linkages between these variables and the associated cost elements and/or activity durations were built and tested. Risk factors such as changes in design and quantities apply to several different cost elements and were therefore included multiple times with different assessments required for each. Since some of the risk factors are best represented by singular events, an events generator module was developed to account for these uncertainties. In some respects, these events, their frequencies, and their impacts were the most difficult to assess and validate; the amount of historical data available for comparison was quite limited. Frequency and level of impact assessments were modified several times before the modeling team was satisfied with the representation.

Several of the built-in modeling tools available within @Risk facilitated the risk model creation, operation, and reporting. The modeling team was responsible for obtaining probabilistic assessments from the most appropriate Authority units and individuals, and then calculating the corresponding parameters for model input distributions. As a result of the model validation process, several of the geotechnical-related distributions were reassessed. Simulation controls are also part of the @Risk toolkit and were used to help manage model execution, especially the ability to observe output convergence to determine the optimal number of simulation cycles. The output presentation tools were valuable in both reporting the key distributions for total cost and commissioning date and analyzing sensitivity of these results to the various risk factors.

Total Cost and Commissioning Date

As mentioned previously, the primary motivation for developing the risk model was to derive reasonable contingencies for both program commissioning date and total cost. Thus, the key model outputs are the two probability distributions for these results; Figs. 6 and 7 show these distributions.

Each distribution can be represented in various ways, including the frequency histogram as shown or as a cumulative probability distribution. In determining an appropriate contingency, management must agree to an acceptable confidence level. In this case, the Panama Canal Authority's senior management used an 80% confidence level to produce an approximately $1 billion total cost subsequently and one-year commissioning date schedule contingencies. Choice of confidence level is further discussed later in this paper.

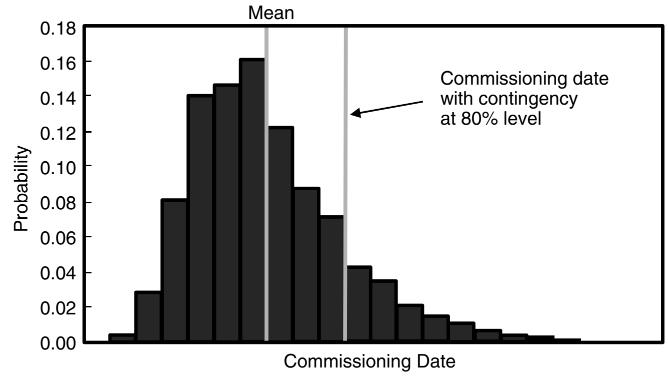

Fig. 6. Commissioning date distribution with time contingency (generic representation)

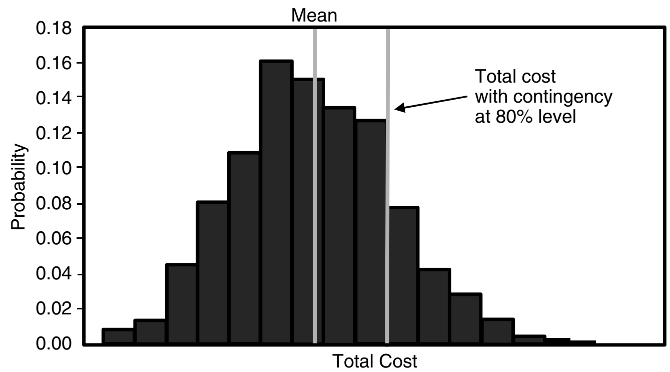

Fig. 7. Total cost distribution with cost contingency (generic representation)

Sensitivity Analyses

Many risk managers agree that sensitivity analyses provide some of the most valuable modeling results. The ability to observe how key output variables vary with changes in input parameters helps with both model validation and interpretation of results. One especially useful graphic, the "tornado diagram" (see Fig. 8 for a generic representation), displays from top to bottom the input risk factors that have the largest impacts on the output variable of interest. Managers can readily see in this analysis the potential advantages in managing or avoiding the underlying risk. They can also begin to understand where to make the most beneficial investments in risk mitigation efforts.

