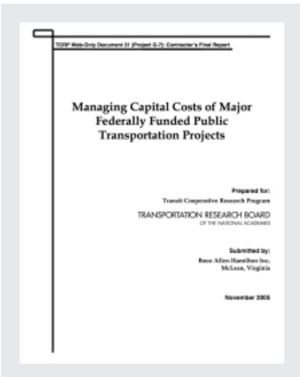
Managing Capital Costs of Major Federally Funded Public Transportation Projects

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TRANSPORTATION RESEARCH BOARD

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ABBREVIATIONS

AA – Alternatives Analysis
AHP – Analytic Hierarchy Process
CM – Construction Management
DB – Design Build
DBB – Design Bid Build
DBOM– Design Build Operate Maintain
DEIS – Draft Environmental Impact Statement
EXT - Extension
FD – Final Design
FEIS – Final Environmental Impact Statement
FFGA - Full Funding Grant Agreement
FTA – Federal Transit Administration
FTE - Full Time Equivalent
HRT – Heavy Rail Transit
ITP - Independent Testing Program
LF - Lineal Feet
LPA – Locally Preferred Alternative
LRT – Light Rail Transit
MA – Multi-criteria Analysis
MPO - Metropolitan Planning Organization
MSM – Multi-criteria Scoring Model
NTP - Notice To Proceed
PE – Preliminary Engineering
PMP - Project Management Plan
REH - Rehabilitation
ROW – Right of Way
TS – Total Sum
UMTA– Urban Mass Transportation Administration/Federal Transit Administration

EXECUTIVE SUMMARY

This project was funded under the Transit Cooperative Research Program for research into the strategies, tools and techniques available to better manage major transit capital projects. This Executive Summary highlights the major findings and conclusions emanating from this research. These results present various estimation, project management and cost containment approaches that have been applied successfully to projects examined within this research. The results of the research indicate which techniques have contributed to more successful project management in the recent past. These strategies, tools and techniques form the basis to the conclusions for this research.

Research Motivation and Objectives

The persistent underestimation of capital costs for major public transportation projects around the country has raised public scrutiny of the industry's ability to estimate, manage, and contain such costs. The goal of this research project, therefore, was to identify and suggest techniques and strategies to better estimate, manage, and contain the capital costs and schedules of major transit projects over $100 million. Of particular interest to this research was the ability to estimate at the planning and engineering developmental stages, with some desired degree of accuracy, the resulting as-built costs for major federally funded public transportation projects. Recent research has documented this issue as a concern noted across other major transportation modes in the United States and abroad. **Section 1** of this report details these research objectives and technical approach applied in this project.

Literature Search and Data Collection

In order to assess the scope of the project cost underestimation or overrun problem and to identify various strategies and techniques used in the control of cost escalation, it was necessary to conduct a comprehensive literature search and a thorough review of available project documentation. The objective of the literature search was twofold. First, it was to document the current state of the industry in responding to the challenges of cost increases in all of the transportation modes. The second objective was to identify sources of data to support the cost and schedule analysis to size the extent of the cost issues. The literature search helped to formulate these issues and clarify the approach used to analyze them. **Section 2** presents a summary of these sources and their general themes. Although these reports had different objectives, they were used in developing an understanding of the cost factors involved in the increasing costs of projects and/or the underestimating of those costs. **Appendix A** presents an annotated bibliography of the results of this literature search. The conclusions of the various researchers were also used to confirm findings of the case study work.

Project Selection Process

An initial set of over 30 candidate projects was reduced to 28 projects conforming to the basic study requirements—fixed guideway transit projects in excess of $100 million, and with sufficient information to support the cost and schedule analysis. Cost and schedule information was collected from each of these 28 projects to establish the extent of the cost and schedule trends. From the set of 28 projects, the hypothesis testing process suggested the priority projects for more in depth analysis. The TCRP project panel selected a subset of 14 projects from this prioritized list for more detailed study of the strategies, tools, and techniques used to estimate, manage, and control capital costs. The case study project selection was made on the basis of identifying a representative number of projects with varying capital cost experiences and approaches. These projects were then examined in greater detail to understand better their management strategies, tools and techniques used to manage these projects and the results achieved from these management approaches to each of the functional areas. This process is summarized in **Section 3** and discussed in detail in **Appendix B**.

Research Approach

The research team documented cost and project definition information used to estimate the costs and the project estimation, management and cost containment approaches used to manage these costs estimates through the course of the project development process. The team developed a database structure to guide the collection of project capital cost data and an approach for analyzing cost changes by major cost drivers through each of phase of project development. The major cost drivers considered in this analysis were initial inflation adjustment, scope changes (including unit cost and quantity), and schedule changes (including the inflationary impact of project delays).

The phases of project development included:

- Alternatives Analysis (AA)/Draft Environmental Impact Statement (DEIS)
- Preliminary Engineering (PE)/Final Environmental Impact Statement (FEIS)
- Final Design (FD)
- Construction/Operations

The project team then examined nine of these projects in more detail to determine the successful strategies, tools and techniques used by these projects to manage better the capital costs of these projects. **Section 3** identifies these projects, their cost and schedule estimates as they progressed through the project development process and their project definition characteristics throughout this process. This section also analyses capital cost history of these projects by cost driver through all phases of project development.

Appendix C provides descriptions of each of these projects within a consistent framework described in **Section 3**.

Findings and Conclusions

This report has examined the strategies, tools, and techniques to better estimate, contain, and manage capital costs based, in part, on the experience of the case study projects. The literature review and case studies built a foundation for the analysis. The analytical structure was shaped by the hypotheses. The extent of the cost and schedule increases encountered in major transit projects has been defined through the project analyses. The related factors and causes behind cost escalation have been identified through the case study analyses. The combination of all of these has shaped the following conclusions to this research.

Project Definition

Project definition entails the conceptualization of the alternatives and the refinement of this project definition through the course of the project development process. The inception and evolution of a project can have a large impact on the capital costs. In particular, the level of design is an important factor affecting the uncertainty of the capital costs and the subsequent variation in the estimates.

Clear cost priorities, established early in project development, are important to cost and schedule performance. These should be reflected in the initial evaluation of alternatives. Establishing clear budget and schedule constraints early in the project development process helped contain scope creep and identify reasonable project development schedules. However, some flexibility with respect to scope and schedule should be maintained in the project development process to adapt to the more unique project conditions identified throughout the development process. This flexibility combined with appropriate budgetary targets and reasonable developmental schedules formed the successful factors in project definition.

Several of the case studies point out that some of the most difficult risks to capital costs and schedule are time to achieve political consensus and the acquisition of private property. As part of the project development process, it is important to manage public expectations and communicate the tradeoffs between scope, cost, and schedule in order to control scope creep. Outreach to community and businesses is important to minimize project redefinition and maximize support. It is also crucial because of the influence of the political process in defining and funding major transit projects. This can be achieved through a transparent alternatives analysis process and clear communication of the project refinement in the engineering process, and its effect upon the capital cost estimate. In summary, while engineering issues were encountered, these were controllable. The larger impacts that were both unexpected and less controllable were the stakeholder, third-party, and real estate acquisition issues and their impacts upon the project definition.

Other project definition strategies that contributed to the control of cost and schedule were value engineering and design-to-budget. Value engineering activities at each phase of project development helped to control project costs by refining the design in consideration of project cost factors. A design-to-budget approach begins design with a fixed budget in mind. This strategy also appeared to contribute to better cost and schedule control and cost containment results.

The project definition strategies that contributed the most success to the project definition process were a transparent development process with extensive stakeholder input, a reasonable project development schedule that reflects sufficient time for stakeholder outreach, a value engineering exercise at each stage that reconsidered the definition results to that point, and a design to budget approach that maintains budgetary considerations within each stage of project development.

Procurement

Within the sample set of projects, the reasons for selecting a particular method of procurement varied from past experience with the chosen method, state and local procurement regulations and interest in achieving a compressed developmental schedule. Design-build and a variant, construction management at risk, offers some potential cost and schedule savings opportunities through consolidating design and construction management with the construction contractor, and reducing agency procurement and project management requirements. However, these savings can be offset by increased project definition to more clearly establish the project expectations before final design is complete. The construction management at risk approach also offers similar consolidation of construction and installation contracts without the inclusion of the final design to gain some of the schedule compression and procurement reductions, and without some of the project definition concerns of design-build. Many of these more recent approaches to project delivery are still under refinement, but seem to offer measurable benefits to the completion of projects within planned schedules and closer to initial cost estimates. The refinement of these approaches may still take additional time.

Other procurement techniques include prequalification of contractors and industry review of contract documents. Prequalification helps to ensure quality and past performance of the contractors. The industry review helps to improve the contracting terms and project management approach within the project cost objectives. Incentives and penalties may also offer some advantages to the project development process, but concerns were raised about the impacts of these measures. The benefits of these procurement incentives were highlighted, but could not be demonstrated through these higher level cost results.

Project Organization

It was found that having a common goal between the owner and contractors of building a high-quality and safe project on time and within budget ensured a successful project outcome for all parties. The approaches to roles and responsibilities to achieve this were varied. However, the following organizational concepts seemed to be in common:

- Develop a good and amicable working relationships with other third-party organizations and the contractor through partnering
- Select and maintain the right staff with dedication to the project
- Limit distractions and identify priorities
- Emphasize leadership attention, involvement, and support including senior staff from all owner and contractor participants, plus ongoing outreach with stakeholder representatives
- Partnerships with contractors and stakeholders helped develop a common sense of project ownership.

These can be achieved through equitable sharing of the responsibilities and credit for project successes.

Capital Cost Estimation

Cost and schedule estimation are important functions during all phases of the development cycle. The importance of good early cost and schedule estimates are particularly important, since they often set internal and external expectations. At the same time, there are greater cost and schedule uncertainties during the planning phases of a project. This is the complex often faced by the cost estimators. Lack of sufficient project definition to estimate capital costs at a higher confidence level.

Most projects used a deterministic cost estimating method. This approach synthesizes hundreds or even thousands of assumptions into one estimate for cost. The deterministic method uses many sources and data points that can account for varying underlying assumptions. As the project develops it is quite difficult to maintain control over these many interrelated project characteristics. Change in individual aspects can have substantial affect upon the cost estimate, yet consistent management of these various project characteristics and maintenance of these impacts upon the cost estimate is illusive.

One of the techniques most mentioned for better cost estimation was the development and maintenance of historical bid estimates on a unit basis. This source of cost information was noted as a good comparative source for these actual as-built costs. These were used to compare with the cost build up estimates developed at the engineering level to ensure full inclusion of all project requirements and use of reasonable unit cost estimates.

A probabilistic cost and schedule estimation approach integrated with a detailed risk assessment process may better convey the assumptions involved in the cost estimate and the risks reflected in the cost estimate. This approach was developed as an improvement to the deterministic cost estimation approach to focus better upon the key risk items and the project unknown affects upon the project capital cost.

Project Management

Project management controls include contract mechanisms for schedule, quality, claims, testing, change orders, subcontracting, progress payment, and closeout. They are also defined by the roles and responsibilities of the owner and contractor, with the aim of ensuring the successful implementation of the project. Project management controls are thought to be influenced by:

- Nature of the project (e.g., technology, complexity)
- Type of contract (e.g., ownership, financing)
- Size and scope of the project
- Experience of owner agency staff
- Project setting (e.g., new start project or extension of an existing line)

The functions of project management control include: project budget and schedule control, change order and claims management, quality assurance and quality control and risk management.

Project Budget and Schedule Control

Project budget and schedule control are functions performed by the management, scheduling, and accounting systems. The related functions include verifying budget to actual costs, level of detail and separation in work breakdown structure, consistency with schedule and progress reporting, and the requirements included in subcontractors' contract terms and clauses. Project schedule management also considers contractor and agency interface, response capabilities, and incentives and disincentives including implications for payment.

These budget and schedule control functions have become increasingly important to the process as the computer systems capabilities have increased. More control is exercised through these systems and they are providing increased visibility into these issues. Reporting the contractor's cost and schedule performance within an electronic format on a monthly basis with the major milestones identical to those in the master schedule provides essential oversight of the budget within detailed task basis. This process has been reported to be contributing to improved cost containment performance and focus upon the risk issues in a timely basis.

However, as evidenced by these results, the schedule control and payment strategy did not determine the success of the project in maintaining either. The contractor results were slightly better when they were assigned responsibility, but only nominally. The actual schedule control and payment strategies appeared to have better performance when the payment approach was tied to specific schedule and cost outcomes. Whether the agency or the contractor, or a shared relationship was used, the outcome was more determined by the quality of the approach rather than the specific approach to schedule and cost control.

Change Order and Claims Management

Scope changes should be defined early, estimated, negotiated, and settled in an expeditious manner. Ideally, the project has estimation staff based on site along with regular support from the engineering and procurement staff for claims negotiations. Design costs can be controlled by releasing the change order for design only with review milestones, if possible. In addition, clear definition of the review process with timely responses was viewed as essential.

Most agencies reported that, as a first step, claims were initially addressed through bilateral negotiations. Most projects had contractual provisions for an alternative dispute resolution board or the like, but only two projects used it. The five projects that used alternative dispute resolution or had provisions for it appeared to exhibit better average cost variance due to scope or schedule changes.

Timeliness of responses to proposed changes is essential. A project may also have an expedited review process available in case schedule adherence is threatened. An attempt was made by some projects to resolve all claims at the lowest level possible unless there was disagreement. Empowering the field staff while maintaining adequate financial authorization is important for fast resolution to issues arising during construction.

Quality Assurance

Addressing quality issues at an early stage helped avoid unnecessary complications. Several innovative quality approaches were identified, including application of a QA/QC manual, a just-in-time training program, preparatory phase inspections, an independent testing program, and use of specific metrics to monitor and recognize contractor's effort on quality.

Risk Management

Risk management entails the comprehensive identification, assessment, and mitigation of risks and responsibilities to the parties involved at early stages of project development, and the subsequent monitoring of these identified risks throughout the project development process. The assignment of the risks to the contractor or agency (or shared responsibilities) and the subsequent division of risk management roles and responsibilities between the owner or agency and the contractor is a key consideration. Risk mitigation is aided through the assignment of individual risks to the party best able to manage it. Also, assignment of blind risks to the contractor does little to minimize cost risk and much to increase bid premiums. Recent federal policies have begun requiring detailed risk assessments for major transit projects. Moreover, relating the risk assessment process to the development of specific line item construction contingencies may be an important step in the development of the risk assessment process. The process to combine these aspects of risk identification, mitigation and management is being refined through much testing and experimentation within the projects. The expectation is that a consolidated process will evolve that considers this entire risk management process within the cost containment objective.

Strategies, Tools, and Techniques

The following conclusions address the five questions originally raised in the research plan. These potential improvement strategies draw from the case studies performed as part of this report. Where possible, supporting statements have been included from the case studies and the literature review.

1. **What can local project sponsors do to estimate costs and schedules reliably at the alternatives analysis, preliminary engineering, final design, and construction phases?**
    - **Use Reasonable Starting Assumptions** – In the early phases, it is imperative that sponsors establish a realistic project scope and schedule based on actual needs and known constraints (e.g., budget, deadlines, regulations). These estimates often set initial expectations and form public opinion. A better-defined scope and

schedule can help minimize uncertainties during estimation. When uncertainties are unavoidable, it is imperative to communicate the assumptions and limitations of the estimates in a way that is easily understood. These uncertainties could also be accounted through targeted contingencies.

The means to accomplish this are to support continued research into the actual costs and schedules of these projects. Early risk assessments could also provide a method to achieve this. This continued research into the actual schedules and as-built costs will help to ensure realistic schedules can be used, as-built unit costs are available, and all of the typically required project scope items are identified for project planners and engineers. Also, these data should be accessible and updated periodically.

- **Improve Estimation Quality** – The case studies show that estimates can be improved in all phases of development using formal estimation manuals and through reviews or validations that are comprehensive and independent. Cost estimation data, or as-builts, from previous projects may be shared or pooled to improve overall data quality and reduce uncertainty as noted above. The cost estimation staff should consistently represent the disciplines of the wider project team, including senior staff, and use formal cost estimating models or systems.
- **Increase Estimation Transparency** – A process that involves the public and is clear to all stakeholders at all phases is more likely to produce reliable estimates. Documentation on estimate assumptions and methodologies that are available to the stakeholders and public may attract wider support and less risk of future change later in the project development process. Moreover, the integrity of the cost estimation can be assured by a system of checks and balances through the use of independent cost estimators, risk assessment processes, independent value engineering processes, and formal cost estimate validation processes. Also, an incentive structure can be developed and implemented to encourage agencies to have more accurate project estimates; and possibly accelerate the project review process.

2. What can local project sponsors do to contain project costs and schedules at each phase?

- **Optimize Project Parameters** – It is important for all project stakeholders to recognize the tradeoffs and interrelationships between scope, schedule, and quality to cost. During the alternatives analysis and preliminary engineering phases, several optimization techniques have proven to be effective at increasing the project's overall "value proposition" by containing costs while not significantly compromising scope, schedule, quality, or the anticipated benefits. Among these techniques are design-to-budget, value planning, value engineering, and risk assessment approaches.

- **Apply a Broad Range of Project Management Controls** – During implementation, the scope, schedule, and QA/QC controls used by project managers varied but usually included each of the following elements:
  - **Problem Resolution** – The quality testing process needs to focus on resolution of the root cause rather than solely on the symptoms.
  - **Efficient Processing** – Changes could be identified early, estimated, negotiated, and settled in an expeditious, pre-defined process. The change order and claims management process should be clear and fair to all parties.
  - **Appropriate Incentive Structure** – Incentives and penalties can be applied to payment mechanisms for schedule management or change order processes to empower staff with appropriate authority for change control. These incentives need to be crafted carefully to focus the effect on the quality outcome and limit the contractor payment without measurable progress.
- **Create an Effective Organization** – The project organization must ensure that responsibilities and risks are placed on the parties that can best affect them. It must also ensure that there is an appropriate level of technical capacity. The effective organization may be achieved through partnering and a dedication to continuous open communications between the owner (including Board of Directors), contractors, consultants and FTA representatives. Integrating the project team in both design and construction can also enhance project ownership. These concepts have shown to be beneficial in several case studies.

3. What can local project sponsors do to complete projects within their estimated costs and schedules?

- **Select the Appropriate Delivery Method** – The selection of the appropriate procurement and delivery method is important to the success of the project development. This selection is best based on the desired level of responsibility, risk, control, expertise, and scope flexibility. With the many procurement approaches available, this assessment of the project characteristics and agency culture can form the basis to this decision. The delivery method may impact cost and schedule by affecting the required level of project management, oversight, and construction management. Public-private partnerships are a recent positive trend.
- **Recognize the Tradeoffs in Contracting** – A single larger contract may decrease competition and increase construction prices in the local market. Multiple smaller contracts increase competition, but also increase the number of potentially costly project interfaces and management complexity. The right balance must be struck to ensure that projects are segmented appropriately and to take advantage of different delivery methods, technical capabilities, project characteristics, and local market conditions.

4. **What changes outside of the direct control of project sponsors could foster the reliable estimation of project costs and schedules?**

   - **Improving Estimation Consistency** – Standard procedures for estimation in the industry may help minimize the inconsistencies observed in estimates. One example is the standard use of YOE dollars for reporting capital cost estimates with realistic schedule assumptions. A consistent and appropriate basis for cost estimation can also help lessen the problem of incompatible estimates between projects and the impact of missed project elements and low unit costs. The omission of some relevant project elements and their reasonably expected unit costs, particularly in the early phases of project estimation, has been a contributing factor to the negative public perception of large cost overruns. Building a cost and schedule database of as-built costs using a consistent capital cost database structure could contribute to improving cost estimation consistency.

   - **Communicating Uncertainties and Limitations in Estimates** – Some uncertainty cannot be avoided, and estimates must reflect all relevant project risks. Deterministic cost estimates with general contingency factors are a crude way of recognizing the expected variability. A detailed, probabilistic risk assessment is becoming a more common and accepted method of identifying risk factors and quantifying their potential impact on project development. The recent federal requirement of a formal risk assessment process could improve both the reliability and public confidence in project cost estimates. A consistent process that links these identified project uncertainties to a focused risk management process could be one improvement opportunity. This would formalize the risk process into identification, quantification, allocation, mitigation, and management. One example of a formal risk assessment approach used in Washington State is the Cost Estimate Validation Process (CEVP)™. The subsequent development of construction phase cost contingencies related to the remaining risk items may be the appropriate direction for increasing the reliability of the project cost and schedule estimates.

5. **What changes outside of the direct control of project sponsors could help contain the costs and schedules of major public transportation projects?**

   - **More Effective Public Outreach and Stakeholder Engagement** – In general, projects are recognizing that early and constant communications with stakeholders maximize public support and build political consensus. However, this effort could be made more effective by enhancing the public understanding of the basic tradeoffs between project scope, schedule, quality, and costs. Although these tradeoffs are sometimes dependent on specific project conditions, it may be more effective to establish and promote a common framework for communicating project constraints to all stakeholders. In this manner, project sponsors can more clearly explain to stakeholders the reasons for any cost variability through the phases of project development. The charts developed for the case studies and presented in **Appendix C** is one example of such a framework. This framework can also include presentation materials regarding the modal options, the more specific project characteristics of station layouts, vehicle and systems options, and the challenges of third-party expectations from the project. With increased availability of as-built cost and schedule databases, the cost impacts of these options can better guide the public debate on these options.

- **Improved Funding Mechanisms** – As federal funding for new projects has declined on a percentage basis, local, state, and private funding and public – private partnerships are becoming more common in transit project development. This trend may help to better control project costs and schedules because it introduces greater accountability at the local level, However, funding mechanisms can be improved by adding flexibility in order to meet the needs of new project delivery mechanisms developed to supplement the decline of federal funding. Funding needs are greater for the design-build project delivery options to meet the specific delivery payment schedules and the combined sizes of the contracts.

Future Research

This section presents several ideas for continued research efforts into this important area of cost estimation, management, and control, and the advancement of certain ideas identified throughout this research.

Continued Study Research

Ideas for continued study research efforts include:

- Expand the sample size for the project cost and schedule analysis to build a more statistically reliable basis
- Complete more case studies into the more successful tools and techniques used to control cost and schedule
- Develop an outreach workshop of interested project development experts to contribute to the identification and validation of tools and techniques and their application process.

Transit Research

Ideas for transit research efforts include:

- Continue to refine the consistent database structure for all capital cost and schedule reporting requirements throughout the project development process
- Develop the guidance necessary to require all project cost and schedule reporting to conform with that structure
- Develop a uniform project element structure for this project data and provide element definitions for it's context within the cost estimating and historical bid cost databases.
- A "basis of estimate" document can then be developed from this
- Continue and enhance the documentation of the as-built cost and schedule databases
- Expand the analysis capability of these databases to examine project cost risk items and values
- Increase the development of the risk assessment process:
  - Analyze technical analysis process improvements
  - Capture schedule risks
  - Better link the risk items to the project budgetary line items
  - Examine the optimal roles and responsibilities within the process
  - Consider the scheduling of the assessment efforts to coincide and better support the project development process
  - Examine the potential application of the risk estimates as construction cost contingencies
- Review current project management oversight guidance procedures to look for opportunities to emphasize cost and schedule management within the process
- Examine the potential application of the cost validation processes, such as the CEVP™, to the transit project development process.

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1. INTRODUCTION

The persistent underestimation of capital costs for major transportation projects around the country has raised public scrutiny of the industry's ability to estimate, manage, and contain such costs. Of particular interest to this research was the ability to estimate at the planning and engineering developmental stages, with some desired degree of accuracy, the resulting as-built costs for major federally funded public transportation projects. Recent research has documented this and other issues of concern across not only public transportation, but all other transportation modes in the U.S. and abroad. This issue has been highlighted in all other public infrastructure modes, including highway, rail and maritime modes.

A number of possible causes to this inability to accurately estimate, manage, and control project costs have been suggested, including:

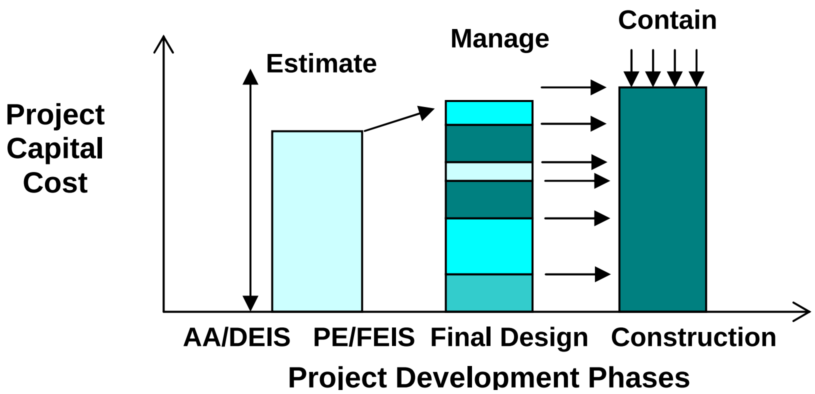
- Economic and market conditions
- Unforeseen engineering and construction complexities
- Relevant costs not included in early estimates
- Organizational and technical capacity to undertake the project
- Procurement approaches
- Relationships among the owner, engineer, construction manager, and cost estimator
- Changes in project scope
- Changes in regulatory requirements
- Local governmental concerns and requirements
- Third-party expectations and requirements
- Community design change expectations.

These potential issues are explored in the literature review (**Section 2** and **Appendix A**), applied in the case study analysis (**Section 3**), and considered in the evaluation of strategies, tools, and techniques for cost estimation, management, and control (**Section 4**). **Appendix B** describes the project selection methodology. **Appendix C** includes case studies of 28 projects. Finally, **Appendix D** synthesizes all case study responses to a survey of strategies, tools, and techniques for cost estimation, management, and control. The conclusions of the report are presented in **Section 5**.

1.1. Research Objective

The goal of this research is to identify and recommend techniques and strategies to better estimate, manage, and contain the capital costs and schedules of transit projects over $100 million. **Figure 1-1** conceptually illustrates the functions of estimation, management, and containment of capital costs over a basic project life cycle from system planning to construction. To better understand the opportunities available to better estimate and manage the costs of these projects, both federally funded and non-federally funded projects were included in this study.

Figure 1-1. Concepts of Estimation, Management, and Containment



Estimation involves the forecasting of costs using the best and most accurate information available on project components, quantities, unit costs, and implementation schedules. Quite often, the estimation process focuses mainly on the accuracy of the unit cost and quantity estimates. The research team has accounted for the full project definition, including the addition and deletion of components, the modification of quantities, and the accurate estimation of the project schedule or its subsequent delay. The cost increase issues identified in this research that were most often encountered in the planning and engineering of a project include:

- Underestimated unit costs
- Omission of necessary components
- Exclusion of components that stakeholders add later
- Unforeseen conditions
- Extension of the project delivery schedule due to many types of delays.

These issues were identified in earlier cost analyses and are used this study as considerations for the collection of the data, analysis of cost and schedule data, and preparation of the case studies. The cost estimating efforts throughout the entire project development process are focused on being inclusive of all components, accounting for unique project conditions, managing this project definition, and then containing any growth in the project definition (scope creep) in the construction phase.

Effective management of capital costs comprises activities to maintain or optimize specific expenditures of the multiple project components, and to allow justified owner-directed changes and contractor claims to the project definition.

The focus of the construction and implementation phase is on containment of the actual costs according to the project plan refined over the project's development life cycle. The research approach reflects these aspects of cost estimation by tracking the project costs, definitions, quantities, and schedules, and documenting the changes in each throughout the project development process.

1.2. Federal Project Funding

Federal funds for these projects came from the Federal Transit Administration’s (FTA) New Starts and Rail Modernization Programs, and matching funds from state and local sources. The federal New Starts Program is intended for investments in new fixed guideway alignments and extensions to existing fixed guideway systems. The program provides discretionary funding for these projects. The Rail Modernization Program provides formula funding for the rehabilitation and replacement of existing fixed guideway systems. Since this is a formula program, individual project budgets are smaller and not estimated or tracked individually throughout completion at the federal level. Major capital projects with well-documented estimated and actual project budgets, therefore, reside within the New Starts Program.

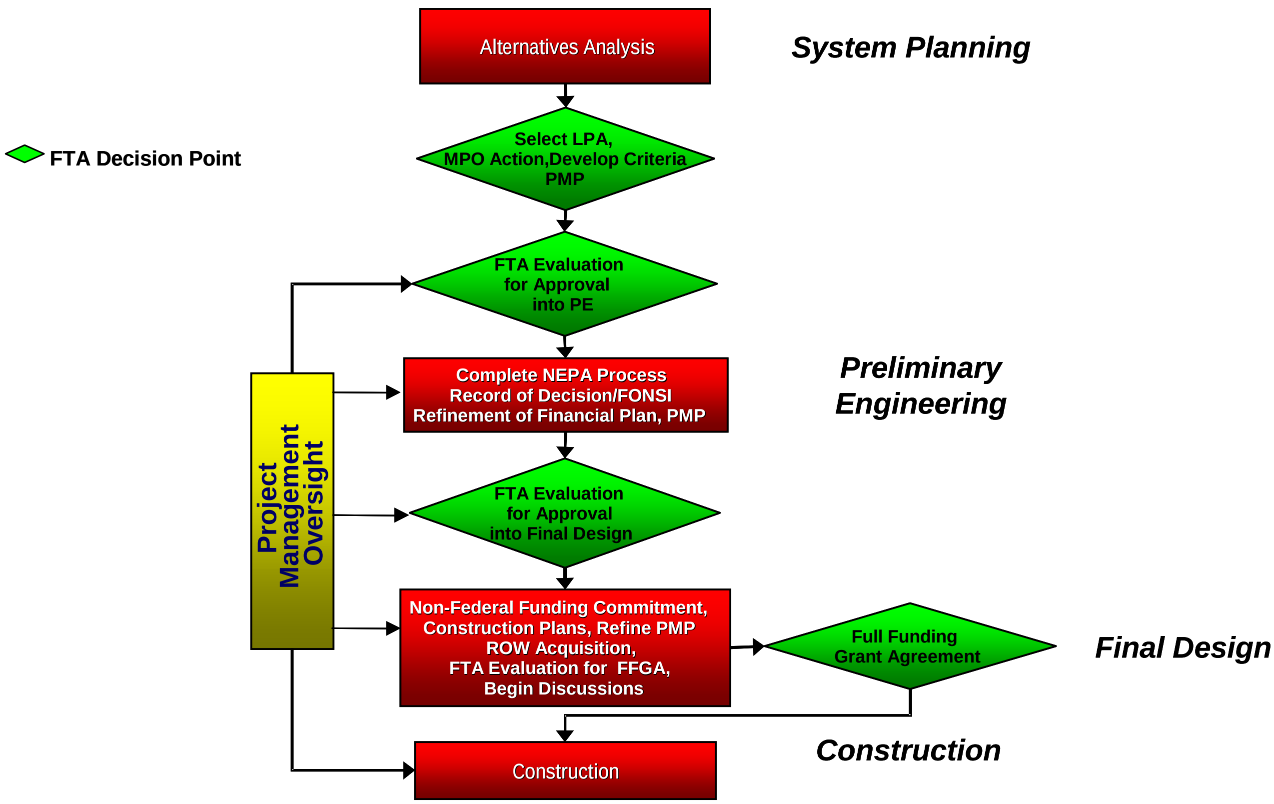
FTA New Starts, the largest discretionary federal program for funding major new capital investments in public transportation, includes several decision points for proceeding, as illustrated in **Figure 1-2**. The process has been depicted graphically following the four stages of project development (rectangular boxes)—System Planning or Alternatives Analysis/DEIS, Preliminary Engineering/FEIS, Final Design, and Construction. The diamonds identify the FTA decision points for entry into each stage. Project developmental aspects and the capital cost estimates at each stage are critical inputs to the FTA decision-making process.

The capital cost estimates at each stage of project development were used to establish a baseline and trend for the estimates, project development schedules, and quantities of each asset type through the development process and into project implementation.

Sponsoring agencies are required to submit documentation, including detailed estimates of project capital costs, for evaluation by the FTA under the New Starts Program process and within the Project Management Oversight (PMO) process. One of the goals of these activities is to ensure reasonable estimation, management, and containment of capital costs.

The study approach considers these decision points and the required reports as a key information source for tracking estimated project costs, definition, and schedule. The project cost estimate varies along this path with unit cost estimates, quantities of project definition, and the project schedule duration. As each of these measures varies, so does the project cost estimate. Whenever possible, these critical variables were tracked along the project development process to document changes and their contribution to the difference between project cost estimates and the actual, as-built costs.

Figure 1-2. FTA New Starts Project Development Process



1.3. Research Approach

Project cost data for a wide range of candidate projects was collected. Specifically, this work collected project cost and related data for 28 major public transportation projects of over $100 million completed in the last 15 years. For each project, the research team collected the cost and cost-related data for as many project phases as were available, including project planning/DEIS, preliminary engineering/FEIS, final design, construction, and initial operations. In addition to documenting the costs for each major project element at each phase, this data collection effort also documented, to the extent available (14 of the 28 analyzed projects), the total unit quantity of individual elements associated with that cost estimate/actual cost for each phase and also the year in which the phase cost amounts were reported (e.g., $2002).

An initial analysis of the data was intended to serve two primary functions. The first was to help identify projects with sufficient cost and related data to support the needs of this project. The project's analytical approach required cost and unit quantity data of sufficient quality and detail to identify both the individual sources of project cost increases (e.g., increases in unit costs and changes to unit quantities by cost element) and the magnitude of those increases.

The second primary function of the initial data collection effort was to identify projects that represent productive case study selections. Hence, while a quality data set was required to support the analysis effort, it was also crucial that the selected case study projects offer useful lessons learned regarding those factors that tend to drive changes in project costs over the life of a project and illustrating various levels of success in predicting and managing project costs throughout the life of the project.

1.3.1. Project Capital Cost Analysis

Following the completion of the initial data collection effort, the research team developed a set of standard project summary charts that profile the cost and schedule histories for all 28 case studies. Specifically, each project case study described in **Section 3** and presented in **Appendix C** shows how the total cost for each project changed from planning through project completion. The case studies also highlight the primary causes of these cost changes including changes in project scope (unit costs and quantities) and schedule.

The second portion of the project analysis included a more detailed analysis of a subset of case study projects using their responses to an interview guide, as presented in **Appendix D**. In support of the goal of this research to identify strategies, tools and techniques for better cost estimation, management, and control, this analysis related the use of specific tools and techniques to the cost and schedule performance of projects.

The underlying cause and effect of cost increases was closely examined by collecting detailed cost and schedule estimate data for the nine case study projects throughout the various phases of the project development process. A typical transit project development lifecycle included the following phases and milestones:

- Alternatives Analysis with a Draft Environmental Impact Statement (DEIS)
- Preliminary Engineering with a Final Environmental Impact Statement (FEIS)
- Final Design (culminating in a Full funding Grant Agreement if federally funded)
- Construction or operation of the system

Project cost estimates are prepared during each phase of a project. As completion of each subsequent phase provides more scope and level of detail, the accuracy of the cost estimate improves. This, in turn, reduces the variance in cost estimates from the actual completed project costs. The potential for cost growth varies among project components. A conceptual estimate for such a project calculates the sum of costs for various project components such as guideway, stations and facilities construction, vehicles, systems project management, etc. The structure of the database has been defined to capture the change in unit costs, component quantities, project definition, and project schedule.

The sample database structure in **Table 1-1** shows only the initial alternatives analysis phase. The three columns of quantities, cost, and midyear of construction were similarly collected for the three other project development phases. The cost information for these phases was collected at the conclusion of each phase. Therefore, the completion of the construction/operations phase represents the as-built or completed project capital costs. The capital cost database structure is based primarily on the FTA Capital Cost studies (completed by Booz Allen Hamilton in 1991, 1994, 2003, and 2004) and parallels the structure of the FTA Standard Cost Categories. The database provides a sound structure for project cost breakdown that can be used in performing project case studies.

This database is similar to that used in the FTA's extensive research of as-built capital costs for major U.S. transit projects, but is updated with capital costs of more recent projects. Improvements to the previous database included the development of a cost and variance analysis model of the individual project cost estimates by line item. For each cell of this matrix, the model can estimate the variance in estimated and actual costs, and the variance with other projects. Using these differences, the project team was able to identify which components were more prone to estimating inaccuracies or cost overruns. These differences are presented in Appendix C, Case Study Project Descriptions, for each of the 14 projects with detailed cost and quantity information by project category. Careful consideration was given to differentiating between project scope and schedule changes, and cost growth for other causes such as, component category omission or inadequate cost estimating techniques.

In addition to the database structure and definitions presented in **Table 1-1**, the data collection strategy focused on obtaining descriptive data designed to differentiate the reasons for cost increases between project phases. These reasons ranged from changes to project scope and schedule to incomplete information. All observed causes of cost increases were documented and later classified into cost categories in a consistent data classification structure. The cost impact of the categorized causes or drivers were then analyzed over the life of a project (or across many projects) to offer insight into effective strategies for cost estimation, management and containment.

Table 1-1. Sample Project Capital Cost Database Structure

FTA FIXED GUIDEWAY CAPITAL COSTING SYSTEM CAPITAL COST DATABASE	**Units of Measure**	**Planning/Alternatives Analysis/DEIS Phase**		
		Select City:		
		Quantity	**Total Cost**	**Year**
0.00 TOTAL PROJECT COST	*L.F. Guideway*	**0**	**$0**	**0**
0.01 PROCUREMENT TYPE	DB / DBB			
0.02 NEW/EXTENSION/REHABILITATION	NEW/EXT/REH			
0.03 PROJECT DEVELOPMENT SCHEDULE IN TOTAL	Total Months			
0.04 SERVICE HEADWAY - PEAK/OFF PEAK				
0.05 RIDERSHIP	Unlinked Trips			
Peak Period - Peak Direction	Unlinked Trips	0		
Maximum Ridership Capacity - Peak Hour, Peak Direction	Unlinked Trips			
0.06 REVENUE ONE WAY TRAVEL TIME END TO END	Minutes			
0.07 STAFFING	FTE's			
1.00 GUIDEWAY ELEMENTS	*L.F. Guideway*	**0**	**$0**	**0**
1.01 AT GRADE GUIDEWAY	L.F. Guideway	0	$0	
1.02 AT GRADE-IN-STREET GUIDEWAY	L.F. Guideway	0	$0	
1.03 ELEVATED STRUCTURE GUIDEWAY	L.F. Guideway	0	$0	
1.04 ELEVATED FILL GUIDEWAY	L.F. Guideway	0	$0	
1.05 UNDERGROUND GUIDEWAY	L.F. Guideway	0	$0	
1.06 RETAINED CUT GUIDEWAY	L.F. Guideway	0	$0	
1.07 TRACKWORK	Track Feet	0	$0	
1.08 GUIDEWAY-SPECIAL STRUCTURES	L.F. Guideway	**0**	$0	
2.00 YARDS & SHOPS	*Rev. Vehicle*	**0**		**0**
3.00 SYSTEMS	*Track Feet*	**0**	**$0**	**0**
3.01 SIGNAL SYSTEM	Track Feet	**0**		**0**
3.02 ELECTRIFICATION	Track Feet	**0**		**0**
3.03 COMMUNICATIONS	Track Feet	**0**	$0	
3.04 REVENUE COLLECTION	Station	**0**		**0**
3.05 CENTRAL CONTROL	L.F. Guideway	**0**	$0	
3.06 ELEVATORS / ESCALATORS	Each			**0**
4.00 STATIONS	*Station*	**0**	**$0**	**0**
4.01 AT-GRADE	Station	0	$0	
4.03 CUT AND COVER	Station	0	$0	
4.05 BORED SUBWAY	Station	0	$0	
4.07 ELEVATED	Station	0	$0	
4.09 PARKING LOTS & GARAGES	Spaces	0	$0	
4.12 BUS, AUTO, PEDESTRIAN ACCESS	Station			
4.14 SIGNAGE & GRAPHICS	Station	**0**	$0	
5.00 VEHICLES	*Rev. Vehicle*			
6.00 SPECIAL CONDITIONS	*L.F. Guideway*	**0**	**$0**	**0**
6.01 UTILITY RELOCATION - AS IS	L.F. Guideway	0	$0	
6.04 DEMOLITIONS	L.F. Guideway	**0**		
6.05 ROADWAY CHANGES	L.F. Guideway	0	$0	
6.06 ENVIRONMENTAL MITIGATION	L.F. Guideway	0	$0	
6.07 LANDSCAPING	L.F. Guideway	0	$0	
6.08 THIRD-PARTY AGREEMENTS	L.F. Guideway	0	$0	
7.00 RIGHT-OF-WAY	*L.F. Guideway*	**0**		**0**
8.00 SOFT-COSTS	*Total*	**$0**	**$0**	**0**
8.01 PLANNING/FEASIBILITY STUDIES	Total	$0	$0	
8.02 PRELIMINARY ENGINEERING & DESIGN	Total	$0	$0	
8.02 FINAL DESIGN	Total	$0	$0	
8.03 CONSTRUCTION MANAGEMENT	Total	$0	$0	
8.04 PROJECT MANAGEMENT	Total	$0	$0	
8.05 PROJECT INITIATION	Total	$0		**0**
8.06 FINANCE CHARGES	Total	$0	$0	
8.07 TRAINING/START-UP/TESTING	Total	$0		**0**
8.08 OTHER SOFT COSTS	Total	$0	$0	

1.3.2. Hypotheses

Project costs increase due to a variety of causes. A critical aspect of the research team's analysis was to isolate these causes of cost increase, as a step toward identifying the strategies and techniques available to help improve the estimation, management, and containment of the cost estimates throughout the project development process. Of particular interest to this research was the ability to estimate, with some desired degree of accuracy, the final as-built costs for major federally funded public transportation projects at a relatively early stage of project development. Recent research has highlighted this concern and the related issue of cost containment throughout project development—not just in the public transportation industry, but also across other major transportation modes in the U.S. and for similar transportation projects abroad. These concerns have been confirmed through our literature search.

Based on these and other related concerns, the research team initially formulated a set of hypotheses on the reasons for overruns in total costs for major transit capital projects. Specifically, the project team structured the research to test the following hypotheses according to the phase of project development:

- **Hypothesis 1** – Project costs are underestimated during planning.
- **Hypothesis 2** – Project costs are increased at the preliminary engineering phase to account for:
  - Project elements excluded from the cost estimate
  - Underestimated project quantities
  - Underestimated unit costs.
- **Hypothesis 3** – Project costs are increased at the final design and construction stages due to:
  - Project modifications (scope creep).
  - Project elements excluded from prior cost estimates
  - Underestimated components costs.
- **Hypothesis 4** – Project costs are increased at the start of construction to account for:
  - Underestimation of the inflation due to project development schedule delays
  - Unforeseen conditions encountered.
- **Hypothesis 5** – Complex projects experience cost escalation. Complexities may include:
  - Tunnels and elevated structures
  - Contingencies underestimated and/or applied inconsistently
  - Unforeseen conditions encountered.

These hypotheses are described in greater detail in **Appendix B** and presented in the context of the selection of candidate projects. These hypotheses are also used in **Section 5** to relate the research findings and conclusions to these initial precepts regarding cost escalation for federally funded major transit projects.

After identifying hypotheses, the project team developed a process for testing them. Specifically, each hypothesis was tested using the following 4 step process:

1. Define hypothesis
2. Identify related cost increase factors and causes
3. Identify relevant cost drivers
4. Recommend potential improvement opportunities

An example of how this testing structure can be applied to a specific hypothesis is illustrated in **Figure 1-3**. Note that this structure is specifically designed to capture the interrelationships between each hypothesis, the associated cause or causes, the cost drivers or metrics required to measure the impact of each individual cause, and, finally, the identification of potential strategies and techniques to mitigate each cause. The intent of this hypothesis testing was to structure the analysis process and maintain consistency across projects and individual hypotheses. This was not intended as a statistical testing process to accept or reject the hypotheses.

From the example provided, it is clear that one or more causes or issues can be associated with each hypothesis, one or more metrics can be used to measure the impact of each cause, and one or more strategies can be associated with all preceding steps (working backwards—metrics, causes, and hypotheses). For example, project costs could increase during preliminary engineering due to desired changes in guideway alignment (vertical or horizontal), unforeseen geotechnical conditions, failure to include important cost components (e.g., project insurance), and/or unexpected environmental mitigation needs. In turn, each of these outcomes could impact project unit costs (e.g., increase in the cost of elevated guideway due to increased vertical profile), unit quantities (e.g., revised alignment causing increased use of elevated guideway feet and decreased at-grade feet), and development schedule (e.g., increased environmental mitigation and outreach efforts). Many improvement opportunities thus relate to causes and cost driver measures.

Finally, it is important to note that the relationship between the individual hypotheses and subsequent causes, metrics, and strategies is far from unique. These interrelationships underscore the critical need to document, as accurately as possible, the precise reasons for individual cost increases (as permitted by the available data) and the phase in which these increases occurred in the project development process (e.g., during alternatives analysis, preliminary engineering, final design, and construction).

Figure 1-3. Example of the Hypothesis Testing Relationships

Hypothesis Testing / Process Improvement Flow

Process Step	**Define Hypothesis**	**Identify Relevant Cost Factors / Causes of Cost Increases**	**Identify Relevant Cost Drivers**	**Identify Potential Improvement Opportunities**
Step Description	*Define hypotheses stating why project costs may be underestimated at specific points in the project development cycle*	*Identify specific reasons why costs may have been underestimated*	*Identify one or more quantitative measures that can be used to measure the impact of each cost factor on total project cost*	*Identify potential techniques and strategies to improve project cost estimation and cost containment*
Examples	I. Project costs are minimized (underestimated) at the planning phase	I. Change to Project Definition: Insufficient data were obtained to properly define alignment location (vertical and horizontal), ridership potential, facilities capacity, etc.	I. Unit Quantities: Have unit quantity values increased / decreased from one project stage to the next? Has the proportion of grade separated investment (e.g., subway guideway, above-grade stations) increased?	I. Devote increased cost evaluation resources to those project components with the highest cost risk (e.g., below/above grade components, geotechnical conditions, ROW acquisition costs, utilities relocation / betterments).
	II. Project costs are increased at the preliminary engineering phase	II. Unforeseen Conditions: Insufficient data were obtained to properly define geotechnical conditions, utility relation needs, etc.	II. Unit Costs: Have unit cost values increased/decreased from one project stage to the next?	II. Conduct independent cost reviews at all stages of project development
	III. Project costs are increased at the final design and construction stages	III. Missing Cost Elements: Prior period cost estimates excluded required cost components (e.g., project insurance, project management)	III. Schedule: Has total project development time increased?	III. Ensure early project definition conforms to corridor needs (e.g., ridership potential, activity center locations) and physical characteristics (existing roadways, structures and natural physical barriers)
		IV. Change Orders / Contract Claims / Environmental Mitigation Needs: Contractual/environmental issues lead to increases in unit costs and/or schedule delays.		IV. Perform "right-sizing" exercises to ensure systems through-put capacity (headways), station sizing, fleet size, facility size, parking capacity, all conform to ridership potential
	Note: Each hypothesis can be associated with multiple cost factors	*Note: Each cost factor can be associated with multiple cost drivers*		*Note: Individual improvement opportunities can correspond to multiple cost drivers, cost factors and originating cause*

1.4. Study Uses

Given that a goal of this research was to identify the strategies, tools and techniques available to better manage major project capital costs, the analysis and conclusions in **Sections 4** and **5** place emphasis on those causes that can been controlled or foreseen. The uses include the initial cost estimator (and hence can be addressed by best practice cost estimation techniques) and then used to better manage and contain any subsequent cost increases. The consistent cost increases experienced by these projects does indicate opportunities are available to better estimate and control costs and, thereby reduce, at least a portion of the cost escalation experienced by most projects. This report also addresses potential strategies for cost drivers that cannot be foreseen at the time preliminary cost estimates are made.

Based on the results of the case studies, this report provides a summary of analysis identifying the primary reasons for project cost increases over all phases of development and proposed potential strategies, tools, and techniques to mitigate this project cost escalation. The intention is to review strategies that sponsoring agencies can apply to better estimate, manage, and contain project costs. The general conclusions in **Section 5** are also organized to address the following questions from the original research plan:

1. What can local project sponsors do to estimate costs and schedules reliably at the alternatives analysis, preliminary engineering, final design, and construction phases?
2. What can local project sponsors do to contain project costs and schedules at each phase?
3. What can local project sponsors do to complete projects within their estimated costs and schedules?
4. What changes outside of the direct control of project sponsors could foster the reliable estimation of project costs and schedules?
5. What changes outside of the direct control of project sponsors could help contain the costs and schedules of major public transportation projects?

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2. LITERATURE REVIEW

In order to assess the scope of the major project cost escalation problem and to identify various strategies and techniques used in the control of cost escalation, it was necessary to conduct a comprehensive literature search and a thorough review of available project documentation. This literature search was twofold. The first objective was to document the current state of the industry in responding to the challenges of cost escalation in all of the transportation modes. The work of many researchers in this area has helped to establish a framework for data collection and interpretation. Although these reports had different objectives, they were used for developing an understanding of the cost factors involved in the increasing costs of projects and/or the underestimating of those costs. The second objective was to identify sources of cost information that could help to quantify this level of cost escalation in major federally funded transit projects nationwide.

The first step was to conduct a comprehensive literature review of related capital project development research from major capital projects for transit and other federally funded transportation modes. This effort entailed research and review of library materials within the U.S. Department of Transportation (DOT) and other associated, large-scale, public works organizations that have reported study results on the causes of cost escalation in federally funded transportation projects, as well as the identification of improvement opportunities to better manage these projects and control cost escalation. This search was conducted through a review of the transportation library and various Web sites of organizations for each of the transportation modes, including:

- FTA
- Federal Highway Administration (FHWA)
- Transportation Research Board (TRB) and its associated research programs
- American Public Transportation Association (APTA)
- American Association of State Highway and Transportation Officials (AASHTO)
- Transportation publications
- Academic transportation programs

These and other relevant organizations were reviewed for the collection and publishing of project cost analyses for large federally funded projects. This initial portion of the literature search formed the foundation regarding the state of the science in cost estimating for transit and non-transit transportation projects, and the strategies and techniques suggested to improve this cost estimating process in the future.

The second portion of the literature search was to identify project data on the definition, cost, and schedule estimates for each of the major project development phases. Many of these sources have been identified and included in the annotated bibliography provided in **Appendix A**. The bibliography is organized by the published studies and reviews on the topic, project technical reports, and Web site references presenting relevant information on the topic.

2.1. Background

The issue of construction cost estimating and cost overrun has been a subject of research for decades. For transportation projects, most studies focus on one or few projects, while few studies contain a large sample of projects. In this section, a review of these studies is presented in three subsections—small sample studies; large sample studies; and studies of factors contributing to cost overruns such as project risk and contingency, estimating technique, and schedule slippage. The section ends with the conclusion of the literature review. The findings of past research efforts, documented in this review, are used in designing the methodology of this research, including project selection, identifying strategies, tools and techniques identified in these other studies and in conducting the case studies.

2.2. Small Sample Studies of Cost Overruns

Several researchers and government agencies have conducted studies of cost overruns or cost underestimation in mega projects consisting of one or more projects. These studies are not limited to the U.S. projects, but our search has been limited to English language sources.

2.2.1. Projects Overseas

Arditi, Akan, and Gurdamar (1985) present results of a survey of public agencies and contractors in Turkey to identify the sources of cost overruns on projects executed between 1970 and 1980. They concluded that the most important sources of cost overruns are inflationary pressures, cost underestimation or errors, increases in material and labor costs, and construction delays. Bruzelius, Flyvbjerg, and Rothengatter (2002) discuss problems with the current process used by European countries for planning and managing major public projects, using two projects as case studies (one in Denmark and the other in Germany). The study found several problems with the planning process, including:

- Probabilistic nature of cost and benefits of transportation projects are being overlooked and not included in the estimating process

- Lack of consideration of project financial commitments and political support at an early stage
- Costly changes due to the lack of consideration of external effects of mega projects in the early planning process (i.e., interest groups and the community at large are not involved early, so their views affect project definition later in the planning process)
- Lack of risk analysis
- Lack of clear regulatory regimes in the decision-making process (i.e., the roles of stakeholders such as the agency, government, etc., are not well defined)
- Too much focus on technical issues, such as engineering and design aspects, instead of the economic, environmental, and safety issues that will eventually have to be considered at later stages.

The study proposed modifications to the planning process, including "(1) Transparency, (2) Performance specifications, (3) Explication of regulatory regimes, and (4) Involvement of risk capital."

Skamris and Flyvbjerg (1996) compared the cost and traffic data of seven bridge and tunnel projects in Denmark to show the inaccuracy of both types of forecasts. The analysis shows that the cost overrun in five completed projects ranges from minus 10 percent to 33 percent with an average of 14 percent. The data used was not sufficient to explain the causes of cost overruns; however, schedule delays and changes in technical specifications are some of the main reasons. Skamris and Flyvbjerg provide a literature overview of other sources of research in transportation projects' forecast data. In general, they concluded that highway projects have fared better in meeting forecasts than rail projects. Skamris and Flyvberg also recognize that the overwhelming predominance of overruns implies that there is a *systematic* bias in the calculations.

Fouracre, Allport, and Thomson (1990) looked at 21 metro systems in developing countries. The number of projects with underestimates in costs and overestimates in ridership far exceeded the number of projects that maintained their original cost estimates and achieved their original ridership estimates.

2.2.2. Projects in the United States

Schumann (1988) describes the planning and design approaches for the Sacramento RT Metro, a light rail transit (LRT) project that at the time achieved the lowest capital cost per route mile of a new federally funded rail system. The paper shows how the design was based on the principle of using available right-of-way and using "off-the-shelf" vehicle components and other systems that have been proven to work elsewhere. It presents the comparison between the estimated (estimate after preliminary engineering) and actual capital costs and ridership. The cost comparison is presented by asset category (right-of-way, stations and parking, etc.). Overall, the project experienced a cost overrun of 34 percent, most of which came from right-of-way construction (guideway and trackwork) and management and engineering.

Pickrell (1990) compared the estimated *versus* actual costs of 10 urban rail transit projects in the U.S. with a total value of $15.5 billion (in year 1988 dollars). Estimated costs were those that were prepared at the alternatives analysis phase to help the decision-makers choose the most preferred alternative. Pickrell attempted to determine the reasons for the differences between actual and estimated costs. The report notes that 9 out of 10 projects studied suffered from cost overruns ranging from 13 percent to 106 percent, and ridership forecasts were overestimated by 28 percent to 85 percent. The author discussed cost underestimates coupled with ridership overestimates in the projects studied. Also, the author noted that a major contributor to the cost escalation appeared to be delay in project start time or construction schedule. Further, in most cases, the project contingencies were insufficient and unrealistically optimistic. This report considers the alternatives analysis phase and actual costs without looking at cost increases between the preliminary engineering, final design, and construction phases.

For the FTA, Booz Allen Hamilton (1991, 1994, 2003, 2004) reported actual as-built costs of 19 light rail, 30 heavy rail, and 9 busway/high occupancy vehicle (HOV) system projects. The 1991 report gave actual costs of five light rail system projects. The objectives included an examination of unit costs that could be used in the planning and conceptual estimating for future similar projects. The report did not attempt to evaluate or explain the unit cost variances among the systems or compare the estimated and actual costs. The 1994 report provided detailed documentation of the component-level or project element-level capital costs typically experienced in the development of major capital heavy rail and busway/HOV transit projects. This report detailed the capital cost elements further, but again, did not evaluate or explain the unit cost variances.

Booz Allen Hamilton (2003, 2004) provided a detailed documentation of the component-level or project element-level capital costs typically experienced in the development of major capital light and heavy rail transit projects. The 2003 study used actual cost data from 19 light rail projects around the U.S. including the 5 projects in the 1991 report. The 2004 study used actual data from 30 projects, including 17 projects from the 1994 report. Data was collected and entered into a spreadsheet with a level of detail similar to the one used in the earlier reports. Cost indexes (for time and location) of U.S. states and cities were used to allow for converting the costs of projects from one city to another and projected into the future. The resulting adjusted and normalized cost estimates and unit cost ranges were used to develop a capital cost estimation model to help project developers better estimate the capital costs of future light and heavy rail projects at every stage of the major capital investment planning and development process. The transit capital cost components provided in these reports are guideway and trackwork, yards and shops, systems, stations, vehicles, special conditions, right-of-way, and soft costs. This classification is widely used by transit agencies in preparing capital cost estimates for light rail, heavy and commuter rail, and other modes.

Faulkner and El-Sharafi (2002) and Faulkner and Martinez (1993) discussed cost overruns by comparing estimates from DEIS and FEIS, and explained reasons for cost growth in the Old Colony Project in Boston, MA. The long duration of project development, exclusion of major cost components during feasibility estimates (as these estimates were considered comparative estimates with alternatives), and scope creep are cited as reasons for project cost underestimation and cost growth. The reports cited a cost increase of $435 million (in 1988 dollars) for the Main/Middlesborough/ Plymouth segment that opened in 1997. According to the authors, the omission of project elements accounted for 38 percent of the cost increase, inflation accounted for 26 percent, items added to the project accounted for 24 percent, and increase in level of design accounted for 12 percent. These reports provide a model for conducting case studies of cost overruns in transit projects.

The U.S. General Accounting Office (1999) conducted reviews of progress and cost estimates of 14 transit projects in the New Starts Program. The report provided the status of each project including any cost increases (or decreases) and their causes. Among the 14 projects reviewed, 6 had experienced cost increases of between 2 to 25 percent (at the time of the report). The report highlighted "higher than anticipated contract cost, schedule delays, project scope changes, and system enhancements" as the main causes of cost increases. The report provided this research with valuable data on some projects.

The Office of Inspector General (1999) of the U.S. DOT, reviewed the Hudson-Bergen LRT MOS-1 project. According to the report, the expectation was that the project would be completed below its Full Funding Grant Agreement (FFGA) budget. The report discussed the project's history and showed that realignment and reduced financing costs could cause the project's capital cost to decrease.

The Office of Inspector General (2000a) conducted an audit of the Bay Area Rapid Transit District (BART) San Francisco International Airport Extension Project. The project had experienced significant cost overruns due mainly to higher than anticipated bid values or market conditions and increases in project scope. Market condition and scope changes increased the project cost estimates by $61.3 million and $176.8 million respectively. Among the cost items affected were trackwork, systems, and stations. This is a case where the contingencies budgeted were not enough to cover the cost increases due to market condition and scope changes. In addition, there were several delays to the project schedule that increased costs that were not reflected in a revised cost estimate. The report suggested that BART underestimated several cost items during the project's planning including right-of-way acquisition, utilities relocation, permits, and project administration.

The Office of Inspector General (2002a) reviewed the cost estimates of the Hiawatha LRT project. The report showed that the project's capital cost estimate increased by about 12 percent, before the FFGA and after some contracts had been negotiated. The report discussed the project's cashflow and showed that adequate funding was secured for the project. The report showed that the project's cost estimate was reasonable and cost overruns were unlikely. The report identified a few risk issues that might potentially increase the project's capital cost. These issues included tunnel work that has a high degree of uncertainty, a lawsuit by a private utility firm, and security reviews prompted by the terrorist attack of September 11, 2001.

The Office of Inspector General (2000b, 2002b) reviewed the capital cost estimates and funding issues of the San Juan Tren Urbano Project. The reports discussed the sources of the significant cost increases on the project. These include scope increases, enhanced fare collection system, engineering services, system integration and quality assurance program, schedule delays, and engineer's low estimates.

Although the reports discussed above had different objectives, they can be used for identifying causes for the differences between estimated and actual costs of major transportation projects. These causes can be analyzed to address the objective of the current research—to help identify reasons for cost underestimation and cost growth and ways to limit the magnitude of escalation. It is important to note, however, that these reports concentrate on relatively few projects, and it is not possible to arrive at statistically significant conclusions using such data. The next section reviews sources with large sample studies of cost overruns and underestimates.

2.3. Large Sample Studies of Cost Overruns

Examples of large sample cost studies in transportation are scarce. Merewitz (1972) calculates cost overruns in about 200 "large projects" including transportation projects. The analysis found that BART projects experienced an average of 45 percent cost overrun. This was found to be similar to other rapid transit projects but worse than the average for all project types. The report also reviewed the cost estimation accuracy of the Army Corps of Engineers and the Bureau of Reclamation. It discussed the challenges of calculating cost overruns in transit projects where early estimates do not consider inflation or are missing some cost elements. The report categorized causes of cost growth into controllable and uncontrollable. Controllable causes include project administration, which can lead to unnecessary scope changes if poorly done; bad contracting practices; and inexperience in project execution for the type of project. Uncontrollable causes include justified scope changes that could not be predicted in the planning phase and inflation, which varies by geographic location. Merewitz (1973a and 1973b) focused on a sample of 66 transportation projects for studying the cost overrun issue. He used regression analysis to show that cost overruns are positively related to project size, engineering uncertainty, inflation, project scope increase, length of time between planning and completion of project, delays, and inexperience of administrative personnel.

More recent works by Flyvbjerg, Holm, and Buhl (2002, 2003) are based on a sample consisting of 258 transportation infrastructure projects. The projects include 58 rail, 33 fixed link (tunnels and bridges), and 167 road projects. The authors compared estimated cost at the time of decision to build with the actual cost of the completed projects. They concluded that cost escalation in transportation projects (including rail, highway, tunnel, and bridge) in the U.S., Europe, and other parts of the world was commonplace and stemmed from overly optimistic estimates of cost when the decision to build is made. Furthermore, the authors contended that the error in cost estimates could not be attributed to lack of sufficient information at the time of preparing the estimates, because they showed a clear pattern of underestimating the costs rather than a pattern of random deviation from the true costs.

The authors concluded that project cost estimates sometimes reflected purposeful underestimation in order to make the projects look economically viable. They showed that 9 out of 10 projects experienced capital cost overrun, with an average overrun of 28 percent. The cost overruns were 44.7 percent for rail, 33.8 percent for fixed link, and 20.4 percent for road projects. The proposed potential solutions to these underestimation issues included process improvements and governmental vigilance in the review and analysis of these estimates. The authors also concluded that the issue of cost overruns had been present in mega projects worldwide and for decades. They showed that no learning curve effect could be seen in the estimation process because today's projects were experiencing cost overruns as projects did decades ago despite the improvement of technologies. The reports also discussed the challenges of obtaining capital cost data from public and private institutions. Data were usually fragmented within public agencies and could take years to gather, while data from private institutions were usually classified. Also, because mega projects took years from planning to completion, the data were not always in an adequate form for tracking changes.

The results from this G-07 analysis suggest that the increases in costs are not as high for rail projects (44.7% in the Flyvbjerg study and 32.8% in this study), not as pronounced in the early stages (Flyvbjerg stated overly optimistic estimates at the decision stage compared with less than half the cost increase found at the initial stage in this study), and no learning curve in the Flyvbjerg projects while cost increase from PE to completion decreased over time in this study from 11.2% prior to year 2000 projects to 8.0% after year 2000.

The Department of Transport, Scottish Department and Welsh Office, Road Planning (1988) conducted a study for the UK's National Audit Office in which they compared actual and forecast traffic data for 41 road projects in the UK. The study concluded that for 22 of the projects, the forecasts were within acceptable bounds (within 20 percent of the actual). They also estimated the impact of inaccurate forecasts on the cost and design standards for the constructed projects.

A recently published book by Flyvbjerg, Bruzelius, and Rothengatter (2003) studied mega projects and motivations of project developers in underestimating project costs in an effort to have these projects approved for funding. The book drew on some of the data that are reported in other Flyvbjerg papers and arrived at the same conclusions. The book provides ways of dealing with the purposeful underestimation of projects by implementing a more transparent development process. In their most recent paper, Flyvbjerg, Holm, and Buhl (2004) concluded that the cost escalation for the 258 projects that they studied earlier was strongly dependent on the length of the project implementation phase. In other words, the longer it took a project to implement (from conceptual design to construction), the higher the percent of cost escalation (constant prices). In our opinion, while this conclusion seems plausible, the material presented in the paper does not necessarily support this assertion. The coefficient of determination (R^2) calculated for the relationship between cost escalation and length of project development is only 12 percent.

2.4. Studies of Factors Affecting Cost Overruns and Underestimates

This subsection presents a review of literature on factors affecting capital costs of mega projects and on the issues relating to the estimation techniques and processes used by transit agencies. These issues include projects risk and contingency, quality assurance and quality control (QA/QC), estimating techniques, and schedule slippage. The studies reviewed here provide this research with insight into the estimating practices of transit agencies and issues that cause cost overruns in mega projects. These insights were used to shape the methodology, analysis, and conclusions of this research.

2.4.1. Risk and Contingency

Capital cost estimates at any phase of the project development process depend on the project's definition and level of design at the time of the estimate, and the perceived risks associated with the project. Touran, Bolster, and Thayer (1994) laid out a framework for managing risk in the design and construction of fixed guideway transit projects. Risks were categorized into two types—design and construction risks and financial risks. The risk management process was presented as having three phases—risk identification, risk measurement, and risk allocation and mitigation. The authors described the process of risk modeling with analytical and probabilistic models and reviewed software available for risk management.

Chaney et al (1996) focused on a single transit project—Baltimore's Central Light Rail Phase II. They performed a detailed probabilistic risk analysis for various components of the transit system and identified high-risk factors for this turnkey project. These high-risk factors—such as uncertainty in utility relocation, potential presence of hazardous waste, and right-of-way acquisition—were then used for budgeting contingencies for the project.

Lee (1997) listed risk items that affect transit capital projects. The author briefly explained each risk item, such as political, funding, and site conditions, and covered typical methods used for risk measurement, allocation, and mitigation. The author contended that probabilistic methods are not at a stage yet that can be used effectively for risk measurement.

Mendes (1997) discussed environmental and community risks that affect project planning and development of DBB and DB transit projects. The author discussed cost, delay, and public relations risks related to environmental issues, and provided suggestions for mitigation.

In a recent article, Reilly et al (2004) presented a general methodology for risk and opportunity analysis for capital projects. The approach, named Cost Estimate Validation Process (CEVP), has been used extensively by the State of Washington's DOT.

Based on the continuing trend toward risk applications and extensive research into the subject, the FTA has started requiring all capital projects to conduct a formal risk assessment followed by a mitigation workshop. The objective of this analysis is to identify the most critical risk factors, quantify their effect on project cost and schedule, and find ways to mitigate these (FTA *Guidance 22*, 2003).

2.4.2. Quality Issues

The importance of QA/QC has also been studied. Luglio, Jr. (1997) discussed the use of value engineering and QA/QC during design and construction of transit projects with emphasis on turnkey. The author examined the issue of the contractor's freedom in implementing QA/QC programs under the turnkey approach. Schneck and Stross (1997) looked at project management controls that a transit owner employs to implement a successful project. Schedule management, cost control, payment mechanisms, and QA/QC are among the topics that were covered. A comparative analysis was performed by looking at several projects that used traditional or turnkey procurement approaches, and their differences were highlighted. These reports mainly discussed the benefits of the DB project delivery method. This is important because DB is becoming one of the common methods of procuring mega transit projects.

2.4.3. Estimation Techniques

The estimation technique used in capital cost estimates has to consider all elements of a project and reflect the perceived risks associated with that project.

Menendez (1993) focused on the role of cost estimating in project development decision-making. He addressed the underestimation of capital and operating costs in urban transportation projects by focusing on the use of cost estimation in the early planning (alternatives analysis) phase, providing a detailed analysis of the cost estimating process using transit case studies from three U.S. cities (Boston, Buffalo, and Santa Clara). Menendez discussed both technical and non-technical (or decision-making) aspects of project cost estimation. The technical aspects of estimating include the techniques and methods used, the data used, and the consideration of uncertainty. The decision-making aspects include the behaviors of stakeholders (interest groups, analysts, decision makers such as politicians, and funding agencies) and each group's view of the importance of cost estimates. He suggested that the planning process is dominated by politics as each group of stakeholders tries to control the process to their advantage. The author proposed that the planning process should consider the stakeholders involved as well as define the role of each stakeholder and the criteria to use for comparing alternatives, and that there is a need for unbiased assumptions (such as ridership forecasts) in cost estimation to fairly compare alternatives and choose the best possible project variables. He suggested that the planning process can be improved by:

- Encouraging better communication between the stakeholders and making information readily available at all levels
- Tying funding to the components that local decision makers evaluate
- Providing more oversight and transparency in the planning process
- Classifying costs to make cost estimates easier to understand and verify
- Analyzing sensitivity to show how changes in project parameters affect costs
- Acknowledging uncertainties in the cost estimates
- Independently reviewing cost estimates
- Providing more comprehensive evaluation criteria that will encourage more accurate estimates.

Leo and Knotwicz (2001) discussed the use of cost estimating as a tool for choosing the right projects as well as executing the projects correctly. The paper focused on corporate capital projects and used the Kodak Company as an example. It discussed the need to incorporate cost estimating in the early stages of project development and to be a part of the decision-making process—thus, ensuring that the right projects are selected.

Schexnayder, Weber, and Fiori (2003) reported the current practices in project cost estimating in the DOTs of various states in the U.S. The authors conducted a survey of all 50 DOTs and presented examples from some of them. The survey results gave a breakdown of the agencies using certain practices. The authors reported that 31 DOTs used the historic bid average method of estimating, while the other 19 used the detailed, or deterministic estimating method. Project analysis from the same study showed the positive results of using the historic bid estimates for highway projects. The authors used cost results from 34 projects valued over $100 million (15 were estimated using detailed estimating, while 19 were estimated using historic bid average methods), to quantify this positive trend for historic bid average estimation process. The authors showed that, from the time of bid, 53.3 percent of projects estimated using detailed cost estimating experienced a cost overrun of more than 5 percent compared to only 21 percent of projects estimated using historic bid average methods. Overall, 35.3 percent of the projects examined had a cost overrun of more than 5 percent. Therefore the historic bid estimation process has some better results than the more detailed deterministic approaches.

Most agencies made modifications to the cost estimates based on project size and location. **Table 2-1** shows the estimating considerations used by the DOTs. For example, of the 50 DOTs, 23 include contingency in the project budget, and 38 adjust their estimates based on the particular location of a project within the state. The report also showed that 10 DOTs had or were developing a formal estimator training and mentoring program to allow junior estimators to gain the knowledge and insight from more experienced estimators within the agency. Also, 16 DOTs had estimating manuals, and 2 were developing estimating manuals, while the remaining 32 had no formal guide for estimating.

The authors also discussed the challenges of estimating mega projects. They proposed that all DOTs have an estimating manual that states the procedure for estimating each cost element and the considerations of estimating projects including the treatment of inflation. Also, estimators need to consider the impact of mega projects on the local economy. For example, suppliers might be forced to team up to bid on the job, which will reduce the competition and likely increase the price. They suggested that separate contingencies be applied (based on and for construction duration, level of design, third-party claims and unforeseen conditions, and high risk items of the project) in order to have estimates in a format that can be understood, checked, verified, and corrected.

Table 2-1. Estimating Considerations of U.S. DOTs
[Adapted from Schexnayder, Weber, and Fiori (2003) page 48]

Factor Considered	Number of DOTs that Consider
Incentive Funds	
• Programmed in the construction estimate	26
• Come from other projects that are below budget	9
• Paid out of project contingency fund	10
• No incentives program in place	5
Contingency Budgeting	
• DOTs with contingency budgets	23
• DOTs without contingency budgets	27
Schedule	
• Estimate adjusted based on schedule	33
• Estimate not adjusted based on schedule	17
Project Conditions	
• Estimate adjusted based on special conditions	38
• Estimate not adjusted based on special conditions	12
Project Location	
• Estimate adjusted based on location within state	38
• Estimate not adjusted based on location within state	12

2.4.4. Schedule Slippage

The importance of schedule control in major capital projects cannot be overemphasized. Studies have shown a high degree of correlation between project delay and cost overrun (Pickrell 1990; Touran, Bolster, Thayer 1994). A 1985 FHWA study showed that more than a third of highway projects finished beyond their original contract time, and the average time delay was 44 percent (Thomas et al 1985). A recent National Cooperative Highway Research Program (NCHRP) project investigated causes of delay in highway projects in order to identify ways to reduce these delays (Ellis and Thomas 2003). The authors identified several causes of schedule delays (and consequently, cost escalation) in highway projects such as utility relocation, differing site conditions, errors in plans and specifications, weather, and permitting issues. These factors are technical in nature and appear to have not been influenced by external and/or political considerations.

2.5. Conclusion

The literature on capital cost overruns shows that estimates tend to be consistently on the low side at each of the project development phases, but particularly at the end of the alternatives analysis or during the planning phase. The small sample studies reviewed provide some insight into the causes of cost increases in particular projects, while the large sample studies provide some statistical data on the magnitude of capital cost overruns. The studies on the issues affecting cost overruns provide the factors and issues that needed to be examined in this research.

Some of the studies have identified the severity of cost overruns in mega transit projects. Flyvbjerg, Holm, and Buhl (2002, 2003) offered the most statistically viable studies, which examined the estimated (alternatives analysis/DEIS estimate) and actual capital costs of 258 transportation projects worldwide and showed that 90 percent of projects experienced cost overruns. The average overrun was found to be 28 percent, but the rail projects performed worst with an average escalation of 44.7 percent. The rail projects consisted of high-speed, urban, and conventional inner-city rail. Although the data did not allow for identifying the sources of cost overruns, the authors concluded that the trend indicated a purposeful underestimation of project costs in order to ensure project approval. The results of this study are comparable to Pickrell's (1990) study of 10 transit projects, which also showed 9 out of 10 projects experienced cost overrun and ridership overestimation.

These reports provided a sense of how common cost overruns are in transit projects. The authors concluded that, in general, causes of cost overrun or, more accurately, cost underestimate, may be due to political pressure and influences eager to have the projects built. Several small sample studies also explain the causes of capital cost growth in several projects. Some of the authors' suggested reasons for cost growth included:

- Inflation, or the underestimation of the rate and schedule impact
- Schedule delay and lengthy project development
- Scope changes and system enhancements
- Cost underestimation
- Market conditions
- Omission of major project components in the estimates.

Inflation remains a main factor of cost increases (Arditi, Akan, and Gurdamar 1985; Merewitz 1972). Thus, it is necessary to consider the estimation of the inflation rate and the inflationary effects of schedule delays when developing the project cost estimates and analyzing cost overruns. The agency preparing the estimate (especially at the planning phase) should adjust the cost estimate to account for the likely project development schedule and the likely midpoint of construction. Accounting for a conservative inflationary rate and schedule estimate of the mid-year of construction aids the decision-making process. All interested parties can then become more aware of the magnitude of capital funds needed for the project in the early stages of project development.

Delays in the planning and construction of transit projects are the most cited reason for cost growth (inflation adjusted). This issue has been cited in large sample studies by Flyvbjerg, Holm, and Buhl (2003) and Merewitz (1972), and in small sample studies by OIG (2000c, 2002a), U.S. General Accounting Office (1999), Pickrell (1990), Skamris and Flyvbjerg (1996), and Thomas et al (1985). Lengthy project development is a somewhat similar condition and has been cited in the reports by Faulkner and El-Sharafi (2002); Faulkner and Martinez (1993); Pickrell (1990); and Flyvbjerg, Holm, and Buhl (2004).

There are three types of schedule impacts on increasing project capital costs, as described below. These three types of time-based or inflationary increases to capital costs often combine to become the largest impact on capital cost increases.

- The capital cost estimate needs to account for the planned schedule and the likely midpoint of construction. Constant dollar estimates based in the planning year of the estimate do not account for the schedule.
- Underestimating the inflationary impact on capital costs is another source of increasing capital costs. This is created by developing an overly ambitious project development schedule that cannot be achieved, or underestimating economic conditions and inflationary rate impacts.
- The third schedule impact is created by project development delays, either controllable or uncontrollable. These delays most often come from right-of-way acquisition, permitting delays, environmental delays, stakeholder and public imposed changes, long lead material acquisition, and contractor difficulties.

Scope changes and enhancements have increased the capital costs of several projects including Boston's Old Colony Commuter Rail (Faulkner and El-Sharafi 2002), San Juan's Tren Urbano (OIG 2002a), and others (Merewitz 1972). These are generally of two types—major enhancement and scope changes, and small incremental improvements (scope creep) that are done over time (mainly during final design and construction) and can add up to a significant percentage of project budget.

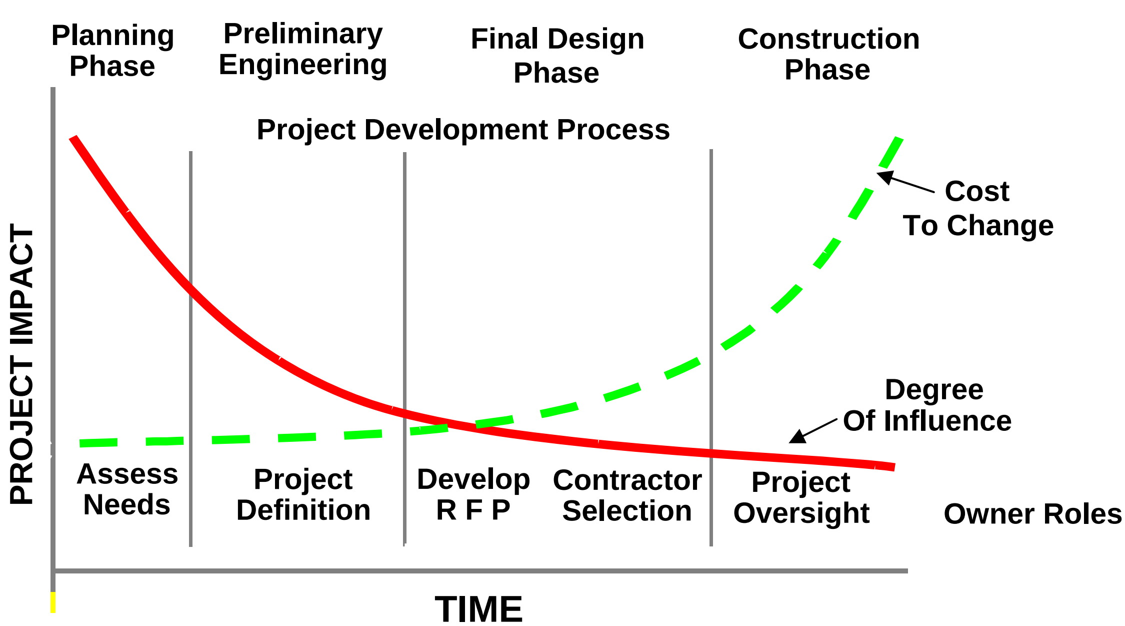
The cost estimation technique studies showed that different agencies have different ways of estimating. According to Schexnayder, Weber, and Fiori (2003), each DOT has its own method of estimating. The literature reviewed indicated a need for a better estimating practice in which estimates are developed, checked, compared, verified, and corrected (if necessary). This was critical information to this research's objective to identify improvements to the cost estimation process that can lead to more accurate and defensible cost estimates.

The role of cost estimation in the planning process is important. Bruzelius, Flyvbjerg, and Rothengatter (2002) and Menendez (1993) identified several problems with the planning process and offered suggestions for improvement. Some of the suggestions included having a more transparent process that acknowledges the needs of all stakeholders and encourages information sharing. Although politics dominate the decision-making process, cost estimation, if used appropriately, can be a significant part of the process.

Another issue observed was the relationship between the risks or uncertainties of a project and the contingency provided for them. Mega transit projects involve risky design and construction challenges that are unique to each. Therefore, risk analysis is necessary for each project to identify the risks involved, quantify those risks, and allocate or mitigate them (Chaney et al 1996; Touran, Bolster, and Thayer 1994). At each stage of project development, the nature of risk analysis is a bit different and the analysis can be conducted at any phase with the objective of quantifying the uncertainties and developing mitigation strategies. The most effective time for doing the risk analysis is at the conceptual or preliminary engineering phases. The changes implemented later during the design have a higher impact on project costs. This is illustrated by the project influence curve presented in **Figure 2-1**. The conclusion to this figure is that the later a decision is made with regard to project design or execution, the more costly it is to implement.

In summary, the referenced sources provided a wealth of data and helped in structuring and executing the research approach of identifying and quantifying the sources of cost changes.

Figure 2-1. Project Influence Curve



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3. CASE STUDY PROJECTS

Over 30 projects were initially considered for case studies based on the results of the literature search, the results of prior studies, capital cost data sources available to the project team, and the team's prior experience with project capital costs. A project selection process was subsequently developed to ensure adequate representation and testing of the hypotheses developed in **Section 1**. This initial set of projects was prioritized accordingly and 10 case study projects were recommended to the TCRP project panel for further study. This process is summarized in **Section 3.1** and discussed in detail in **Appendix B**.

The initial set was eventually reduced to 28 projects conforming to the basic study requirements—fixed guideway transit projects in excess of $100 million, and with sufficient information to support the cost and schedule analysis. This set of 28 projects is presented in **Section 3.1**. Individual case study descriptions for the 28 projects are presented in **Appendix C** based on the case study format developed in **Section 3.2**.

Section 3.3 presents the cost variance analysis performed on the wider set of 28 projects by project development phase and cause. In addition, there were sufficient data to perform a more detailed cost variance analysis by cost category and phase on half of these projects. The results of this detailed analysis are also discussed in **Section 3.3**.

From the wider set of 28 projects, the TCRP project panel ultimately selected a subset of 14 projects for more detailed study of the strategies, tools, and techniques used to estimate, manage, and control capital costs. The selection was made on the basis of the Hypothesis Testing process presented in **Appendix B** and the refinement of the TCRP project panel. The objective of this project selection process was to identify a reasonable set of projects with varying capital cost experiences and approaches for the more detailed case study interviews.

A sample of 9 projects was successfully surveyed and the results are presented in **Section 4**. Their responses to the interview guide are presented in **Appendix D**. Although this set of projects does not represent a statistically significant sample, it is sufficient to provide valuable insight into the potential cost impact of various strategies, tools, and techniques.

3.1. Project Selection Process

This section describes the process that identified the initial set of 28 projects, 14 projects selected by the TCRP project panel for further research, and the 9 responding projects ultimately used to focus the more detailed analysis of the strategies, tools, and techniques for cost estimation, control, and management.

3.1.1. Initial Set of Projects

The research team began by identifying major, completed transit projects for potential case studies based on a preliminary review of the literature with the objective of understanding how and why project costs changed from initial planning through operations. This initial list of over 30 candidate projects represented different transit modes, agencies with differing levels of investment experience (i.e., New Starts and greenfield investments versus extensions to existing systems), and projects in large and medium sized urban areas.

The list of candidate projects was eventually reduced to 28 fixed guideway transit projects based on the availability of cost information from recently completed projects and studies and FTA New Starts documentation. At a minimum, the case studies were also to include two or more projects with final costs that did not vary significantly from initial estimates as to yield insights and best practices for cost estimation, management, and control.

Some of the basic characteristics of the 28 case study projects are summarized in **Table 3-1**. In this set, there are 7 heavy or commuter rail, 18 light rail, and 3 busway projects. A majority of the projects (23) used a Design-Bid-Build (DBB) for at least one portion of the project, while 8 used Design-Build (DB), 3 used Design-Build-Operate-Maintain (DBOM) and one used Construction Management at Risk (CMR). Some projects used a combination of procurement methods. The differences in these procurement methods are discussed in **Section 4**. The majority of the projects (17) were extensions, while 10 were New Starts and 1 was a rehabilitation project. Two projects were completed in the 1980s, 10 projects in the 1990s, and 16 projects in 2000 or later.

3.1.2. TCRP Project Panel Selected Projects

Given limited research resources, the research team was to collect detailed information on 8 to 10 representative projects. This limited set of projects would not be statistically representative but would be sufficient to provide valuable insight into the tools and techniques used for successful project management. Within this set, it was intended that 2 to 4 would exhibit little or no cost overruns in order to highlight potential successes. This was meant to provide a minimum basis for comparison between projects that experienced significant cost growth and those that did not exhibit such a problem.

Table 3-1. Characteristics of the 28 Case Study Projects

ID	Case Study Projects	Mode	Procurement Approach	Project Setting	Year Completed	Panel Selected
1	Atlanta North Line Extension	Heavy rail	DBB	Extension	1999	X
2	Boston Old Colony Rehabilitation	Heavy rail	DBB	Rehab.	1997	
3	Boston Silver Line (Phase 1)	Busway	DBB	New Start	2004	X
4	Chicago Southwest Extension	Heavy rail	DBB	Extension	1989	
5	Dallas South Oak Cliff Extension	Light rail	DBB	Extension	2002	X
6	Denver Southwest Line	Light rail	DBB	Extension	1999	X
7	Los Angeles Red Line MOS 1	Light rail	DBB	New Start	1991	
8	Los Angeles Red Line MOS 2	Light rail	DBB	Extension	1994	
9	Los Angeles Red Line MOS 3	Light rail	DBB	Extension	1995	
10	Minneapolis Hiawatha Line	Light rail	DB	New Start	2004	X
11	New Jersey Hudson-Bergen MOS1	Light rail	DBOM	New Start	2000-2002	X
12	New York 63rd Street Connector	Heavy rail	DBB	Extension	2001	X
13	Pasadena Gold Line	Light rail	DB	Extension	2003	X
14	Pittsburgh Airport Busway (Phase 1)	Busway	DBB/DB/DBOM	New Start	2000-2002	X
15	Portland Airport MAX Extension	Light rail	DB	Extension	2001	X
16	Portland Banfield Corridor	Light rail	DBB	New Start	1984	
17	Portland Interstate MAX	Light rail	CMR	Extension	2004	X
18	Portland Westside/Hillsboro MAX	Light rail	DBB	Extension	1998	
19	Salt Lake North-South Line	Light rail	DBB	New Start	1999	X
20	San Francisco SFO Airport Ext.	Heavy rail	DBB/DB	Extension	2003	X
21	San Juan Tren Urbano	Heavy rail	DB/DBOM	New Start	2005	
22	Santa Clara Capitol Line	Light rail	DBB	Extension	2003	
23	Santa Clara Tasman East Line	Light rail	DBB	Extension	2001	
24	Santa Clara Tasman West Line	Light rail	DBB	Extension	1999	
25	Santa Clara Vasona Line	Light rail	DBB	Extension	2004	
26	Seattle Busway Tunnel	Busway	DBB	New Start	1990	
27	St Louis Saint Clair Corridor	Light rail	DBB	Extension	2000	
28	Washington Largo Extension	Heavy rail	DBB/DB	Extension	2004	X

The candidate projects were prioritized in a multi-criteria decision-making process in order to recommend about 10 projects to the TCRP project panel for detailed study. A list of the 10 projects originally recommended is presented in Ap**pendix B** along with a full description of the methodology. The prioritization process was modeled as a combination of the Total Sum Multi-criteria Scoring Model and the Analytic Hierarchy Process, and is discussed in detail in **Appendix B**. Among the criteria considered were:

- Availability of data and willingness of project representatives to support the research efforts
- Geographic location of the project
- Mode type – Light rail, heavy and commuter rail, and busway

- Procurement approach – Design-Build (DB), Design-Bid-Build (DBB), Design-Build-Operate-Maintain (DBOM), Construction Management At Risk (CMR) or some combination thereof
- Project setting – New Starts, extension, or rehabilitation

The TCRP project panel ultimately selected a slightly different set of 14 priority projects for further study. These 14 panel selected projects, shown in **Table 3-1**, represent a subset that is generally more recent in order to highlight newer strategies and techniques. The TCRP project panel selected projects also include 2 non-federally funded projects (Pasadena Gold Line and Portland Airport MAX) for comparison purposes.

Of the 14 TCRP project panel selected projects, detailed information was ultimately gathered for 9 projects on strategies, tools, and techniques used to estimate, manage and control costs. These 9 projects represented those that provided responses to the interview guide (see **Appendix D**) regarding the process used in the development of the project through all phases and the detailed cost information to document the results.

3.2. Case Study Format

Changes in project costs and schedule were tracked throughout the life of each of the 28 case study projects. The research team also gathered all available project cost data at the cost category and subcategory level through all project phases—from the initial planning estimates to the final or actual costs. This was important for tracking the causes of cost increase and discerning the changes in project scope, cost, and schedule. Depending on the availability of information, changes in the reported unit cost, quantity, and schedule values can be attributed to specific cost factors or "events." Examples of such events include changes in project definition, alignment and design, revisions to unit cost values, schedule delays, claims, greater than estimated inflationary effects, unexpected environmental impact costs, and responses to unforeseen conditions. As these events accumulate over the life of the project development process, they tend to increase total project costs. A case study format was developed in order to effectively convey this information in a comparable manner for all case study projects.

3.2.1. Case Study Templates

A standard template was developed for project descriptions and graphs representing the capital cost history for each of the 28 case studies. **Figures 3-1** and **3-2** are template summary charts based on hypothetical project data to illustrate the information provided in this standard format. The following sections describe this format in detail.

Appendix C includes the project descriptions, cost variance experience, and summary charts for the 28 case study projects in this format.

Project Descriptions

Each project description begins by detailing the project's purpose, managing organization, physical characteristics (e.g., mode, length of alignment, and number of stations), and other pertinent facts that are available. The details of each case study project are presented in **Appendix C**.

For several projects, the initial DEIS cost estimate was reported in constant year dollars in the planning phase reporting year. In these cases, the capital cost estimate was adjusted (i.e., inflated) to the planned midpoint of construction year. This adjustment to constant dollar estimates accounts for the project development schedule and its inflationary impact on the project cost estimates, and provides a baseline planning estimate. Projects reporting the capital cost estimate in inflated dollars already accounted for the planned project development schedule (assuming a planned midpoint of construction). In those cases, therefore, no adjustment was required and the baseline planning estimate equals the reported DEIS cost estimate.

Total Project Cost by Phase

This section provides background for the "*Total Project Cost by Phase*" figure for each project (see template in **Figure 3-1**). The figure contains four main areas:

- The top chart (*Key Events*) identifies significant changes that occurred during each phase of the project. Four principal phases were defined in the project development lifecycle:
  - Planning/DEIS
  - Preliminary Engineering/FEIS
  - Final Design/FFGA
  - Construction/Operations

  The duration in years for each phase of each particular project is represented by the width of the text box for that phase. The scale follows the axis label (in years) at the very bottom of the template. Using the template presented in **Figure 3-1** as an example, the project development period took eight years from the initiation of the planning phase in 1993 to the beginning of operation in year 2000. This top chart also notes the midpoint of construction year anticipated at each project development phase. This provides for the planned construction midpoint year of estimate (YOE) and serves as a basis to estimate the inflationary impacts from project delays. These delays are demonstrated by the deferral of the midpoint of construction from the planned year (1997) in the planning and preliminary engineering phases, to year 1998 in final design, and to year 1999 in the eventual midpoint of construction. The final midpoint of construction, year of expenditure (YOE), provides the basis for the actual YOE cost value, or as-built cost for the completed project.

- The arrows (*Anticipated Project Duration at Each Phase*) convey the adherence of the project schedule through the phases of the project. Each arrow represents the project duration from the initial planning year to the anticipated completion year for each development phase. The bottom arrow, representing the construction/ operations phase, extends from the initial planning year to the actual opening year. The planned midpoint of construction years are noted at the end of each project schedule arrow for the planning, engineering, and final design phases, and the actual midpoint of construction is noted for the construction/operations phase.
- The upper line graph (*Project Cost by Phase*) focuses on the cost impacts from the project development schedule. This section illustrates the project cost estimates at each phase of the project. Both lines are initiated at the completion of the planning phase and valued at the initial planning year estimate, in the dollar value of the planned midpoint of construction. Both lines then track the changes in the project cost from this initial planning estimate to the final project cost. The cost estimates for each phase are measured at the end year corresponding to that project development phase. Using the template as an example, the PE/FEIS cost estimate is measured at the conclusion of that phase in year 1997, final design in year 1998, and construction in year 2000. The trend of the lines indicates whether costs increased or decreased through the project planning, design, and construction phases. The solid line follows each phase cost estimate in the dollar value of the planned construction midpoint year at the time of the estimate. This line tracks the change in capital costs from the initial planning estimate to the completion of project development, with the final project cost in the YOE dollar value. The dashed line provides a baseline comparison to the initial project planning estimate (all estimates denominated in the year of the initially planned midpoint of construction). The difference in the two lines represents the inflationary cost impact of a project schedule delay or "slippage". Many projects experienced schedule slippage as represented by the year of the midpoint of construction. In the template, the schedule slipped a total of 2 years—from 1997 to 1999 for the midpoint of construction and 1998 to 2000 for the year of completion.
- The lower line graph (*Sources of Change*) illustrates the cost impacts on the initial planning estimate due to scope and unit changes introduced throughout the project's development. The dark line represents changes in scope, while the lighter line represents changes in unit costs. Scope changes are modifications to the quantities planned for the project (e.g., an increase in the number of stations or miles of guideway) as an aggregate of all cost categories. Unit cost changes as an aggregate for all cost categories are represented by the gray line. Using the template as an example, the initial planning estimate increased slightly due to scope additions, while the unit costs of the project scope increased more significantly.

Figure 3-1. Total Project Costs by Phase (Template)

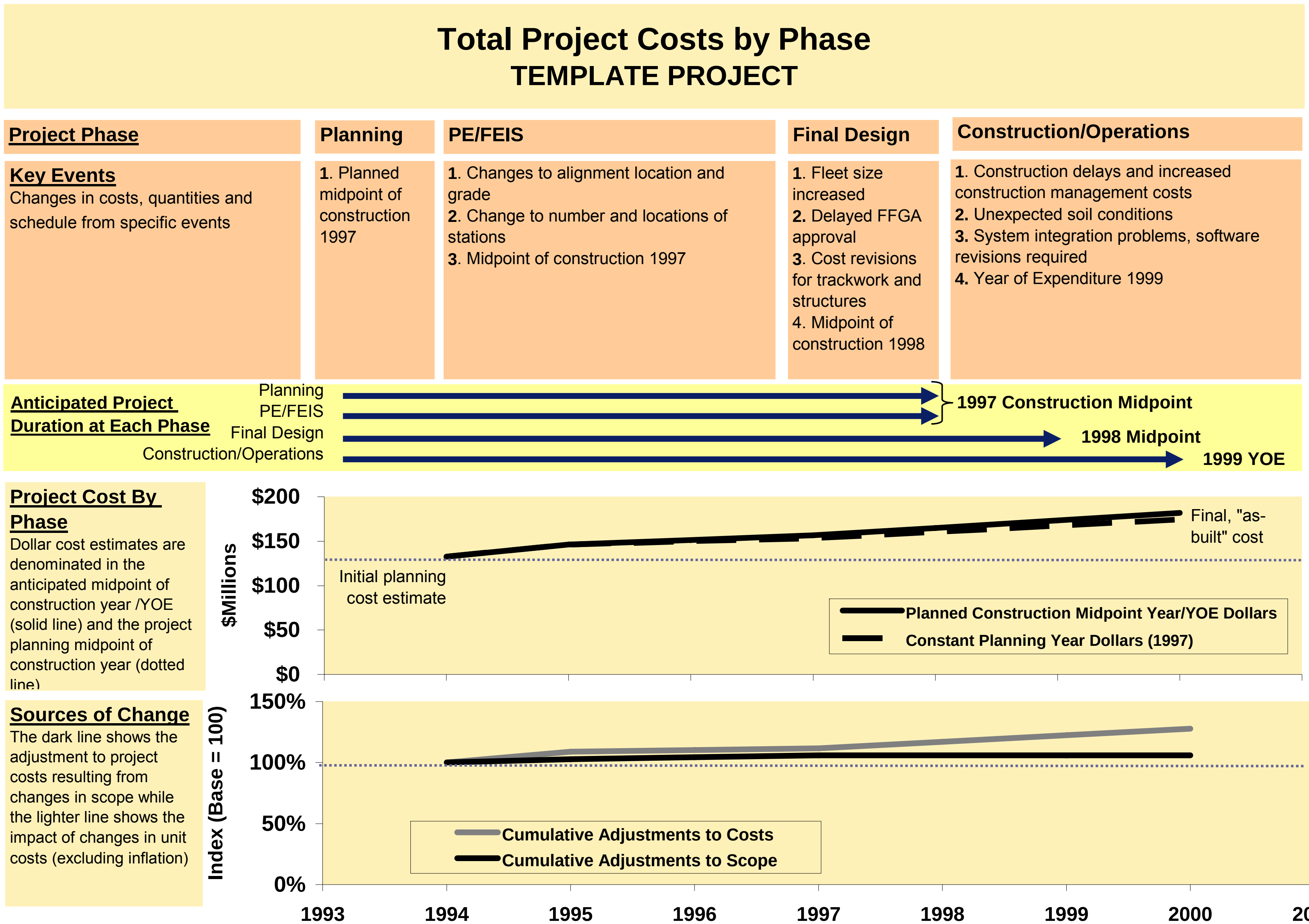
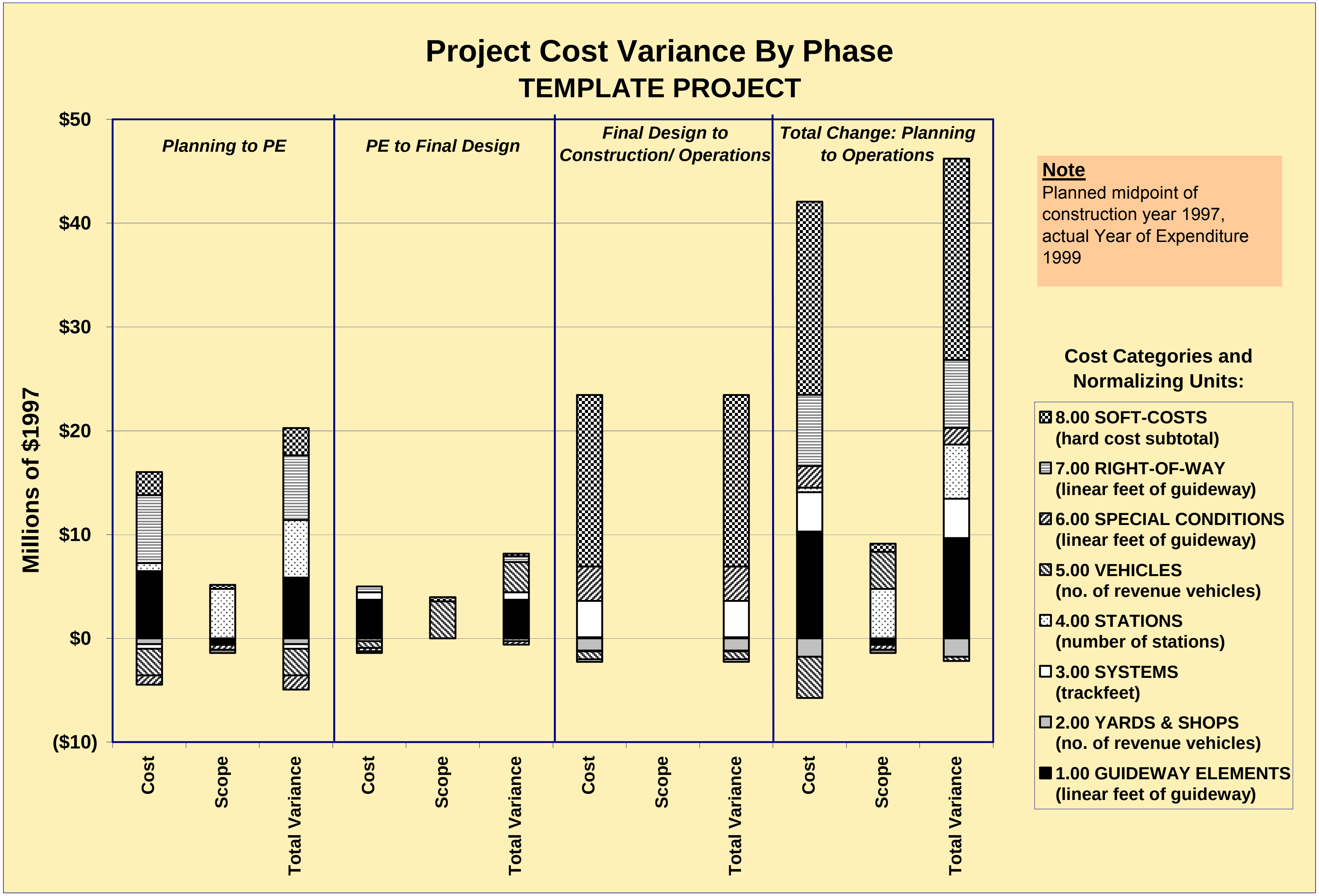


Figure 3-2. Project Cost Variance by Phase (Template)



Detailed Cost Variation by Phase

This section provides background and descriptive information for the "*Project Cost Variance by Phase*" figure (see template in **Figure 3-2**) for the case study projects with sufficient data**.** This figure is presented for 14 of the 28 case study projects in **Appendix C**.

Figure 3-2 synthesizes the types of cost variation, the cost categories of these changes, and the total amount of change between each of the development phases and for the overall project lifecycle. The project cost variation is presented in four scenarios:

- Planning to Preliminary Engineering
- Preliminary Engineering to Final Design
- Final Design to Construction/Operations
- Total Change from Planning to Operations

The project cost variation by phase illustrated in **Figure 3-2** is only for scope and unit cost changes, and does not account for schedule change impacts on project capital cost. The cost variation from each phase is also separated into cost (i.e. unit cost) change and the scope (i.e., unit quantity) change. Cost and scope changes are normalized for each of the 8 standard cost categories by the units presented in the figure's legend. The total project cost change between the baseline planning estimate and actual project cost is represented by the scenario in the far right (*Total Change: Planning to Operations*), while the change between project phases (e.g., planning to PE) is illustrated by the 3 other scenarios. The amount of change for each cost category is represented by the vertical length of the bar. The stacked bar structure also represents the total increase and decrease in capital costs as positive values and negative values, respectively.

The cost variation is measured from the planning baseline cost estimate. In this example, the planning year is 1997 and the cost is measured in millions of $1997. All capital cost variation is maintained in the planning year estimate dollars in these figures to eliminate the impact of schedule change from this cost and scope analysis.

Summary

This section of the template summarizes the total change in project cost between the initial estimate and the actual cost for the project. The change is addressed in two steps. First, for several projects, adjusting the initial cost estimate into planned midpoint of construction year dollars to account for the project development schedule increased the initial estimate. Once the baseline planning estimate is established, changes in project cost throughout project development can be attributed to the following factors:

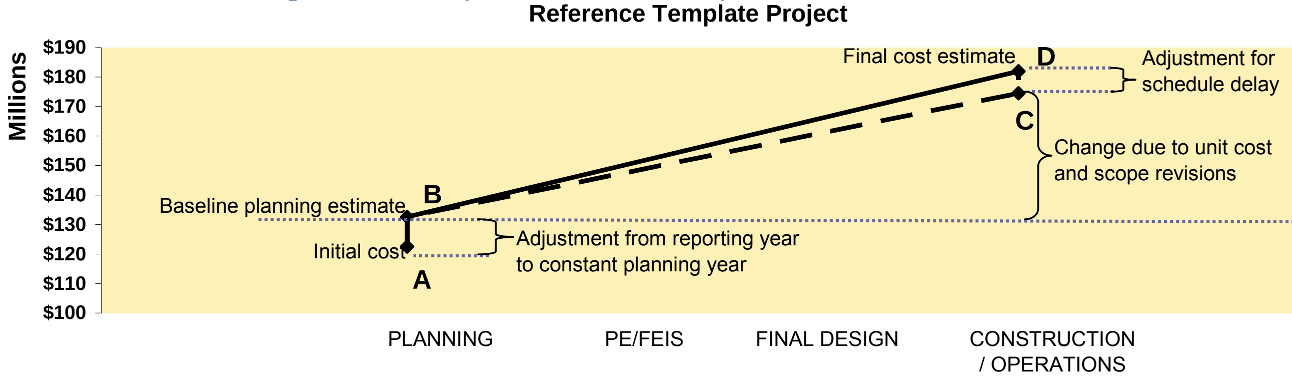
- Many projects experienced changes in schedule (usually delays) that caused a shift in the estimated midpoint of construction. The adjustment required to denominate the final project cost in the year of the baseline midpoint of construction equals the impact of the schedule delay.
- The remaining difference is due to the net change in unit cost and scope, occurring between planning and construction/operations.

3.2.2. Major Capital Cost Drivers

The changes in project cost between planning and construction/operations can be attributed to three major cost drivers described below. These drivers are illustrated in **Figure 3-3** and by the upper line graph template in **Figure 3-1**.

- **Initial Inflation Adjustment (A to B)** - For several projects, an initially reported (uninflated) cost estimate (point A) was adjusted to a dollar value for the baseline midyear of construction to yield a baseline planning estimate in YOE dollars (B). This inflation adjustment accounted for the initial project development schedule and, in some cases, increased the initially reported estimate.
- **Scope Change (B to C) –** This is the sum of cost changes due to unit cost and quantity revisions as the project progressed from point B to point C in **Figure 3-3**. Where data was available, this factor could be broken down into specific cost categories for deeper analysis. The lower line graph in **Figure 3-1** illustrates the aggregate cost and scope changes by phase, and **Figure 3-2** provides a breakout by cost category.
- **Schedule Change (C to D)** - Many projects experienced schedule delays that caused a shift in the initially planned midpoint of construction. The adjustment required to denominate the final project cost (point D) in the year of the baseline midpoint of construction (point C) was calculated as the impact of schedule delay. This is also illustrated graphically by the difference in the dashed and solid lines in the upper line graph in **Figure 3-1** and in **Figure 3-3** below.

Figure 3-3. Major Drivers of Project Cost Variation



3.3. Cost Variance Analysis

This section investigates the variation of the capital cost estimates according to the major cost drivers and the phases of project development using the two sets of projects described in **Section 3.1**—28 case study projects and 14 TCRP project panel projects. The capital cost data for these projects was gathered from a variety of sources including the following:

- FTA Light Rail and Heavy Rail Capital Cost Databases developed and updated by Booz Allen Hamilton in 2004 and 2005, respectively
- New Starts submittals and Annual Reports from FY1992 to FY2004 for federally-funded projects[1]
- Detailed capital cost data by phase supplied by individual projects
- Information available on project or agency web sites
- Published papers and studies as reported in the annotated bibliography (**Appendix A**)
- Other published reports or articles on individual non-federally funded projects[2]

3.3.1. Set of 28 Case Study Projects

Table 3-2 is a detailed analysis of the capital cost changes attributed to the three major cost drivers for all 28 case study projects. Column (A) presents the initially reported estimates in constant year dollars, column (B) presents the baseline (inflated) estimates in YOE dollars, column (C) presents the scope adjusted estimate, and column (D) presents the schedule adjusted final cost. The columns in between these show the differences (in dollars and as a percent change). The last column on the right presents the real change in cost from the baseline estimate to the final cost including all schedule and scope changes.

Table 3-3 is a detailed analysis of the capital cost changes by phase of project development – Planning/DEIS, Preliminary Engineering/FEIS, Final Design/FFGA, and Actual (Construction/Operations). All costs are shown in YOE dollars. The columns in between these phases show the differences (in dollars and as a percent change). The last column on the right presents the total change in cost from the earliest planning estimate to the final cost. The full background and major events for each of the 28 projects is presented as individual case studies in **Appendix C**.

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1 *FTA New Starts reports for FY1997 and after are available at http://www.fta.dot.gov/library/policy/ns/ns.htm*

2 *For the Pasadena Gold Line project, information was gathered from:*
Born, M. and Burner, C., "Project Highlights of the Los Angeles Gold Line LRT," APTA Rail Conference, June 2004

Table 3-2. Capital Cost Variation by Major Cost Driver

ID	Case Study Projects	**Initial Reported Estimate (A)**	Initial Inflation Adjustment (A to B)		**Baseline Estimate (B)**	Scope Change (unit cost and quantities) (B to C)		**Scope Adjusted Estimate (C)**	Schedule Change (C to D)		**Schedule Adjusted, Final Cost (D)**	Real Change from (B) to (D)	
		Millions planning year $	Millions planning year $	(B-A)/A	**Millions YOE$**	Millions YOE$	(C-B)/B	**Millions YOE$**	Millions YOE$	(D-C)/C	**Millions YOE$**	Millions YOE$	(D-B)/B
1	Atlanta North Line Extension	**$370.2**	$52.2	14.1%	**$422.4**	$1.1	0.3%	**$423.5**	$49.1	11.6%	**$472.7**	$50.2	11.9%
2	Boston Old Colony Rehabilitation	**$368.2**	$79.0	21.5%	**$447.2**	$74.7	16.7%	**$521.9**	$43.1	8.2%	**$565.0**	$117.8	26.3%
3	Boston Silver Line (Phase 1)	**$318.1**	--		**$318.1**	$187.2	58.9%	**$505.3**	$99.1	19.6%	**$604.4**	$286.3	90.0%
4	Chicago Southwest Extension	**$453.0**	--		**$453.0**	($19.1)	-4.2%	**$433.9**	$40.7	9.4%	**$474.6**	$21.6	4.8%
5	Dallas South Oak Cliff Extension	**$347.1**	--		**$347.1**	$63.9	18.4%	**$411.0**	$26.2	6.4%	**$437.2**	$90.1	26.0%
6	Denver Southwest Line	**$127.5**	$10.5	8.2%	**$138.0**	$24.0	17.4%	**$162.0**	$15.1	9.3%	**$177.1**	$39.1	28.3%
7	Los Angeles Red Line MOS 1	**$620.7**	$75.1	12.1%	**$695.8**	$688.2	98.9%	**$1,383.9**	$106.2	7.7%	**$1,490.1**	$794.4	114.2%
8	Los Angeles Red Line MOS 2	**$949.7**	$167.0	17.6%	**$1,116.6**	$619.1	55.4%	**$1,735.7**	$185.9	10.7%	**$1,921.6**	$805.0	72.1%
9	Los Angeles Red Line MOS 3	**$898.3**	$215.0	23.9%	**$1,113.3**	$20.8	1.9%	**$1,134.1**	$93.6	8.2%	**$1,227.6**	$114.3	10.3%
10	Minneapolis Hiawatha Line	**$581.0**	--		**$581.0**	$58.7	10.1%	**$639.7**	$75.6	11.8%	**$715.3**	$134.3	23.1%
11	New Jersey Hudson-Bergen MOS1	**$775.0**	--		**$775.0**	$239.5	30.9%	**$1,014.5**	$98.5	9.7%	**$1,113.0**	$338.0	43.6%
12	New York 63rd Street Connector	**$488.4**	--		**$488.4**	$102.7	21.0%	**$591.1**	$41.2	7.0%	**$632.3**	$143.9	29.5%
13	Pasadena Gold Line	**$997.5**	--		**$997.5**	($414.7)	-41.6%	**$582.8**	$94.8	16.3%	**$677.6**	($319.9)	-32.1%
14	Pittsburgh Airport Busway (Phase 1)	**$170.2**	--		**$170.2**	$95.5	56.1%	**$265.7**	$61.1	23.0%	**$326.8**	$156.6	92.0%
15	Portland Airport MAX Extension	**$125.0**	--		**$125.0**	$2.0	1.6%	**$127.0**	$0.0	0.0%	**$127.0**	$2.0	1.6%
16	Portland Banfield Corridor	**$214.0**	--		**$214.0**	$1.4	0.6%	**$215.4**	$31.4	14.6%	**$246.8**	$32.8	15.3%
17	Portland Interstate MAX	**$278.9**	$34.5	12.4%	**$313.4**	$36.0	11.5%	**$349.4**	$0.0	0.0%	**$349.4**	$36.0	11.5%
18	Portland Westside/Hillsboro MAX	**$479.8**	$52.1	10.9%	**$531.9**	$337.1	63.4%	**$869.1**	$94.4	10.9%	**$963.5**	$431.6	81.1%
19	Salt Lake North-South Line	**$256.3**	$20.6	8.0%	**$276.9**	$28.6	10.3%	**$305.6**	$6.2	2.0%	**$311.8**	$34.9	12.6%
20	San Francisco SFO Airport	**$1,046.0**	$129.3	12.4%	**$1,175.3**	$222.5	18.9%	**$1,397.8**	$152.4	10.9%	**$1,550.2**	$374.9	31.9%
21	San Juan Tren Urbano	**$766.0**	$199.0	26.0%	**$965.0**	$1,085.9	112.5%	**$2,050.9**	$199.1	9.7%	**$2,250.0**	$1,285.0	133.2%
22	Santa Clara Capitol Line	**$147.1**	--		**$147.1**	$15.4	10.5%	**$162.5**	$0.0	0.0%	**$162.5**	$15.4	10.5%
23	Santa Clara Tasman East Line	**$197.7**	--		**$197.7**	$70.9	35.9%	**$268.7**	$7.5	2.8%	**$276.2**	$78.5	39.7%
24	Santa Clara Tasman West Line	**$251.3**	--		**$251.3**	$29.4	11.7%	**$280.6**	$0.0	0.0%	**$280.6**	$29.4	11.7%
25	Santa Clara Vasona Line	**$269.1**	--		**$269.1**	$47.8	17.7%	**$316.8**	$0.0	0.0%	**$316.8**	$47.8	17.7%
26	Seattle Busway Tunnel	**$288.3**	$25.8	9.0%	**$314.1**	$247.4	78.8%	**$561.5**	$49.6	8.8%	**$611.1**	$297.0	94.6%
27	St Louis Saint Clair Corridor	**$337.3**	--		**$337.3**	($0.8)	-0.2%	**$336.5**	$0.0	0.0%	**$336.5**	($0.8)	-0.2%
28	Washington Largo Extension	**$397.1**	--		**$397.1**	$47.0	11.8%	**$444.1**	$11.9	2.7%	**$456.0**	$58.9	14.8%
	Sum	**$12,518.7**	**$1,060.2**	**8.5%**	**$13,578.9**	**$3,912.1**	**28.8%**	**$17,491.0**	**$1,582.8**	**9.0%**	**$19,073.8**	**$5,494.9**	**40.5%**
	Unweighted Average			**14.7%**			**25.9%**			**7.9%**			**36.3%**

Table 3-3. Capital Cost Variation by Project Development Phase

ID	Case Study Projects	Planning/ DEIS (1)	Change from Planning to Preliminary Engineering		PE/ FEIS (2)	Change from Preliminary Engineering to Final Design		Final Design/ FFGA (3)	Change from Final Design to Construction		Final Cost (4)	Total Change from Earliest Estimate to Final Cost	
		Millions YOE$	Millions YOE$	%	**Millions YOE$**	Millions YOE$	%	**Millions YOE$**	Millions YOE$	%	**Millions YOE$**	Millions YOE$	%
1	Atlanta North Line Extension	**$422.4**	$16.5	3.9%	**$438.9**	($57.6)	-13.1%	**$381.3**	$91.4	24.0%	**$472.7**	$50.2	11.9%
2	Boston Old Colony Rehabilitation	**$447.2**	$28.9	6.5%	**$476.1**	$75.8	15.9%	**$551.9**	$13.1	2.4%	**$565.0**	$117.8	26.3%
3	Boston Silver Line (Phase 1)	**$318.1**	$66.3	20.8%	**$384.4**	$29.0	7.5%	**$413.4**	$191.0	46.2%	**$604.4**	$286.3	90.0%
4	Chicago Southwest Extension	**$453.0**	$43.0	9.5%	**$496.0**	($145.1)	-29.2%	**$350.9**	$123.7	35.2%	**$474.6**	$21.6	4.8%
5	Dallas South Oak Cliff Extension	**$347.1**	$170.1	49.0%	**$517.2**	$0.0	0.0%	**$517.2**	($80.0)	-15.5%	**$437.2**	$90.1	26.0%
6	Denver Southwest Line	**$138.0**	$14.1	10.2%	**$152.1**	$24.3	15.9%	**$176.3**	$0.8	0.4%	**$177.1**	$39.1	28.3%
7	Los Angeles Red Line MOS 1	**n/a**	--		**$695.8**	$264.5	38.0%	**$960.3**	$529.9	55.2%	**$1,490.1**	$794.4	114.2%
8	Los Angeles Red Line MOS 2	**n/a**	--		**$1,116.6**	$408.0	36.5%	**$1,524.6**	$397.0	26.0%	**$1,921.6**	$805.0	72.1%
9	Los Angeles Red Line MOS 3	**n/a**	--		**$1,113.3**	$232.3	20.9%	**$1,345.6**	($118.0)	-8.8%	**$1,227.6**	$114.3	10.3%
10	Minneapolis Hiawatha Line	**$581.0**	($32.4)	-5.6%	**$548.6**	$126.8	23.1%	**$675.4**	$39.9	5.9%	**$715.3**	$134.3	23.1%
11	New Jersey Hudson-Bergen MOS1	**$775.0**	($136.4)	-17.6%	**$638.6**	$353.5	55.4%	**$992.1**	$120.9	12.2%	**$1,113.0**	$338.0	43.6%
12	New York 63rd Street Connector	**$488.4**	$49.5	10.1%	**$537.9**	$107.1	19.9%	**$645.0**	($12.7)	-2.0%	**$632.3**	$143.9	29.5%
13	Pasadena Gold Line	**$997.5**	($193.7)	-19.4%	**$803.8**	($109.9)	-13.7%	**$693.9**	($16.3)	-2.3%	**$677.6**	($319.9)	-32.1%
14	Pittsburgh Airport Busway (Ph 1)	**$170.2**	$115.0	67.6%	**$285.2**	$41.6	14.6%	**$326.8**	$0.0	0.0%	**$326.8**	$156.6	92.0%
15	Portland Airport MAX Extension	**$125.0**	$0.0	0.0%	**$125.0**	$0.0	0.0%	**$125.0**	$2.0	1.6%	**$127.0**	$2.0	1.6%
16	Portland Banfield Corridor	**n/a**	--		**$214.0**	$72.5	33.9%	**$286.6**	($39.8)	-13.9%	**$246.8**	$32.8	15.3%
17	Portland Interstate MAX	**$313.4**	$16.5	5.3%	**$329.8**	($15.0)	-4.5%	**$314.9**	$34.5	11.0%	**$349.4**	$36.0	11.5%
18	Portland Westside/Hillsboro MAX	**$531.9**	$381.1	71.6%	**$913.0**	($2.8)	-0.3%	**$910.2**	$53.3	5.9%	**$963.5**	$431.6	81.1%
19	Salt Lake North-South Line	**$276.9**	$8.7	3.1%	**$285.6**	$26.4	9.2%	**$312.0**	($0.2)	-0.1%	**$311.8**	$34.9	12.6%
20	San Francisco SFO Airport Ext.	**$1,175.3**	($1.4)	-0.1%	**$1,173.9**	($6.9)	-0.6%	**$1,167.0**	$383.2	32.8%	**$1,550.2**	$374.9	31.9%
21	San Juan Tren Urbano	**$965.0**	$157.0	16.3%	**$1,122.0**	$128.0	11.4%	**$1,250.0**	$1,000.0	80.0%	**$2,250.0**	$1,285.0	133.2%
22	Santa Clara Capitol Line	**n/a**	--		**$147.1**	$12.7	8.6%	**$159.8**	$2.7	1.7%	**$162.5**	$15.4	10.5%
23	Santa Clara Tasman East Line	**$197.7**	$78.1	39.5%	**$275.9**	($0.8)	-0.3%	**$275.1**	$1.1	0.4%	**$276.2**	$78.5	39.7%
24	Santa Clara Tasman West Line	**$251.3**	$76.5	30.5%	**$327.8**	$4.7	1.4%	**$332.5**	($51.9)	-15.6%	**$280.6**	$29.4	11.7%
25	Santa Clara Vasona Line	**n/a**	--		**$269.1**	$44.5	16.5%	**$313.6**	$3.2	1.0%	**$316.8**	$47.8	17.7%
26	Seattle Busway Tunnel	**$314.1**	$45.6	14.5%	**$359.7**	$35.7	9.9%	**$395.4**	$215.7	54.6%	**$611.1**	$297.0	94.6%
27	St Louis Saint Clair Corridor	**$337.3**	$39.4	11.7%	**$376.7**	($37.5)	-10.0%	**$339.2**	($2.7)	-0.8%	**$336.5**	($0.8)	-0.2%
28	Washington Largo Extension	**$397.1**	$36.8	9.3%	**$433.9**	$0.0	0.0%	**$433.9**	$22.1	5.1%	**$456.0**	$58.9	14.8%
	Sum	**$10,023.0**	**$979.1**	**9.8%**	**$14,558.0**	**$1,612.0**	**11.1%**	**$16,169.9**	**$2,903.8**	**18.0%**	**$19,073.8**	**$5,494.9**	**37.7%**
	Unweighted Average			**15.3%**			**9.5%**			**12.2%**			**36.3%**

Capital Cost Variation by Major Driver

It can be seen in **Table 3-2** that the sum of the initial inflation adjustments (A to B) for the 12 projects reporting in planning year dollars is about $1.06 billion, which represents a 8.5% increase as a weighted average over the sum of the initially reported estimates. The remaining 16 projects were already reported in YOE dollars. The unweighted average of the inflation adjustment for the 12 projects yields a 14.7% increase. This adjustment converts the initial estimates in constant year dollars to YOE (baseline) dollars. The unweighted average, as reported in the last row of **Table 3-2**, is arguably a more appropriate measure of the increase exhibited by these projects because it treats each project as a distinct observation and is not influenced by their magnitude.

The sum of scope changes (B to C) for all projects is about $3.9 billion in YOE dollars, or an unweighted average increase of 25.9% (Table 3-2). Scope changes is the sum of unit cost and quantity adjustments from planning to completion in YOE (baseline year of estimate) dollars. There was sufficient data to separate unit cost and quantity changes for 14 of the 28 case study projects. These more detailed results are presented in **Table 3-4**.

Table 3-4. Detailed Breakdown of Scope Changes for 14 Projects

ID	Subset of Case Study Projects	Baseline Estimate (B)	Unit Cost Adjustment		Quantity Adjustment		Scope Change (Sum of unit cost and quantity adjustments)		Scope Adjusted Estimate (C)
		Millions YOE$	Millions YOE$	%	Millions YOE$	%	Millions YOE$	%	Millions YOE$
1	Atlanta North Line Extension	**$422.4**	$41.6	9.9%	($40.5)	-9.6%	$1.1	0.3%	**$423.5**
4	Chicago Southwest Extension	**$453.0**	$29.5	6.5%	($48.6)	-10.7%	($19.1)	-4.2%	**$433.9**
6	Denver Southwest Line	**$138.0**	$21.7	15.8%	$2.3	1.7%	$24.0	17.4%	**$162.0**
7	Los Angeles Red Line MOS 1	**$695.8**	$814.3	117.0%	($126.1)	-18.1%	$688.2	98.9%	**$1,383.9**
8	Los Angeles Red Line MOS 2	**$1,116.6**	$555.3	49.7%	$63.8	5.7%	$619.1	55.4%	**$1,735.7**
9	Los Angeles Red Line MOS 3	**$1,113.3**	$25.4	2.3%	($4.6)	-0.4%	$20.8	1.9%	**$1,134.1**
16	Portland Banfield Corridor	**$214.0**	($7.8)	-3.6%	$9.1	4.3%	$1.4	0.6%	**$215.4**
17	Portland Interstate MAX	**$313.4**	$56.8	18.1%	($20.8)	-6.6%	$36.0	11.5%	**$349.4**
19	Salt Lake North-South Line	**$276.9**	$5.1	1.8%	$23.5	8.5%	$28.6	10.3%	**$305.6**
22	Santa Clara Capitol Line	**$147.1**	$15.4	10.5%	$0.0	0.0%	$15.4	10.5%	**$162.5**
23	Santa Clara Tasman East Line	**$197.7**	($7.2)	-3.6%	$0.0	0.0%	$70.9	35.9%	**$268.7**
24	Santa Clara Tasman West Line	**$251.3**	($47.2)	-18.8%	($0.0)	0.0%	$29.4	11.7%	**$280.6**
25	Santa Clara Vasona Line	**$269.1**	$47.8	17.7%	$0.0	0.0%	$47.8	17.7%	**$316.8**
27	St Louis Saint Clair Corridor	**$337.3**	$94.4	28.0%	($95.2)	-28.2%	($0.8)	-0.2%	**$336.5**
	Sum	$5,946.0	$1,645.2	27.7%	($237.1)	-4.0%	$1,562.7	26.3%	**$7,508.7**
	Unweighted Average			17.9%		-3.8%		19.1%	

Using this subset of 14 projects, the unweighted average of unit cost adjustments is an 17.9% increase, while the unweighted average for quantity adjustments is a 3.8% decrease. Most of these projects exhibited a unit cost increase. A majority of projects also exhibited a unit quantity decrease or no change. This quantity decrease represented a cost control response to the cost increases. Quantity reductions were developed to counter the unit cost and schedule cost increases. The sum of changes in unit cost and quantities, therefore, is a 19.1% increase. This atypical unweighted average result is due to the first two Los Angeles projects that dominate the results in both size of project and size of increase.

Appendix C includes the unit cost and quantity line graphs and "Project Cost Variance by Phase" charts introduced in **Figures 3-1** and **3-2** for these 14 projects. The cost impact of schedule change is captured by the difference between columns (C) and (D) in **Table 3-2**. An unweighted average increase of 7.9% was experienced by the 28 case study projects due to schedule changes. In real terms (baseline YOE dollars), there was an unweighted average 36.3% increase (B to D) in capital costs over the life of the 28 case study projects. About 70% of this increase was due to scope changes (B to C) while the remaining 30% was due to schedule changes (C to D). Nonetheless, the experience of individual projects varied widely. The full background for all 28 case study project is presented in **Appendix C**.

A summary of the descriptive statistics for the change in the cost estimate due to the three major cost drivers is shown in **Table 3-5**. These statistics demonstrate the quality and characteristics of the data set. Kurtosis indicates the concentration of the data around the mean. Skewness is the lack of symmetry of the data set above and below the mean. In general, the change is dominated by the larger projects and this supports the use of the unweighted average change rather than the weighted change.

Table 3-5. Summary Statistics for Change in Cost by Major Driver

Summary Statistics	*Initial Inflation Adjustment (A to B)*	*Scope Change (B to C)*	*Schedule Change (C to D)*
Mean	14.7%	25.9%	7.9%
Standard Error	1.8%	6.3%	1.2%
Median	12.4%	17.1%	8.5%
Standard Deviation	6.2%	33.5%	6.1%
Sample Variance	0.4%	11.2%	0.4%
Kurtosis	-65.9%	107.9%	7.6%
Skewness	81.2%	94.7%	46.8%
Range	17.9%	154.1%	23.0%
Minimum	8.0%	-41.6%	0.0%
Maximum	26.0%	112.5%	23.0%
Count	12*	28	28

Capital Cost Variation by Phase of Development

Capital cost data for all 28 case study projects is presented in **Table 3-3** according to the four major phases of project development. A summary of the descriptive statistics for the change in the baseline estimate (YOE dollars) between development phases is shown in **Table 3-6**. This average is greater for the earlier phase (1 to 2) than for the later phases (2 to 3, and 3 to 4). From planning to PE, the 22 sample projects which reported an estimate for both phases exhibited a 15.3% increase in cost. From PE to final design and from final design to operations, there was a similar increase of about 9.5% for 28 samples.

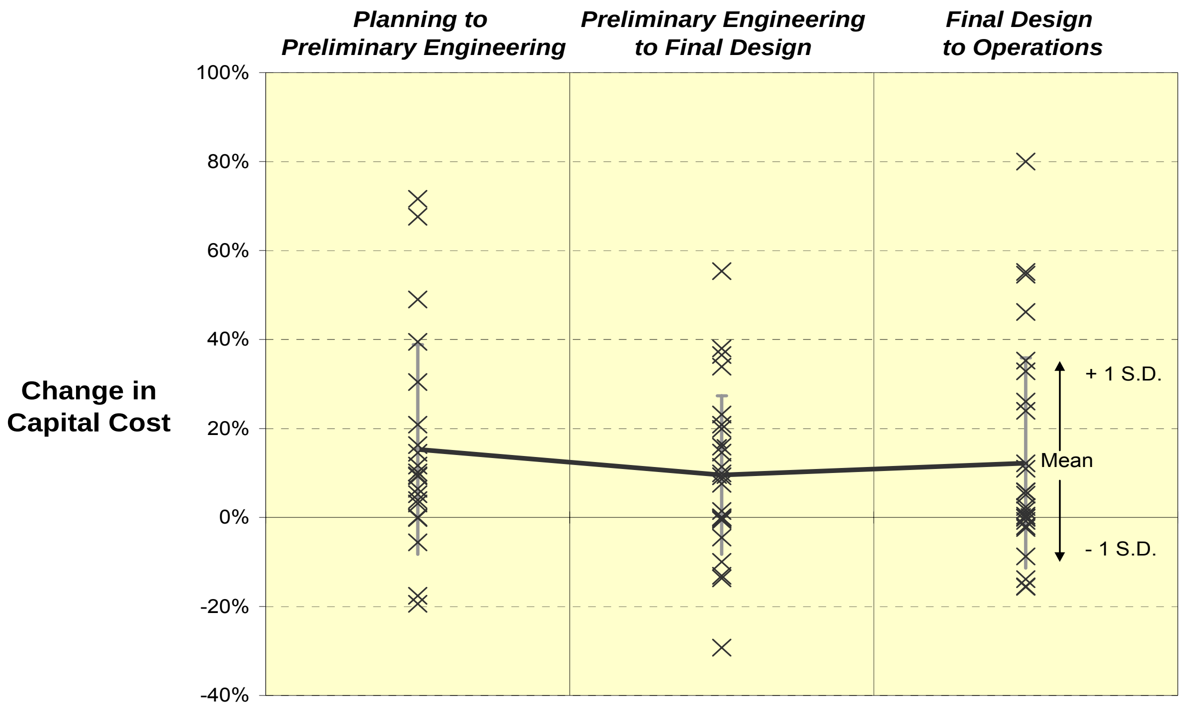
The range of the observations also tended to decrease slightly from the earlier phase to later phases. However, there was a very similar distribution between PE to final design and final design to operations as evidenced by the statistics for each series in **Table 3-6**. The statistics present mean values that demonstrate a consistent increase in capital costs between each of the development stages. In each case, the median point value is below the mean, and this occurs most substantially in the last stage of project construction. These differences indicate that the mean cost increase values are affected somewhat by a few larger project cost increases that skew the mean values higher. **Figure 3-4** illustrates the distribution of capital cost variation between each phase. This graphically demonstrates the capital cost percentage changes by phase and the trend in mean and the standard deviations, plus and minus.

Table 3-6. Summary Statistics for Change in Cost Between Development Phases

Summary Statistics	*Planning to PE (1 to 2)*	*PE to Final Design (2 to 3)*	*FD to Operations (3 to 4)*
Mean	15.3%	9.5%	12.2%
Standard Error	5.0%	3.4%	4.5%
Median	9.8%	8.9%	2.0%
Standard Deviation	23.6%	17.8%	23.6%
Sample Variance	5.6%	3.2%	5.6%
Kurtosis	107.2%	78.6%	133.3%
Skewness	111.1%	42.6%	133.0%
Range	91.1%	84.6%	95.6%
Minimum	-19.4%	-29.2%	-15.6%
Maximum	71.6%	55.4%	80.0%
Count	22*	28	28

* These statistics do not include the 6 projects for which a Planning/DEIS estimate was not available or could not be determined because the scope of the project changed significantly between planning and PE (e.g. Los Angeles Red Line MOS 1, 2, and 3)

Figure 3-4. Distribution of Capital Cost Variation by Phase



Capital Cost Variation by Phase and Cost Driver

The 28 project data set allowed for analysis of capital cost variations between 4 phases of development and according to 2 major cost drivers – scope and schedule. **Table 3-7** presents this analysis by attributing capital cost change (as a percent change from the baseline YOE estimate) to either scope or schedule changes during the period from Planning to PE (column 1 to 2), PE to Final Design (column 2 to 3), and Final Design to Operations (column 3 to 4). From Planning to PE, scope changes caused an average 10.5% increase in capital cost while schedule changes caused an average 4.8% increase. From PE to Final Design, scope changes caused an average 5.8% increase in capital cost while schedule changes caused an average 4.0% increase. From Final Design to Final Cost, scope changes caused an average 11.2% increase in capital cost while schedule changes caused an average 3.3% increase. Overall, about two-thirds of cost variation was attributed to scope changes in this detailed analysis.

Table 3-8 presents a more detailed analysis of average capital cost changes due to unit cost, quantity, and schedule changes by phase of development. From Planning to PE, unit cost and quantity changes caused a 20.8% increase and a 13.6% decrease in capital costs, respectively. From PE to Final Design, unit cost and quantity changes caused a 9.8% increase and a 4.4% decrease in capital costs, respectively. From Final Design to Final Cost, unit cost and quantity changes resulted in a 7.7% increase and a 0.9% decrease in capital costs, respectively.

Table 3-7. Capital Cost Variation by Phase and Major Cost Driver

ID	Case Study Projects	Planning/ DEIS (1)	Change from Planning to Preliminary Engineering		PE/ FEIS (2)	Change from Preliminary Engineering to Final Design		Final Design/ FFGA (3)	Change from Final Design to Construction		Final Cost (4)	Total Change from Earliest Estimate to Final Cost
		Millions YOE$	Scope Change	Sched. Change	Millions YOE$	Scope Change	Sched. Change	Millions YOE$	Scope Change	Sched. Change	Millions YOE$	
1	Atlanta North Line Extension	**$422.4**	3.9%	0.0%	**$438.9**	-13.6%	0.0%	**$381.3**	12.1%	9.5%	**$472.7**	11.9%
2	Boston Old Colony Rehabilitation	**$447.2**	4.1%	2.4%	**$476.1**	10.0%	7.0%	**$551.9**	2.7%	0.2%	**$565.0**	26.3%
3	Boston Silver Line (Phase 1)	**$318.1**	13.0%	7.9%	**$384.4**	8.5%	0.6%	**$413.4**	37.4%	22.7%	**$604.4**	90.0%
4	Chicago Southwest Extension	**$453.0**	9.5%	0.0%	**$496.0**	-35.1%	3.1%	**$350.9**	21.4%	5.9%	**$474.6**	4.8%
5	Dallas South Oak Cliff Extension	**$347.1**	44.9%	4.1%	**$517.2**	-8.8%	8.8%	**$517.2**	-17.7%	-5.3%	**$437.2**	26.0%
6	Denver Southwest Line	**$138.0**	0.8%	9.4%	**$152.1**	16.1%	1.5%	**$176.3**	0.5%	0.0%	**$177.1**	28.3%
7	Los Angeles Red Line MOS 1	**n/a**			**$695.8**	31.6%	6.5%	**$960.3**	67.3%	8.8%	**$1,490.1**	114.2%
8	Los Angeles Red Line MOS 2	**n/a**			**$1,116.6**	29.5%	7.0%	**$1,524.6**	25.9%	9.6%	**$1,921.6**	72.1%
9	Los Angeles Red Line MOS 3	**n/a**			**$1,113.3**	15.1%	5.8%	**$1,345.6**	-13.2%	2.6%	**$1,227.6**	10.3%
10	Minneapolis Hiawatha Line	**$581.0**	-10.1%	4.5%	**$548.6**	17.1%	4.8%	**$675.4**	3.1%	3.7%	**$715.3**	23.1%
11	New Jersey Hudson-Bergen MOS1	**$775.0**	-19.5%	1.9%	**$638.6**	42.1%	3.6%	**$992.1**	8.3%	7.3%	**$1,113.0**	43.6%
12	New York 63rd Street Connector	**$488.4**	3.0%	7.2%	**$537.9**	20.5%	1.4%	**$645.0**	-2.4%	-0.2%	**$632.3**	29.5%
13	Pasadena Gold Line	**$997.5**	-23.1%	3.7%	**$803.8**	-17.0%	6.0%	**$693.9**	-1.4%	-0.2%	**$677.6**	-32.1%
14	Pittsburgh Airport Busway (Phase 1)	**$170.2**	51.1%	16.5%	**$285.2**	10.4%	14.0%	**$326.8**	-5.4%	5.4%	**$326.8**	92.0%
15	Portland Airport MAX Extension	**$125.0**	0.0%	0.0%	**$125.0**	0.0%	0.0%	**$125.0**	1.6%	0.0%	**$127.0**	1.6%
16	Portland Banfield Corridor	**n/a**			**$214.0**	16.9%	17.0%	**$286.6**	-16.2%	-2.4%	**$246.8**	15.3%
17	Portland Interstate MAX	**$313.4**	5.3%	0.0%	**$329.8**	-4.8%	0.0%	**$314.9**	11.0%	0.0%	**$349.4**	11.5%
18	Portland Westside/Hillsboro MAX	**$531.9**	67.8%	3.9%	**$913.0**	-13.4%	12.9%	**$910.2**	9.0%	1.0%	**$963.5**	81.1%
19	Salt Lake North-South Line	**$276.9**	-1.1%	4.2%	**$285.6**	9.1%	0.4%	**$312.0**	2.3%	-2.3%	**$311.8**	12.6%
20	San Francisco SFO Airport	**$1,175.3**	-4.2%	4.1%	**$1,173.9**	-0.6%	0.0%	**$1,167.0**	23.7%	8.9%	**$1,550.2**	31.9%
21	San Juan Tren Urbano	**$965.0**	11.3%	4.9%	**$1,122.0**	10.1%	3.2%	**$1,250.0**	91.1%	12.5%	**$2,250.0**	133.2%
22	Santa Clara Capitol Line	**n/a**			**$147.1**	8.6%	0.0%	**$159.8**	1.8%	0.0%	**$162.5**	10.5%
23	Santa Clara Tasman East Line	**$197.7**	27.6%	11.9%	**$275.9**	-3.8%	3.4%	**$275.1**	0.5%	0.1%	**$276.2**	39.7%
24	Santa Clara Tasman West Line	**$251.3**	19.4%	11.1%	**$327.8**	1.7%	0.2%	**$332.5**	-18.9%	-1.8%	**$280.6**	11.7%
25	Santa Clara Vasona Line	**n/a**			**$269.1**	16.5%	0.0%	**$313.6**	1.2%	0.0%	**$316.8**	17.7%
26	Seattle Busway Tunnel	**$314.1**	12.3%	2.2%	**$359.7**	3.3%	8.0%	**$395.4**	63.1%	5.6%	**$611.1**	94.6%
27	St Louis Saint Clair Corridor	**$337.3**	11.7%	0.0%	**$376.7**	-11.1%	0.0%	**$339.2**	-0.8%	0.0%	**$336.5**	-0.2%
28	Washington Largo Extension	**$397.1**	3.5%	5.7%	**$433.9**	2.9%	-2.9%	**$433.9**	5.4%	0.1%	**$456.0**	14.8%
	Sum	**$13,578.9**			**$14,558.0**			**$16,169.9**			**$19,073.8**	
	Unweighted Average		**10.5%**	**4.8%**		**5.8%**	**4.0%**		**11.2%**	**3.3%**		**36.3%**

Table 3-8. Capital Cost Variation by Phase and Detailed Cost Driver

ID	Case Study Projects	Planning/ DEIS (1)	Change from Planning to Preliminary Engineering			PE/ FEIS (2)	Change from Preliminary Engineering to Final Design			Final Design/ FFGA (3)	Change from Final Design to Construction			Final Cost (4)
		Millions YOE$	Unit Cost Change	Quantity Change	Sched. Change	**Millions YOE$**	Unit Cost Change	Quantity Change	Sched. Change	**Millions YOE$**	Unit Cost Change	Quantity Change	Sched. Change	**Millions YOE$**
1	Atlanta North Line Extension	$422.4	60.3%	-79.8%	0.0%	$438.9	30.7%	-44.3%	0.0%	$381.3	-10.5%	22.6%	9.5%	$472.7
4	Chicago Southwest Extension	$453.0	53.1%	-2.0%	0.0%	$496.0	-13.6%	-21.5%	3.1%	$350.9	10.3%	11.1%	5.9%	$474.6
6	Denver Southwest Line	$138.0	0.0%	0.0%	9.4%	$152.1	12.6%	3.5%	1.5%	$176.3	2.3%	-1.8%	0.0%	$177.1
7	Los Angeles Red Line MOS 1	n/a				$695.8	31.6%	0.0%	6.5%	$960.3	85.5%	-18.1%	8.8%	$1,490.1
8	Los Angeles Red Line MOS 2	n/a				$1,116.6	31.7%	-2.2%	7.0%	$1,524.6	18.0%	7.9%	9.6%	$1,921.6
9	Los Angeles Red Line MOS 3	n/a				$1,113.3	15.1%	0.0%	5.8%	$1,345.6	-12.8%	-0.4%	2.6%	$1,227.6
16	Portland Banfield Corridor	n/a				$214.0	14.7%	2.2%	17.0%	$286.6	-18.3%	2.1%	-2.4%	$246.8
17	Portland Interstate MAX	$313.4	11.7%	0.0%	0.0%	$329.8	-35.5%	30.7%	0.0%	$314.9	48.4%	-37.4%	0.0%	$349.4
19	Salt Lake North-South Line	$276.9	0.0%	0.0%	4.2%	$285.6	0.3%	8.8%	0.4%	$312.0	2.6%	-0.3%	-2.3%	$311.8
22	Santa Clara Capitol Line	n/a				$147.1	8.6%	0.0%	0.0%	$159.8	1.8%	0.0%	0.0%	$162.5
23	Santa Clara Tasman East Line	$197.7			11.9%	$275.9	-3.8%	0.0%	3.4%	$275.1	0.5%	0.0%	0.1%	$276.2
24	Santa Clara Tasman West Line	$251.3			11.1%	$327.8	1.7%	0.0%	0.2%	$332.5	-18.9%	0.0%	-1.8%	$280.6
25	Santa Clara Vasona Line	n/a				$269.1	16.5%	0.0%	0.0%	$313.6	1.2%	0.0%	0.0%	$316.8
27	St Louis Saint Clair Corridor	$337.3	0.0%	0.0%	0.0%	$376.7	27.0%	-38.2%	0.0%	$339.2	-2.4%	1.6%	0.0%	$336.5
	Sum	$10,044.7				$14,558.0				$16,169.9				$19,073.8
	Unweighted Average		20.8%	-13.6%	4.8%		9.8%	-4.4%	4.0%		7.7%	-0.9%	3.3%	

3.3.2. Set of 14 TCRP Project Panel Selected Projects

The 14 projects selected by the TCRP project panel represent a more recently completed subset of the 28 case study projects (2.7 years newer on average). As can be seen in **Table 3-9,** these TCRP project panel selected projects exhibited a slightly lower unweighted average cost increase of 27.5% compared to the 36.3% for the 28 case study projects. The average scope change was also lower at a 16.1% increase, but the schedule change was slightly higher at a 9.3% increase. The scope and schedule changes of these 14 projects are examined in detail in **Section 4** to understand the impact of numerous cost estimation, management, and control strategies.

Table 3-9. Capital Cost Variation of Panel Projects by Major Cost Driver

ID	Panel Selected Case Study Projects	Initial Inflated Estimate (B)	Sum of unit cost and scope adjustments		Scope Adjusted (C)	Schedule Change (inflation due to delays)		Schedule Adjusted (D)	Real Change From (B) to (D)	
		Millions YOE$	Millions YOE$	(C-B)/B	Millions YOE$	Millions YOE$	(D-C)/C	Millions YOE$	Millions YOE$	% Change
1	Atlanta North Line Extension	**$422.4**	$1.1	0.3%	**$423.5**	$49.1	11.6%	**$472.7**	**$50.2**	**11.9%**
3	Boston Silver Line (Phase 1)	**$318.1**	$187.2	58.9%	**$505.3**	$99.1	19.6%	**$604.4**	**$286.3**	**90.0%**
5	Dallas South Oak Cliff Extension	**$347.1**	$63.9	18.4%	**$411.0**	$26.2	6.4%	**$437.2**	**$90.1**	**26.0%**
6	Denver Southwest Line	**$138.0**	$24.0	17.4%	**$162.0**	$15.1	9.3%	**$177.1**	**$39.1**	**28.3%**
10	Minneapolis Hiawatha Line	**$581.0**	$58.7	10.1%	**$639.7**	$75.6	11.8%	**$715.3**	**$134.3**	**23.1%**
11	New Jersey Hudson-Bergen MOS1	**$775.0**	$239.5	30.9%	**$1,014.5**	$98.5	9.7%	**$1,113.0**	**$338.0**	**43.6%**
12	New York 63rd Street Connector	**$488.4**	$102.7	21.0%	**$591.1**	$41.2	7.0%	**$632.3**	**$143.9**	**29.5%**
13	Pasadena Gold Line	**$997.5**	($414.7)	-41.6%	**$582.8**	$94.8	16.3%	**$677.6**	**($319.9)**	**-32.1%**
14	Pittsburgh Airport Busway (Phase 1)	**$170.2**	$95.5	56.1%	**$265.7**	$61.1	23.0%	**$326.8**	**$156.6**	**92.0%**
15	Portland Airport MAX Extension	**$125.0**	$2.0	1.6%	**$127.0**	$0.0	0.0%	**$127.0**	**$2.0**	**1.6%**
17	Portland Interstate MAX	**$313.4**	$36.0	11.5%	**$349.4**	$0.0	0.0%	**$349.4**	**$36.0**	**11.5%**
19	Salt Lake North-South Line	**$276.9**	$28.6	10.3%	**$305.6**	$6.2	2.0%	**$311.8**	**$34.9**	**12.6%**
20	San Francisco SFO Airport Extension	**$1,175.3**	$222.5	18.9%	**$1,397.8**	$152.4	10.9%	**$1,550.2**	**$374.9**	**31.9%**
28	Washington Largo Extension	**$397.1**	$47.0	11.8%	**$444.1**	$11.9	2.7%	**$456.0**	**$58.9**	**14.8%**
	Sum	**$6,525.5**	$694.1	10.6%	**$7,219.5**	$731.2	10.1%	**$7,950.7**	**$1,425.3**	**21.8%**
	Unweighted Average			16.1%			9.3%			**27.5%**

The following paragraphs are summaries of the most significant cost drivers and events affecting the capital cost estimates throughout the life of the 14 TCRP project panel selected projects. **Appendix C** includes additional information on each project.

- **Atlanta North Line** – Most of the cost variation can be explained by the significant variance in scope (e.g., alignment length, number of vehicles, and longer functional life) at various stages, and difficult or unexpected field conditions (e.g., heavy traffic and excavation work). The scope changed because of unanticipated service-level increases, station parking enhancements, and impacts to the project right-of-way from the proposed widening of the adjacent GA 400 freeway. The project included the purchase of 56 rail cars, twice the number included in the original plan. The project is currently estimated to cost $472.7 million.
- **Boston Silver Line** – After a 1994 FFGA, the original project was reorganized. The South Boston Piers Transitway project and the locally funded Washington Street Replacement became one bus rapid transit project known as the "Silver Line.” A 2001 recovery plan was submitted to the FTA to reflect the capital cost growth due in some measure to delays in the project's implementation schedule. The escalation of the total project cost was the responsibility of local project sponsors.
- **Denver Southwest Line** – Early estimates underestimated costs for guideway, ROW, track, facilities, and soft costs because of changes to station design and railroad relocation plans.
- **Dallas South Oak Cliff Extension** – In 1997, the DART Board of Directors approved the double tracking of the entire project (five additional miles of track). Favorable bid conditions reportedly allowed DART to realize $80 million in cost savings on this project. DART had requested an amendment to the FFGA to use the savings to add an additional station, parking, and the purchase of 20 additional railcars.
- **Minneapolis Hiawatha Line** – In August 1999, Metro Transit completed a re-evaluation of the 1985 FEIS on a segment of the alignment extending from the Minneapolis CBD to Interstate 494. An environmental assessment on the segment extending from I-494 to the Mall of America was also completed at that time. The resulting changes in the final route alignments serving downtown Minneapolis, the airport, and the Mall of America drove the revision of cost (particularly ROW acquisition) and ridership estimates.
- **New Jersey Hudson-Bergen LRT** – The minimum operating segment was defined in 1996 and the alignment was shortened, although, an alignment shift in Hoboken increased the number of stations. Revenue operations were phased over two years with the segment to Exchange Place (Phase A) opening in April 2000, three additional stations in November 2000, and full service to the Hoboken Terminal in the Spring of 2002.
- **New York 63rd Street Connector –** Early estimates were affected by labor costs, working around active roadway and railroad, and limited allowable work hours.

- **Pasadena Gold Line** – The original budget forecast in 1993 was $997.7 million with Revenue Operation Date (ROD) of November 1997. In 1994, the agency purchased the Atchison & Topeka – Santa Fe railroad right-of-way to be used for the alignment. After the budget began to escalate, the agency requested a cost containment study be completed in 1996 and the budget was reduced to $803.9 million while the ROD was extended out to May 2001. Shortly thereafter, the Los Angeles MTA continued with the constrained design and began minimal construction of the project. By 1998, the MTA had expended an estimated $242.23 million on design and construction, and the ROD was again extended out to July 2002. The MTA then decided to suspend the project due to budget concerns. The project was eventually restarted in 1999 under the Metro Gold Line Construction Authority with significant changes to the scope of the stations and maintenance facilities, as well as a new name—the Gold Line. The key cost center or drivers identified were systems, trackwork, stations, elevated structures, differing site conditions, and third-party influence on scope.
- **Pittsburgh Airport Busway** – In 1997, the FTA asked the agency for a recovery plan because of significant cost and schedule overruns. Under the FFGA, any overruns were the responsibility of the agency. The result was that the Mon River Bridge and Conrail shelf portions of the Airport Busway/Wabash HOV Project were dropped from the project in the recovery plan. The principal cost drivers were the purchase of rail rights-of-way, elevated structures and tunnels, higher than expected property acquisition costs, design changes, and inflationary factors due to schedule delay.
- **Portland Airport MAX** – Although the project was delivered on budget, early cost estimates were influenced by insurance, start date of construction, and management overhead.
- **Portland Interstate MAX** – In November 1998, voters rejected a $475 million General Obligation bond measure previously approved to fund construction of the South-North LRT. Consequently, Tri-Met evaluated alternative alignments and funding strategies to implement the system. Once redefined, the project stayed on budget and reportedly finished $25 million under budget due to unused contingencies, and used the savings to purchase seven additional light rail vehicles.
- **Salt Lake North South Line** – Scope growth early in project development included changes to a maintenance facility, vehicles, stations, and park-and-ride centers. The LRT project was part of Interstate 15 corridor improvements, which included reconstruction of a parallel segment of I-15. The principal cost drivers were right-of-way and track elements, LRT vehicles, systems, stations and parking.
- **San Francisco SFO Extension** – Initial cost increases were due to the fact that new alignments were evaluated in 1995 to 1996 and the preferred alternative was revised to include an aerial design option (wye stub) into the Airport. Later in the project's development, the SFO airport added $113 million in civil works (new facilities) on

airport property. The SFO airport was a major partner in this extension project, although, the airport work was outside the scope of the FFGA. There was also $80 million in additional local funding for scope growth.

- **Washington Largo Extension** – In 1998, capital cost estimates were updated based on the continuing development of preliminary engineering plans and the FEIS. A 10-percent cost contingency was built into the cost estimate. Maryland Transit Administration managed the project through preliminary engineering and WMATA assumed responsibility for managing the final design and construction activities. In September 2002, Prince Georges County and the Maryland Department of Transportation authorized an additional $13.6 million for the project to add a parking structure and day care center at the Largo station. In the same month, WMATA's Board approved $9 million from its Transit Infrastructure Investment Fund for the increase in scope.

3.3.3. Results

Capital cost variation is a function of many variables—most importantly changes to scope (including unit costs and quantities) and schedule. This section summarizes the results of the cost variance analysis and major cost drivers. All changes were calculated from actual costs using inflation-adjusted baseline YOE dollars.

Table 3-10 is a summary of the scope, schedule, and cost changes for all 28 case study projects using the following scale:

- Significant Increase (change ≥ 20%)
- Moderate Increase (20% > change ≥ 5%)
- Minor Increase (5% > change > 0%)
- No change (0%)
- Minor Decrease (0% > change > -5%)
- Moderate Decrease (-5% ≥ change > -20%)
- Significant Decrease (change ≤ -20%)

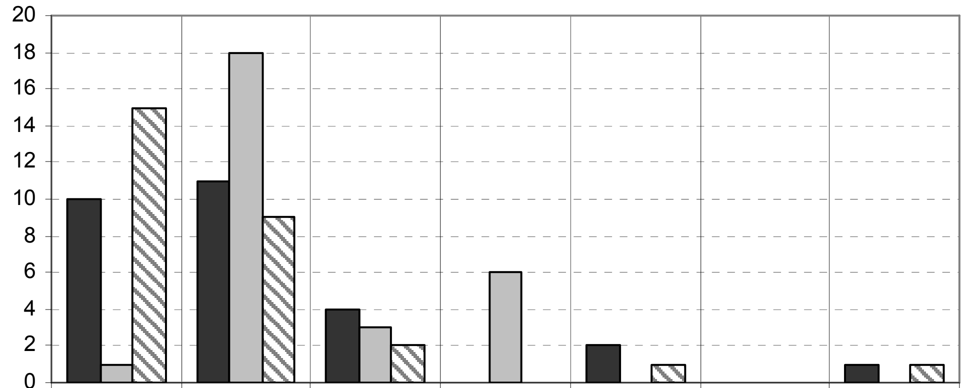
Figure 3-5 is a histogram of the scope, schedule, and cost changes for all 28 case study projects. **Table 3-11** is a summary of the unit cost, quantity, and schedule variation from actual for 14 projects with more detailed data. **Figure 3-6** is a histogram of this more detailed analysis of 14 case study projects.

Finally, **Table 3-12** and **Figure 3-7** present the results of an analysis of capital cost variation by phase.

Table 3-10. Summary of Scope, Schedule and Cost Variation from Actual

ID	Case Study Projects	Scope Change	Schedule Change	YOE Capital Cost Change
1	Atlanta North Line Extension	Minor Increase	Moderate Increase	Moderate Increase
2	Boston Old Colony Rehabilitation	Moderate Increase	Moderate Increase	Significant Increase
3	Boston Silver Line (Phase 1)	Significant Increase	Moderate Increase	Significant Increase
4	Chicago Southwest Extension	Minor Decrease	Moderate Increase	Minor Increase
5	Dallas South Oak Cliff Extension	Moderate Increase	Moderate Increase	Significant Increase
6	Denver Southwest Line	Moderate Increase	Moderate Increase	Significant Increase
7	Los Angeles Red Line MOS 1	Significant Increase	Moderate Increase	Significant Increase
8	Los Angeles Red Line MOS 2	Significant Increase	Moderate Increase	Significant Increase
9	Los Angeles Red Line MOS 3	Minor Increase	Moderate Increase	Moderate Increase
10	Minneapolis Hiawatha Line	Moderate Increase	Moderate Increase	Significant Increase
11	New Jersey Hudson-Bergen MOS1	Significant Increase	Moderate Increase	Significant Increase
12	New York 63rd Street Connector	Significant Increase	Moderate Increase	Significant Increase
13	Pasadena Gold Line	Significant Decrease	Moderate Increase	Significant Decrease
14	Pittsburgh Airport Busway (Phase 1)	Significant Increase	Significant Increase	Significant Increase
15	Portland Airport MAX Extension	Minor Increase	No Change	Minor Increase
16	Portland Banfield Corridor	Minor Increase	Moderate Increase	Moderate Increase
17	Portland Interstate MAX	Moderate Increase	No Change	Moderate Increase
18	Portland Westside/Hillsboro MAX	Significant Increase	Moderate Increase	Significant Increase
19	Salt Lake North-South Line	Moderate Increase	Minor Increase	Moderate Increase
20	San Francisco SFO Airport Extension	Moderate Increase	Moderate Increase	Significant Increase
21	San Juan Tren Urbano	Significant Increase	Moderate Increase	Significant Increase
22	Santa Clara Capitol Line	Moderate Increase	No Change	Moderate Increase
23	Santa Clara Tasman East Line	Significant Increase	Minor Increase	Significant Increase
24	Santa Clara Tasman West Line	Moderate Increase	No Change	Moderate Increase
25	Santa Clara Vasona Line	Moderate Increase	No Change	Moderate Increase
26	Seattle Busway Tunnel	Significant Increase	Moderate Increase	Significant Increase
27	St Louis Saint Clair Corridor	Minor Decrease	No Change	Minor Decrease
28	Washington Largo Extension	Moderate Increase	Minor Increase	Moderate Increase

Figure 3-5. Histogram of Results for 28 Case Study Projects

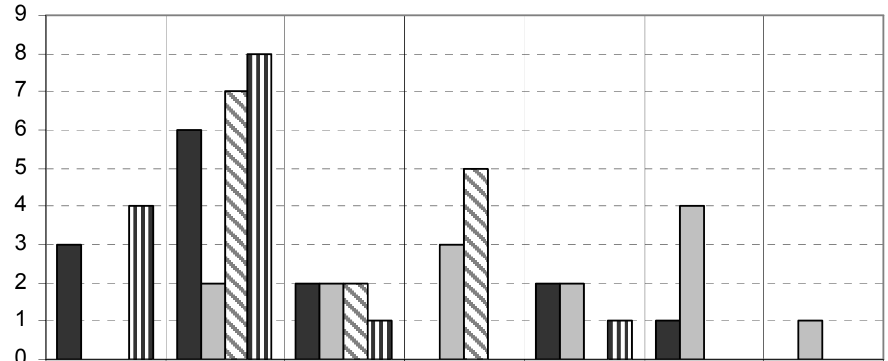


	Significant Increase	Moderate Increase	Minor Increase	No Change	Minor Decrease	Moderate Decrease	Significant Decrease
Scope Change	10	11	4	0	2	0	1
Schedule Change	1	18	3	6	0	0	0
YOE Capital Cost Change	15	9	2	0	1	0	1

Table 3-11. Summary of Detailed Variation for 14 Case Study Projects

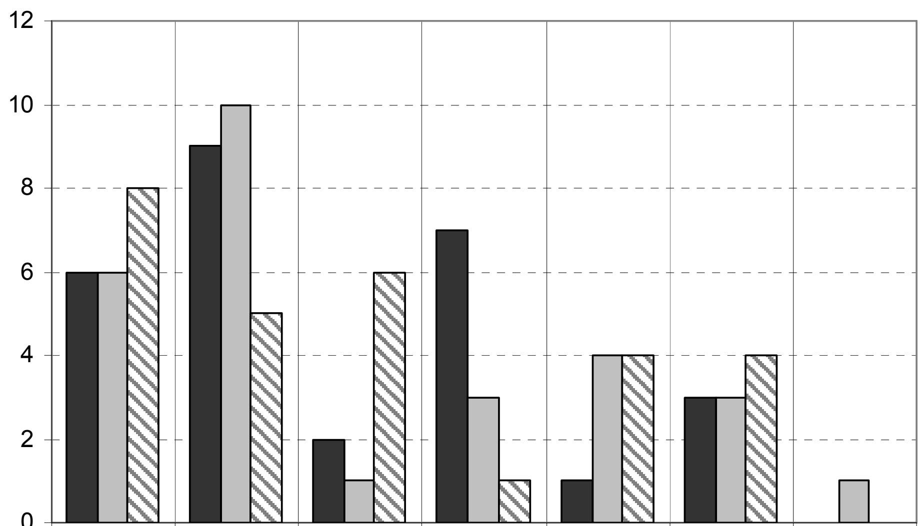
ID	Subset of Case Study Projects	Unit Cost Change	Quantity Change	Schedule Change	YOE Cost Change
1	Atlanta North Line Extension	Moderate Increase	Moderate Decrease	Moderate Increase	Moderate Increase
4	Chicago Southwest Extension	Moderate Increase	Moderate Decrease	Moderate Increase	Minor Increase
6	Denver Southwest Line	Moderate Increase	Minor Increase	Moderate Increase	Significant Increase
7	Los Angeles Red Line MOS 1	Significant Increase	Moderate Decrease	Moderate Increase	Significant Increase
8	Los Angeles Red Line MOS 2	Significant Increase	Moderate Increase	Moderate Increase	Significant Increase
9	Los Angeles Red Line MOS 3	Minor Increase	Minor Decrease	Moderate Increase	Moderate Increase
16	Portland Banfield Corridor	Minor Decrease	Minor Increase	Moderate Increase	Moderate Increase
17	Portland Interstate MAX	Moderate Increase	Moderate Decrease	No Change	Moderate Increase
19	Salt Lake North-South Line	Minor Increase	Moderate Increase	Minor Increase	Moderate Increase
22	Santa Clara Capitol Line	Moderate Increase	No Change	No Change	Moderate Increase
23	Santa Clara Tasman East Line	Minor Decrease	No Change	Minor Increase	Significant Increase
24	Santa Clara Tasman West Line	Moderate Decrease	Minor Decrease	No Change	Moderate Increase
25	Santa Clara Vasona Line	Moderate Increase	No Change	No Change	Moderate Increase
27	St Louis Saint Clair Corridor	Significant Increase	Significant Decrease	No Change	Minor Decrease

Figure 3-6. Histogram of Detailed Variation for 14 Case Study Projects



	Significant Increase	Moderate Increase	Minor Increase	No Change	Minor Decrease	Moderate Decrease	Significant Decrease
Unit Cost Adjustment	3	6	2	0	2	1	0
Quantity Adjustment	0	2	2	3	2	4	1
Inflation due to Schedule Delay	0	7	2	5	0	0	0
YOE Cost Variance	4	8	1	0	1	0	0

Figure 3-7. Histogram of Results for 28 Case Study Projects by Phase



	Significant Increase	Moderate Increase	Minor Increase	No Change	Minor Decrease	Moderate Decrease	Significant Decrease
Planning to PE	6	9	2	7	1	3	0
PE to Final Design	6	10	1	3	4	3	1
Final Design to Operations	8	5	6	1	4	4	0

Table 3-12. Summary of Capital Cost Variation Results by Phase

ID	Case Study Projects	Planning to PE	PE to Final Design	Final Design to Operations
1	Atlanta North Line Extension	Minor Increase	Moderate Decrease	Significant Increase
2	Boston Old Colony Rehabilitation	Moderate Increase	Moderate Increase	Minor Increase
3	Boston Silver Line (Phase 1)	Significant Increase	Moderate Increase	Significant Increase
4	Chicago Southwest Extension	Moderate Increase	Significant Decrease	Significant Increase
5	Dallas South Oak Cliff Extension	Significant Increase	No Change	Moderate Decrease
6	Denver Southwest Line	Moderate Increase	Moderate Increase	Minor Increase
7	Los Angeles Red Line MOS 1	No Change	Significant Increase	Significant Increase
8	Los Angeles Red Line MOS 2	No Change	Significant Increase	Significant Increase
9	Los Angeles Red Line MOS 3	No Change	Significant Increase	Moderate Decrease
10	Minneapolis Hiawatha Line	Moderate Decrease	Significant Increase	Moderate Increase
11	New Jersey Hudson-Bergen MOS1	Moderate Decrease	Significant Increase	Moderate Increase
12	New York 63rd Street Connector	Moderate Increase	Moderate Increase	Minor Decrease
13	Pasadena Gold Line	Moderate Decrease	Moderate Decrease	Minor Decrease
14	Pittsburgh Airport Busway (Phase 1)	Significant Increase	Moderate Increase	No Change
15	Portland Airport MAX Extension	No Change	No Change	Minor Increase
16	Portland Banfield Corridor	No Change	Significant Increase	Moderate Decrease
17	Portland Interstate MAX	Moderate Increase	Minor Decrease	Moderate Increase
18	Portland Westside/Hillsboro MAX	Significant Increase	Minor Decrease	Moderate Increase
19	Salt Lake North-South Line	Minor Increase	Moderate Increase	Minor Decrease
20	San Francisco SFO Airport Extension	Minor Decrease	Minor Decrease	Significant Increase
21	San Juan Tren Urbano	Moderate Increase	Moderate Increase	Significant Increase
22	Santa Clara Capitol Line	No Change	Moderate Increase	Minor Increase
23	Santa Clara Tasman East Line	Significant Increase	Minor Decrease	Minor Increase
24	Santa Clara Tasman West Line	Significant Increase	Minor Increase	Moderate Decrease
25	Santa Clara Vasona Line	No Change	Moderate Increase	Minor Increase
26	Seattle Busway Tunnel	Moderate Increase	Moderate Increase	Significant Increase
27	St Louis Saint Clair Corridor	Moderate Increase	Moderate Decrease	Minor Decrease
28	Washington Largo Extension	Moderate Increase	No Change	Moderate Increase

3.4. Schedule Analysis

The data collected for the 28 case study projects allowed for an analysis of two schedule factors: duration and delay. Because it is difficult to determine when a project was first conceived, the schedule analysis does not consider the planning phase. Wherever possible, the DEIS date was used as the date of the first formal planning estimate, kicking off the preliminary engineering phase.

Table 3-13 presents the schedule durations, by phase and total, for each case study project. The average total duration for all projects was 8.4 years, with preliminary engineering lasting 2.3 years, final design lasting 2.7 years, and construction requiring 4.0 years on average. The trend for construction to require more time than the engineering phases was evident when looking at the average durations for each mode as well. The average total duration for light rail projects was 7.6 years, while for heavy rail projects it was 10 years and for busway projects was 9.7 years. The light rail projects on average required less time for construction than the other modes. One contributing factor may have been the use of existing infrastructure.

Comparing projects within modes; for heavy rail, projects completed using Design-Bid-Build lasted 9.7 years on average, Design-Build projects lasted 10.3 years, and DBOM projects lasted 12 years. For light rail, DBB projects lasted 7.4 years, DB projects lasted 8 years, and DBOM projects lasted 9 years. Busway projects required approximately 10 years on average regardless of the procurement method. The longer duration for rail projects completed using Design-Build and DBOM may be due to other contributing factors such as guideway requirements, size and complexity of the project. The projects may have also switched procurement methods after experiencing difficulties with delay.

Heavy rail was the only mode including New Starts, rehabilitation, and extension projects. On average, the New Starts projects lasted 12 years, while the rehabilitation and extension projects averaged between 9 and 10 years. The longer duration of the New Starts projects reflects additional complexity of designing and constructing a brand new system.

Table 3-13 also presents the delays experienced by each of the case study projects. The average total delay was 3.1 years, with an average delay of 1.8 years during preliminary engineering, 1 year during final design, and 0.8 year during construction. The length of delay thus decreased as the project moved through the development phases. The average delay was shortest during construction. This may be expected given that the project definition does not typically change after final design. Also, construction is a highly visible phase, and public pressure may be higher to complete this phase on-time.

New Start projects experienced greater delays, with an average total delay of 4.7 years, compared to 3 years for rehabilitation projects, and 2.2 years for extensions. The greater delay may be expected of brand new projects, which have greater uncertainty than rehabs and extensions.

With respect to procurement mode, the delay was largest for DBOM projects. DBB projects experienced an average delay of 3 years, DB projects a delay of 3.75 years, and DBOM projects a delay of 6 years. As mentioned earlier regarding duration, the greater delay for Design-Build and DBOM projects may also reflect other contributing project characteristics such as size, complexity or the possibility that some projects switched procurement methods after experiencing delay difficulties.

Table 3-13. Case Study Project Characteristics and Schedule Analysis

	Case Study Projects	Approx. Project Duration by Phase (Years)			Total Project Duration	Approximate Project Delay by Phase (Years)			Total Project Delay
		PE/ FEIS	Final Design	Construction		PE/ FEIS	Final Design	Construction	
1	Atlanta North Line Extension	1	3	6	10	0	0	4	4
2	Boston Old Colony Rehabilitation	1	6	2	9	1	2	0	3
3	Boston Silver Line (Phase 1)	1	1	10	12	4	0	4	8
4	Chicago Southwest Extension	2	3	3	8	0	1	2	3
5	Dallas South Oak Cliff Extension	2	1	3	6	1	2	-1	2
6	Denver Southwest Line	4	1	3	8	4	0	0	4
7	Los Angeles Red Line MOS 1	n/a	5	1	6	n/a	1	2	3
8	Los Angeles Red Line MOS 2	n/a	7	4	11	n/a	2	2	4
9	Los Angeles Red Line MOS 3	n/a	10	5	15	n/a	2	1	3
10	Minneapolis Hiawatha Line	6	1	4	11	3	1	1	5
11	New Jersey Hudson-Bergen MOS1	3	1	5	9	1	1	2	4
12	New York 63rd Street Connector	3	2	7	12	3	1	0	4
13	Pasadena Gold Line	3	4	3	10	2	4	0	6
14	Pittsburgh Airport Busway (Phase 1)	2	1	7	10	4	3	0	7
15	Portland Airport MAX Extension	n/a	2	4	6	n/a	0	0	0
16	Portland Banfield Corridor	n/a	3	1	4	n/a	2	0	2
17	Portland Interstate MAX	1	2	2	5	0	0	0	0
18	Portland Westside/Hillsboro MAX	1	3	4	8	1	3	0	4
19	Salt Lake North-South Line	1	3	1	5	2	0	-1	1
20	San Francisco SFO Airport Exten.	4	1	6	11	2	0	2	4
21	San Juan Tren Urbano	3	1	8	12	2	1	4	7
22	Santa Clara Capitol Line	n/a	1	4	5	n/a	0	0	0
23	Santa Clara Tasman East Line	3	4	2	9	2	1	0	3
24	Santa Clara Tasman West Line	1	3	3	7	2	0	-1	1
25	Santa Clara Vasona Line	n/a	1	5	6	n/a	0	0	0
26	Seattle Busway Tunnel	1	3	3	7	1	3	0	4
27	St Louis Saint Clair Corridor	3	1	2	6	0	0	0	0
28	Washington Largo Extension	3	1	4	8	2	-1	0	1
	Average (Years)	***2.3***	***2.7***	***4.0***	***8.4***	***1.8***	***1.0***	***0.8***	***3.1***

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4. STRATEGIES, TOOLS, AND TECHNIQUES

The 14 major transit projects selected by the TCRP project panel for detailed investigation are presented in **Table 4-1**. Appropriate project management representatives were identified for each of these projects to answer the questions in the interview guide used to gather the responses documented in **Appendix D**. Table 4-1 classifies the projects by transit mode and indicates whether or not responses to the interview guide were received. Survey responses were gathered for a sample of 9 projects of the 14 interview requests.

The respondents from the 9 participating projects represented the following positions within their respective project organizations:

- Assistant General Manager for Engineering and Construction
- Construction Project Manager
- Engineering Design Manager
- Engineering and Design Consulting Project Manager
- Project Chief Estimator
- Project Quality Director
- Environmental and Planning Consulting Project Manager

This section synthesizes the responses received in a narrative or tabular format. Not all of the nine sample projects responded to every question; therefore, the number of responding projects is indicated for every question. Specific project responses are cited using the city and project name or simply the city name. A complete summary of all responses to the interview guide is provided in **Appendix D**.

This section also describes the general strategies, techniques, and initial findings to better estimate, manage, and contain capital costs of major transit projects. **Table 4-2** presents the broad categories of strategies and their applicability to each project development phase. This section is organized according to these categories with descriptions and observations. Many of the strategies were identified from the responses to the interview guide questions. Where possible, specific examples are provided from the 9 sample projects.

It is important to note that although 9 case study projects do not represent a statistically representative sample, they can provide valuable lessons for improving cost estimates and how these costs can be managed throughout the project development process. The effectiveness of the strategies, tools, and techniques used by the 9 sample projects are explored in this section using unweighted averages of the capital cost variance due to scope changes or schedule changes over the life of projects. Due to the limited sample size, the initial findings presented in this section can be strengthened with further investigation.

Table 4-1. List of Panel-Selected Case Study Projects and Respondents

Panel-Selected Case Study Projects	Transit Mode	Response to Interview Guide was received and complete?
1. Atlanta – Metropolitan Atlanta Rapid Transit Authority (MARTA) North Line Extension	Heavy rail	Yes
2. Washington -- Washington Metropolitan Area Transit Authority (WMATA) Largo Extension	Heavy rail	Yes
3. New York – New York City Transit (NYCT) 63rd Street Connector	Heavy rail	Yes
4. Pasadena – Los Angeles County Metropolitan Transportation Authority (LACMTA) Gold Line*	Light rail	Yes
5. Pittsburgh – Port Authority of Allegheny County (PAAC) Airport/West Busway Phase 1	Busway	Yes
6. Portland – Tri-County Metropolitan Transportation District of Oregon (TriMet) Interstate Max Extension	Light rail	Yes
7. Portland – TriMet Airport Extension	Light rail	Yes
8. Salt Lake City – Utah Transit Authority (UTA) North South Line	Light rail	Yes
9. Denver – Regional Transp. District (RTD) Southwest Line	Light rail	Yes
10. Hoboken – New Jersey Transit (NJT) Hudson-Bergen Phase 1	Light rail	No
11. Minneapolis -- Metro Transit Hiawatha Line	Light rail	No
12. San Francisco – San Francisco Bay Area Rapid Transit District (BART) SFO Extension	Heavy rail	No
13. Boston – Massachusetts Bay Transportation Authority (MBTA) Silver Line Initial Phase	Busway	No
14. Dallas – Dallas Area Rapid Transit (DART) South Oak Cliff Extension	Light rail	No

** In the case of the Pasadena Gold Line, cost variances from scope and schedule changes were calculated after the project was re-started and re-scoped in 1999.*

Table 4-2. Applicability of Categories of Strategies by Phase

Categories of Strategies	Alternatives Analysis	Preliminary Engineering	Final Design	Construction/ Operations
Project Definition	X	X		
Estimation	X	X	X	X
Procurement		X	X	
Project Organization		X	X	X
Project Management Controls		X	X	X

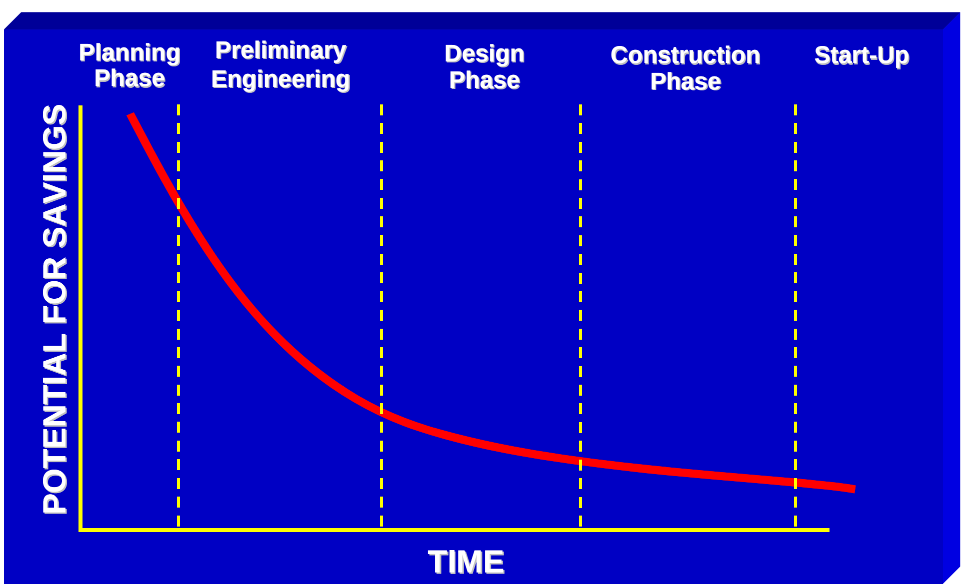
4.1. Project Definition

Project definition entails the conceptualization of the alternatives and the method of selecting the preferred alternative. The inception and evolution of a project can have a large impact on the capital costs. In particular, the level of design is an important factor in the uncertainty of the capital cost estimate.

All 9 of the sample projects were selected as a result of alternatives analysis, with varying degrees of public participation, and where cost was one of many criteria or considerations. These criteria sometimes conflict or require a difficult tradeoff in benefits or costs. If clear cost priorities are not established, designs may not fit the reality of the project's situation, leading to costly changes as the project advances. Even when the projects are taken through a comprehensive alternatives analysis with extensive stakeholder outreach, subsequent project changes can be imposed upon the project. This was evident by the late alignment change imposed by stakeholders in Hoboken, New Jersey for the Hudson-Bergen Line. However, it appears that extensive outreach efforts at the earliest stages of project development and the communication of clear cost and benefit tradeoffs in the alternatives analysis may help to lessen subsequent changes throughout the development process.

Value engineering (VE) activities at each phase of project development are used formally or informally by projects to control costs by refining the design. It is most effective early on, as the potential for cost savings declines as a project advances toward start up. The further the project advances, the less opportunity there is for cost savings (see **Figure 4-1**).

Figure 4-1. Declining Potential for Value Engineering Savings



VE activities were employed by all but one project (i.e., the Pasadena Gold Line), as shown in **Table 4-3**. As such, there was not enough data to determine whether VE had an impact on scope and schedule changes, but several projects did report success in controlling costs using this strategy.

Table 4-3 also shows that organized or team-oriented VE exercises were reported by at least seven projects. The frequency and timing of VE activities varied by project. Only the Denver Southwest project cited use of VE during all phases of project development. Three projects used VE early in project design, while two other projects used VE during final design. In the cases of Pittsburgh and Denver, use of VE was encouraged to the contractors by offering to share cost savings of creative alternatives.

A design-to-budget approach begins with a fixed budget in mind. This type of approach was formally adopted by two projects (Portland Interstate and Portland Airport) with apparently beneficial results in terms of scope and schedule change. **Table 4-3** shows that these projects appeared to exhibit lower average scope and schedule increases compared to the five projects not using the approach. Nevertheless, the design-to-budget approach was the reality for several projects, even if not the explicit policy of the project or sponsoring agency.

Table 4-3. Responses to Project Definition Questions

Interview Guide Question	Average of % Scope Change	Average of % Schedule Change	Number of Projects	Corresponding Projects
Were VE practices used?				
No	-61.2%	14.0%	1	Pasadena
Yes	8.0%	3.6%	6	Atlanta, New York, Portland Airport, Portland Interstate, Salt Lake, Washington
Yes, with incentive to share savings	21.4%	13.6%	2	Denver, Pittsburgh
Were there organized or team-oriented VE exercise?				
--	0.2%	10.4%	1	Atlanta
No	-61.2%	14.0%	1	Pasadena
Yes	12.9%	5.5%	7	Denver, New York, Pittsburgh, Portland Airport, Portland Interstate, Salt Lake, Washington
Were design-to-budget procedures used?				
--	5.3%	6.5%	2	Atlanta, Washington
No	1.4%	9.9%	5	Denver, New York, Pasadena, Pittsburgh, Salt Lake
Yes	5.9%	0.0%	2	Portland Airport, Portland Interstate

Some project representatives suggested that establishing clear budget and schedule constraints early in the project development process helped contain scope creep. In the case of the Portland Airport project, for example, there was no budget for contingency and such constraints were used to positively affect the outcome. Furthermore, bus and LRT systemwide integration and staffing issues influenced the scheduled opening date of the project. However, it was found that some flexibility with respect to scope and schedule must be maintained in a project with significant budget pressures.

Table 4-4 highlights other major issues or challenges faced in the development and implementation of the sample projects. Outreach to community and businesses is important to minimize project redefinition and maximize support. It is also crucial because of the influence of the political process in defining and funding major transit projects. Engineering challenges are often the most manageable, because they can be defined and resolved. In fact, several respondents stated that among the most difficult risks to consider with impact on capital costs and schedule are time to achieve political consensus and the acquisition of private property. It is important to manage public expectations and communicate the tradeoffs between scope, cost, and schedule in order to control scope creep. In Pasadena, for example, third-party management and design control were major concerns as described. The project traversed five communities, which made early and constant communication with the public essential.

Table 4-4. Main Issues or Challenges Cited by Responding Case Study Projects

Panel Projects	Main Issues or Challenges Cited
Atlanta North Line Extension	Contractor cited tight construction zones, multiple NTPs and milestones, limited access and work with private property owners
Denver Southwest Line	Change orders, negotiating with both railroads upfront, schedule coordination issues
New York 63rd Street Connector	Time to achieve political consensus, change in economic conditions, seizure of private property
Pasadena Gold Line	At-grade crossing applications, third-party management, property acquisition, and station and artwork design
Pittsburgh Airport Busway	Real estate issues and unforeseen site conditions
Portland Interstate Max Extension	Project scope reduced to meet federally imposed contingency levels
Portland Airport Extension	DB procurement issues including communication of critical requirements from agency staff to contractor, design control and acceptability
Salt Lake North South Line	Keeping third parties satisfied and containing scope creep, intense pressure to build the project within budget and ahead of schedule
Washington Largo Extension	Ensuring that all operating revisions and changes were addressed

In sum, while engineering challenges were encountered, these were controllable. The factors with arguably larger impacts (both unexpected and uncontrollable) were stakeholder, third-party, and real estate acquisition issues.

4.2. Estimation

Cost and schedule estimation are important functions during all phases of the development cycle. The importance of good early cost and schedule estimates are particularly important, since they often set internal and external expectations. At the same time, there are greater cost and schedule uncertainties during the planning phases of a project.

This problem underscores the tradeoff between accuracy and precision in early estimates. Accuracy represents freedom from error and the approach toward true cost, while precision is the significant digits used to arrive at the estimate. Therefore, one can be precise, but inaccurate. However, a tradeoff exists between providing more detail that may become less understandable to the audience. Similarly, establishing a realistic project schedule and managing multiple schedules can be challenging for some projects, due to external pressures or unknown conditions.

A detailed analysis of the responses to estimation questions is presented in **Table 4-5**. Of the nine sample projects, five relied on both in-house and consultant estimates, and four relied only on consultant estimates. The basis of the estimates was typically the scope defined by the project sponsor or agency. The average scope change for the sample projects relying on both estimates was measurably higher than for projects using only consultant estimates. The average schedule change for projects relying on both estimates appeared to be slightly lower than that of consultant-only estimates.

Of the different methods for estimating the capital costs over the life of a project, six projects reported using YOE (inflated) dollars, and three reported using both YOE and constant dollar methods as presented in Table 4-5. The six projects using only YOE estimates exhibited a lower scope and schedule increase than the others. The only reason cited for using a certain method was that it was part of the policy of the sponsoring agency.

Four agencies reported having an estimating manual or process for their respective project, while five agencies reported having no such formal document or procedure at the time. As shown in Table 4-5, projects having an estimating manual or process exhibited a lower scope variance and about the same schedule increase as the other projects. A DOT referenced study of these effects (Schexnayder et al., 2003) indicated that the use of historic bid averages in the build up of the cost estimate had the better performance.

Table 4-5. Responses to Estimation Questions

Interview Guide Question	Average of % Scope Change	Average of % Schedule Change	Number of Projects	Corresponding Projects
Who did the estimates, in-house or consultant?				
Both	10.1%	5.6%	5	Atlanta, Denver, New York, Portland Interstate, Washington
Consultant	5.3%	8.7%	4	Pasadena, Pittsburgh, Portland Airport, Salt Lake
Was the estimate reported in Year-of-Expenditure (YOE) dollars or in constant dollars?				
Both	12.9%	10.4%	3	Atlanta, Pittsburgh, Salt Lake
YOE only	1.5%	5.3%	6	Denver, New York, Pasadena, Portland Airport, Portland Interstate, Washington
Does agency have an estimating manual or guide?				
No	14.5%	6.4%	5	Denver, Pittsburgh, Portland Interstate, Salt Lake, Washington
Yes	10.8%	7.7%	4	Atlanta, New York, Pasadena, Portland Airport
Cost estimate reviewed internally or externally?				
--	10.3%	0.0%	1	Portland Interstate
Both	9.0%	2.8%	3	New York, Portland Airport, Salt Lake
Internally	1.6%	10.8%	5	Atlanta, Denver, Pasadena, Pittsburgh, Washington
Were the estimates reviewed by a Program Management Oversight (PMO) Contractor?				
No	4.0%	9.1%	5	Atlanta, Pasadena, Pittsburgh, Portland Airport, Washington
Yes	12.3%	4.3%	4	Denver, New York, Portland Interstate, Salt Lake
Formal independent cost estimate completed?				
--	10.3%	0.0%	1	Portland Interstate
No	7.6%	11.6%	3	Pasadena, Pittsburgh, Salt Lake
Yes	8.4%	5.6%	5	Atlanta, Denver, New York, Portland Airport, Washington
How were unit cost data gathered?				
Past projects	16.0%	16.3%	2	Pasadena, Pittsburgh
Past projects, other agencies	6.6%	5.0%	3	Atlanta, Salt Lake, Washington
Past projects, previous bids	16.2%	6.5%	1	New York
Past projects, previous bids, RS Means, local suppliers	7.6%	4.3%	2	Denver, Portland Airport
Past projects, RS Means	10.3%	0.0%	1	Portland Interstate
Were contractors or suppliers involved in the cost estimation during any of the phases?				
No	9.7%	1.0%	2	Portland Interstate, Salt Lake
Yes	1.4%	8.7%	7	Atlanta, Denver, New York, Pasadena, Pittsburgh, Portland Airport, Washington
Were any changes made to the estimation process because of the lessons learned on this project?				
No	2.7%	7.5%	7	Denver, New York, Pasadena, Pittsburgh, Portland Airport, Salt Lake, Washington
Yes	5.3%	5.2%	2	Atlanta, Portland Interstate

Of the 9 sample projects, eight reported that the cost estimate was reviewed internally multiple times and by key project staff other than the estimator. Three projects (New York, Portland Airport, and Salt Lake) reported that the cost estimates were also reviewed externally at least once, and these projects exhibited higher average scope increase but a lower schedule increase. Four projects (Denver, New York, Portland Interstate, and Salt Lake) reported a PMO review of the cost estimate, and these projects experienced similarly higher average scope increase but a slightly lower average schedule increase as shown in Table 4-5.

Five of the eight responding projects also reported having completed at least one formal independent cost estimate. These five projects (Atlanta, Denver, New York, Portland Airport, and Washington) exhibited a higher average scope change, but a lower schedule change compared with the other projects.

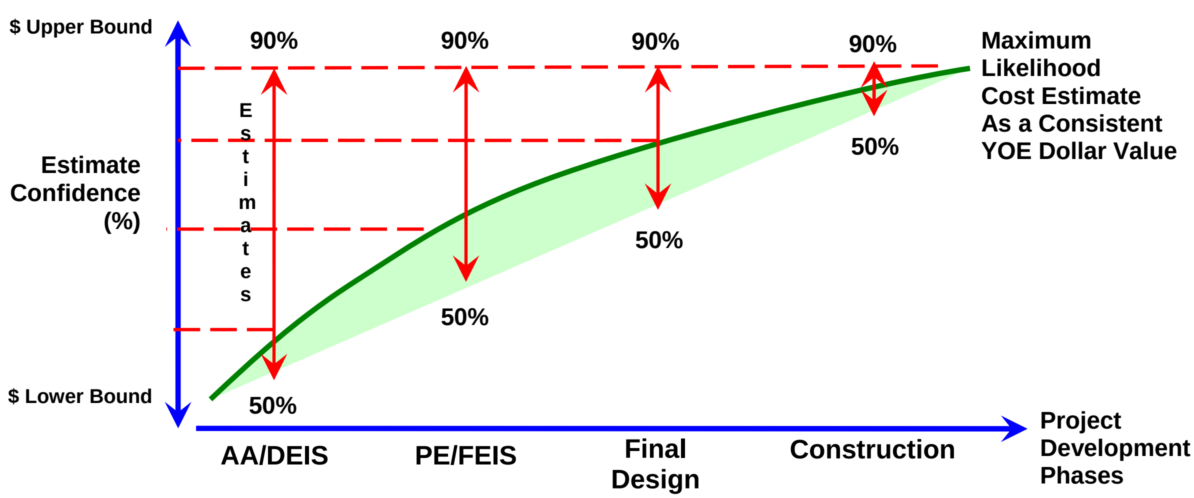
All nine sample projects reported having estimators with more than 10 years of experience on similar projects. Unit costs from previous projects were used for estimation on all nine responding projects, while three projects also reported using data from other agencies or projects, and three reported using data from RS Means. With the limited data set, it was not possible to determine whether the number of data sources for unit costs had an impact on the scope and schedule variance exhibited by the projects. Contractors or suppliers were involved in the cost estimation (typically by providing price quotes) for all except two projects (Portland Interstate and Salt Lake). These two projects had a slightly higher average scope increase but lower schedule increase.

When asked whether any changes were made to the estimation process because of the lessons learned over the course of the project, only two of nine responding projects (Atlanta and Portland Interstate) reported any changes beyond updating their unit cost databases for future projects. Portland Interstate, for example, cited the earlier involvement of contractors to take advantage of current market information and construction techniques as a change. Although most agencies have added ongoing project data to their historical cost databases, there is a general lack of as-built unit cost data for future projects.

In sum, the responses to the cost estimation questions indicate minor differences among the various approaches to cost estimation. It appears from these results that the case study projects all utilized the preferred approaches and included many of the most recent cost estimation techniques. Most projects used a deterministic cost estimating method, synthesizing hundreds or thousands of assumptions into one estimate for cost. This potentially increases the risk of inconsistently communicating the expected costs of the project throughout to the project team and to the stakeholders.

Based on the literature search results, a probabilistic estimation approach integrated with a detailed risk assessment may better convey the assumptions involved in the cost estimate and the risks reflected in the cost estimate. **Figure 4-2** presents a view of how this probabilistic approach to capital cost estimation can be applied to the project development process. The range estimate represents the higher and lower bound cost estimates that tend to compress through the increasing stages of project development. The maximum likelihood cost estimate represents a consistent year of estimate cost value throughout this process as long as the project remains consistent and the cost estimation process was based on good unit costs and a reasonable developmental schedule. The compression of the cost range and the increase in the confidence level occur as the project definition becomes more clear and the unknowns are reduced or eliminated. The consistent cost estimate dollar value approaches the higher confidence range as the unknowns and risk items are reduced, mitigated and eliminated. The range cost estimates are developed in line with the risk assessment and the risk impacts upon the project cost. As risks are reduced or mitigated, the cost confidence range compresses. This range and the risk impacts upon the cost estimate can be used to manage the project contingencies as the project approaches completion. The maximum likelihood cost estimate would occur somewhere within the range, depending upon the risk impacts and the project development dependencies.

Figure 4-2 Capital Cost Estimation as a Probability-Based Range of Costs



The major capital cost drivers identified by the representatives of eight of the nine responding projects are summarized in **Table 4-6**. These responses indicate those cost drivers that had the most impact on the completed project cost. These cost drivers would form the basis to the development of the risk register for the probabilistic cost approach illustrated above. The potential cost impact of the cost drivers would help to form the probability range estimates. The table indicates that the more complex structural components of each project were often cost drivers. In addition, unique project characteristics that impacted project costs were noted. Right-of-way and third-party impacts were included in many cases. In summary, the more complex structural components, right-of-way acquisition, and third-party relationships were indicated most often as the key cost drivers.

Table 4-6. Major Capital Cost Drivers Identified by Sample Projects

Panel Projects	Major Cost Drivers Identified By Each Sample Project
Atlanta MARTA North Line Extension	Scope of work and scope growth (material and system with a longer functional life), design and construction change orders, difficult and unexpected field conditions (heavy traffic, excavations)
Denver RTD Southwest Line	Station design and railroad relocation
Pasadena LACMTA Gold Line	Systems, trackwork, stations, elevated structures, differing site conditions, third-party influence on scope
Pittsburgh PAAC Airport Busway	Elevated structures, purchase of right-of-way, and tunnels
Portland TriMet Airport Extension	Insurance, start of construction, management overhead
New York NYCT 63rd Street Connector	NYC labor costs, working around active roadway and railroad, limited allowable work hours
Salt Lake City UTA North South Line	Right-of-way and track elements, LRT vehicles, systems, stations and parking
Washington Largo Extension	Cost of materials (metals and concrete), specialty equipment to meet WMATA standards, utility relocation, regulatory compliance for stormwater management, sewer and water installation, and power supply

4.3. Procurement

The nine sample projects represented a wide variety of procurement strategies. As summarized in **Table 4-7**, four projects used the conventional design-bid-build (DBB) process, two used a design-build (DB) approach, and three reported a mix of approaches including DBB, DB, construction management at risk (CMR), and design-build-operate-maintain (DBOM). For example, the Pittsburgh Busway used DBB for line and stations, DB for park-and-ride lots, and DBOM for ITS components. Portland Interstate used CMR for most of its construction except for a DB bridge. The Washington Largo project used DBB for the high-risk site preparation contract, which included the construction of the bridge over the Capitol Beltway, and DB for the line, trackwork, systems, stations, and parking facilities.

Within the sample set of projects, the reasons for selecting a particular method of procurement varied from past experience with the chosen method to compressed schedules. There are potential cost savings from a reduced project development schedule with DB. It also offers potential cost savings opportunities through consolidating construction management with the DB contractor, and reducing agency procurement and project management requirements. However, these savings can be offset by increased project definition and oversight responsibilities for the agency.

Table 4-7. Selected Project Procurement Methods

Panel-Selected Projects	Procurement Method	Selection Criteria for General Engineering Contractor (GEC) and Construction Contractor
Atlanta MARTA North Line Extension	DBB	GEC by qualification; low bid for most construction
Denver RTD Southwest Line	DBB	Low bid (construction); RTD was GEC
New York NYCT 63rd Street Connector	DBB	Low bid
Pasadena LACMTA Gold Line	DB	Two-step (qualified low bid)
Pittsburgh PAAC Airport Busway	DBB (line and stations), DB (park-and-ride lots), DBOM (ITS)	Low bid (construction contracts); Two-step (GEC)
Portland TriMet Interstate Max Extension	CMR (for most of construction), DB (bridge)	N/A
Portland TriMet Airport Extension	DB	N/A
Salt Lake City UTA North South Line	DBB	Low bid
Washington WMATA Largo Extension	DBB (Bridge over the Capitol Beltway) DB (Line, station and parking facilities)	Two-step (qualifications first, best value second)

The CMR also offers similar consolidation of construction and installation contracts to gain some of the schedule incentives and procurement reductions, and without some of the project definition concerns of DB. Many of these more recent approaches to project delivery are still in the developmental stages, but all seem to offer measurable benefits to the completion of projects within planned schedules and closer to initial cost estimates. The refinement of these approaches may still take some additional time.

The choice of a procurement method did not ensure that budget or schedule were maintained. As shown in **Table 4-8,** the four DBB projects exhibited a higher average scope change but about the same schedule change compared with the five non DBB projects. The five non DBB projects include design build, construction management at-risk and a combination of the various approaches for individual project elements.

Table 4-8. Responses to Procurement Questions

Interview Guide Question	Average of % Scope Change	Average of % Schedule Change	Number of Projects	Corresponding Projects
Procurement method				
DBB	9.8%	6.9%	4	Atlanta, Denver, New York, Salt Lake
Other than DBB	2.0%	7.1%	5	Pasadena, Portland Airport, Pittsburgh, Portland Interstate, Washington
What were the cost drivers during procurement?				
Contract size and complexity	14.9%	7.5%	2	Denver, New York
Marketplace	10.3%	1.3%	2	Portland Interstate, Washington
Marketplace, process, terms, contract size, and complexity	9.2%	2.0%	1	Salt Lake
Process, terms, marketplace, contract size, and complexity	14.7%	14.5%	2	Atlanta, Pittsburgh
Terms	-29.8%	7.0%	2	Pasadena, Portland Airport

Several of the sample projects reported that the choice of procurement was based on past experience of the sponsoring agency. If a project is the first major project for an agency, DBB may make more sense for the control it affords. However, DB allows a newer agency to contract for much of the technical capacity it needs to deliver the project and then only maintain the necessary capability to maintain the new system in house. On the other hand, if the agency already has significant technical capacity for the mode and project systems, DBB allows the agency to better apply this capability. For example, in New York, DBB may have been a more expensive option, but it allowed the agency to use the necessary level of design and operational control with its in-house technical capacity. Either way, it was imperative that the designer and owner's representatives were on site or immediately available to respond to field conditions that threatened to slow the job.

If a project is an extension to an existing system or a speedy delivery is essential, DB may make more sense. In this case, however, there is potential for higher bids if the project definition is not fully established to minimize project risk to both sides. Without clear project definition and project management approaches in the contract, there is increased risk for higher bids and/or reduced standards in the project delivery. Contractors will add premium pricing contingencies to protect themselves against blind risks or reduce the quality or standard of the project delivery with insufficient project definition. A higher level of design or scope definition can reduce contingency risks, but can also reduce the overall benefits of DB. Balancing the level of design with the contingency risks is key. Several of the sample DB projects expressed the difficulty in achieving this balance. **Table 4-9** is a summary of the generally favorable and unfavorable conditions for using the DB procurement approach or some variant.

Table 4-9. Favorable and Unfavorable Conditions for Design-Build

Favorable Conditions	Unfavorable Conditions
• Single point of responsibility • Agency staff project development expertise is limited • Agency is open to sharing risk to reduce schedule and costs • Agency has sufficient flexibility in project definition • Unique factors require special knowledge or expertise • 100-percent design is not required to get high-quality product • Funding is secure or private capital is required	• Many unknowns in the project definition and development conditions • Complete design may be required to confirm cost estimates and/or obtain required permits • There may be local policy or regulations against DB (e.g., low bid is required, without qualifications to satisfy "Brooks Bill") • Agency wants to be extensively involved in the design • Project relatively small to attract qualified contractors

The sample projects were also asked to identify the most significant cost drivers in procurement. As noted in **Table 4-8**, most projects cited the marketplace and/or the contract size and project complexity as major cost drivers. The limited sample size did not allow for the cost variance performance of these responses. Contract terms were also an issue for three projects. For example, there are apparent tradeoffs in segmenting a project into separate contracts. As noted by a representative from the New York project, larger contracts may minimize interfaces but may also reduce competition and impact bonding capacity.

Several sample projects also noted the importance of beginning procurement negotiations as early as possible. In Denver, the agency negotiated with two freight railroads one year prior to letting out the first segment contract to address the design, use of right-of way, construction, freight railroad dispatching, and maintenance. This early procurement of the right-of-way allowed the procurement to be independent of the project delivery pressures and the potential for price escalation from that. In addition, the right-of-way was free and clear for the construction to begin with full access.

Table 4-7 also summarizes the criteria used for selecting the general engineering contractor (GEC) and construction contractors. These criteria included low bid only and a combination of low bid and qualification in a two-step process. The number of bidders on each project ranged from one (unsolicited proposal for the Portland Airport project) to 12. The prequalification of bidders was generally not used, except for the projects in Pasadena and Washington. Moreover, an industry review for procurement was generally not conducted except in the cases of Atlanta, Denver, and Washington. Nonetheless, both of these practices were identified as offering benefits to the quality and performance of the contractors, to the contracting terms, and project management approach of the project contracts.

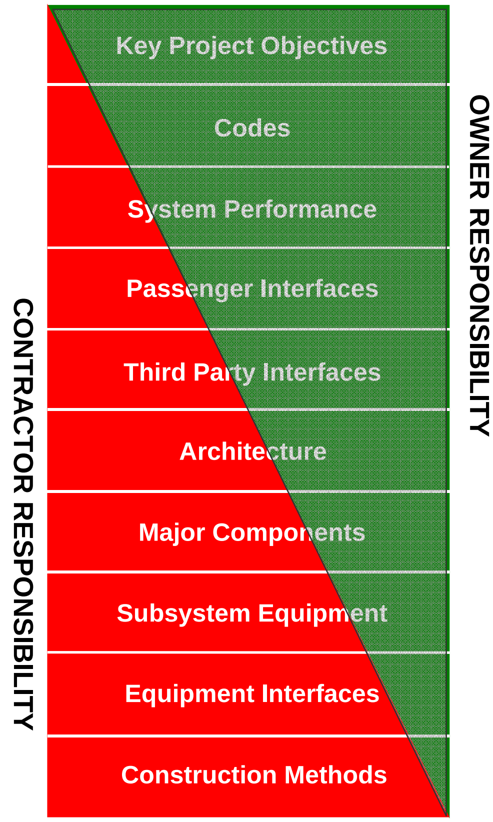
Few incentives or penalties were mentioned in the design contracts for the projects surveyed. Liquidated damages were stipulated for the projects in New York and Salt Lake. A performance-based fee was employed in Pittsburgh for design but no penalties were enforced. In Washington, one construction contract had an incentive for early completion. These incentives and penalties offer some benefits to the project development process, but there were also some concerns about the contractual risk and associated cost impacts.

4.4. Project Organization

Project organization can include the staffing plan, the technical capacity of the staff, partnering concepts, and the roles and responsibilities assigned to the parties involved in project development. **Figure 4-3** depicts the general responsibilities that can be shared by the project agency (i.e., owner) and contractor. This figure illustrates the various functional roles in the development of the project and the general preferences of agency roles compared with contractor roles. Those listed in the center of the figure present the most likely functions to be shared in some DB or CMR project delivery approaches. The decision to contract versus use of in house staff depends upon the skill base and availability of in house staff. A new rail project may require more contracting for a mainly bus agency than a more mature agency with internal design and development expertise. In the more mature agencies, availability of this staff to dedicate to particular tasks becomes the more critical question. In addition, the more unique functional areas typically require contracting support to gain access to this expertise. It is not organizationally effective to keep specialty staff underutilized on an internal agency staff. Therefore, the decision to contract or staff is mainly focused on availability of existing staff and access to new and unique expertise.

Project organizational structures varied considerably among the nine sample projects according to the sponsoring agency's development approach. Likewise, the number of full-time project staff varied significantly from 15 to over 100 depending on the size of the project, size of the agency, procurement method, and other factors.

Figure 4-3. General Responsibilities Shared by Project Owner and Contractor



All project organizations relied on both in-house technical resources and external consulting services. As shown in **Table 4-10**, two projects (Denver and Portland Airport) relied mostly on internal technical resources. On average these projects performed slightly better than other projects in terms of scope and schedule change. Six projects used separate systems consultants. In Denver, the agency chose to act as the GEC to have greater control over cost and schedule. The agency project team was lean, but successfully transitioned from design to construction with the aid of knowledgeable staff. Outside consultants were only used for the design of the LRT, railroad structures, and geotechnical services.

Most project organizations were created through modifications to the sponsoring agency's organizational structure, typically through a matrix approach using internal staff combined with contracted staff appended into the project organization. This structure was typically prepared for the procurement and execution of the project after funding was committed. The disciplines usually covered all technical and engineering fields including civil, structural, architectural, systems, etc. Several projects reported that it was difficult to maintain experienced staff because of very competitive labor market conditions. Nevertheless, all projects reported having project staff with greater than 10 years of experience.

Table 4-10. Responses to Project Organization Questions

Interview Guide Question	Average of % Scope Change	Average of % Schedule Change	Number of Projects	Corresponding Projects
Did the project rely on in-house technical resources or external consultant services?				
Both	2.0%	7.7%	7	Atlanta, New York, Pasadena, Pittsburgh, Portland Interstate, Salt Lake, Washington
Mostly internal	7.6%	4.3%	2	Denver, Portland Airport
Was there a separate systems consultant?				
No	7.7%	7.0%	3	Atlanta, Denver, Salt Lake
Yes	1.1%	7.0%	6	New York, Pasadena, Pittsburgh, Portland Airport, Portland Interstate, Washington

Partnering sessions and concepts were used by all nine sample projects. The frequency and timing of these sessions varied from quarterly meetings during the entire project development cycle to meetings held as needed during a specific phase. Several respondents mentioned that partnering sessions were very beneficial. In Atlanta, for example, partnering and goal sharing early on proved effective because it ensured a common goal between the owner and contractors of building a high-quality and safe project on time ensured a successful project for all parties.

Several of the same project organizational lessons were cited for the New York 63rd Street Connector and the Washington Largo extension including:

- Developing good and amicable working relationships with other departments and the contractor through partnering
- Selecting and maintaining the right staff with dedication to the project (e.g., the budget/cost control team was fully dedicated only to the project)
- Emphasizing leadership attention, involvement, and support
- Teaming with contractors and all other project participants
- Maintaining staff through all phases for continuity

4.5. Project Management Controls

Project management controls include contract mechanisms for schedule, quality, claims, testing, change orders, subcontracting, progress payment, and closeout. They are also defined by the roles and responsibilities of the owner and contractor, with the aim of ensuring the successful implementation of the project. Project management controls are thought to be influenced by:

- Nature of the project (e.g., technology, complexity)
- Type of contract (e.g., ownership, financing)
- Size and scope of the project
- Experience of owner agency staff
- Project setting (e.g., new start project or extension of an existing line)

As described in the following subsections, the functions of project management control include:

- Project budget and schedule control
- Change order and claims management
- Quality assurance and quality control
- Risk management.

4.5.1. Project Budget and Schedule Control

Project budget and schedule control are functions performed by the management, scheduling, and accounting systems. The related functions include verifying budget to actual costs, level of detail and separation in work breakdown structure, consistency with schedule and progress reporting, and the requirements included in subcontractors' contract terms and clauses. Project schedule management also considers contractor and agency interface, response capabilities, and incentives and disincentives including implications for payment.

Table 4-11 summarizes the cost characteristics of the nine sample case study projects including the share of the project funds supplied by federal sources and the share of soft costs (i.e., non-construction). It is important to note that the Portland Airport and Pasadena projects did not use federal funds. It is also important to point out that the soft costs for the Washington Largo and Denver Southwest projects were considerably lower than the others—the former possibly because this project was an extension along existing right-of-way and the sponsoring agency was the GEC for the project.

The table responds to several industry perceptions that federal funding increases the project management costs of the projects. These project management costs are presented as the soft costs and their amount is measured as a percentage of the total project costs. In addition, observers have suggested that higher levels of non-federal funds may create more pressure to better define projects early and thereby have less cost escalation. Since more project decision making control would be with the local and state funding agencies for these projects, the expectation is that non federal stakeholders would have imposed financial constraints earlier in the project development process.

However, no clear relationship was identified between the cost containment results of the projects and the share of federal funds. Also, neither higher soft cost percentage or increased capital cost variance was apparent from the project data set. Therefore, higher and lower federal funding levels did not appear to impose measurably higher soft cost percentages.

Table 4-11. Summary of Sample Project Cost Characteristics

Panel Projects	Final Capital Cost as (million YOE $)	Year Completed or First Phase Opened	Est. Federal Funding Share	Est. Share of Soft Costs
Atlanta MARTA North Line Extension	$472.7	2000	80%	27%
Denver Southwest Line	$177.1	2000	78%	19%
New York NYCT 63rd Street Connector	$632.3	2001	55%	31%
Pasadena LACMTA Gold Line	$535.4	2003	N/A	28%
Pittsburgh PAAC Airport Busway Ph 1	$326.8	2000	80%	36%
Portland TriMet Airport Max Extension	$127.0	2001	N/A	21%
Portland TriMet Interstate Max Exten.	$349.4	2004	74%	29%
Salt Lake City North South Line	$311.8	1999	80%	23%
Washington WMATA Largo Extension	$456.0	2004	60%	10%

Table 4-12 presents the analysis of the responses to the project cost and budget control questions. Federal funds appropriations were delayed in the case of Denver, Portland Interstate, Salt Lake, and Washington. Respondents reported that such delays were typically absorbed by the project without significantly affecting total costs of the projects. In fact, as shown in Table 4-12, a federal appropriations delay did not appear to negatively impact average capital cost variance from scope or schedule changes for these projects. Any cost increases beyond the federal full grant agreement were typically covered by state and local funds.

As previously reported, both constant year and YOE cost estimates were used by the nine sample projects. Eight sample projects reported that the proposed project implementation schedule was reflected in the cost estimates, as shown in Table 4-12. Due to the limited data set, it was not possible to compare the impact this had on cost variance due to scope or schedule changes.

Agency staff were responsible for project cost control in six sample projects. By virtue of the DB procurement approach, Pasadena and Portland Airport assigned cost control responsibility to the contractor. Despite the limited data, the analysis in Table 4-12 suggests that these two projects exhibited a lower average cost variance due to scope changes and similar cost increases due to schedule changes.

Table 4-12. Responses to Project Cost and Budget Control Questions

Interview Guide Question	Average of % Scope Change	Average of % Schedule Change	Number of Projects	Corresponding Projects
Were federal appropriations delayed?				
--	-19.8%	7.0%	2	Pasadena, Portland Airport
No	15.2%	11.9%	3	Atlanta, New York, Pittsburgh
Yes	10.8%	3.3%	4	Denver; Portland Interstate; Salt Lake; Washington
Was the project schedule reflected in the cost estimates?				
--	13.6%	8.5%	1	Denver
Yes	2.0%	6.8%	8	Atlanta, New York, Pasadena, Pittsburgh, Portland Airport, Portland Interstate, Salt Lake, Washington
Who had the cost control responsibility?				
Agency	13.3%	7.8%	6	Atlanta, Denver, New York, Pittsburgh, Portland Interstate, Washington
Both	9.2%	2.0%	1	Salt Lake
Contractor	-29.8%	7.0%	2	Pasadena, Portland Airport
Who had the schedule control responsibility?				
Agency	10.3%	1.3%	2	Portland Interstate, Washington
Both	14.8%	11.0%	4	Atlanta, Denver, New York, Pittsburgh
Contractor	-16.8%	5.3%	3	Pasadena, Portland Airport, Salt Lake

The responsibility for schedule control varied among the nine responding projects, as shown in Table 4-12. The agency was responsible for schedule control in two projects, the contractor was responsible in three projects, and the agency and contractor shared the responsibility in the remaining four projects. The three projects with contractor schedule control tended to perform better in terms of average cost variance due to scope and schedule change.

Table 4-13 summarizes the schedule control strategies employed by each of the responding projects. This includes the roles and responsibilities of the agency (owner) and consultant or contractor. A centralized schedule electronic repository was only required in one project investigated—Atlanta. In this case, each contract included specifications for providing the contractor's schedule in an importable electronic format on a monthly basis with the major milestones identical to those in the master schedule. **Table 4-13** also summarizes the payment approach used by each project.

As evidenced by these results, the schedule control and payment strategy did not determine the success of the project in maintaining either. The contractor results were slightly better, but only nominally. The actual schedule control and payment strategies appeared to have better performance when the payment approach was tied to specific schedule and cost outcomes. Whether the agency or the contractor, or a shared relationship was used, the outcome was more determined by the quality of the approach rather than the specific approach to schedule and cost control.

Table 4-13. Sample of Schedule Control and Payment Strategies

Panel Projects	Schedule Control Strategy	Payment Approach
Atlanta MARTA North Line Extension	• Schedule control responsibility: Both • Weekly meetings and monthly reports • Baseline schedule used to measure progress was changed only with management approval • Contractor maintained the project resource-loaded schedule on a monthly basis and submitted it to the CEI to track progress and interface issues	Cost-loaded CPM schedule with progress payments
Denver Southwest Line	• Schedule control responsibility: Agency • Contractor provided monthly updates • Agency reviewed and accepted schedule	Earned value on all contracts
New York NYCT 63rd Street Connector	• Schedule control responsibility: Both • Agency had overall project schedule responsibility and contractor was responsible for schedule performance and slippage mitigation measures according to the terms and conditions	Lump sum based on cost-loaded CPM schedules and jointly established baseline
Pasadena LACMTA Gold Line	• Schedule control responsibility: Contractor	Lump sum
Pittsburgh PAAC Airport Busway Ph 1	• Schedule control responsibility: Agency • Control with funding availability • Contractually defined roles	Cost plus not to exceed (program manager and designers) lump sum and unit price items (construction contracts)
Portland TriMet Airport Extension	• Schedule control responsibility: Contractor with agency oversight • Contractor maintained project schedule and provided updates and reports • Agency maintained schedule used to coordinate project support efforts with all departments within the Agency and to inform the public. TriMet reviewed and commented on the schedule submittals from contractor	Lump sum with monthly progress evaluations
Portland TriMet Interstate Max Extension	• Schedule control responsibility: Agency • Contract Control Board approval • The contractor was responsible for producing a monthly schedule with changes noted • TriMet reviewed and commented on the schedule, directed and discussed any required changes to conform to the master schedule, and maintained the master schedule	Payment tied to completion of milestones
Salt Lake City North South Line	• Schedule control responsibility: Contractor • The contractor submitted all documents that were logged by the Document Control Center • The consultant provided oversight and advice as needed to set up the Expedition transition	Schedule of values based on unit price, lump sum by pay item

Panel Projects	Schedule Control Strategy	Payment Approach
Washington WMATA Largo	• Schedule control responsibility: Agency • The contractor submitted all documents electronically followed by a hard copy • Contractor took the lead in developing the schedule, owner reviewed /approved • Verified completed work each month and reviewed updated schedule • The consultant assisted staff in verification or any other areas as requested	Cost-loaded CPM for completed work and lump sum

4.5.2. Change Order and Claims Management

Based on the project responses, scope of changes should be defined early, estimated, negotiated, and settled in an expeditious manner. Ideally, the project has estimation staff based on site along with regular support from the procurement staff for claims negotiations. Design costs can be controlled by releasing the change order for design only with review milestones, if possible. In addition, clear definition of the review process with timely responses was viewed as essential.

Table 4-14 summarizes the change order process employed for all responding projects. It describes how owner-directed and contractor-initiated change orders were addressed, and provides detail on how a scope change was authorized and controlled throughout the planning, engineering, and design phases. It also describes any unique procedures employed for change order management. In Atlanta, for example, change order practices included meeting to discuss the exact scope change and ensure that all parties involved understood the changes, and determining a date or percent complete when no more discretionary changes would be accepted.

Table 4-14. Sample of Change Order Processes

Case Study Projects	Change Order (CO) Process
Atlanta MARTA North Line Extension	• Change order RFPs were issued, priced, and agreed to prior to performing work unless performed on a force account basis when the project schedule did not allow for time to complete the change procedures • Same process for owner-directed except the scope was reviewed for compliance with the contract to issue RFP for pricing • Contractor-initiated changes were evaluated and processed according to the Resident Engineer's Manual and the General Conditions • Authorization and control during (1) planning: project definition documents; and (2) design: work authorization letters provided to the designer by agency to add scope for the project and the estimated amount of design effort to accomplish the work. Many scope changes were handled in this fashion, including major revisions such as separating the earthwork contract for schedule advantage and changing the surface parking to garage.
Denver Southwest Line	• All changes are incorporated into the various contracts through contract amendments. RFPs are addressed through change notices and unilateral

Case Study Projects	Change Order (CO) Process
	changes are addressed through change orders. • The agency project manager sends RFP through a change notice and prepares an independent cost estimate prior to negotiations with the contractor. Negotiations start upon receiving the contractor's pricing and ultimately are incorporated into the contract through a contract amendment. • In emergencies or in situations where agreements are not reached with the contractor's pricing, unilateral COs are used, which are ultimately incorporated into a contract amendment • The contractor sends his change request to the agency project manager. If the change request has merit, the RTD project manager will negotiate with the contractor and process the change through a contract amendment. • All claims were attempted to be resolved at the lowest level possible. In case of a disagreement between the agency and the contractor's project managers, the claim would be taken to the construction manager, project director, and ultimately the agency general manager.
New York NYCT 63rd Street Connector	• CO begins with a scope meeting, preparation of schedule and cost estimate by day 15, agency review by day 20, negotiations and NTP before day 90 or extended to day 120 • Scope discussions for extra work took place before receipt of proposals • Claims went to the NYCT-CPM chief engineer for review and resolution. There were only four to six claims cited for the project
Pasadena LACMTA Gold Line	• The primary process used was a biweekly CM/CC meeting in which the CEO, CFO, engineering manager, construction managers, and program manager met with the contracts manager to review and approve all changes within the CEO's authority. • The changes beyond the CEO's authorization were taken to the Board of Directors Construction Committee, which consisted of two Authority Board members. To accomplish the goal of completing the project without any claims, the Authority, PMC, and DB used informal Dispute Review Boards (DRB), Escrow Bid Documents (EBD), DRB Avoidance meetings (DRBA), and risk-based settlement agreements. Together, these techniques allowed the settlement of all claims prior to them reaching the dispute status. • Only two COs for a differing site condition (totaling $450,000) were submitted to the Authority after the project was restarted in 1999.
Portland TriMet Airport Extension	• Order of magnitude estimates were prepared for most changes to support a decision. • If decision to proceed was taken, then detailed scope would be developed and priced by the contractor. This change order package would be reviewed and fair cost estimate prepared by agency.
Portland TriMet Interstate Max Extension	• All COs were documented in Prolog as the resident engineer entered information with an order-of-magnitude estimate, and tracked additional information related to the potential change as it developed • Any changes involving schedule or greater than $50,000 required approval by the Contract Control Board • There were no claims
Salt Lake City North South Line	• Agency had a change control board that reviewed design and construction changes >$25,000 on a weekly basis. • COs <$25,000 required signature from the project manager while COs > $25,000 required review through the change order committee, signature from the general manager, legal, director and project manager. • Negotiation of cost/quantity with contractor using independent estimate • On the consultant side, scope change was managed by a task and drawing

Case Study Projects	Change Order (CO) Process
	control log. When direction impacted the estimate to complete, then a change order was initiated.
Washington WMATA Largo Extension	• CO begins with the preparation of scope and an independent estimate; a PCO review board at the project level and approval to proceed with issuance; scope meeting with the contractor once the direction is received, contractor estimate, negotiations and settlement; and modification issued through appropriate process. • For contractor claims that were determined to have merit, a full scope was agreed to and COs were issued after the project representative developed a cost estimate. Negotiations and settlement with the appropriate modification follow. • COs over $200,000 are taken to the staff through agency offices, Planning, Development and Administration Committee, and to the Board for Approval. • The change may be issued in phases

Most agencies reported that, as a first step, claims were initially addressed through bilateral negotiations. Most projects had contractual provisions for an alternative dispute resolution board or the like, but only two projects used it. As shown in **Table 4-15**, the five projects that used alternative dispute resolution or had provisions for it appeared to exhibit better average cost variance due to scope or schedule changes.

Three projects out of eight responding tracked changes and claims by cause, as presented in Table 4-15. These three projects exhibited improved average cost variances due to scope changes, but higher cost variances due to schedule changes compared to the other projects. This may indicate the cost benefits of these approaches, but the time cost of them too by the greater schedule delays.

Table 4-15. Responses to Change Order and Claim Management Questions

Interview Guide Question	Average of % Scope Change	Average of % Schedule Change	Number of Projects	Corresponding Projects
Was an alternative dispute resolution process used?				
No	14.8%	11.0%	4	Atlanta, Denver, New York, Pittsburgh
No, but contract allowed for one	7.0%	0.7%	3	Portland Airport, Portland Interstate, Salt Lake
Yes	-25.4%	8.3%	2	Pasadena, Washington
Were changes and claims tracked by cause?				
--	1.6%	0.0%	1	Portland Airport
No	11.9%	3.9%	5	Denver, New York, Portland Interstate, Salt Lake, Washington
Yes	-10.6%	14.4%	3	Atlanta, Pasadena, Pittsburgh

Timeliness of responses to proposed changes is essential. A project may also have an expedited review process available in case schedule adherence is threatened. In Denver, an attempt was made to resolve all claims at the lowest level possible unless there was disagreement. Empowering the field staff while maintaining adequate financial authorization is important for fast resolution to issues arising during construction. In New York, claims and agreement on scope changes between the agency and contractor were required prior to receiving cost proposals for the extra work.

4.5.3. Quality Assurance/Quality Control (QA/QC)

The definition of the contractor and agency roles for QA/QC varied among the sample projects. In general, the agencies defined the QA plans at a minimum, and the contractor's role was primarily QC. For several projects including Denver, addressing quality issues at an early stage helped avoid unnecessary complications. In New York, several innovative quality programs were featured as a case study in the FTA QA/QC guidelines, including a just-in-time training program, preparatory phase inspection, and use of metrics to monitor and recognize the contractor's effort on quality.

Table 4-16 analyzes the responses to the QA/QC questions. When asked whether the project used an existing QA/QC manual or whether one was developed for the project, seven sample projects reported developing a manual based on a model from a previous agency or contractor project. Eight projects reported using an independent inspection and testing program (ITP) organization. There was not sufficient data with the limited sample to confirm the impact of these QA/QC program features on the cost variance. However, those agencies that used them thought that there were measurable benefits to the use of the QA/QC manual and the ITP testing program.

Table 4-16. Responses to QA/QC Questions

Interview Guide Question	Average of % Scope Change	Average of % Schedule Change	Number of Projects	Corresponding Projects
Was there an existing QA/QC manual or was one developed for the project?				
--	0.2%	10.4%	1	Atlanta
Developed	3.9%	7.5%	7	Denver, New York, Pasadena, Pittsburgh, Portland Interstate, Salt Lake, Washington
Existing	1.6%	0.0%	1	Portland Airport
Did the project use an independent testing organization?				
--	0.2%	10.4%	1	Atlanta
Yes	3.6%	6.5%	8	Denver, New York, Pasadena, Pittsburgh, Portland Airport, Portland Interstate, Salt Lake, Washington

Table 4-17 summarizes roles and responsibilities of the agency (owner) and contractor and how the quality audit process was conducted. These highlights present many variations to the management of the quality program. Success was found in each of these variants. It did not seem to be the process as much as how well it was managed.

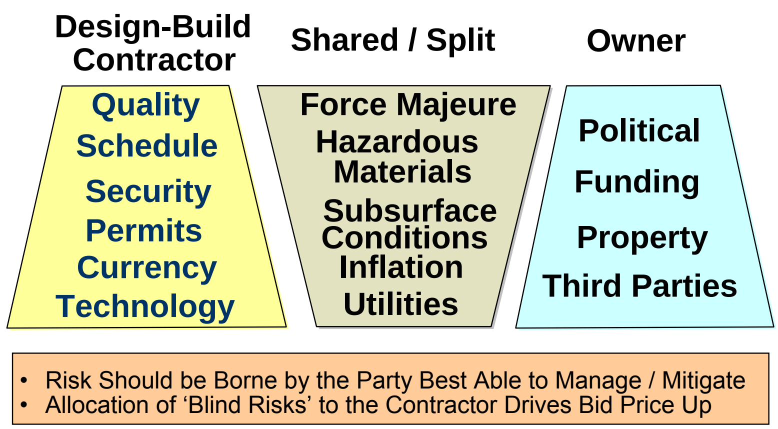
Table 4-17. Features of the Project QA/QC Program

Panel Projects	Features of the Project QA/QC Program
Denver Southwest Line	• Contractor responsible for all QC • Agency responsible for inspections, surveillance and QA audits; also employed an independent testing contractor • Design audits were conducted at various milestones; construction audits were conducted regularly to ensure workmanship, testing, and construction documentation.
New York NYCT 63rd Street Connector	• Contractor responsible for the quality of the construction and all QA/QC work, and ITP with agency monitoring • Contractor also responsible for audits with agency staff of subcontractors, subconsultants, and vendors • Agency responsible for oversight, ensuring that the contractor implemented its QA/QC • Project performed its own QC to supplement contractor's QC • Internal audits (ad hoc) and contractor audits (quarterly) were performed
Pasadena LACMTA Gold Line	• Contractors were responsible for performing their own QC according to contract; also subbed QA/QC and used an independent lab • Agency performed quality compliance auditing of these contractors' QC programs • A compliance audit system (comprised of a proprietary, computer-based database that allowed for random sampling of work in both design and construction) made it possible to track, trend, and develop monthly reports
Pittsburgh PAAC Airport Busway Ph 1	• Contractor responsible for all QA/QC work • The CM, as a subconsultant to the GEC/PM, provided construction inspection services
Portland TriMet Airport Extension	• Contractor responsible for most QC/QA work, and ITP with agency monitoring • Agency responsible for overseeing field inspection and QA audit activities
Portland TriMet Interstate Max Extension	• Contractor responsible for all QC/QA work, and ITP with agency monitoring • Agency responsible for reviewing and approving QA/QC work • The agency's QA manager was on site daily during construction and observed all key construction activities and inspected manufacturing facilities. The FTA Project Management Oversight field representative frequently accompanied the QA manager during the audits.
Salt Lake City North South Line	• Contractor responsible for all QC and contractor project manager performed the role of Quality Manager • Agency responsible for QA and oversight and had a QA manager full time on the project; also employed an independent testing contractor for random audits or for third-party data in disputes • Quality audit conducted by agency contract staff for design at progress submittal milestones and for construction on a monthly basis
Washington WMATA Largo Extension	• Contractor responsible for all QC • Agency responsible for inspections, surveillance and QA audits • Agency focused on verifying that the approved plan was being followed • DB did use independent testing agencies for specific tests

4.5.4. Risk Management

Risk management entails the comprehensive identification, assessment, and efficient allocation of risks and responsibilities to the parties involved, and the monitoring and mitigation of these identified risks. The assignment or sharing of the risks between the contractor or agency, and the subsequent division of risk management roles and responsibilities was a key consideration. As an example, **Figure 4-4** depicts one arrangement for the divisions of risks between the contractor and owner under a DB procurement approach. This figure illustrates the assignment of the risks to the party best able to manage and mitigate them and then the potential for sharing of the risks, again with the allocation of portions or aspects of each risk to the party best able to manage them. The figure also emphasizes that the allocation of blind or ill-defined risks to the contractor to avoid risk to the agency tends to drive the bids much higher.

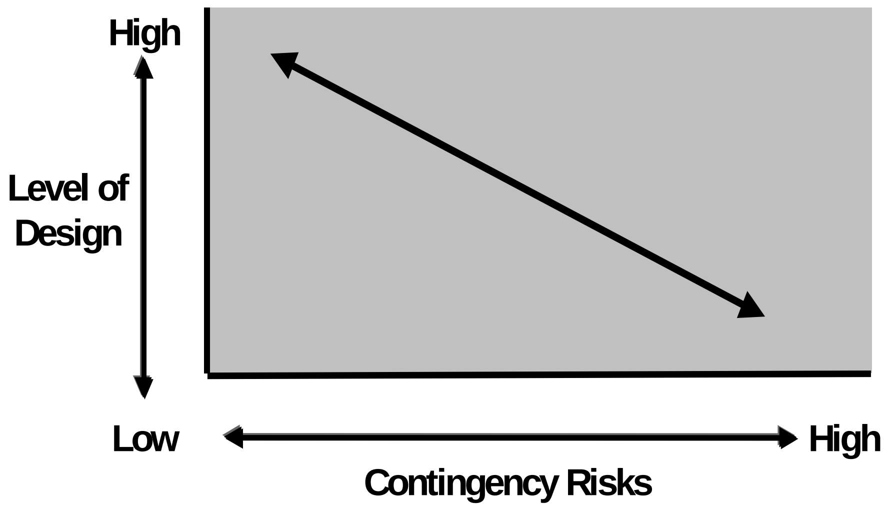
Figure 4-4. Typical Division of Risk for Design-Build



When asked to describe the risk management plan used to form the basis for the procurement, the sample projects cited several different arrangements for allocating risks between the agency and the contractors. Not surprisingly, the risk elements that challenged the contractor bids the most were the same cost drivers cited previously in **Table 4-6**.

Recent federal policies have begun requiring detailed risk assessments for major transit projects. Contingencies have been stipulated by federal guidelines for many years using the model depicted in **Figure 4-5**. According to new FTA requirements," Risk Methodologies and Procedures", May 2004, all transit projects underway go through a formal probabilistic risk assessment following this FTA *Guidance 22*. [i]

Figure 4-5. Model for Allocation of Contingency Risks



One approach to comprehensively evaluate cost and risks for complex infrastructure projects has been developed by a team including the Washington State Department of Transportation—the Cost Estimate Validation Process (CEVP).[ii] CEVP includes the following steps: [iii]

- Evaluation of the cost estimate, in terms of quantities and unit costs, to the extent possible based on the project information available
- Review and validation of schedule estimate and markups
- Reduction of reliance on general contingency by identifying project-specific risk associated with both cost and schedule
- Consideration and quantification of risk and opportunity
- Production of a probabilistic cost and schedule range for the identified scope

Table 4-18 presents a summary of the responses to the risk management questions. When asked about the risk assessment approach used to develop or evaluate the cost estimates and contingencies, only one project (Washington) reported using a probabilistic risk assessment methodology, but several projects used an informal and/or deterministic approach to assess risks and assign contingencies. The Washington project used a Monte Carlo simulation to establish cost confidence level and identify contingencies. However, the New York project did perform a risk assessment for line-by-line contingency allocation for known risks such as support of excavation and groundwater control. This relationship between the risk assessment process and the development of specific line item construction contingencies seemed to be an important step in the development of the risk assessment process.

No unique techniques to generate the cost estimate were reported except for the New York and Washington projects. In New York, the construction contractor based estimates on actual site and field conditions for all trades (as opposed to preparing a baseline engineering estimate and applying complexity factors). In Washington, the agency prepared a probabilistic risk assessment to relate the risk estimates to line item budgetary risk values. Risk management was highlighted as a likely area of project management enhancements in the near term.

Table 4-18. Responses to Risk Management Questions

Interview Guide Question	Average of % Scope Change	Average of % Schedule Change	Number of Projects	Corresponding Projects
What was the type of risk assessment approach used?				
--	10.3%	0.0%	1	Portland Interstate
Contingency allocation	-4.2%	9.0%	5	Atlanta, Pasadena, Pittsburgh, Portland Airport, Salt Lake
Risk mitigation plan	13.4%	5.9%	3	Denver, New York, Washington
Were any unique techniques used to generate the cost estimate?				
No	0.4%	7.7%	7	Atlanta, Denver, Pasadena, Pittsburgh, Portland Airport, Portland Interstate, Salt Lake
Yes	13.3%	4.6%	2	New York (Actual field conditions), Washington (Probabilistic Risk Assessment)

[i] In addition, FHWA's Major Project Program Cost Estimating Guidance, dated June 8, 2004.
[ii] Reilly, et al (2004), "The Development of a New Cost-Risk Estimating Process for Transportation Infrastructure Projects," *CE Practice*, Vol. 19, No. 1, 53-75.
[iii] http://www.wsdot.wa.gov/projects/cevp/pdf/whatisCEVP.pdf

5. CONCLUSIONS

The results of this analysis of capital cost changes for major federally funded public transportation projects provide interesting insight into the management of capital costs during the project development process. Conclusions are drawn based on the cost variance and schedule analysis (**Section 3**), case study results (**Section 4**), and related literature review (**Section 2**). These conclusions are focused upon the strategies and techniques identified in the analysis that can contribute to the improvement in managing the capital costs of major federally-funded transit projects.

It is important to note, however, that the limited number of projects investigated may not provide a statistically representative sample of major transit projects completed over this time period. Nonetheless, the cost and schedule performance of the 28 case study projects provides a good foundation for understanding the major cost drivers and the strategies, tools, and techniques to better estimate, manage and control capital costs. These findings and conclusions are summarized here.

5.1. Findings

An initial set of over 30 candidate projects was focused upon 28 projects conforming to the basic study requirements—fixed guideway transit projects in excess of $100 million, and with sufficient information to support the cost and schedule analysis. From the set of 28 projects, the TCRP project panel identified a subset of 14 of these 28 projects for more detailed study of the strategies, tools, and techniques used to estimate, manage, and control capital costs. The selection was made on the basis of identifying a reasonable number of projects with varying capital cost experiences and approaches. A survey was developed and distributed to these project sponsoring agencies. Completed surveys were received for 9 projects that provided insight into the various project management approaches used in each project. These surveys offered valuable insight into the more successful strategies, tools and techniques that were used in the management of these major projects. This insight combined with the analyses of actual project experiences provides the basis to the development of these conclusions.

5.1.1. Literature Review

Related studies of the development and implementation of major projects tended to focus on the cost and schedule management aspects. Cost overruns or underestimation of project costs for transportation projects from the last several decades document a range of results. The 28 projects included in this analysis of federally funded public transit projects achieved better results than those published elsewhere, but encountered many of the same challenges in managing the costs of these major projects.

- Schedule delays and changes in technical specifications are noted as main reasons for cost escalation
- Costly changes due to the lack of consideration of external effects of mega projects in the early planning process (i.e., interest groups and the community at large are not involved early enough, so their opinions come into play later in the planning process)
- Lack of risk analysis and the probabilistic nature of costs and benefits of transportation projects are being overlooked and not included in the estimating process
- Lack of clear regulatory regimes in the decision-making process (i.e., the roles of stakeholders such as the agency, government, etc., are not well defined)
- Too much focus on technical issues instead of the economic, environmental, and safety issues that will eventually have to be considered at later stages.

In summary, the long duration of project development, exclusion of major cost components during feasibility estimates (as these estimates were considered comparative estimates with alternatives), and scope creep are cited as reasons for project cost underestimation and cost growth. Ways of dealing with the underestimation of cost and schedule were focused on implementing a more transparent development process.

Some authors concluded that project cost estimates sometimes reflected purposeful underestimation in order to make the projects look economically viable. The proposed potential solutions to these underestimation issues included process improvements and governmental vigilance in the review and analysis of these estimates. The authors also concluded that the issue of cost overruns had been present in mega projects worldwide and for decades. They showed that no learning curve effect could be seen in the estimation process because today's projects were experiencing cost overruns as projects did decades ago despite the improvement of technologies.

The results from this G-07 analysis suggest that the increases in costs are not as high for rail projects (44.7% in the Flyvbjerg study and 32.8% in this study), not as pronounced in the early stages (Flyvbjerg stated overly optimistic estimates at the decision stage compared with less than half the cost increase found at the initial stage in this study), and no learning curve in the Flyvbjerg projects while cost increase from PE to completion decreased over time in this study from 11.2% prior to year 2000 projects to 8.0% after year 2000.

5.1.2. Application of Hypotheses

The following hypotheses for capital cost changes were used to structure the analysis process and maintain consistency across projects and individual hypotheses. The analysis was not intended as a statistical testing process to accept or reject the hypotheses. Rather, these hypotheses were developed and applied to the analysis process to ensure these issues were fully considered and answered as part of the study process. The relevant findings, nevertheless, are applied here as commentary or supporting evidence for each hypotheses.

- **Hypothesis 1:** Project costs are underestimated during planning. Costs were confirmed to be underestimated during planning. The cost growth was highest for this phase of project development. The increase was due mainly to scope changes, unit cost increases and exclusion of relevant cost elements. Insufficient project schedule estimates also contributed to early cost increases. However, there was no indication of political expediency in the consistency of these elements or in the amounts of the increases. No indication of political influence in the underestimation of costs was found in the study surveys.

  The largest average cost increase between phases occurred between planning and PE (15.3% for 22 projects). Scope changes drove about two-thirds of this cost increase. The case studies indicate that this cost increase mostly reflects a low level of design (i.e., scope definition) and the exclusion of relevant cost elements (i.e., basis of estimation), rather than political issues or contingency. Although several projects experienced cost escalation after an FFGA was issued, cost growth after Final Design was no larger than between PE and Final Design.

- **Hypothesis 2:** Project costs are increased at the Preliminary Engineering stage to account for project elements omitted from the earlier planning phase and unrealistically low unit-cost estimates. The cost increase from planning to PE was 15.3% and the increase from PE to Final Design was 9.6%. The majority of this cost escalation was due mainly to omission of project elements and to low unit cost estimates. This extent of element omission and low unit costs was confirmed.

  The average cost increase from PE to Final Design for all 28 case study projects was 9.6%. About 5.9% of this increase was due to scope changes including additional unit cost and quantity increases. An analysis of a subset of 14 projects suggests that unit cost increases between PE to Final Design contributed most of this increase.

- **Hypothesis 3:** Project costs are increased at the final design and construction stages due to (a) the incremental project modifications to improve and enhance the project definition (scope creep) or (b) simple omission of project elements or the underestimation of some project components. The majority of cost increase at the final design and construction phases was mainly due to unit cost increases and schedule delays. This hypothesis was refuted. Earlier phases of project development had already accounted for most of the project definition aspects.

  There was an average cost increase of 9.5% from Final Design to Construction/ Operations for the 28 case study projects. About three-quarters of this increase was due to scope changes. An analysis of a subset of 14 projects suggests that unit cost increases contributed to the vast majority of this increase. The remaining cost increase was schedule based. There were scope reductions encountered to counter balance some of the unit cost and schedule cost increases.

- **Hypothesis 4:** Project costs are increased at the start of construction to account for the inflationary effects of project schedule delays during all of the project development phases leading up to construction. This hypothesis was refuted, since schedule delays decreased as the project moved toward construction.

  Schedule changes represented about 30% of the capital cost increase for the 28 case study projects. There was an 4.8% increase of the capital cost estimate due to schedule changes from Planning to PE. From PE to Final Design, there was a 3.9% increase due to schedule changes. From Final Design to Construction/Operations, there was a 3.4% increase of the capital cost due to schedule changes. Therefore, the contribution and impact of schedule changes to capital costs decreased slightly from Planning to Operations.

- **Hypothesis 5:** Projects with a high degree of complexities experience cost escalation. Project complexities were difficult to define. However, projects with greater lengths of underground and elevated sections did have greater cost escalation. This hypothesis was confirmed through this definition of complexity.

  Although there was insufficient data to analyze further this complexity aspect of the hypothesis, several projects cited tunnels, underground stations, elevated structure, utilities relocation, unforeseen site conditions as key cost drivers. In addition, these same cost categories elicited the largest cost variance in the detailed analyses. All else being equal, the complexity of the project did influence the reliability of cost estimates.

5.1.3. Case Study Analysis

The major cost drivers considered in this analysis were initial inflation adjustment, scope changes (including unit cost and quantity), and schedule changes (including the inflationary impact of project delays). The following are the major findings of the case study analysis reported as the unweighted average of cost changes for multiple projects:

- Initial inflation adjustment for 12 projects reporting planning estimates in constant year dollars (in order to convert them to YOE dollars) resulted in an average increase of 14.7%
- Scope changes (sum of unit cost and quantity adjustments) over the life of 28 case study projects resulted in an average increase of 25.9% in YOE dollars
- Schedule changes over the life of the 28 case study projects resulted in an average increase of 7.9% in YOE dollars

It was possible to distinguish between unit cost and quantity changes for a subset of 14 projects with more detailed scope data. These 14 projects exhibited a 19.1% average increase in scope changes over their life, composed of:

- An average unit cost increase over the life of the projects of 17.9%
- An average quantity decrease over the life of the projects of 3.8%

Cost and schedule data for a different subset of 14 projects selected by the TCRP project panel were collected using the interview guide for strategies, tools, and techniques. The average cost change in YOE dollars for these projects was 27.5%. These projects were generally more recent than the 28 case study projects (2.7 years newer on average) and exhibited the following characteristics:

- Initial inflation adjustment for 5 projects reporting planning estimates in constant year dollars was an average 11.0%increase
- Scope changes (sum of unit cost and quantity adjustments) resulted in an average increase of 16.1% in YOE dollars
- Schedule changes resulted in an average increase of 9.3% in YOE dollars

For the 9 TCRP project panel projects that responded to the interview guide questions, the average cost change in YOE dollars was 18.9%. Again, these 9 projects were also more recent than the 28 case study projects and exhibited the following characteristics:

- Initial inflation adjustment for 4 projects reporting planning estimates in constant year dollars was an average 10.7%increase

- Scope changes (sum of unit cost and quantity adjustments) resulted in an average increase of 9.8% in YOE dollars
- Schedule changes resulted in an average increase of 8.0% in YOE dollars

The analysis of cost changes for the case study projects by phase of development yielded the following findings:

- An average increase of 15.3% from Planning to PE (22 projects)
- An average increase of 9.5% from PE to Final Design (28 projects)
- An average increase of 12.2% from Final Design to Construction (28 projects)

The analysis of cost changes in YOE dollars for the 28 case study projects by both phase and major cost driver (scope and schedule change) yielded the following findings:

- From Planning to PE, there was an 10.5% increase due to scope changes and a 4.8% increase due to schedule changes (22 projects)
- From PE to Final Design, there was an 5.8% increase due to scope changes and a 4.0% increase due to schedule changes (28 projects)
- From Final Design to Construction/Operations, there was an 11.2% increase due to scope changes and a 3.3% increase due to schedule changes (28 projects)

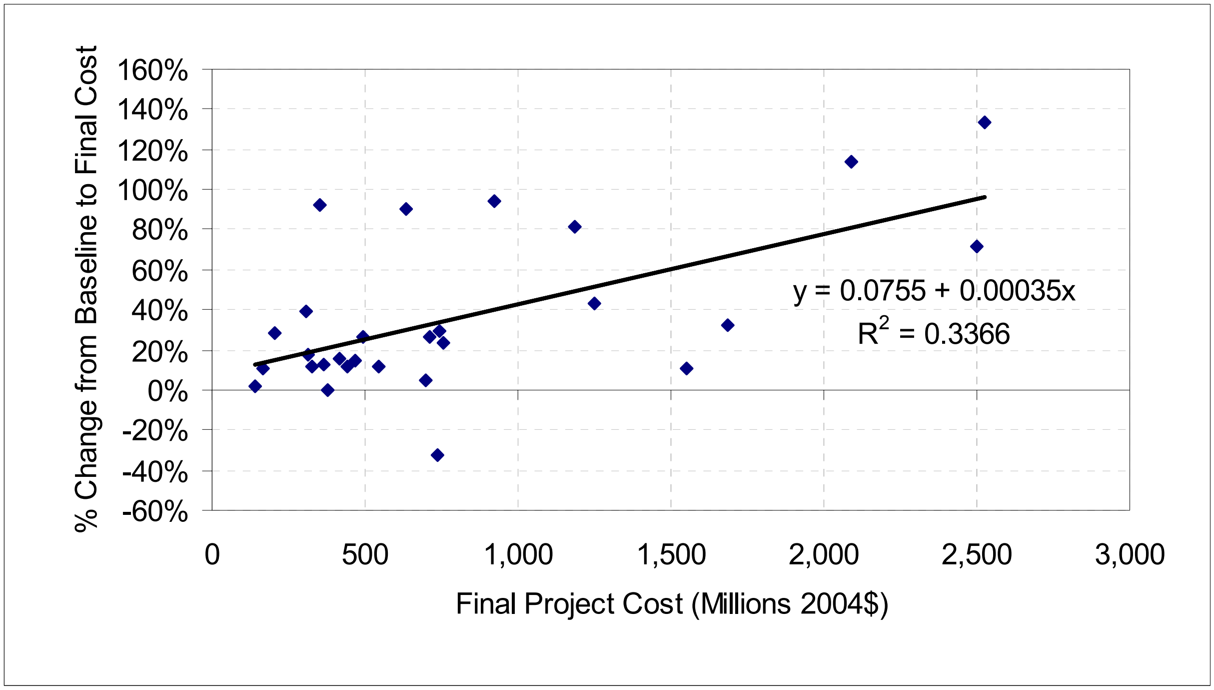
A more detailed analysis of average capital cost changes due to scope changes (in terms of unit cost and quantity changes) by phase yielded the following findings:

- From Planning to PE, unit cost and quantity changes caused a 1.0% and 4.0% increase in capital costs, respectively (6 projects)
- From PE to Final Design, unit cost and quantity changes caused a 9.8% increase and a 4.4% decrease in capital costs, respectively (14 projects)
- From Final Design to Final Cost, unit cost and quantity changes caused a 7.7% increase and a 0.9% decrease in capital costs, respectively (14 projects)

Project Size or Cost

As hypothesized, the larger projects tended to have larger cost increases as shown in the figure. The results of a regression analysis for the 28 projects confirm a statistically significant positive relationship between the final project cost in $2004 and the percent change from baseline to final cost (i.e., the percent increase in cost tends to increase as total size increases). These results are presented in **Figure 5-1** below.

Figure 5-1. Linear Regression of Project Final Cost and Cost Change



All Sample Projects (28)	*Coefficients*	*Standard Error*	*t Stat*	*P-value*
Intercept	0.0755	0.096383	0.783338	0.440506
Project Cost (2004 $M)	0.000351	9.15E-05	3.834007	0.00072

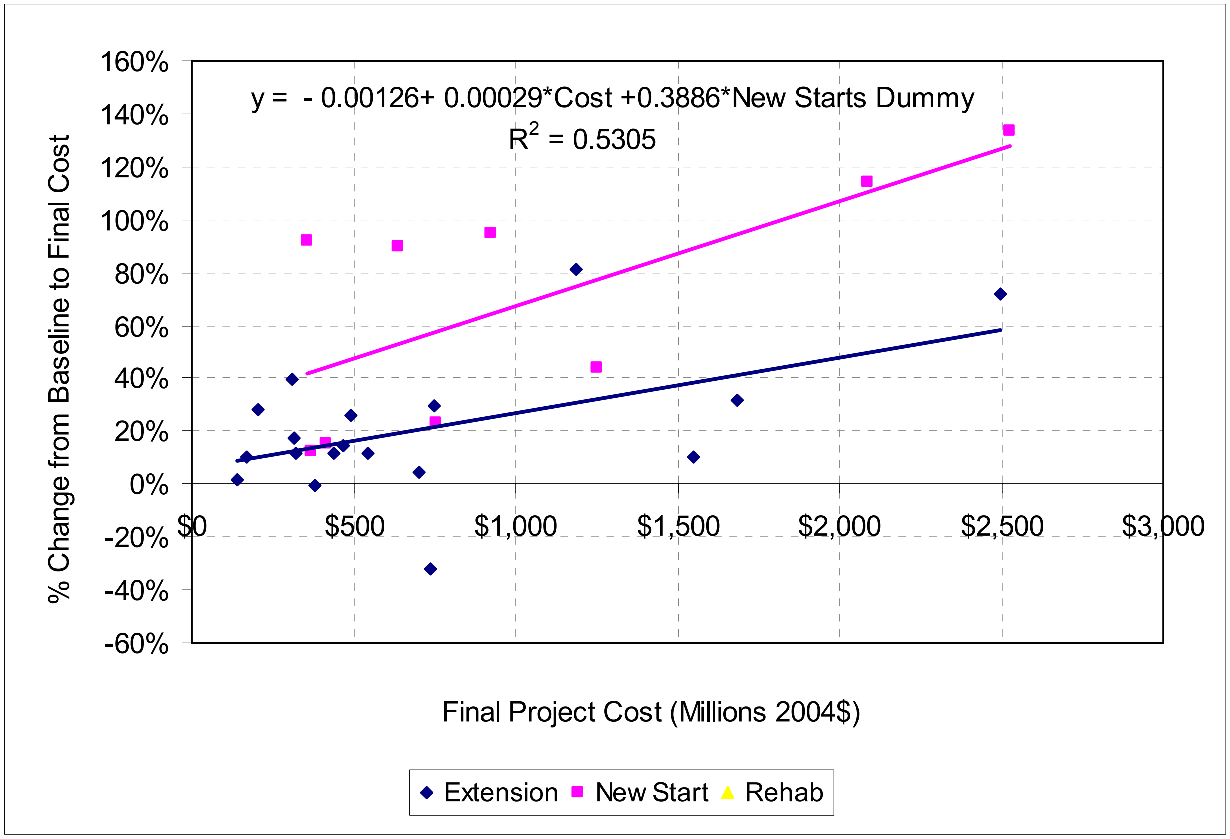
New Start/Extension/Rehabilitation

It is also possible to segregate the 28 projects by type—whether a new start (10), extension of an existing system (17), or rehabilitation (1). The un-weighted average cost increase from baseline to final for new start projects is 56.8%. This is considerably higher than the un-weighted average for extension projects of 23.7% or for the single rehabilitation project of 26.3%.

This finding is to be expected given that most new starts projects represent the first major transit project built in an area and the managing organization may have less experience in that environment. Note however that this analysis does not account for differences in project size between new starts projects and extensions to existing systems. As noted above, there is a positive relationship between project cost and the percentage increase in final costs versus the baseline cost (see trend line above). If new starts projects tend to be larger than extensions, this may account (at least in part) for the higher percent increase in costs for new starts investments. In fact, this is the case. Within the sample of 28 projects, the average cost for a new starts project is roughly 40%

higher than that of the average extension. The question remains then as to whether the expected percent increase in costs for new starts projects is significantly higher than for extensions, *when adjusted for differences in project size*. This question was addressed using the regression analysis presented in **Figure 5-2** below.

Figure 5-2. Linear Regression of Project Final Cost and Change With Project Type



All Sample Projects (28)	Coefficients	Standard Error	t Stat	P-value
Intercept	-0.00126	0.086653	-0.01452	0.988532
Project Cost (M of 2004$)	0.00029	8.04E-05	3.599697	0.001439
New Start Dummy	0.388553	0.115041	3.377523	0.002491

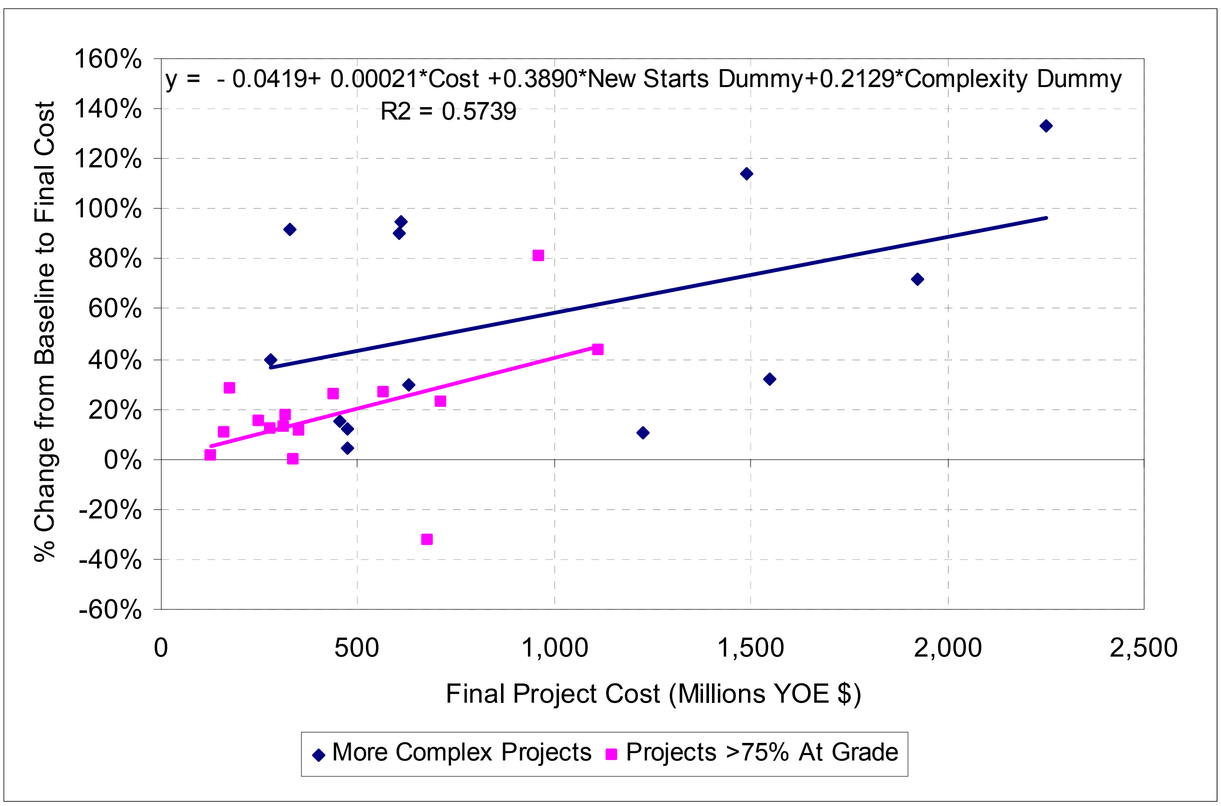
This regression expanded the earlier analysis to a include a "dummy variable" designed to evaluate the significance of cost differences between new starts and extension projects (specifically, the dummy variable was set to 1 if the project was a new starts investment and set to 0 for extensions). Based on this analysis, the expected percent increase in costs for a new starts project is close to 40% higher as compared to an extension project of the same size. In addition to being statistically significant, the addition of the dummy variable greatly improved regression model's ability to explain project cost increases (i.e., the adjusted-R^2 increased from 0.336 to 0.531).

Alignment Complexity

The project complexity as measured by the proportion of the alignment that is elevated or below ground was hypothesized to be a factor in cost changes. Thus, the 28 projects were segmented into two groups— 15 projects had 75% or more of the alignment at-grade while 13 projects did not. The latter group represented more complex projects which included significant tunnel or elevated sections. The more complex projects had an un-weighted average cost increase of 56.8% from baseline to final. As expected, the 15 "simpler" projects experienced less cost change with an un-weighted average increase of 18.5%.

Once again, however, much of this difference can be accounted for by differences in total project cost: with the average cost of complex projects being roughly twice that of predominantly at-grade investments. To determine whether cost increases for complex projects really are higher than those for non-complex projects, the earlier regression model was modified once again, this time to include a dummy to denote project complexity (specifically, the new dummy variable was set to 1 for complex investments and 0 for non-complex investment). The results are presented in **Figure 5-3** below.

Figure 5-3. Linear Regression of Project Final Cost and Change With Complexity



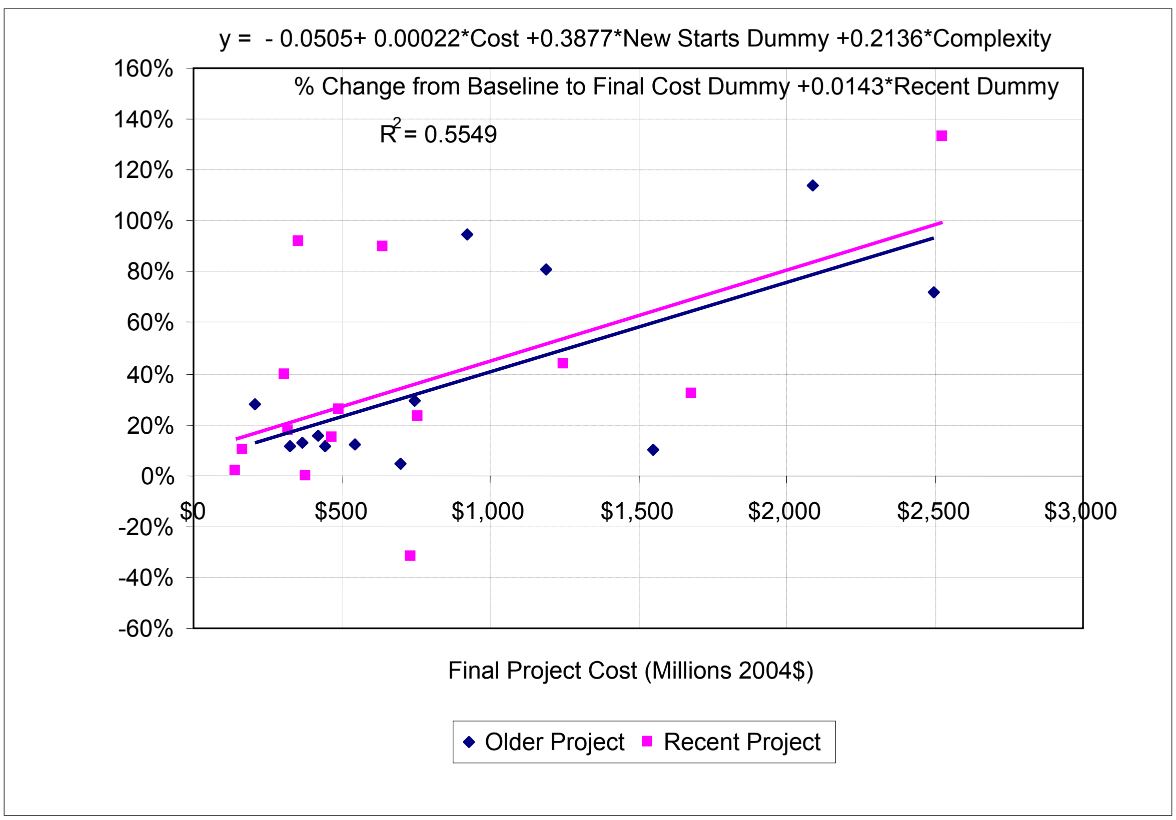
All Sample Projects (28)	Coefficients	Standard Error	t Stat	P-value
Intercept	-0.04191	0.085405	-0.49071	0.62828
Project Cost (M of 2004$)	0.000214	8.67E-05	2.470308	0.021344
New Start Dummy	0.389003	0.109593	3.549521	0.001709
Complexity Dummy	0.212854	0.114673	1.856186	0.076284

Based on this analysis, the expected percent increase in costs for a "complex" project is roughly 20% higher as compared to a non complex project of the same size and type (new start or extension). In addition to being statistically significant, the addition of the complexity dummy variable further improved regression model's ability to explain project cost increases (i.e., the adjusted-R^2 increased from 0. 531to 0.574).

More Recent Project Results

Finally, it has been hypothesized that projects completed since 2000 have tended to experience lower increases in project costs as compared to projects completed pre-2000. The results of this analysis are presented in **Figure 5-4**.

Figure 5-4. Linear Regression of More Recent Project Results



All Sample Projects (28)	Coefficients	Standard Error	t Stat	P-value
Intercept	-0.05045	0.107303	-0.47013	0.642889
Project Cost (M of 2004$)	0.000216	8.93E-05	2.416108	0.024434
New Start Dummy	0.387658	0.11244	3.447687	0.002294
Complexity Dummy	0.213622	0.117335	1.820624	0.082295
Recent Project Dummy	0.014307	0.104589	0.136796	0.892436

This hypothesis has been tested by again expanding the regression model developed above, this time to include a dummy variable to compare the cost increases of older with more recent projects (specifically, the new dummy variable was set to 1 for investments completed on or after 2000 and 0 for projects completed prior to 2000).

Based on this analysis, there is no statistical difference in the cost increase experience of projects completed before and after the year 2000 (similar results were found when comparing projects completed pre- and post 1995). Hence, the hypothesized difference between these prior and more recently completed projects must be rejected.

Since prior studies all showed cost increases at rates greater than this set of 28 projects, it was hypothesized that these projects would continue to show this improving trend. This was not demonstrated by the above analysis, therefore it is likely the case that these differences result from differences over time in project size, project type (new starts, extension), project complexity or a mix of these factors. So while these projects demonstrate an improving trend in an overall comparison with prior study results, this continuing trend could not be demonstrated with these more recent projects.

5.2. Conclusions

This report has examined the available strategies, tools, and techniques to better estimate, contain, and manage capital costs based, in part, on the experience of the case study projects. The literature review and case studies built a foundation for the analysis. The analytical structure was shaped by the hypotheses. The extent of the cost and schedule increases encountered in major transit projects has been defined through the project analyses. The related factors and causes behind cost escalation have been identified through the case study analyses. The combination of all of these has shaped the following conclusions to this research.

5.2.1. Project Definition

Clear cost priorities, established early in project development, are important to cost and schedule performance. These should be reflected in the initial evaluation of alternatives. Establishing clear budget and schedule constraints early in the project development process helped contain scope creep and identify reasonable project development schedules. However, some flexibility with respect to scope and schedule should be maintained in the project development process to adapt to the more unique project conditions identified in the development process.

Several of the case studies point out that some of the most difficult risks to capital costs and schedule are time to achieve political consensus and the acquisition of private property. It is important to manage public expectations and communicate the tradeoffs between scope, cost, and schedule in order to control project definition and development schedule. Outreach to community and businesses is important to minimize project redefinition and maximize support. It is also crucial because of the influence of the political process in defining and funding major transit projects. This can be achieved through a more transparent alternatives analysis and preliminary engineering process. In summary, while engineering issues were encountered, these were controllable. The larger impacts that were both unexpected and less controllable were the stakeholder, third-party, and real estate acquisition issues.

Other project definition strategies that contributed to the control of cost and schedule were value engineering and design-to-budget. Value engineering activities at each phase of project development helped to control project costs by refining the design. A design-to-budget approach begins design with a fixed budget in mind. It also appeared to contribute to cost and schedule control.

5.2.2. Estimation

Good early cost and schedule estimates are particularly important since they often set internal and external expectations. At the same time, there are greater cost and schedule uncertainties during the planning phases of a project. Most projects used a deterministic cost estimating method. This approach synthesizes hundreds or even thousands of assumptions into one estimate for cost. This underscores the tradeoff between accuracy and precision in early estimates. Accuracy represents freedom from error and the approach toward true cost, while precision is the significant digits used to arrive at the estimate. Therefore, one can be precise, but inaccurate. A tradeoff exists between providing more detail that may become less understandable to the audience. Similarly, establishing a realistic project schedule and managing multiple schedules can be challenging for some projects, due to external pressures or unknown conditions.

A probabilistic cost and schedule estimation approach integrated with a detailed risk assessment may better convey the assumptions involved in the cost estimate and the risks reflected in the cost estimate. Also, although most agencies have added ongoing project data to their historical cost databases, there is a general lack of as-built unit cost data for future projects.

5.2.3. Procurement

Within the sample set of projects, the reasons for selecting a particular method of procurement varied from past experience with the chosen method to compressed schedules. Design-build offers some potential cost savings opportunities through consolidating design and construction management with the contractor, and reducing agency procurement and project management requirements. However, these savings can be offset by increased project definition and oversight responsibilities for the agency. The construction management at risk also offers similar consolidation of construction and installation contracts to gain some of the schedule compression and procurement reductions, and without some of the project definition concerns of design-build. Many of these more recent approaches to project delivery are still under development, but seem to offer measurable benefits to the completion of projects within planned schedules and closer to initial cost estimates. The refinement of these approaches may still take additional time.

Prequalification and industry review of contract documents may help ensure quality and past performance of contractors, and improve the contracting terms and project management approach. Incentives and penalties may offer advantages to the project development process, but concerns were raised about impacts of these measures.

5.2.4. Project Organization

It was found that having a common goal between the owner and contractors of building a high-quality and safe project on time ensured a successful project for all parties. The approaches to roles and responsibilities to achieve this were varied. However, the following organizational concepts seemed to be in common:

- Develop a good and amicable working relationships with other third-party organizations and the contractor through partnering
- Select and maintain the right staff with dedication to the project
- Limit distractions and identify priorities
- Emphasize leadership attention, involvement, and support including senior staff from all owner and contractor participants, plus ongoing outreach with stakeholder representatives

- Partnerships with contractors and stakeholders helped develop a common sense of project ownership.

These can be achieved through equitable sharing of the responsibilities and credit for project successes.

5.2.5. Project Management Controls

Project management controls include contract mechanisms for schedule, quality, claims, testing, change orders, subcontracting, progress, payment, and closeout.

Budget and Schedule

Contractor responsibilities and ramifications for budget and schedule performance can be clearly established in the contract terms and monitored in the reporting procedures. Contract terms can include specifications for providing the contractor's cost and schedule performance in an importable electronic format on a monthly basis with the major milestones identical to those in the master schedule.

Change Order and Claims Management

Scope and justification of changes and claims can be defined early, estimated, negotiated, and settled in an expeditious manner. Ideally, the project has estimation staff based on site along with regular support from the procurement staff for claims negotiations. Design costs can be controlled by releasing the change order for design only, if possible, with review milestones. Alternative dispute resolution provisions in the contract can limit changes and/or their cost impact. Timeliness of responses to proposed claims and changes is essential. In addition, clear definition of the review process with a concise resolution structure was voiced as essential.

Quality Assurance/Quality Control (QA/QC)

Addressing quality issues at an early stage helped avoid unnecessary complications. Several innovative quality approaches were identified, including application of a QA/QC manual, a just-in-time training program, preparatory phase inspections, an independent testing program, and use of specific metrics to monitor and recognize contractor's effort on quality.

Risk Management

Risk management entails the comprehensive identification, assessment, and efficient allocation of risks and responsibilities to the parties involved, and the monitoring of these identified risks. The assignment of the risks to the contractor or agency (or shared responsibilities) and the subsequent division of risk management roles and responsibilities between the owner or agency and the contractor is a key consideration. Recent federal policies have begun requiring detailed risk assessments for major transit projects. Moreover, relating the risk assessment process to the development of specific line item construction contingencies seemed to be an important step in the development of the risk assessment process.

5.3. General Strategies

The following general conclusions address the five questions originally raised in the research plan. These potential improvement strategies generally draw from the case studies performed as part of this report. Where possible, supporting statements have been included from the case studies and the literature review.

1. **What can local project sponsors do to estimate costs and schedules reliably at the alternatives analysis, preliminary engineering, final design, and construction phases?**

   - **Use Reasonable Starting Assumptions** – In the early phases, it is imperative that sponsors establish a realistic project scope and schedule based on actual needs and known constraints (e.g., budget, deadlines, regulations). These estimates often set initial expectations and form public opinion. A better-defined scope and schedule can help minimize uncertainties during estimation. When uncertainties are unavoidable, it is imperative to communicate the assumptions and limitations of the estimates in a way that is easily understood. These uncertainties could also be accounted through targeted contingencies.

     The means to accomplish this are to support continued research into the actual costs and schedules of these projects. Early risk assessments could also provide a method to achieve this. This continued research into the actual schedules and as-built costs will help to ensure realistic schedules can be used, as-built unit costs are available, and all of the typically required project scope items are identified for project planners and engineers. Also, these data should be accessible and updated periodically.

   - **Improve Estimation Quality** – The case studies show that estimates can be improved in all phases of development using formal estimation manuals and through reviews or validations that are comprehensive and independent. Cost estimation data, or as-builts, from previous projects may be shared or pooled to improve overall data quality and reduce uncertainty as noted above. The cost estimation staff should consistently represent the disciplines of the wider project team, including senior staff, and use formal cost estimating models or systems.

- **Increase Estimation Transparency** – A process that involves the public and is clear to all stakeholders at all phases is more likely to produce reliable estimates. Documentation on estimate assumptions and methodologies that are available to the stakeholders and public may attract wider support and less risk of future change later in the project development process. Moreover, the integrity of the cost estimation can be assured by a system of checks and balances through the use of independent cost estimators, risk assessment processes, independent value engineering processes, and formal cost estimate validation processes. Also, an incentive structure can be developed and implemented to encourage agencies to have more accurate project estimates; and possibly accelerate the project review process.

2. What can local project sponsors do to contain project costs and schedules at each phase?

- **Optimize Project Parameters** – It is important for all project stakeholders to recognize the tradeoffs and interrelationships between scope, schedule, and quality to cost. During the alternatives analysis and preliminary engineering phases, several optimization techniques have proven to be effective at increasing the project's overall "value proposition" by containing costs while not significantly compromising scope, schedule, quality, or the anticipated benefits. Among these techniques are design-to-budget, value planning, value engineering, and risk assessment approaches.
- **Apply a Broad Range of Project Management Controls** – During implementation, the scope, schedule, and QA/QC controls used by project managers varied but usually included each of the following elements:
  - **Problem Resolution** – The quality testing process needs to focus on resolution of the root cause rather than solely on the symptoms.
  - **Efficient Processing** – Changes could be identified early, estimated, negotiated, and settled in an expeditious, pre-defined process. The change order and claims management process should be clear and fair to all parties.
  - **Appropriate Incentive Structure** – Incentives and penalties can be applied to payment mechanisms for schedule management or change order processes to empower staff with appropriate authority for change control. These incentives need to be crafted carefully to focus the effect on the quality outcome and limit the contractor payment without measurable progress.
- **Create an Effective Organization** – The project organization must ensure that responsibilities and risks are placed on the parties that can best affect them. It must also ensure that there is an appropriate level of technical capacity. The effective organization may be achieved through partnering and a dedication to continuous open communications between the owner (including Board of Directors), contractors, consultants and FTA representatives. Integrating the

project team in both design and construction can also enhance project ownership. These concepts have shown to be beneficial in several case studies.

3. **What can local project sponsors do to complete projects within their estimated costs and schedules?**

   - **Select the Appropriate Delivery Method** – The selection of the appropriate procurement and delivery method is important to the success of the project development. This selection is best based on the desired level of responsibility, risk, control, expertise, and scope flexibility. With the many procurement approaches available, this assessment of the project characteristics and agency culture can form the basis to this decision. The delivery method may impact cost and schedule by affecting the required level of project management, oversight, and construction management. Public-private partnerships are a recent positive trend.
   - **Recognize the Tradeoffs in Contracting** – A single larger contract may decrease competition and increase construction prices in the local market. Multiple smaller contracts increase competition, but also increase the number of potentially costly project interfaces and management complexity. The right balance must be struck to ensure that projects are segmented appropriately and to take advantage of different delivery methods, technical capabilities, project characteristics, and local market conditions.

4. **What changes outside of the direct control of project sponsors could foster the reliable estimation of project costs and schedules?**

   - **Improving Estimation Consistency** – Standard procedures for estimation in the industry may help minimize the inconsistencies observed in estimates. One example is the standard use of YOE dollars for reporting capital cost estimates with realistic schedule assumptions. A consistent and appropriate basis for cost estimation can also help lessen the problem of incompatible estimates between projects and the impact of missed project elements and low unit costs. The omission of some relevant project elements and their reasonably expected unit costs, particularly in the early phases of project estimation, has been a contributing factor to the negative public perception of large cost overruns. Building a cost and schedule database of as-built costs using a consistent capital cost database structure could contribute to improving cost estimation consistency.
   - **Communicating Uncertainties and Limitations in Estimates** – Some uncertainty cannot be avoided, and estimates must reflect all relevant project risks. Deterministic cost estimates with general contingency factors are a crude way of recognizing the expected variability. A detailed, probabilistic risk assessment is becoming a more common and accepted method of identifying risk factors and

quantifying their potential impact on project development. The recent federal requirement of a formal risk assessment process could improve both the reliability and public confidence in project cost estimates. A consistent process that links these identified project uncertainties to a focused risk management process could be one improvement opportunity. This would formalize the risk process into identification, quantification, allocation, mitigation, and management. One example of a formal risk assessment approach used in Washington State is the Cost Estimate Validation Process (CEVP)™. The subsequent development of construction phase cost contingencies related to the remaining risk items may be the appropriate direction for increasing the reliability of the project cost and schedule estimates.

5. **What changes outside of the direct control of project sponsors could help contain the costs and schedules of major public transportation projects?**

   - **More Effective Public Outreach and Stakeholder Engagement** – In general, projects are recognizing that early and constant communications with stakeholders maximize public support and build political consensus. However, this effort could be made more effective by enhancing the public understanding of the basic tradeoffs between project scope, schedule, quality, and costs. Although these tradeoffs are sometimes dependent on specific project conditions, it may be more effective to establish and promote a common framework for communicating project constraints to all stakeholders. In this manner, project sponsors can more clearly explain to stakeholders the reasons for any cost variability through the phases of project development. The charts developed for the case studies and presented in **Appendix C** is one example of such a framework. This framework can also include presentation materials regarding the modal options, the more specific project characteristics of station layouts, vehicle and systems options, and the challenges of third-party expectations from the project. With increased availability of as-built cost and schedule databases, the cost impacts of these options can better guide the public debate on these options.
   - **Improved Funding Mechanisms** – As federal funding for new projects has declined on a percentage basis, local, state, and private funding and public – private partnerships are becoming more common in transit project development. This trend may help to better control project costs and schedules because it introduces greater accountability at the local level, However, funding mechanisms can be improved by adding flexibility in order to meet the needs of new project delivery mechanisms developed to supplement the decline of federal funding. Funding needs are greater for the design-build project delivery options to meet the specific delivery payment schedules and the combined sizes of the contracts.

5.4. Future Research

This section presents several ideas for continued research efforts into this important area of cost estimation, management, and control, and the advancement of certain ideas identified throughout this research.

5.4.1. Continued Study Research

Ideas for continued study research efforts include:

- Expand the sample size for the project cost and schedule analysis to build a more statistically reliable basis
- Complete more case studies into the more successful tools and techniques used to control cost and schedule
- Develop an outreach workshop of interested project development experts to contribute to the identification and validation of tools and techniques and their application process.

5.4.2. Transit Research

Ideas for transit research efforts include:

- Continue to refine the consistent database structure for all capital cost and schedule reporting requirements throughout the project development process
- Develop the guidance necessary to require all project cost and schedule reporting to conform with that structure
- Continue and enhance the documentation of the as-built cost and schedule databases
- Develop a uniform project element structure for this project data and provide element definitions for it's context within the cost estimating and historical bid cost databases.
- A "basis of estimate" document can then be developed from this
- Expand the analysis capability of these databases to examine project cost risk items and values
- Increase the development of the risk assessment process:
  - Analyze technical analysis process improvements
  - Capture schedule risks
  - Better link the risk items to the project budgetary line items
  - Examine the optimal roles and responsibilities within the process

  - Consider the scheduling of the assessment efforts to coincide and better support the project development process
  - Examine the potential application of the risk estimates as construction cost contingencies
- Review current project management oversight guidance procedures to look for opportunities to emphasize cost and schedule management within the process
- Examine the potential application of the cost validation processes, such as the CEVP™, to the transit project development process.

APPENDICES

Appendix A: Annotated Bibliography A-1
Appendix B: Hypothesis Testing for Project Selection B-1
Appendix C: Case Study Project Descriptions C-1
Appendix D: Summary of Responses to Interview Guide D-1

Appendix A: Annotated Bibliography

A.1 Books, papers, technical reports:

Arditi, D., G. T. Akan, and S. Gurdamar. 1985. "Cost Overruns in Public Projects." *International Journal of Project Management*. Elsevier Science Ltd.: 3(4), 218-224.

The authors present results of a survey of public agencies and contractors in Turkey to identify the sources of cost overruns on projects executed between 1970 and 1980. They concluded that the most important sources of cost overruns are inflationary pressures, cost underestimation or errors, increase in material and labor costs, and construction delays.

Booz Allen Hamilton (Schneck, D. C.). 1991. "Light Rail Transit Capital Cost Study." *UMTA-MD-08-7001*. Washington, DC: U.S. Department of Transportation.

Booz Allen Hamilton, a consulting firm that worked on several transit projects, reported actual costs of five light rail system projects. The objectives included an examination of unit costs that could be used in the planning and conceptual estimating for future similar projects. The report did not attempt to evaluate or explain the unit cost variances among the systems or compare the estimated and actual costs.

Booz Allen Hamilton (Schneck, D. C. and R. Amodei). 1994. "Fixed Guideway Capital Costs – Heavy Rail and Busway/HOV." Federal Transit Administration.

This report provides a detailed documentation of the component-level or project element-level capital costs typically experienced in the development of major capital heavy rail and busway/high occupancy vehicle lane transit projects.

Booz Allen Hamilton (Schneck, D. C. and R. Laver). 2003. "Light Rail Transit Capital Cost Study Update." Federal Transit Administration.

This report provides a detailed documentation of the component-level or project element-level capital costs typically experienced in the development of major capital light rail transit projects. The resulting normalized cost estimates and unit cost ranges were used to develop a capital cost estimation model to help project developers better estimate the capital costs of future light rail projects at every stage of the major capital investment planning and development process.

Booz Allen Hamilton (Schneck, D. C. and R. Laver). 2004. "Heavy Rail Transit Capital Cost Study Update." Federal Transit Administration.

> This report provides a detailed documentation of the component-level or project element-level capital costs typically experienced in the development of major capital heavy rail transit projects. The resulting normalized cost estimates and unit cost ranges were used to develop a capital cost estimation model to help project developers better estimate the capital costs of future heavy rail projects at every stage of the major capital investment planning and development process.

Bruzelius, N., B. Flyvbjerg, and W. Rothengatter. 2002. "Big Decisions, Big Risks. Improving Accountability in Mega Projects." *Transport Policy*. UK: 9(2), 143-154.

> The paper discusses problems with the current process used by European countries for planning and managing major public projects using two projects as case studies. It proposes modifications to the planning process.

Chaney, V., et al. 1996. "Probabilistic Risk Analysis for Turnkey Construction: A Case Study." *FTA-MD-26-7001-96-2*. Washington, DC: U.S. Department of Transportation.

> The authors in this report focused on a single transit project (Baltimore's Central Light Rail Phase II), did a detailed risk analysis for various components of the transit system, and identified high risk factors for this turnkey project. Identification of these high risk factors such as uncertainty in utility relocation, potential presence of hazardous waste, and right-of-way acquisition was then used for establishing contingency budget for the project.

Civil Engineering. 1992. "Standing Room Only at Portland Bid Meeting." *Civil Engineering*: 62(12), 14.

Duffy, J. 1998. "Inside New Jersey Transit's $1.1 Billion Hudson-Bergen DBOM Light Rail Project." *Mass Transit*: 25(5), 10-23.

Ellis, R. D., and H. R. Thomas. 2003. "The Root Causes of Delays in Highway Construction." *Proceedings, TRB Annual Meeting*. Washington, DC.

> The paper presents the results of a research funded by the U.S. Department of Transportation that studied delay causes in highway construction. The causes of delays are prioritized. The causes receiving the highest priority were utility relocation delay, errors in plans and specifications, and differing site conditions.

Enfiedjian, B. 1997. "Transit Turnkey Procurement Lessons Learned." *Lessons Learned: Turnkey Applications in the Transit Industry, FTA-MA-90-8005-97-1*, V-1-V-58. Washington, DC: U.S. Department of Transportation.

This paper provides a detailed description of turnkey procurement, its advantages, when it can be used, how it compares with traditional methods of project procurement, and the laws governing project procurements in various states in the U.S. The paper does not provide cost data but describes some case studies.

Engineering News Record. 1986. "Bids Low on Seattle Tunnel." *ENR*. McGraw-Hill, Inc.: Sept. 18, 1986, p.28.

Faulkner, B., and M. El-Sharafi. 2002. "From Rehab to First Class: Analyzing the Increase in Costs of the Old Colony Commuter Railroad Project." *Proceedings of TRB*. Boston, MA.

The paper discusses cost overruns by comparing estimates from DEIS and FEIS estimates, and explains reasons for cost growth in the Old Colony Project.

Faulkner, B., and R. Martinez. 1993. "Sensitivity Analysis of Financial Forecasts for MBTA Infrastructure Investment Program." *Proceedings of the Infrastructure Planning and Management*. Denver, CO: 511-520.

The paper discusses cost overruns by comparing estimates from DEIS and FEIS estimates, and explains reasons for cost growth in the Old Colony Project. Escalation costs due to the long duration of project development, exclusion of major cost components during feasibility estimate as these estimates were considered comparative estimates with alternatives, and scope creep are cited as reasons for project cost underestimate and cost growth.

Figura, R. 1997. "Turnkey Financing for Public Transportation Projects." *Lessons Learned: Turnkey Applications in the Transit Industry, FTA-MA-90-8005-97-1*, I-1-I-60. Washington, DC: U.S. Department of Transportation.

Turnkey projects have different financing requirements from traditional DBB contracts because the compressed schedule requires revenue needs to match construction drawdowns. Alternative sources of funding and various financial instruments for turnkey projects are described and several case studies are discussed.

Flyvbjerg, B., N. Bruzelius, and W. Rothengatter. 2003. *Megaprojects and Risk: An Anatomy of Ambition*. UK: Cambridge University Press.

This book studies mega projects and motivations of project developers in underestimating project costs in an effort to have these projects approved for funding. It draws on some of the data that are reported in other Flyvbjerg papers.

Flyvbjerg, B., M. S. Holm, and S. Buhl. 2002. "Underestimating Costs in Public Works Projects." *Journal of American Planning Association*: Vol. 68, No. 3, 279-295.

This study is based on a sample consisting of 258 transportation infrastructure projects. The authors compared estimated cost at the time of decision-to-build with the actual cost of the completed projects. They conclude that cost escalation in transportation projects (rail, highway, tunnel, bridge) in the United States, Europe, and other parts of the world is commonplace and stems from overly optimistic estimates of cost at the point of making the decision-to-build. Further, they contend that the error in cost estimates cannot be attributed to lack of sufficient information at the time of preparing the estimates, because they show a clear pattern of underestimating the costs rather than showing a pattern of random deviation from the true costs. They conclude that project cost estimates reflect purposeful underestimation in order to make the projects look economically viable.

Flyvbjerg, B., M. S. Holm, and S. Buhl. 2003. "How Common and How Large Are Cost Overruns in Transport Infrastructure Projects?" *Transport Reviews*. 23(1), 71-88. UK: Taylor & Francis Ltd.

This is a follow-up to the earlier paper by the authors (Flyvbjerg, Holm, and Buhl 2002). It does not include new information.

Flyvbjerg, B., M. S. Holm, and S. Buhl. 2004. "What Causes Cost Overrun in Transport Infrastructure Projects?" *Transport Reviews,* Vol. 24, No. 1, 3-18.

This paper uses data from 258 projects to examine the causes of cost escalation in transportation projects. The authors contend that the length of project implementation is positively correlated and a cause of project cost escalation.

Fosbrook, Jr., G. A., and S. I. Gonzalez. 1997. "Puerto Rico's Tren Urbano." *Mass Transit*: 23(2), 48-51, 54-55.

Fouracre, P. R., R. J. Allport, and J.M. Thomson. 1990. "The Performance and Impact of Rail Mass Transit in Developing Countries." *Research Report 278*. Crowthorne, Berkshire, England: UK Transport and Road Research Lab.

This is a comparative study that looked at 21 metro systems in developing countries. The number of projects with underestimates in costs and overestimates in ridership far exceeded projects where estimates of cost and ridership were accurate.

Gasper, J. 2003. "Los Angeles to Pasadena Metro Gold Line: Light Rail Design-Build Project Zips Along on Time, within Budget." *Kieways*. The Magazine of Peter Kiewit Sons', Inc.: 59(4), 1-6.

Lee, D. B. 1997. "Identification and Management of Risk on Turnkey Transit Projects." *Lessons Learned: Turnkey Applications in the Transit Industry*. *FTA-MA-90-8005-97-1,* III-1-III-24. Washington, DC: U.S. Department of Transportation.

The paper lists risk items that affect transit capital projects. Each risk item, such as political, funding, and site conditions risk, is briefly explained. Typical methods used for risk measurement, allocation, and mitigation are covered. The author contends that probabilistic methods are not at a stage yet that can be used effectively for risk measurement.

Leo, D. W., and S. W. Knotwicz. 2001. "Cost Estimates: A Decision-Making Tool." *2001 AACE International Transactions*. Pittsburgh, PA: AACE International.

This paper discusses the use of cost estimating as a tool for choosing the right projects besides executing the projects correctly. The paper focuses on capital projects of corporations and uses Kodak Company as an example.

Loetterle, F. E. 2003. "Procurement of Federal Property for Light Rail Transit, Case Study of the Minneapolis Hiawatha Line." *Proc. of the Ninth Light Rail Transit Conference*. No. E-C058, 536-550. Portland, OR: Transportation Research Board of the National Academics.

Luglio, Jr., T. J. 1997. "Transit Turnkey Design and Construction: Value Engineering and Quality Assurance." *Lessons Learned: Turnkey Applications in the Transit Industry, FTA-MA-90-8005-97-1*. IV-1-IV-21. Washington, DC: U.S. Department of Transportation.

The author discusses the use of Value Engineering and QA/QC during design and construction of transit projects with some emphasis on turnkey. The paper

examines the issue of contractor's freedom in implementing QA/QC programs under the turnkey approach.

Mendes, D. 1997. "Environmental Considerations." *Lessons Learned: Turnkey Applications in the Transit Industry*. *FTA-MA-90-8005-97-1*. VI-1-VI-28. Washington, DC: U.S. Department of Transportation.

The author discusses environmental and community risks that affect project planning and development of DBB and DB transit projects. Cost, delay, and public relations risks related to environmental issues are discussed, and suggestions for mitigation are provided.

Menendez, A. 1993. *Estimating Capital and Operating Costs in Urban Transportation Planning*. World Bank. Praeger Publishers.

Addressing the chronic underestimation of capital and operating costs in urban transportation projects, this book provides a detailed analysis of the cost estimating process using case studies from three U.S. cities, and outlines a practical framework for this process. The work goes beyond a simple quantitative approach to explaining cost underestimation and looks at the planning process as a tool for both argumentation and structuring the argumentation. This approach highlights the difficulties in several components of the estimating process and suggests specific and practical actions to address these problems.

Merewitz, L. 1972. "Cost Overruns in Public Works with Special Reference to Urban Rapid Transit Projects." *working paper No. 196/BART8*. Institute Of Urban and Regional Development. University of California, Berkeley.

The original source document describing the study of cost overruns in transportation projects; refer to other references by the same author.

Merewitz, L. 1973a. "How Do Urban Rapid Transit Projects Compare in Cost Estimate Experience?" *Reprint No. 104*. Institute of Urban and Regional Development. University of California, Berkeley.

Merewitz, L. 1973b. "Cost Overruns in Public Works," in Niskanen, et al. (Eds.). *Benefit Cost and Policy Analysis*. Aldine, Chicago: 277-295.

Merewitz (1973a and b) used a sample of 66 transportation projects to study cost overruns. Flyvbjerg et al (2002) reviewed this paper and discussed its characteristics.

Middleton, W. D. 1997. "Boston Rebuilds Its Regional Rail System." *Railway Age*: 198(11), G1.

National Audit Office. 1988. "Department of Transport, Scottish Department and Welsh Office, Road Planning." HMSO, London, England.

> This study was carried out for the UK's National Audit Office. They compared actual and forecast traffic data for 41 road projects in the UK. The study concluded that in 22 of these forecasts were within acceptable bounds (within 20 percent of the actual). They also estimated the impact of inaccurate forecasts on the cost and design standards for the constructed projects.

Office of Inspector General. 1999. "Hudson-Bergen Light Rail Transit System." *RT-1999-123,* U. S. Department of Transportation, Washington, D.C.

Office of Inspector General. 2000a. "Final Report on the Audit of the Bay Area Rapid Transit District Extension to San Francisco International Airport." *IN-2000-085,* U.S. Department of Transportation, Washington, D.C.

Office of Inspector General. 2000b. "Report of the Financial Plan for the Tren Urbano Rail Transit Project." *RT-2000-091,* U.S. Department of Transportation, Washington, D.C.

Office of Inspector General. 2002a. "Review of the Hiawatha Corridor Light Rail Transit Project." *IN-2002-078,* U.S. Department of Transportation, Washington, D.C.

Office of Inspector General. 2002b. "Report in the Tren Urbano Rail Transit Project." *IN-2002-085,* U.S. Department of Transportation, Washington, D.C.

Pickrell, D. 1990. "Urban Rail Transit Projects: Forecast versus Actual Ridership and Cost." *DOT-T-91-04*. Washington, DC: U.S. Department of Transportation.

> The author compared the estimated versus actual costs of 10 urban rail transit projects in the United States. Estimated costs were those that were prepared at the alternatives analysis phase to help the decision-makers choose the most preferred alternative. Pickrell's report attempted to determine the reasons for the differences between actual and estimated costs. The report noted that 9 out of 10 projects studied suffered from cost overruns ranging from 13 percent to 106 percent. The author discussed cost underestimates coupled with ridership overestimates in the projects studied. