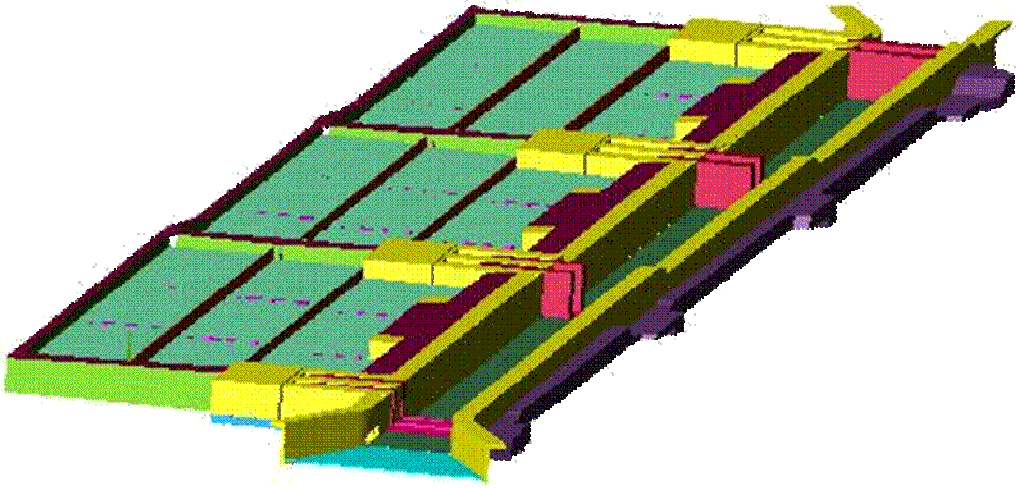
Review of the

Cost Estimates and Schedule for the

Panama Canal 3rd Lane Locks

Atlantic and Pacific Locks, Pacific Access Channel, and Navigation Channel



Prepared for the
Autoridad del Canal de Panamá
by the
Expert Technical Committee

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1. 0 INTRODUCTION

The academic Expert Technical Committee (ETC) performed an independent review of the methods used to prepare the current Autoridad del Canal de Panamá (ACP) construction cost estimates and schedules for the Panama Canal 3rd Lane Locks Master Plan. Specifically, the ETC reviewed the methodology and assumptions that were used to develop the estimates and schedules. The ETC examined estimate and schedule supporting documentation prepared for the Atlantic and Pacific locks, the Pacific Access Channel, and the Navigation Channel by the Cost Estimation Team (ET).

Autoridad del Canal de Panamá specifically requested that the ETC evaluate:

1. The cost estimating methodology.
2. The scheduling methodology.
3. The basic premises and assumptions behind the estimate and schedule.
4. The overall cost estimating and scheduling process in terms of approach.

1.1 ETC Members

The members of the Expert Technical Committee are:

- Dr. Stuart D. Anderson, P.E. (Professor, Department of Civil Engineering, Texas A&M University, College Station, Texas and currently Chairman of the Transportation Research Board, Construction Management Committee; formally a Principal Engineer, Fluor Corporation, Irvine, California)
- Dr. David B. Ashley (Executive Vice Chancellor and Provost, Shaffer-George Chair in Engineering, University of California, Merced; formerly Dean, College of Engineering, Ohio State University)
- Dr. Keith R. Molenaar (Assistant Professor, Construction Engineering and Management Program, Department of Civil, Environmental, and Architectural Engineering, University of Colorado at Boulder; past Chairman of American Society of Civil Engineer's Construction Research Council)
- Dr. Debbie A. Niemeier, P.E. (Professor, Department of Civil & Environmental Engineering, University of California, Davis; formally Department Chair; previously with the Texas Department of Highways, Austin, Texas)
- Dr. Clifford J. Schexnayder, P.E. (Eminent Scholar Emeritus, Del E. Webb School of Construction, Arizona State University; retired COL US Army Corps of Engineers and past Chairman of the Transportation Research Board, Construction Section)

1.2 Importance of Estimate Quality

The importance of project cost estimate and schedule quality cannot be overemphasized as demonstrated by cost overruns on major projects around the world. One comprehensive study of 258 projects in 20 countries found that nearly all of the projects suffered cost overruns[1] and an earlier study of 52 mega projects[2] reported

[1] Flyvbjerg, Bent; Holm, Matte Skamris; Buhl, Soren (2002). Underestimating costs in public works projects: Error or lie? *Journal of the American Planning Association, 68(3),* American Planning Association, Chicago, IL., 279-295.

similar findings. When water and public works projects are considered as a subset of these studies the average cost growth was greater than 30%. The management of large and complex capital construction projects requires the coordination of a multitude of human, organizational, and technical resources. At the same time, the engineering and construction complexities of such projects are often overshadowed by economic, societal, and political challenges.

In general, estimates early in project development contain uncertainty due to unforeseen engineering complexities and constructability issues–*scope changes and scope creep*; and changes in economic and market conditions, changes in regulatory requirements, governmental and stakeholder pressures, and a transformation of public expectations–*unforeseen events*. ACP and the stakeholders in this project must realize that the cost estimate is dynamic and must be continuously updated during the master plan development process. Proper project management and communication of the estimate and associated uncertainty throughout the master plan development process is absolutely imperative for overall project success.

1.3 Bottom Up Cost Estimating Approach at Conceptual Design

The ACP cost estimation team used a "bottom up" approach in estimating the project cost. This technique is most commonly employed by contractors when preparing bid estimates. Although the designs for the locks are not yet complete, The ETC believes, in this instance, the use of a bottom up approach is appropriate given the lack of reference cost data for developing a conceptual estimate using parametric or other conceptual estimating techniques. When properly used and applied to solidly engineered design, this method produces a large data set of detailed item-cost information. The challenge is to ensure that the detail does not obscure the unknowns imbedded in early project design by preventing a clear vision of the top-down risks.

This type of estimating requires the development of crews for each estimated work item, and the calculation and assessment of crew production rates, material costing, and data on the Ownership and Operating (O&O) cost of construction equipment. Costs for labor burdens and benefits, as applicable, are usually included in the hourly labor rates and contractor markup is added to the total estimated direct cost. In order to calculate the total cost of each item, material quantities and placement locations must be identified or assumed if not available from the incomplete drawings. This bottom-up approach provides a wealth of detailed information upon which to base engineering decisions and for calculating explicitly the cost of item changes as the design progresses. So, although there is great precision in the costing of items, it is important to note that precision in item details does not necessarily lead to accuracy in the estimate.

Precision – The quality of being exact. Mathematics: The number of significant digits.

Accurate – Capable of providing a correct measurement.

[2] Merrow, Edward W.; McDonnell, Lorraine M.; Yilmaz Arguden, R. (1988). *Understanding the outcomes of mega-projects: A quantitative analysis of very large civilian projects*. Rand.

The American Heritage Dictionary of the English Language, 3rd. ed. (1992). Houghton Mifflin Company.

Figures 1 and 2, which are the result of past research, depict the uncertainty that accompanies project estimates in early design phases and illustrate how a deterministic, bottom-up estimate can cause a false sense of accuracy early in the project development process. To prevent this false sense of accuracy, cost estimating methods and tools must be understood in terms of the design definition (detail) available during the various phases of project development. Overall project risk is not embedded in the detailed line items but must be analyzed and priced as project contingency.

More generally, at any stage in the development of a significant infrastructure project, cost estimates will be composed of three components for which there are differing amounts of information: "Known/Knowns," (known and quantifiable costs), "Known/Unknowns," (known but not quantified costs), and "Unknown/Unknowns" (as yet unrecognized costs), these are illustrated in Figure 1. Note that in Fig. 1 the contingency cost component extends into the known/knows cost percentage. All too often when using a bottom up estimating method, if the cost of an item is not known, it does not get included in early project cost estimates. There is also opportunity for other items, e.g. environmental or construction inspection costs, to be entirely left out of early estimates. The costs associated with the three components require different methods and tools to define and quantify their possible contribution to the estimate at any particular time in the project development process.

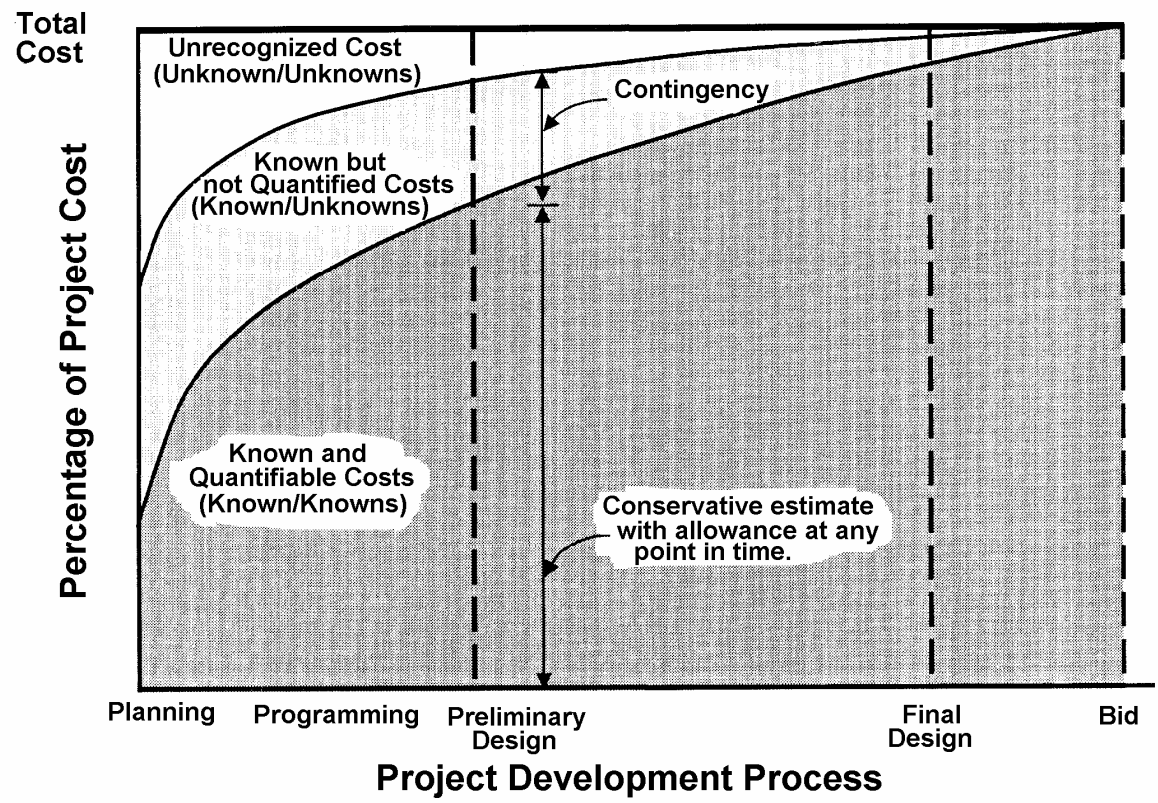

FIGURE 1. COMPONENTS OF A COST ESTIMATE

Figure 2 illustrates how identifying, quantifying, and managing cost and schedule uncertainty relates to management of final project cost. Two crucial points are illustrated in Figure 2, which applies to situations where the scope is unchanged and where an estimate, at some early stage in the design process, has included uncertainty. The first point is that the range of cost or schedule uncertainty should decrease as a project proceeds from concept to final design. Estimate accuracy improves as design develops, cost variables are better defined, and uncertainty is eliminated. The second point is that if the uncertainties included in the estimate, as a contingency amount, in the early stages of project design materialize, then the estimated total will still be as expected. However, as risk management and other cost control processes are applied to the identified uncertainties (risk), it is often possible to mitigate risks (contingency costs) and deliver the project at a lower cost.

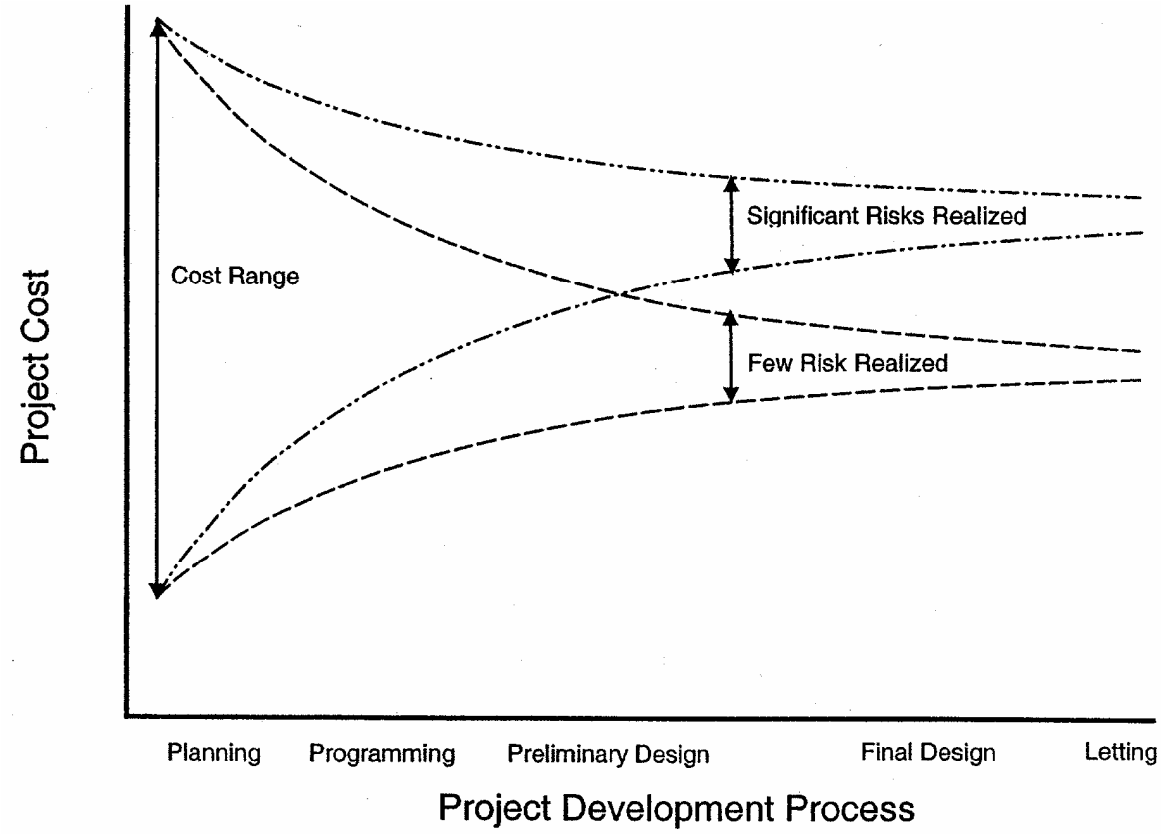

FIGURE 2. REFINEMENT OF A COST ESTIMATE

Figures 1 and 2 illustrate the false accuracy that can appear when using a deterministic, bottom up approach to cost estimating at the early stages of project design. The method is effective for contractors bidding competed designs, but the bottom up approach can miss the uncertainty that is inherent in every project and correspondingly in a project estimate developed with only limited project design definition. To mitigate this, a thorough and detailed risk assessment and risk pricing exercise should be completed to complement the engineering cost analysis, and the combined

results–bottom up estimate and contingency–should be considered the baseline cost of the project.

The Association for the Advancement of Cost Engineering International (AACEI) has developed a Cost Estimate Classification System, which defines five estimate classifications. This system provides an expected range of accuracy for each project development phase, Table 1[3]. A Class 5 estimate is one prepared at the earliest stage of project definition, and a Class 1 estimate is one prepared closest to complete project definition and final design. The current estimate for the locks should be classified as Class 3 while the Pacific Access Channel estimate and definitely the Navigation Channel estimate would be classified as Class 2. Table 1 also describes the methodological approach to the estimate as either stochastic or deterministic, depending upon the level of design and information available. AACEI recommends that Class 3 estimates be developed primarily as stochastic estimates; however, as previously noted, the ET has *relied almost exclusively on a deterministic approach in developing these estimates*.

TABLE 1. AACEI GENERIC COST ESTIMATE CLASSIFICATION MATRIX

	Primary 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 +/– range
Class 5	0% to 2%	Screening or Feasibility	Stochastic or Judgment	+40/–20 to +200/–100
Class 4	1% to 15%	Concept Study or Feasibility	Primarily Stochastic	+30/–15 to +120/–60
Class 3	10% to 40%	Budget, Authorization, or Control	Mixed, but Primarily Stochastic	+20/–10 to +60/–30
Class 2	30% to 70%	Control or Bid/ Tender	Primarily Deterministic	+10/-5 to +30/-15
Class 1	50% to 100%	Check Estimate or Bid/Tender	Deterministic	+10/-5

[3] Association for the Advancement of Cost Engineering International (1997). *AACE International Recommended Practice No. 17R-97: Cost Estimate Classification System*, AACEI, Morgantown, West Virginia, 2-6.

The ETC would normally have expected to review a parametric-type estimate with costs developed based on major project scope parameters such as type and size of lock. The parametric approach is common practice in the early stages of project development because, in most cases, projects have many components that simply cannot be defined in detail during the earliest phases of design. In the case of the Panama Canal 3rd Lane Locks master plan, however, the number of components that describe this project is relatively small. Thus, these components can be described by schematic drawings to such an extent that they can be quantified in gross terms and estimated using the bottom up approach. Because there are fewer component parts in the 3rd Lane Locks Project, there is reasonable assurance that most of the components comprising the estimate can be defined sufficiently to support a bottom up estimating approach and therefore it is an acceptable methodology.

However, using this type of methodology, at this stage in design development, requires particular attention to risk assessment and risk pricing, as the *exclusion* of a solid risk analysis can lead to a false sense of accuracy in the overall estimate because of the precision in costing specific work items.

1.4 Creating a Baseline Estimate

Cost estimating is a continuous and repetitive process during a project's design development. Cost estimates must be done to support the various alternative solutions that are being explored at the earliest stages of design. The total project cost estimate should only be communicated as a range when the preferred alternative is not known. When the preferred design does become known or when project-funding limits are set, a "baseline" cost estimate must be established. That baseline can best be defined as the estimate that is used to manage change and make design decisions that affect project cost. It is the sum of known and quantifiable costs (known/knowns) plus an estimated value for the known but as yet unquantifiable costs (known/unknowns–often called the risk premium) and a contingency for as yet unrecognized costs (unknown/unknowns). The baseline estimate sets the basis for funding and for measuring project performance. It is important to note that the baseline refers to a project of a certain scope and dimension; any future design or scope changes that alter the actual capacity of the project *by definition* change the project and require a *new* baseline, and not just an adjustment to the existing cost and schedule estimates.

As of the date when the ETC review was accomplished, the baseline cost for the project had not been established. The preferred design alternative has yet to be completely fixed and the team was not managing to a baseline project cost. Additionally, the risk component had not yet been integrated with the capital construction costs to sum to the baseline. Nevertheless, the ET has completed a thorough estimate with the design information available, and has included in its estimate an allowance for design changes that is appropriate at this stage. However, to finalize the baseline estimate and schedule, the risk evaluations for the Locks, Pacific Access Channel, and the Navigation Channel work must be completed. Until such time as that is completed, the ETC recommends that project cost estimates should *only* be communicated as a range.

Once the baseline is set, the project team must begin a process of active cost management. Cost estimating management is a critical activity during design. Periodic estimate updates must be constantly compared to the project baseline. Further, changes in scope, design development changes, and changes related to project site or market conditions must be evaluated from a cost and time impact to effectively manage overall project cost. Cost estimating management aids project decision makers when changes in scope or other issues require increased project funding.

1.5 The Scope of the 3rd Lane Locks Master Plan

In order to properly define a baseline estimate, the project scope must also be definitively defined. Future changes that do not affect the capacity of the project can be dealt with by comparison to the baseline cost and schedules; a major change of scope that alters capacity will require creation of a new baseline to track against. The current project definition includes:

- Two sets of three step locks with three water saving basins per step. The locks will have 8 steel rolling gates per lock complex. The locks have a lateral filling and emptying system.
  - One three-step lock in the Pacific: total excavation required for the locks, 14.2 million cubic meters
  - One three-step lock in the Atlantic: total excavation required for the locks, 18.1 million cubic meters and 6 million cubic meters for the access channel
  - Locks sizes: 427 m long, by 55 meters wide by 15.2 meters in depth
- New access channel in the Pacific (PMD) 218 meters wide, approx. 6.5 km long, and with a bottom level of 9.14 PLD. Total excavation required for the new Pacific Access channel: 63 million cubic meters including dredging (dry excavation 40.2 million cubic meters).
- The construction of two reversible flow rock-fill dams, one 1,860 meters long and one 1,020 meters long.
- Improvements to the existing navigational channel: The Pacific and Atlantic Ocean entrances will be deepened to allow for a 45 feet salt water draft. The total amount of excavation and dredging for the deepening of the entrances and the widening of the existing channel is 32 million cubic meters.
  - Widening the Pacific channel to 225 meters from the entrance to the Bridge of the Americas and to 218 meters from the Bridge of the Americas to the New Post Panamax Lock
  - Widening of the Navigational channel in Gatún Lake to 280 meters in the straight segments and to 366 in the curves
  - Deepening of the existing navigational channel in Gaillard Cut and Gatún Lake to 30 ft PLD

2. 0 BASIS OF ESTIMATE REVIEW

The external ETC review of the 3rd Lane Locks cost estimating process is a critical step in ensuring the methodology used to produce the current estimate is the best possible for such a master plan. This review should be used together with the other internal and external reviews that critically evaluate the estimate calculations and the unit costs of major items.

2.1 Timing of the Review

The ETC met with two members of the Cost Estimation Team on 8 and 9 September 2005 in Sacramento, California, and on 10 and 11 September 2005 in Seattle, Washington to review the current (as of those dates) construction estimates for the 3rd Lane Locks Project. Specifically, the ETC considered relevant ET studies and reports, conducted interviews with Engineers Yolanda M. Chin of ACP and Corina Briceno-Hinojosa of PBI, and then conducted a comparison between the 3rd Lane Locks estimating methodology and process, and those employed by other U.S. and International organizations and agencies. This was a review of methodology and process–not of calculations and unit costs.

2.2 Basis of Review

The ETC based the conclusions stated in this report on relevant ET studies, reports, and other pertinent supporting materials including assumptions that are the basis of the estimate, and on interviews with key project team members. Based on those sources, considered in total, a comparison judgment was made regarding the estimating processes employed by the ET and current international estimating practice. Table 2 provides a summary of the internal documents and reports provided by the ET for the review. Table 3 lists the names and titles of individuals interviewed in the course of this review.

TABLE 2. DOCUMENTS PROVIDED BY THE ET FOR ETC REVIEW

Cost Estimate and Schedule of the Post-Panamax Locks and the Pacific Access Channel (*Excel and HCSS Estimates, and Primavera Schedule*), as of July 14, 2005
Cost Estimate and Schedule of the Post-Panamax Locks and the Pacific Access Channel (*PowerPoint Presentation*), July 14, 2005
EFCO Forms for the Pacific Lock Wall Monoliths, May 29, 2005
First Draft Report- Project site visit- April 25th through May 6th 2005, Clair Harry Murdock, PQS, Re: Panama Canal, Third Lane Project- Pacific Locks Component, May 21, 2005
Technical Analysis on the Proposed Panama Canal Post-Panamax Navigation Channel, Panama Canal Authority, Department of Engineering and Projects, (*Bound Report*), August 2005
Programa de Dragado Presentation (PowerPoint Presentation), July 2005

TABLE 3. COST ESTIMATION TEAM MEMBERS INTERVIEWED BY THE ETC

Yolanda M. Chin, Navigational Channel Team Leader, ACP Canal Capacity Projects Division, Autoridad del Canal de Panamá
Corina Briceñno-Hinojosa, Project Specialist, Parsons Brinckerhoff International

When reviewing the provided information, the ETC employed a data collection framework that allowed for analysis of the supplied information and provided a consistent method for benchmarking the processes against those used for civil works mega-projects. Table 4 provides a listing of the sources of external documents used in the review.

TABLE 4. EXTERNAL REFERENCE DOCUMENTS

Independent Research Assessment of Project Management Factors Affecting Department of Energy Project Success (2004). prepared for the U.S. Department of Energy, by the Civil Engineering Research Foundation (CERF), October.
Intercounty Connector Project (ICC) - Project Cost Estimate and Schedule Review (2004). Maryland Department of Transportation, October.
Major Project Program Cost Estimating Guidance (2004). Federal Highway Administration, Washington, D.C., June.
Management of Large Highway and Transit Projects (2002). Federal Highway Administration, Washington, D.C., Inspector General U.S. Department of Transportation, May.
Procedures for Estimation and Management for Highway Projects During Planning, Programming, and Preconstruction, *Interim Report* (2004). National Cooperative Highway Research Program, Project 8-49 December (data from 23 DOTs).
Project Cost Estimating a Synthesis of Highway Practice (2003). National Cooperative Highway Research Program, Project 20-07/Task 152 *Final Report*, (data from 50 DOTs).
Project Management Book of Knowledge (PMBOK), Third Ed. (2004). Project Management Institute.
"Project Risk Management" (2000). *A Guide to the Project Management Body of Knowledge*, Chapter 11, pp. 127-146.
Washington State Department of Transportation – Cost Estimating Validation Process (CEVP) through the following references:
http://www.wsdot.wa.gov/projects/cevp/default.htm
Cost Estimating Validation Process (CEVP) Initiation Report (2002). Washington State Department of Transportation, July.
"Programmatic Cost Risk Analysis for Highway Mega-Projects" (2005). *ASCE*

Journal of Construction Engineering and Management, 131(3), 11 pp., March.

2.3 Review Methodology

The ETC review methodology is a comparison between established and documented processes for developing project cost estimates and schedules and the documents submitted by the ET. The industry standards methodology is comprised of seven steps as shown in Figure 3. The steps in Figure 3 are further described in Tables 5 and 6. Step 6–Communicate Estimate–is important to managing an estimate and is therefore discussed in this report. Step 7–Obtain Approval–is not part of the charge to the ETC. The information required to perform the various process steps is represented on Figure 3. The steps and their descriptions, plus additional information shown on the flowchart, provide a general structure for evaluating the ET estimating and scheduling methodology and processes.

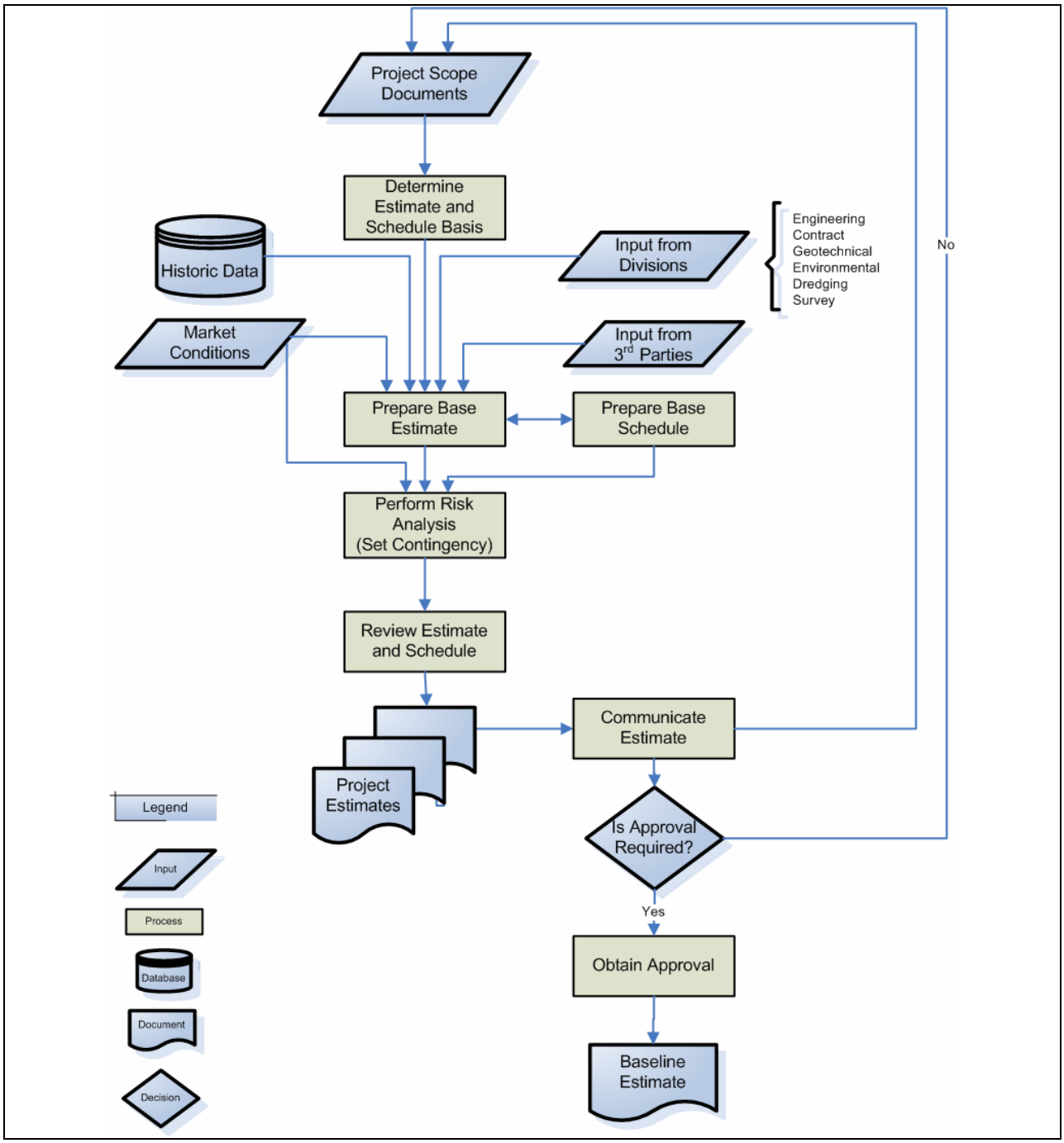

FIGURE 3. PROJECT COST ESTIMATING AND SCHEDULING FLOW DIAGRAM

TABLE 5. COST ESTIMATING AND SCHEDULING PROCESS

COST ESTIMATING AND SCHEDULING STEPS	DESCRIPTION

COST ESTIMATING AND SCHEDULING STEPS	DESCRIPTION
STEP 1: Determine Estimate and Schedule Basis	Document project type and scope: • Scoping documents • Drawings that are available (percentage engineering and design completion) • Project design parameters • Other attributes of the project
STEP 2: Prepare Base Estimate	Estimate cost: • Prepare an estimate file that compiles information and data used to prepare the estimate • Document estimate assumptions • Application of appropriate estimate techniques • Coverage of all known project elements • Reflect known project conditions
STEP 3: Prepare Base Schedule	Schedule Development: • Prepare a schedule file • Document schedule assumptions • Identification of activities, logical relationships, and activity durations • Evaluation of impact of resources (labor, material, and equipment) • Check key milestones
STEP 4: Determine Risk and Set Contingency	Identify and quantify areas of uncertainty related to: • Project knowns and unknowns • Potential risks elements associated with these uncertainties • Appropriate level of contingency congruent with project risks
STEP 5: Review Estimate and Schedule	Review estimate basis and assumptions: • Methods used to develop estimate and associated costs • Verify estimate completeness relative to the project scope • Verify cost data reflects conditions at the project location Review schedule basis and assumptions: • Methods used to develop schedule (e.g., activities and their durations) and logical relationships • Verify schedule completeness • Check key activity relationships and resource impacts

TABLE 6. COST ESTIMATE AND SCHEDULE MANAGEMENT PROCESS

COST ESTIMATE AND SCHEDULE MANAGEMENT STEPS	DESCRIPTIONS
STEP 6: Communicate Estimate	Communication should include: • Determining the mechanism for communication of the cost estimates and schedules for their intended purpose • Determining the level of estimate and schedule uncertainty that should be communicated given the information upon which they are created • Determining the mechanism to communicate estimate and schedule to external parties
STEP 7: Obtain Approval	Obtain management authorization to proceed: • Reviewing current project scope, and estimate and schedule • Ensuring that appropriate levels of approval • Approving current estimates and schedules including any changes from previous estimates and schedules

The other information shown on the flow chart further expands areas of analysis and evaluation. The ETC gathered background information on how the project estimators used “Historical Data” to prepare the cost estimates. Information was gathered on how market conditions and inflation influenced the estimates. The use of “Third Parties” to provide input when preparing the estimates is considered. The use of input from various divisions within ACP is also considered. That material was assessed in relation to industry standards and how it was used in preparing the cost estimates and schedules for the Project.

2.4 Limitations of the Review

This review constitutes an independent external review of the cost estimating and scheduling methodology and assumptions used to prepare the current estimates and schedules. It provides a quality assurance of the process and guidance for any improvements that might be needed.

The ETC did not create a new estimate nor review every detail of the cost or itemized amounts that resulted from the cost estimating process. Similarly the ETC did not review the detail of individual items, which compose the project schedule.

3.0 ESTIMATE AND SCHEDULE REVIEW

This section is organized around the steps shown in Figure 3 and Table 5 previously described in Section 2. These steps are: 3.1 Estimate and Schedule Basis; 3.2 Prepare Base Estimate; 3.3 Prepare Base Schedule; 3.4 Perform Risk Analysis and Set Contingency; 3.5 Review Estimate and Schedule: 3.5 Communicate Estimate and Schedule; and 3.7 Obtain Approval. Additionally, sub-sections discuss the Navigation Channel, Pacific Access Channel and the Atlantic and Pacific Locks separately when appropriate.

3.1 Estimate and Schedule Basis

The estimate for the Panama Canal 3rd Lane Locks is divided into three major portions of work: 1) a navigation channel: for which design and cost estimating, are the responsibility of ACP, 2) the Pacific Access Channel: for which the design is by ACP with the ET having estimate responsibility, and 3) the Atlantic and Pacific Locks: for which design is by CPP with the ET having estimate responsibility. The Navigation Channel estimates and schedules are based on excellent and extensive geotechnical data and detailed historic cost data. The Atlantic and Pacific Locks, and the Pacific Access Channel are based on conceptual designs that are in a fairly early stage of development.

3.1.1 Navigation Channel Estimate Basis

The scoping and design (nearing 100% layout) for the navigation channel work required to support the 3rd Lane Locks was preformed by the Autoridad del Canal de Panamá. The expectation is that the dry-land excavation work and about 50% of dredging work will be contracted out to private contractors. Specifically, ACP expects to hire two rock cutter dredges, a hopper dredge, and two hydraulic backhoe dredges. In general, the data for developing the Navigation Channel estimate came from ACP's Department of Engineering and Projects. The data consisted predominantly of results from recently externally bid work and historical cost records of similar work ACP performed with its own forces. This approach is consistent with industry practices when there is data available from similar work that can be used for estimating the new project. As presented in the *Technical Analysis on the Proposed Panama Canal Post Panamax Navigation Channel* report, the level of detailed information is to the very highest standards.

While the ETC would agree, that because of ACPs extensive experience and historical production databases there are very few physical work factors that are likely to introduce uncertainty into the estimate, the estimate does not yet take into account the top-down risks associated with large projects that are due to macroeconomic (market) conditions.

3.1.2 Pacific Access Channel Estimate Basis

ACP preformed the design for the Pacific Access Channel work that is required to provide a waterway between the Pacific 3rd Lane Lock and Gatún Lake. ACP's Department of Engineering and Projects has years of experience with both dry-land excavation and dredging. In terms of dry-land excavation, ACP's experience is primarily

with laying backside slopes to improve the canal and not with open-pit methods of the type that will be required for the Pacific Access Channel. Additionally, this work involves construction of a clay core rock fill dam that will separate the Pacific Access Channel from the existing Miraflores Lake and the Pedro Miguel Lock. This is required because of the water elevation differences between the Access Channel and these existing canal features. A further complication is the fact that for non-engineering reasons this work is being divided into six individual work packages and a portion of the excavated rock is to serve as the aggregate source for constructing both the Atlantic and Pacific Locks. From the ETC review and experience reviewing project estimates, it is clear that:

1. The division of the work into six separate contracts
2. The inclusion of the dam construction in one of the contracts
3. Using the excavated but uncrushed material as the source of concrete aggregate

are all risk factors that influence the Pacific Access Channel cost estimate. During the risk analysis, it is strongly advised that the potential cost impact of these work-packaging decisions be assessed.

3.1.3 Atlantic and Pacific Locks Estimate Basis

The Atlantic and Pacific Locks are being designed by Consorcio Post-Panamax and are still in the early stages of development (<30%). A complete set of quantities is not available from these drawings. Therefore, the many of the quantities of materials required to construct the locks are assumed based on the ET's experience from other projects and input from consultants (e.g. Clair Harry Murdock). It must be realized that these are subject to change as the design is refined. The estimate does include a contingency for design changes. This contingency percentage amount (20%) is considered by the ET as an allowance for additional Lock elements that are expected to be added as the design is further developed; thus, this is the type of allowance often included directly in the cost estimate. The ET has two choices for dealing with the design contingency/allowance; it can continue with the allowance portion within the estimate or it can utilize the risk analysis for capturing these effects. Should the ET continue to include this item in the base cost estimate, then care should be taken to not include a duplicate item in the risk analysis leading to double counting of the Lock design changes.

3.1.4 Schedule Basis

The schedule for the Panama Canal 3rd Lane Locks project is divided into two major portions: 1) the navigation channel, for which both design and scheduling are the responsibility of ACP; and 2) Pacific Access Channel, and the Atlantic and Pacific Locks with the ET having scheduling responsibility. ACP is handling design of the Pacific Access Channel and Consorcio Post-Panamax is responsible for the design of the Atlantic and Pacific Locks.

3.1.5 Navigation Channel Schedule Basis

The scoping and design of the Navigation Channel work required to support the project is performed by ACP. The schedule for this work has been developed by ACP using estimate elements, and construction knowledge and experience from similar work they

have preformed. Some data used to develop the schedule is related to recently bid external work. The schedule includes both dry-land activities, such as excavation requiring drilling and blasting, and dredging. As indicated under the Estimate Basis section 3.2.1, ACP will perform about 50% of the dredging work while the remaining dredging and all dry land work will be contracted to private contractors. The activities on the schedule reflect this approach.

The schedule was developed in Microsoft Project and the underlying logic is represented in a Gantt bar chart format. Major schedule assumptions and the basis for schedule development are discussed in Chapter 13 of the bound report "Technical Analysis on the Proposed Panama Canal Post Panamax Navigation Channel," Panama Canal Authority, Department of Engineering and Projects, August 2005. Key milestones are reflected on the schedule.

3.1.6 Pacific Access Channel, and Atlantic and Pacific Locks Schedule Basis

The schedule for the Pacific Access Channel, and the Atlantic and Pacific Locks was developed by the ET based on project scope information provided by ACP, the ET, and Consorcio Post-Panamax. The activities on the schedule are tied closely to elements in the cost estimates. The Pacific Access Channel shows six activities as external contracts. The Atlantic and Pacific Locks are shown separately on the schedule, although the activities for each are almost identical. The activities for each of these two work areas are shown under three main categories: 1) general, 2) civil works, and 3) electromechanical works.

The overall schedule, including the Pacific Access Channel, and Atlantic and Pacific Locks, is developed in Primavera Project Planner. The schedule is represented as a logic-based Gantt bar chart. The schedule does show preconstruction activities. Key milestones are reflected on the schedule. Velocity diagrams and linear scheduling were used to support the development of a portion of the Locks schedule. These techniques provided a detailed analysis of the work progression based on crews and production rates.

3.2 Prepare Base Estimate

Estimates serve as critical inputs to key project decisions, establish the metrics against which project success is measured, and communicate the status of a project at any given point in time.

1. Cost estimates must be calculated through a transparent process–have **integrity**–and any uncertainties should be explained in laymen's terms and in an easily understood manner.
2. Cost estimates should include all costs needed to complete the design, environmental mitigation, construction, and project management–**completeness**.
3. Cost estimates must clearly specify how inflation is considered –**year-of-expenditure dollars**.

These criteria serve as the ETC benchmarks in our review of the prepared cost estimates.

3.2.1 Navigation Channel Base Estimate

ACP has significant experience with navigation type projects and the design for this work is close to being completed (nearing 100% layout). The navigation estimate is extremely detailed and well documented. This estimate is based on historical data from similar type work and it is clear ACP has a great deal of recent experience constructing similar works. The estimators used both historical cost data and external discussions with contractors and consultants to verify work item costs.

Integrity: Two types of estimate assumptions are discussed and documented in the material given to the ETC: 1) assumptions that are more general in nature that apply to the Navigation estimate in total and 2) assumptions relevant to specific items of work, such as geotechnical data. These assumptions were documented to a high standard in the *Technical Analysis on the Proposed Panama Canal Post Panamax Navigation Channel* report and further information is found in the "Programa de Dragado Presentation."

The distribution of the material quantities by type has been calculated and the locations of available and potential disposal sites have been investigated. Adjustments to cost, based on type of work and equipment, are clearly documented and traceable.

The methodology used meets the standards of practice for similar type work.

Completeness: The calculations of direct costs are very detailed and complete because of ACP's extensive experience with this type of work. ACP excavation and dredging indirect costs have been estimated as 20% and 15%, respectively. These costs were verified against the actual costs accrued to date for a similar project. The indirect costs for the navigational project include approximately 3% each for environmental mitigation, design and project administration. There are also additional costs related to navigational aids, disposal, site preparation, and survey support included in the indirect calculations. In total, indirect costs represent approximately 14% to 15% of total excavation and dredging costs. Although these percentages are less than the percentages used in the project cost estimation, the ACP elected to retain in the project estimation 20% and 15% for indirect costs respectively for excavation and dredging.

The ACP anticipates that external contractors will perform about 50% of the dredging work. For this work, ACP would be expected to provide project oversight and some project support, most prominently in the form of contract management specialist and marine piloting personnel and aids. These indirect project management and support costs have been estimated at about $0.90 per cubic meter of dredging for the Atlantic entrance. This unit cost was based on ACP support costs of approximately $0.85 per cubic meter for contractor dredging conducted at the Atlantic entrance through June 2005. The Pacific entrance costs are expected to be significantly higher, on the order of $2.00 per cubic meter.

For the dredging and excavation work that ACP performs directly, overhead costs are included in the unit costs for each of the respective divisions conducting the work. For example, the dredging division uses an 11% indirect rate for overhead on division/personnel services, which is built directly into the relevant unit costs. The ET said that the 11% includes the cost of benefits, overtime, and rotational differences.

Year-of-expenditure dollars: The total estimated cost, direct cost plus overhead, has been escalated at a 2% inflation rate to the scheduled midpoint of construction. This inflation rate was supplied to the ET by the ACP Financial Department.

3.2.2 Pacific Access Channel Base Estimate

The Pacific Access Channel estimate was the responsibility of the Cost Estimation Team. The estimate has been developed using a bottom up approach supported by calculations of equipment spread productivity. This work is largely multiple-face conventional excavation–mass excavation–that can most economically be accomplished using large mining-type equipment. The work also includes construction of a 2.4 million cubic meter clay-core rock-fill dam. The level of cost estimation detail employed at this stage of project development far exceeds typical practice for estimating both direct cost and overhead expenses. However, with the exception of the rock-fill dam, it must be noted that the design for this part of the total 3rd Lane project is fairly well developed, so utilization of a bottom up approach yields a much more refined estimate.

Integrity: This estimate was developed using HeavyBid software, which is a commercial estimating product of Heavy Construction Systems Specialists, Inc. (HCSS). The HCSS software has been used by large engineering firms and contractors to develop billion dollar plus estimates for other projects. There is supporting documentation, predominantly in the form of Excel spreadsheets, which clearly show how the different equipment spread productivities were calculated and which document the assumptions supporting the productivity calculations. These backup calculations and documentation provide a traceable record of how the estimate was developed. The bottom up estimate development, using HCSS software, is compatible with the best industry practices usually found only in the very largest contracting organizations.

Completeness: The direct costs for individual construction activities are presented in great detail and all normally expected items of work are included in the estimate. For most of the construction activities, the variable costs were calculated from the bottom up and based on hourly spread productions required to complete the activity (e.g., tons per hour). There has been a 50 min-hour efficiency factor applied to the calculated peak spread productions so productivity is reduced to the 83% level. The fixed and variable indirect contractor costs are calculated and included in the estimate. Because variable costs were calculated using activity durations, the estimate is directly linked to the assigned quantities and drives the schedule durations.

In addition to contractor indirect costs, an additional 13.5% has been added to the project estimate to account for anticipated owner indirect costs. Owner indirect costs are composed of the following:

- Design costs, at 5% of construction costs
- ACP administration costs, at 3% of construction costs
- Construction management costs, at 5.5% of construction costs

These percentages were based on historical data from similar heavy civil projects executed internationally. Members of the ETC have examined the indirect costs for two recent large dollar projects executed in the United States (each had a total cost well

over a billion dollars). The indirects for those projects were in the range of 18 to 20% of project direct cost but it is difficult to make direct comparisons, as there is no standard structure for what expenses are classified as indirects. The ETC believes a major reason for the lower owner indirect cost amount on the 3rd Lane Locks Master Plan estimate may be the substantial amount of ACP support given to the project that may not be consider a direct project charge. The two recent external projects referenced above by the ETC were more clearly separated from the operations of the performing agencies and they were thus able to isolate more precisely the owner support costs. The ETC has seen agencies use a bottom up methodology in estimating these cost instead of applying a historical percentage values.

To the total estimated cost for project direct and indirect charges a 10% contractor profit has been added and finally a 20% allowance for design changes was added to yield the total estimated cost before inflation. The 10% contractor profit add is necessary when calculating cost from the bottom up based on market labor rates and equipment ownership and operating expenses. The 20% allowance for design changes as described previously essentially represents a placeholder for expected additional design elements. Both of these are acceptable allowances in this context.

The completeness of the estimate is excellent and it has been developed in great detail.

Year-of-expenditure dollars: The total estimated cost (directs, overhead, profit, and design contingency) has been escalation at a 2% inflation rate to the scheduled midpoint of construction. This inflation rate was supplied to the ET by the ACP Financial Department.

3.2.3 Atlantic and Pacific Locks Base Estimate

The construction cost estimate for the Atlantic and Pacific Locks was the responsibility of the Cost Estimation Team. The design of both locks is less than 30% complete and there are still many design issues to be resolved. These are principally engineering issues having to do with the three water-saving basins and the configuration of the water system for filling the locks. The quantities used are from the current drawings, and have been confirmed in a review by Clair H. Murdock, who has stated the “concrete quantities seem good.” As the design is refined, these quantities will need to be revisited and changed to reflect the final lock design.

The estimate has been developed using a bottom up approach supported by calculations of crew productivity. The majority of the work is mass concrete–aggregate production, forming systems, and concrete production, transport, placement, and curing.

Integrity: The estimate methodology is extremely robust and detailed for work that has not yet been fully defined. As with the Pacific Access Channel work the estimate cost were developed using HeavyBid software. There is supporting documentation, predominantly in the form of Excel spreadsheets. The documentation shows how the crew productivities were calculated and describes the assumptions supporting those calculations. These backup calculations and documentation provide a traceable record of how the estimate was developed. The bottom up estimate development, using HCSS software, is compatible with the best industry practices usually found only in the very largest contracting organizations.

Completeness: The same estimating methodology is used for the Pacific Access Channel and Locks portions of the project. For the concrete and excavation construction activities, the variable costs were calculated from the bottom up and based on hourly spread productions required to complete the activity (e.g., cubic meters per hour). Practical equipment capabilities in relation to the work conditions were accessed to develop the crew production rates, then a 50 min-hour efficiency factor applied to the calculated spread productions so productivity is reduced to the 83% level. The ETC does not interpret the 50 min-hour as a contingency, but rather as an expectation of production efficiency based on historical data on similar work activities.

The direct costs for individual construction activities, in this case primarily concrete work items, are presented in great detail and all normally expected items of work are included in the estimate. Within the Lock's estimate the Electromechanical work has been treated as subcontract work and the estimated cost represented industry pricing information instead of a bottom up estimate based on individual work activities and calculated productivities. The cost for this portion of the work is 17% of the total direct cost for the locks and it includes a contingency amount equal to 19% of its total cost. As described in Section 3.1.3, this item is considered to be an allowance for additional project elements expected to be added as design evolves. The fixed and variable indirect contractor costs are calculated and included in the estimate. Because variable costs were calculated using activity durations, the estimate is directly linked to the assigned quantities and drives the schedule durations.

As with the Access Channels, the same additional 13.5% has been added to the project estimate to incorporate anticipated owner indirect costs, as well as a 10% contractor profit (this was handled slightly differently in the case of the subcontracted items) and finally a 20% allowance for design changes was added to yield the total estimated cost before inflation.

The completeness of the estimate is excellent and it has been developed to much greater detail than would be found with most projects at this stage of development.

Year-of-expenditure dollars: The total estimated cost, directs and overhead, has been escalation at a 2% inflation rate to the scheduled midpoint of construction. This inflation rate was supplied to the ET by the ACP Financial Department.

3.3 Prepare Base Schedule

Schedules are critical inputs to key project decisions, establish the metrics against which project success is measured, and communicate the status of a project at any given point in time. Schedules should be integrated with costs using data and information derived from project estimates. Both the Navigation Channel and Access and Atlantic and Pacific Locks schedules reflect the same level of detail consistent with their respective cost estimates. Both schedules are linked directly to their respective estimates and use estimate data as the basis for developing activities and activity durations.

3.3.1 Navigation Channel Base Schedule

ACP has significant experience with similar navigation projects. ACP understands the type of equipment needed to perform this work, has historical data concerning the

typical production rates that can be achieved using the equipment, and fully understands the logical sequences of dry excavation and dredging work. The ACP Department of Engineering and Projects has excellent historical data and experience. ACP clearly used estimate data related to major equipment and production rates in building their schedule. Major assumptions related to the schedule, as discussed in the report (*Technical Analysis*, 2005), list equipment types, portion of equipment furnished by external contractors, use of ACP equipment including a new rock cutter suction dredge, and adjustments to production rates to account for down time during the year. Down time includes preventive maintenance, emergency repairs, dredging maintenance, and crew relief. All such assumptions appear to be reasoned and defensible.

The activities on the schedule are grouped by location and type of work. The logical relationships between activities are based primarily on efficient use of equipment. The cost estimate contained total cost and overall production rates by equipment type. However, for scheduling purposes each equipment type is allocated to the various activities that the equipment supports. Production rates are estimated for a given activity but are adjusted based on the type of work and the work schedule assumptions discussed above. Based on quantities of materials for each activity, durations were estimated. Costs-per-unit are also allocated to each activity and when combined with production rates and durations, an estimated cost for each activity on the schedule is provided. Durations, costs, and volumes of material are included on the Gantt bar chart. All costs are summarized and checked against cost estimate totals. In this way, the schedule is resource loaded. This feature of the schedule supports development of cash flow information. Key milestones are shown on the schedule. The logical relationships between activities are also shown. This is an excellent approach for developing the schedule, however in reviewing the progression of activities through the schedule it is clear that there is little float within the activity chains. The ETC would recommend that there be an in-depth review of schedule logic and activity sequencing due to the current lack of float in the schedule.

The methodology used to create the schedule meets the standards of practice followed in other industries for planning and scheduling complex work.

3.3.2 Pacific Access Channel and Atlantic and Pacific Locks Base Schedule

The schedule for the Pacific Access Channel and the Atlantic and Pacific Locks is the responsibility of the Cost Estimation Team. All this work is shown on a single schedule. In building the Atlantic and Pacific Locks portions of the schedule the ET used estimate-generated data related to each activity including crews and associated production rates for the crews.

The Pacific Access Channel activities are based on six contracts, one activity per contract. Contracts 1, 2, and 3 are performed concurrently. Contract 4 starts after Contract 3 is complete. Similarly, Contract 5 starts after Contract 1 is completed and Contract 6 starts after Contract 2 is completed. Relative durations for these six activities are consistent with the volume of material removed. The volume of materials involved in each contract is directly related to the estimate. Additionally, a plan view of the location of the six contracts is provided in the presentation, “Cost Estimate and

Schedule of the Post-Panamax Locks and the Pacific Access Channel." The sequence of the six contracts appears reasonable based on the location and length of excavation for each contract per the plan view. There is no other information available with respect to assumptions behind this component of the overall schedule. Yet the ETC knows from the presentations during the meetings in Sacramento and Seattle that there is the issue of stockpiling material for later crushing and use as concrete aggregate.

The Atlantic and Pacific Lock portions of the schedule include work activities related to mobilization/testing, detailed design, excavation, reinforced concrete, rolled compacted concrete, gates and valves. The Atlantic Lock construction commences approximately four months prior to the Pacific Lock construction. The main emphasis of the schedule focuses on the construction of the four lock heads and three lock chambers with their respective water-saving basins. The schedule for this portion of work is based on twelve activities for which crews and production rates are derived from the cost estimate. Activity durations are based on this information and estimated material quantities. The construction sequence is carefully planned based on the construction knowledge and experience of the Cost Estimation Team personnel and other consultants. The number and magnitude of the concrete placements is carefully planned based on schematic drawings and activity sequencing simulations of the lock head construction that the ET developed. The schematic drawings are used to plan the flow of trucks to and from the planned work areas. Velocity diagrams and linear scheduling is used to show the progress of work based on crews and production over the duration of each activity. The results of this analysis are used to build the logic-based portion of the schedule for the lock heads, chambers, and basins. This part of the schedule reflects the majority of work involved in the Atlantic and Pacific Lock segments of the project. The electromechanical work, that is, installation of gates and valves, occurs toward the completion of the lock heads and chambers. The procurement of the electromechanical materials requires a long lead-time, as shown by an activity for the delivery of this item.

The schedule shows reasonable logical relationships between activities and key milestones. The level of detail is consistent with the bottom up estimate approach and level of detail contained in the cost estimate. However, other than the connection to the estimated production rates there are very few assumptions documented in the information received to date. In addition, the schedule has very little activity float, and is therefore a risk area of concern to the ETC. Consequently, the ETC would recommend that there be an in-depth review of schedule logic and activity sequencing due to the current lack of float.

The start of construction is dependent on many pre-construction activities being completed in a timely fashion. This portion of the schedule was not reviewed.

The methodology used to create the schedule meets the standards of practice followed in other industries for planning and scheduling complex work. The level of detail is consistent with the estimate information used to calculate activity durations. However, areas for specific emphasis during the risk assessment should be craft availability, skill level, and work site access in relation to production rates.

3.4 Perform Risk Analysis and Set Contingency

A reasoned and rationale basis for assigning an estimate contingency is a very important component of creating the project estimate. The simplest starting point is to map the design completion level to an historical pattern for similar projects. A *conceptual* design level for typical water resource and transportation projects would likely equate to a contingency of 20% to 25% or possibly more. As noted in Figure 3, Step 4, direct identification of potential risks and their assessed impacts can also be utilized to establish a project cost contingency for inclusion in the estimate. The contingency component of an estimate is valuable because it serves to highlight the potential variations in cost and/or schedule; the explicit identification and assessment of risk is especially valuable because it allows management to proactively manage and mitigate these risks to the benefit of the project. This section addresses the current status of risk analysis and contingency inclusion in the Panama Canal 3rd Lane Locks Project estimates and schedules.

First and foremost, the Panama Canal 3rd Lane Locks Project is not typical; its size, functional uniqueness, location, and technology all contribute to its one-of-a-kind nature. Thus, using an all-inclusive percentage contingency of say 30% would have little basis or reliability. This project requires explicit consideration of construction risk exposures. These could include such items as resource availability, crew productivity, impacts of unusual weather, lock technology modifications, or rock quantity variations. This review will catalog where contingencies have been applied and their relationships to perceived risks.

The primary conclusion of the ETC risk and contingency review is that to date only a limited risk contingency amount has been incorporated into the project estimate. Two primary factors seem to contribute to this situation. First, as mentioned in a preceding section, the Panama Canal 3rd Lock Master Plan estimate has not yet been fixed as a *baseline* estimate, as the risk assessment piece of the baseline has lagged the cost estimating. Secondly, as mentioned previously, the creation of a bottom up estimate is providing a detail that may be misinterpreted with a false sense of accuracy. This section concludes with suggestions on how to advance the risk planning for the project.

3.4.1 Contingencies in the Estimates

Atlantic and Pacific Locks and the Pacific Access Channel: The estimates prepared by the Cost Estimation Team on both Locks and the Pacific Access Channel are extraordinarily thorough for a project at the current design level. In several instances construction process details and contract award approaches are advanced beyond the design status to support them. Creation of these bottom up estimates requires planning on methods and logistics of construction; for example, the sequence of excavation in the Pacific section is used to establish an aggregate source for other portions of the project.

The two Lock projects contain one prominent contingency, a 20% “contingency” for design. As described in Section 3.1.3, this item is considered to be an allowance for additional project elements expected to be added as design evolves. This is an explicit recognition of the current state of the design. Design changes, including possible variations in material or excavation quantities, are meant to be covered by this

allowance amount. Other variations such as unit prices due to market changes or delay impacts are not accounted for in this item and need to be addressed during the project risk analysis and determination of the project contingency.

The estimate does recognize that one integral design feature–the filling system–is not yet fully resolved. As already indicated in the estimate discussion, there is a modest allowance, on the order, of 3% for the open question of final selection of the hydraulic design; this allowance should be considered as a placeholder for an expected cost of the system, rather than a true contingency reflecting risk.

One essential aspect of using the bottom up estimate approach is that it requires the creation of a production plan and the creating of crews with equipment to execute items of work. Each crew as a unit must have a productivity rate including a provision for how many minutes each hour the crew is productive. Engineers Briceno-Hinojosa and Chin both expressed considerable confidence in the productivity values. They relied on a long Canal history of similar work with known equipment and/or methods in similar geology to derive the productivity values. The 50 minute-hour was similarly based on local records. These estimates are therefore seemingly quite reasonable from an expectation point-of-view. Again, however, it must be noted that neither estimate, includes any contingency or buffer for such potential top-down variations as changing market conditions or unforeseen circumstances.

Navigation Channel: The Navigation Channel layout is considered to be 100% complete. A high level of design completion does seem appropriate to the ETC given the history of similar work performed on a continuing basis by ACP. Half of the Navigation Channel dredge work is to be executed with an internal workforce and an internal dredge equipment fleet. As a consequence of assuming complete design, the estimate does not include a design contingency component as did the Atlantic and Pacific Locks and Pacific Access Channel.

There is a modest amount of contingency in the excavation portion of the estimate. The “dry” excavation contains an explicit 8.5% contingency in the unit rate; this appears to be recognition of the intended use of outside contractors for the dry excavation. This small contingency may be included to account for productivity or resource availability variations. The “wet” excavation, which is to be performed by ACP forces, does not contain an explicit contingency. Further exploration, however, indicates that a modest contingency of up to 3% may be implicitly contained in each of the wet and dry unit rates. This is derived by building up the 20% (for dry excavation) and 15% (for wet excavation) indirect amounts using components of the indirect costs. The gap of approximately 3% in each case can be considered as an implicit contingency. Thus, the ETC perceives estimated contingencies for dry and wet excavation as 11.5% and 3%, respectively. The Cost Estimation Team has completed a review of the numbers since meeting with the ETC in early September and states that the actual contingency percentages are 8.5% for the dry excavation and 5% for the wet excavation. As mentioned previously, stripping the contingencies from these cost elements to define a base cost and then explicitly analyzing their associated, potential variations in a risk analysis would be a preferable approach.

The minimal contingency percentages on the Navigation Channel are strongly connected to ACP's assumptions. In addition to the 100% layout basis, ACP assumed that dredge equipment availability would be very high, including that for the new equipment on order or those pieces to be ordered. Although a dredge equipment back-up plan was provided, it did not modify the estimated contingencies. The back-up plan appears to provide adequate recourse to substantially eliminate the risk of dredge equipment not being available or being out of service. ACP also assumed an earlier start for the Navigation Channel work so as not to adversely impact the work at the two Locks and for the Pacific Access Channel. Taken together, these contingencies appear to be adequate given the circumstances. Again, the preference would be to strip these contingencies from the cost estimate and then assess their impacts within a risk analysis.

3.4.2 Contingencies in the Schedules

As noted in section 3.3 above, the schedule detail seems consistent with the level of the detailed, bottom up cost estimates. Like the estimates, there is a danger of assuming a greater precision than is appropriate for a conceptual design. This problem is amplified by the use of productivity rates in the estimate to calculate the activity durations in the schedule. Although the logic and detail seem extremely well thought out, the corresponding durations could well turn out to be more variable than assumed. The schedules do not seem to have much identifiable contingency built into either the logic or durations. Although the deterministic schedule developed for the Master Plan is possible, the likely variations in activity durations combined with very little activity float imply that the overall schedule may be especially sensitive to these risk factors. The risk assessment should thus carefully consider potential schedule variations and the costs associated with them.

Like the cost estimates, the schedules do not seem to account for market factors or resource interactions and availability. When the sections of the project are at maximum overlap in terms of construction activity at the same time, lack of available skilled labor and other critical resources may start to have interactive, adverse affects. ACP has recognized the fact that labor could be an issues and the Department of Human Resources is working to mitigate the risk. On the positive side, it does appear that ACP has paid considerable attention to schedule so as to minimize the dependence of the individual projects on one another. This includes starting the Navigation Channel as soon as possible after a successful public referendum.

3.4.3 Contingencies from the Financial Risk Model

Review of the Financial Risk Model prepared by AON and ACP was outside the scope of this review. Nevertheless, it is worth mentioning some of the potential relationships between the Financial Model and the construction estimates and schedules. To appropriately support Board of Directors decision making, the Financial Model must be able to project such factors as net present value, commissioning year, maximum debt, and total investment; these results should also contain their potential probability distributions. The total construction costs and construction duration are key inputs to the business model. This should include possible variations of cost and schedule so that the decision criteria and their possible distributions can be correctly forecast.

Conversely, the Financial Risk Model has the potential to influence the construction performance if project acceleration or delay is anticipated due to financial considerations. Likewise, funding or debt considerations may influence timing of specific construction activities, or even influence market rates for the project resources. The critical activity required uniting the cost estimate and the risk model into a baseline estimate is the completion of the risk model and its integration with the engineering cost estimate.

3.4.4 Project Risk Planning and Assessment

The basic conclusion derived from reviewing the estimate and schedule for the Atlantic and Pacific Locks and Pacific Access Channel is that non-design driven risks and contingency included in both the estimate and schedule are minimal. Where contingencies are included, it is to address quite specific causal factors such as potential quantity variation. A more rigorous and complete treatment of risks allows a more reasonable estimation of project contingency and serves as a basis for pursuing risk management strategies during construction. The completion of the risk assessment and its integration with the cost estimate should resolve this issue.

The Navigation Channel, on the other hand, has a much further developed design and less uncertainty in the resource and productivity factors. Risk planning on the Navigation Channel would also be useful, but may not be as critical since it is less likely to significantly change the overall project cost or schedule. Additionally, the contingencies included in the Navigation Channel estimate may be reasonable and aligned with the principal exposures. However, since it will be necessary to carry out full risk management planning on the Atlantic and Pacific Locks and the Pacific Access Channel, ETC recommends that ACP also include the Navigation Channel in this assessment.

Formal project risk management normally includes the following six steps (Project Risk Management, 2000):

- Risk management planning
- Risk identification
- Qualitative risk analysis
- Quantitative risk analysis
- Risk response planning
- Risk monitoring and control

At the time of the preparation of this report, the ETC had not had the opportunity to review the ongoing risk assessment work ACP is completing, so this discussion is necessarily generic. Nonetheless, it is meant to provide useful guidance to those members of the project team involved in risk management.

For purposes of supporting the process of establishing an estimate and schedule contingency for these projects, it is recommended that ACP concentrate on the *risk identification* and *quantitative risk analysis* steps of the process.

Development of the risk plan will require even more focus on potential risks. Table 7 is a modification of the Project Management Institute's Body of Knowledge basic risk checklist. This or similar lists often serve as a starting point for the identification of specific project risks. The risks in this checklist are organized into the general categories of technical, external, environmental, organizational, project management and construction. Not all these risks will apply, but many will. As a point of reference, the risks already considered in the estimates and schedules by inclusion of a contingency are indicated by **bold type** in the table. Thus, it is clear that there are many additional risks needing further consideration and assessment.

TABLE 7. SAMPLE PROJECT RISK CHECKLIST (DERIVED FROM *PMBOK*)

Technical Risks	External Risks
▸ **Design incomplete** ▸ Environmental analysis incomplete or in error ▸ Unexpected geotechnical issues ▸ Change requests because of errors ▸ **Inaccurate assumptions on technical issues in planning stage** ▸ Materials/geotechnical/foundation in error ▸ Waste site analysis incomplete or in error ▸ **Need for design exceptions** ▸ Consultant design not up to standards ▸ Scaling up the lock and water saving basin designs	▸ Priorities change on existing program ▸ Funding changes for fiscal year ▸ Political factors change ▸ Stakeholders request late changes ▸ Public awareness/support ▸ Market competition for key materials or equipment
Environmental Risks	**Organizational Risks**
▸ Permits or agency actions delayed or take longer than expected ▸ New information required for environmental clearance or permits ▸ Environmental regulations change ▸ Water quality regulation changes ▸ Lack of specialized staff (biology, anthropology, archeology, etc.) ▸ Water quality issues ▸ Pressure to compress the environmental schedule	▸ Inexperienced staff assigned ▸ Losing critical staff at crucial point in the project ▸ Insufficient time to plan ▸ Internal "red tape" causes delay getting approvals, decisions ▸ Functional units not available, overloaded ▸ Lack of understanding of complex internal funding procedures ▸ Priorities change on existing program ▸ Agreements
Project Management Risks	**Construction Risks**
▸ Project purpose and need is poorly defined ▸ Project scope definition is poor or incomplete ▸ Unanticipated project manger workload ▸ No control over staff priorities ▸ Consultant or contractor delays ▸ Estimating and/or scheduling errors ▸ Unplanned work that must be accommodated ▸ Communication breakdown with project team ▸ Pressure to deliver project on an accelerated schedule ▸ Lack of upper management support	▸ Inaccurate contract time estimates ▸ Inaccurate productivity estimates ▸ **Inexperienced workforce/inadequate staff/resource availability** ▸ **Quantity variations**

Once the more critical risks are identified, then quantitative analysis can be used to assess net impacts on schedules and total cost. A typical approach for this type of project and available data is a Monte Carlo simulation. The spreadsheet form of the estimates lends itself relatively easily to simulation using one of the spreadsheet add-in products such as Crystal Ball® or @Risk. Similar add-in software is also available to simulate schedule risks. The contingency amounts can then be derived by using a specific percentile, such as 80%, as a basis. Separate contingencies can then be associated with individual risk factors if desired, or a global contingency to achieve a project cost or schedule confidence level, again such as 80%, to establish a project contingency.

By performing a detailed risk plan at the conceptual design level, ACP can focus management efforts to eliminate, mitigate, manage or insure the most damaging risks. The most important risks can then be managed effectively during construction and monitored as the project progresses. It is ETC's understanding that the approach outlined above is indeed that which is currently being followed by the ACP.

3.5 Review Estimate and Schedule

This ETC report constitutes an independent external review of the methods used to prepare the current construction cost estimates and schedules. Specifically, the report documents a review of the methodology and assumptions that supported development of the estimates and schedules. The ETC review encompassed all three parts of the project.

External estimate and schedule reviews of the process are one form of estimate quality assurance. Other forms of review for major international construction projects include internal and external peer reviews of calculations and unit costs. The ETC found evidence of these other forms of estimate reviews, but additional reviews should be conducted in specific areas as design is further refined.

3.5.1 Navigation Channel Estimate Reviews

The comments on estimate review are based primarily on the ETC interviews with the ET and not on the formal documentation provided to the ETC. The ACP Department of Engineering and Projects is currently reviewing the estimating and contracting assumptions. ACP's own engineering staff is preforming this internal peer review. This process is somewhat informal in that it is not triggered by any periodic process, but rather is being instituted as design issues arise. There is not a formal documented process for the estimate review. ACP staff is the natural choice for the internal peer review due to their extensive experience and long history with the project.

The formal reviews are usually preformed using outside experts. In addition to this ETC review, the ACP has conducted other external reviews. Questions on equipment resources and contractor resources have triggered appraisals of new dredging equipment, and contractor capacity. Specifically, Great Lakes Dredging and Ogden Beeman, an independent dredging consultant participated in workshops with ACP where they reviewed aspects of the estimate.

Although the ETC was not presented formal evidence of a structured process for internal or external estimate and schedule reviews, it is comfortable from discussions about on-going reviews. When a project baseline is set, these reviews should be instituted as a formal-structured process that serves as a critical tool supporting cost and schedule management.

The ET that prepared the estimate should conduct its first review. This is essentially a screening review that ensures the math is correct, the process is documented, and that it was developed following agency guidelines.

An objective estimate review can be accomplished by a group of experienced third party agency individuals who did not participate in development of the estimate. For large or complex projects, the review is usually conducted with the project team and estimators so that the reviewers can better understand the execution plan, estimate basis, and project challenges in regards to scope and pricing. Such a peer review checks the estimate for completeness and correctness, including but is not limited to the following:

- Check mathematical extensions and correctness;
- Check takeoff for omissions or oversights;
- Check for conformity between amounts of work (item quantities) with the schedule durations to determine correctness;
- Check the calculations of the indirect costs; and
- Examine the estimate for buried contingency.

Large and unique projects should have an external review of the estimate by qualified professionals. The most indispensable tool for estimate review is judgment. Judgment is what identifies mistakes, detects flawed assumptions, and identifies where the process has missed critical cost drivers. The surest way of conducting a successful external review is by selecting a panel of independent reviewers that have as broad a range of engineering experience as the project demands and providing this panel with enough time and resources to conduct a diligent review. This review can take the form of an audit on only the most critical items with additional review as needed if the initial audit finds any problems.

3.5.2 Pacific Access Channel and Atlantic and Pacific Locks Estimate Review

The design for the Locks is not as complete as that for the Navigation Channel or the Pacific Access Channel. Therefore, the lock estimates have not received the same level of review. The ACP Department of Engineering and Projects is conducting an internal peer review of the Pacific Access Channel and Locks Estimate. ACP can provide good review of the Pacific Access Channel estimate given their knowledge of the project site geology and expertise with local labor productivity, however, there are portions of this work with which they have little experience and those should receive an external review. The ETC is comfortable with the level of external review of quantities and unit cost calculations for the current estimate, however, it would be prudent for ACP to obtain an external review of these items at the time of next major design package submission

Questions about equipment resources and contractor resources have triggered reviews of particular items of work related to the estimate for the Locks. For example, multiple vendors have quoted the lock gates and the ET has met with concrete formwork suppliers to obtain pricing and use information. While these meetings focused on the development of unit costs, they also serve as external peer reviews. Likewise, value-engineering workshops conducted on the lock designs have served as peer reviews of the estimates and schedules.

Because there is extensive design work yet to be accomplished, the ETC is very comfortable with the level of review, to date, that has probed the estimate. The intensity of review will need to be increased once the project baseline is determined. Additionally, when the ongoing risk analysis is completed, a peer review of both the process and the unit costs calculations should be performed.

3.6 Communicate Estimate and Schedule

Effective communication builds and sustains partnerships and project delivery. Communication of the project estimate both internally and externally is critical to successful completion of this project. Communication of cost and schedule estimates within the ACP must convey both the importance and the uncertainty involved with each. Communication with the public must communicate the importance and *uncertainty* of the estimate at this early point in project design. As previously stated, the estimate should only be communicated as a range until the project baseline is set.

Internal communication of the project estimate and schedule is through well-established channels between the Department of Engineering and Projects, the PMAT, the designers, and the Board of Directors. However, the estimates are currently communicated as definitive values or with rough ranges (i.e. +/- 15%) within the team. From its experience, ETC strongly recommends that the uncertainty involved in the estimates is clearly communicated and understood by all internal parties, and that there is common agreement within ACP on how the estimate will be communicated externally.

External communication was not explored in depth by the ETC, as it was not in the scope of the review. The ETC, considering the limited lock design development, would recommend that the ACP in communicating the total project cost to external parties (the public) speak in terms of cost ranges that will become more refined as design is finalized. The cost should not be publicly stated as a single number until a formal contingency analysis has been conducted and a project baseline cost established.

3.7 Obtain Approval

The estimate approval process generally occurs in conjunction with setting the project baseline. A discussion of the estimate approval process is not in the scope of the ETC review at this time.

3.8 Baseline Estimate and Schedule

As discussed in Section 1.4, the ETC determined that a true project baseline has not yet been established. Upon a thorough review of the construction and macro-environmental risks associated with the Locks, Pacific Access Channel, and Navigation Channel an appropriate contingency can be determined and the project baseline cost

established. Until that point, the project team should only communicate the estimate total as a cost range.

> **Risk and Uncertainty:** Costs should be attached to uncertainties. Contingency should be defined and quantified as specific risk elements that can be used to create a risk management plan.
>
> ACP must deal with project risks before determining a project contingency amount and only after the contingency amount is set should a cost baseline value be established.

Setting a baseline is imperative to an effective project cost and schedule control system. Currently, cost and schedule management are accomplished though an "informal" process. With the Locks portion of the project, the ET performs a new estimate every time there is a new design package. Estimates are also done in conjunction with value engineering workshops to support design. However, the ETC did not find a formal cost and schedule tracking system in place or the use of a formalized change management process. ETC came to this conclusion by questioning how the original ACP and Harza estimates of 2004 differed and in trying to determine how the cost changed during the "harmonization" of the design in 2005. Without a cost baseline, such comparisons are difficult to formulate. Likewise, the first cost estimates on the Navigation Channel were done in 2001, but they have not been used as a baseline to track cost and schedule changes. ETC strongly recommends that ACP implement a state-of-the-art program controls system at this stage of project development so that the soon-to-be-determined baseline can be tracked as the project progresses.

4.0 CONCLUSIONS

Autoridad del Canal de Panamá specifically requested that the ETC evaluate the methodology used to create the estimate and schedule for the Panama Canal 3rd Lane Locks Master Plan, the basic premises and assumptions behind the estimate and schedule and the overall cost estimating and scheduling process in terms of approach. The reviewers' overall conclusion is that the reviewed cost estimate is a well-constructed and a well-documented engineering cost estimate, but that it needs to be integrated with the results of the ongoing risk assessment to create a true master plan baseline estimate against which future changes can be measured. The sections below discuss each part of the estimate separately.

4.1 The cost estimating methodology:

The ETC found that the current project estimating methodology is to the highest standards and in many instances superior to the estimating practices found on large public infrastructure projects at this stage of design. The estimators have demonstrated an ability to identify, analyze, and incorporate into the estimate the effect of the many construction challenges associated with this master plan. It is necessary to develop an estimate contingency amount, through a rigorous risk analysis, and include it in the estimate before the project's baseline cost is set.

4.2 The scheduling methodology:

The ETC found that the current project scheduling methodologies are very strong and could be judged superior to the practices found on many large public infrastructure projects at this stage of design. The estimator/schedulers have effectively analyzed the relevant information and displayed a high level of technical competence. It is necessary to develop a schedule contingency, through a rigorous risk analysis, and include it in the schedule before the project's baseline schedule is set.

4.3 The basic premises and assumptions behind the estimate and schedule

The ETC found that the basic premises and assumption supporting the estimate are well documented and provide solid foundation for creating the estimate and schedule. The ET team has called upon the advice of outside experts, made objective evaluations, and weighed alternative decisions before establishing the important estimate and schedule parameters. However, a rigorous risk analysis is still required to set the baseline estimate and schedule and ensure that the bottom up approach used did not mask any top down risks.

4.4 The overall cost estimating and scheduling process in terms of approach

The estimate approach is rigorous and demonstrates strong analytical reasoning on the part of the ET. The direct linkage between the activity productivities in the estimate and the schedule durations contributes to the ETC's confidence in the schedule.

4.5 Strengths of the Estimate and Schedule

It is evident to the ETC that the individuals performing the estimates are extremely competent professionals who, as required, are formulating sound engineering assumptions to complete a cost estimate and schedule when there is still much scope definition and design to be accomplished. These individuals are employing historical cost data and following prudent processes. The estimates, and the schedules built from the estimates, have a very high level of detail for this stage of project development; the known/knowns have been precisely costed. The ETC would caution that the *precision* in the costing of individual items can create a false sense of *accuracy* when not considered alongside the costs of the known/unknowns.

The estimates and schedules precisely follow "what is known about the project at this point in time," but there is little or no contingency in the current estimate or float in the schedule for the uncertainties that are involved in a project of this magnitude, complexity, and importance. Before a baseline cost (estimate) is set, the ETC strongly endorses the completion of a risk assessment tied to the estimate contingency. At that point, the project team can formulate a risk management plan to mitigate project risks and successfully deliver the project within the baseline cost and schedule.

The ETC is highly impressed with the professionalism and competence of the individuals working on this project. Specifically:

- Estimate and schedule basis is extremely detailed
- Schedules are linked directly to their respective estimates and use estimate data as the basis for developing activities and activity durations

- Estimating personal are extremely competent professionals who are intimately familiar with the project and construction processes
- Historical data is robust and applied in a prudent manner
- Costs are estimated in year-of-construction dollars
- Overhead costs are accounted for using a rigorous process
- There is some contingency planning in very specific areas (i.e. the possible loss of dredging equipment)
- Value engineering studies have been initiated early
- Peer reviews of the estimate have been conducted

4.6 Future Considerations

Early in project development a bottom up estimate can cause a false sense of accuracy. Cost estimating methods and tools must relate and adapt to the various phases of project development. In general, estimates early in project development contain uncertainty due to unforeseen engineering complexities and constructability issues, changes in economic and market conditions, changes in regulatory requirements, governmental and stakeholder pressures, and a transformation of public expectations. ACP and the stakeholders in this project must realize that the project cost estimate is dynamic and must be continuously updated during the project development process.

The basic conclusion derived from reviewing the Atlantic and Pacific Locks, and Pacific Access Channel parts of the estimate is that only design contingency has been included in the estimates. Additional, contingency amounts based on a formal risk assessment analysis have not generally been included. Where contingencies have been included, they are to address quite specific causal factors such as potential quantity variation. At this level of design, the ETC would recommend that a project of this magnitude and importance have a comprehensive assessment of the potential risks and that the resulting risk appraisal:

- Serve as the basis of the contingency amount included in the estimate and
- Shape the schedules on which the costs are based.

4.7 Toward a Baseline Estimate

A baseline estimate can best be defined as the estimate that is used to manage change and make design decisions that affect project cost. It is the sum of known and quantifiable costs (known/knowns) plus an estimated value for the known but as yet unquantifiable costs (known/unknowns–often called the risk premium) and a contingency for as yet unrecognized costs (unknown/unknowns). The baseline estimate sets the basis for funding and for measuring project performance. It is important to note that the baseline refers to a project of a certain scope and dimension; any future design or scope changes that alter the actual capacity of the project *by definition* change the project and require a *new* baseline, and not just an adjustment to the existing cost and schedule estimates.

The specific steps in creating this baseline estimate are:

- Explicitly define the master plan scope on which the baseline is established. This should be both in terms of physical project components and the *operating characteristics/performance* (e.g., capacity).
- Review the cost estimate and remove (strip out) hidden or implicit contingency amounts to yield a true base cost. Note that the ETC found only a small number of these items that would require removal in the current estimate.
- Review the owner indirect costs included in the estimate for possible missing components. The amounts currently used are lower than the ETC found for two comparable-scale projects. This may be because certain ACP support activities are not being fully charged against the master plan.
- Review the schedule and likewise remove any activities or durations representing contingencies. Note that the ETC did not find any such items in its review.
- Perform a comprehensive risk analysis as described in Section 3.4.4. The analysis should identify the most important risks for both construction and the overall project implementation. It should include macroeconomic, political, and major resource factors as part of this process. Each of the major identified risks should be analyzed for contributions to cost and/or schedule of the capital construction of the project.
- A global contingency amount should be developed from the risk analysis. This master plan contingency should be based on a statistically derived confidence level on the risk analysis predicted values for project cost and duration. The ETC has most often seen 80% as the selected confidence level, and would recommend that ACP use this for establishing the baseline.
- Implement a state-of-the-art program control system with the baseline cost estimate, schedule, and contingencies as the bases for project control and tracking.