Interpretation of Results and Management Actions

Selecting a Confidence Level for Contingency

The risk model produces a range of possible cost and schedule outcomes, as shown in Figs. 6 and 7. The percentile level used in establishing contingency is directly related to the level of risk aversion of the decision maker (or agency in this case); the more risk adverse, the higher the percentile. The 50% value of the outcome total cost distribution is the median and would in most instances be approximately equal to the mean. Using this value would imply a risk-neutral, or expected value, decision maker—this would be highly unusual for an investment of this very large scale. One standard deviation above the mean would be at approximately the 85% level, and it is sometimes used as a basis

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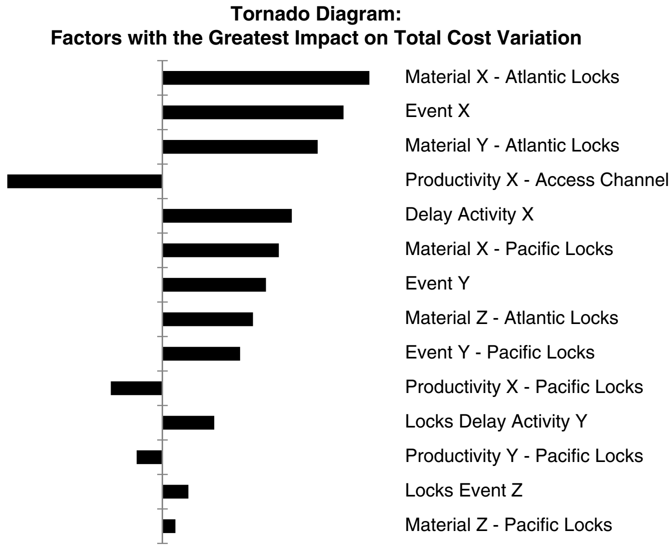

Fig. 8. Risks with greatest impact on cost variation (generic representation)

for setting the project contingency. The more typical value used in the industry for projects of this magnitude is 80%, but some agencies, such as the Washington State Department of Transportation, use 90% (FTA 2004, Anderson et al. 2009; Washington State Department of Transportation 2010WSDOT 2010).

The engineering staff and the board of directors for the Panama Canal Authority had extensive discussions about the percentile level and contingency to use in setting the cost and schedule estimates. The contingencies shown in Table 1 in the next section were generated from the 80th percentile level in the model. An 80% value implies that one in five times a project such as this would exceed this 80% value; four out of five times the final cost would be below this number. In summary, 80% is a reasonable criterion for projects of this magnitude and has a straightforward interpretation.

Contingency Management

Owing to the program's large-scale and long duration, it has substantial levels of budget and schedule contingency built into its forecasts. In its Proposal for the Canal Expansion Program, the Canal Authority published a contingency of more than $1 billion and one year in duration. This contingency was also published in line item contingencies as shown in Table 1 and explained in the text that follows.

The new locks comprised the largest component of the Canal Expansion Program's estimate at approximately $1,110 million and $1,030 million, respectively, plus a $590 million provision for possible contingencies during design and construction. The water reutilization basins estimate was $270 million and $210 million for the Atlantic and Pacific sides, respectively, plus a $140 million provision for contingency. In total, the cost estimate for the new locks, including their water reutilization basins and contingency, was $3,350 million. The new lock access channels were estimated to be $820 million, which included $400 million for dry excavations and $250 million for drilling, blasting, and dredging works, plus a $170 million provision for contingency. The cost estimate for the navigation channel improvements was $290 million, which included $90 million to widen Gatun Lake's navigational channels and $150 million to deepen and widen canal entrances, plus a $50 million contingency. Finally, there was a water supply

Table 1. Canal Expansion Program Cost Estimate [Reprinted with Permission from Autoridad del Canal de Panamá (ACP) 2006]

Project components	Estimate ($ million)
New locks	
Atlantic locks	1,110
Pacific locks	1,030
Contingency for new locks	590
Total for new locks	2,730
Water-saving basins	
Atlantic water-saving basins	270
Pacific water-saving basins	210
Contingency for water-saving basins	140
Total for water-saving basins	620
Access channels for new locks	
Atlantic access channels (dredging)	70
Pacific access channels (dry excavation)	400
Pacific access channels (dredging)	180
Contingency for access channels	170
Total for new locks access channels	820
Existing navigational channel improvements	
Deepening and widening of Atlantic entrance	30
Widening of the Gatun Lake channels	90
Deepening and widening of Pacific entrance	120
Contingency for existing channel improvements	50
Total for navigational channel improvements	290
Water supply improvements	
Increase the maximum level of Gatun Lake	30
Deepening of the navigation channel	150
Contingency for water supply improvements	80
Total for water supply improvements	260
Inflation to midpoint of construction	530
Total Estimate	5,250

improvements cost estimate of $260 million, including $150 million to deepen the navigational channels and $30 million to elevate Gatun Lake's maximum operational level plus an additional $80 million for contingency. These program components, added to an estimated $530 million for inflation to the midpoint of construction, represent a total program cost estimate of $5,250 million (ACP 2006).

While the contingency amounts shown in Table 1 are fully justified on the basis of inherent uncertainties, their magnitude and continuing presence represent an opportunity to actively manage key program and project resources. Large-scale, civil infrastructure projects contain significant uncertainties, especially in the early design stages. Variations in cost and schedule estimates are represented by contingencies reflecting a buffer beyond the expected value to account for these uncertainties. The risks or uncertainties may be specific or systemic; for example, labor availability may be a programwide systemic risk, while delivery of the rolling steel gates may be characterized as specific or unique to the project. Both risk types contribute to the contingencies—to both cost and schedule. As design development evolves, the contingency is proportionately reduced. Similarly, as construction progresses, the underlying uncertainties such as geological conditions or labor availability become known and are handled and contingency is lessened. Contingency should then be either expended to address encountered risks

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including design evolution or removed from the project budget so that it is not misappropriated.

Since contingency represents a valuable resource, control of this component is often debated. Just as with schedules and the question of "who owns the float?" the question of "who owns the contingency?" must be raised. In the absence of an active, iterative risk management system, contingency is often considered a static budget item. As such, it is often completely expended by the time of project completion whether or not the risks are realized. With contingencies of over $1 billion and one year in duration, the Canal Authority considers these as significant resources and actively controls their distribution.

One way of viewing the total program is as a portfolio of projects; thus the Canal Authority unarguably holds both the portfolio risk and the associated contingency. As a matter of delegation of authority and responsibility, each project would normally be allocated to the control of a project manager. A corresponding proportion of contingency should be allocated with the project so that the manager has resources to appropriately deal with anticipated project variations. Ideally, the contingency allocation would be set by determining a proportional (most likely based on total cost) share of systemic risk and an assessment of project unique risk. More pragmatically, the allocation would typically be based on a simple measure such as dollar percentage.

As each project progresses in time, there is a reduction in the remaining risk exposure. As an example, if the first construction activities are excavation, the geotechnical risks associated with soil types and ground water would disappear once these tasks are completed. This implies a risk resolution based on project progress and time. As shown in Fig. 9, one can conceptually map a decrease in total risk (and thus contingency) over time based on organizational, design, and construction activity completion.

As the project evolves, the foreseen risks either occur or do not occur. The concept of risk resolution is to either spend contingency on the risks that occur or remove the associated contingency when the risks do not occur. This removal from the project budget is to ensure that such unused contingency is not misspent on other project activities or accounts.

Since the program is a portfolio of projects, the total contingency reflects total portfolio variance. Given that the projects are not perfectly positively correlated, the sum of the project variances is greater than the variance of the portfolio. In other words, the portfolio has less risk than the sum of its projects. The effect of having unique risks in each project leads to a balancing of risk exposure at the program level. The logical consequence is thus to move the contingency from an unrealized risk at the project level to a program-level account so that it is available for distribution when a risk is realized elsewhere. A process would need to be developed for projects to apply for contingency from the program account. A key component of this philosophy is that the contingencies need to be retained by the program rather than taken completely out of the budgets; this is because the Canal Authority continues to hold the portfolio risk throughout the program.

Most of these assumptions/philosophies highlight the cost contingencies. Similar reasoning would apply to schedule contingency, except allocation on a per project basis would be more complicated. The notion of a program-level schedule contingency is probably a more meaningful way to track and update the use of schedule contingency.

The Canal Authority's comprehensive risk management philosophy provides for a continuing role in contingency management. Since the initial contingency allocations and risk resolution schedules are derived from the risk model, the model helped establish baselines for each project. In particular, the linkage of contingency amounts to project activities/phase requires additional modeling. Periodic risk model updates provide new contingency estimates that need to be reconciled with the baseline cost and schedule estimates for risk resolution by project. The risk management process also directly supports the project managers in tracking risks, revising risk registers, and updating contingency accounts. The status of contingency budgets per project and overall is perhaps one of the best ways of summarizing and communicating risk management status.

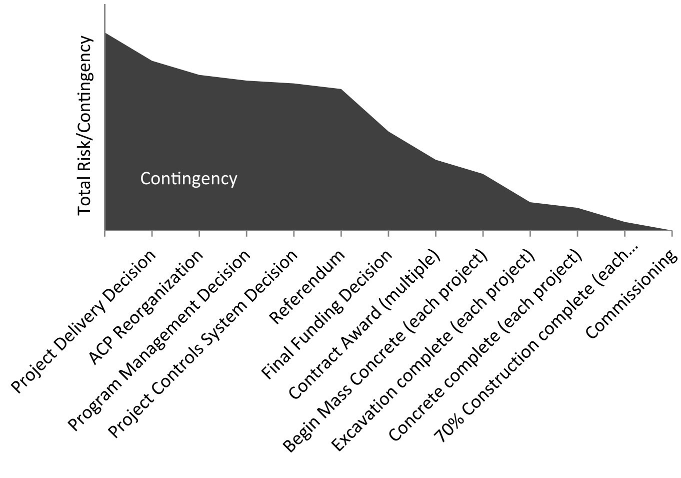

Fig. 9. Risk resolution

The project manager role in this process is also ongoing, focusing mostly on managing the contingency as another budget item. Regular updates should include not only costs and schedule but also risk register elements. On the occasion where an extraordinary request for program contingency funds is made by a project, the project manager will need to structure the request so that it ties to risk exposures, variation from expectations, mitigation strategies pursued, and remaining risk.

The Canal Authority has the essential responsibility for efficiently managing all resources associated with the Canal Expansion Program, including cost and schedule contingencies. Contingency management starts with an assessment of total contingency based on the program risk model, and then a proportional allocation to individual projects. Projects then utilize contingencies to fund variations caused by anticipated risks or return an appropriate amount to the master program budget when the risks do not materialize. Regular project updating includes reporting on risks and risk register elements and leads to subsequent reruns of the risk model. The ultimate goal is the active and continuing management of the more that $1 billion in cost and one year in schedule in program contingencies.

Communications

Communication of cost and schedule estimates must convey both the importance and the uncertainty involved with each. In addition to support of contingency management, the risk resolution schedule (Fig. 9) helps establish critical risk communication points in the project. Beside the risk resolution schedule, other communication techniques such as e-mail updates, periodic risk-based reports, or circulation of readings on risk facilitate a culture of risk management within the Panama Canal Authority. Most of all, developing the risk model and associated cost and schedule contingencies must not be viewed as a one-time event applied only to the initial proposal. The Authority's adopted risk management process (as shown previously in Fig. 4) requires ongoing communications

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focused on the most important risk factors, mitigation strategies, and status updates.

Informing Decisions

The cost and schedule risk model was used to guide multiple Canal Expansion Program decisions. An understanding of the probability and potential impact of risks helped the Canal Authority focus its planning and engineering efforts on the items that could severely impact the project cost and schedule. The project delivery method decision for the new Atlantic and Pacific locks provides an excellent example. Allocation of risk through the selection of an appropriate combination of project delivery, procurement, and contracting methods was essential to the success of the program. After scrutinizing the risks and opportunities involved with the Atlantic and Pacific locks, the Canal Authority determined that a design-build project delivery method using a best-value procurement of a lump sum contract would provide the optimal allocation of risk and opportunity while expediting the schedule and introducing innovation to the project.

At an estimate of $3.35 billion, the new locks and water-saving basins represented the majority of the project cost in the program. The locks also represented a key element in the critical path to opening the project. Speed to market for the canal expansion could be ultimately determined by this portion of the program. The Atlantic and Pacific locks ultimately defined the operating capacity, compatibility, and reliability of the Canal Expansion Program. The balancing of risk and opportunity while assuring critical technical performance was crucial to project success. The risk model helped inform the amount of technical design that the Canal Authority needed to develop to prove that the project concept was "buildable" for design-builders. By providing an understanding of which risks the design-builder could control and the severity of the risks that they could not, the risk model informed the writers of the performance specifications and design-build contract provisions that could add costs to the design-builders' proposals. In essence, the risk model assisted the Canal Authority in developing a design-build contract that provided for the optimal risk allocation (i.e., balance of risks and opportunities) on the project.

Conclusions

Since its opening and first operations almost 100 years ago, the Panama Canal has been considered one of the greatest engineering achievements of all time. Although there have been constant modifications, enhancements, and ongoing maintenance, the basic operation as a two-lane system has remained unchanged. The Canal Expansion Program that includes a third-lane locks and access channel promises to greatly expand capacity at completion in 2015. With a total cost of approximately US$5.25 billion and construction duration of 8 years, the Canal Expansion Program competes with the largest current civil infrastructure projects for scale and impact. The associated uncertainties require state-of-the-art assessment and industry-leading risk management processes to match the importance of this investment.

The canal and its revenue generation represent the single most valuable asset in the Panamanian economy. The Panama Canal Authority has managed this asset with extraordinary care and has utilized best practices in its operations and planning. Market and revenue forecasting approaches have for some time engaged stochastic, modeling techniques to obtain better representations of future financial expectations. Applying these same techniques to expansion program cost and duration estimates was a natural extension of the Authority's existing management approach. Unlike traditional risk modeling approaches that analyze cost and schedule risks using different and independent models, the model approach developed for the canal expansion integrates cost and schedule models into a single risk model providing cost and schedule estimates that are consistent and the result of the same risk factors. The resultant models helped to produce contingency estimates for total cost and a commissioning date for the completed program. Additionally, these models helped identify the key factors influencing cost and time variations, as well as breakdowns of when the risk exposures will be most prominent. With contingencies of approximately one year and US$1 billion, managing the risks and release of contingency are important areas for management oversight and control. The concept of risk resolution helps frame the active management of the contingencies over time and their careful utilization to achieve program goals. The Panama Canal Expansion Program offers an outstanding case study and best practices example of project risk management.

Acknowledgments

The writers would like to acknowledge the efforts of the many engineers from around the world who put significant time and effort into designing, estimating, and scheduling this historic project, particularly the efforts of the Panamanian engineers of the Panama Canal Authority. The writers would also like to acknowledge the efforts of our colleagues who assisted with the cost and schedule review of the estimate: Stuart D. Anderson, Debbie A. Niemeier, and Clifford J. Schexnayder.

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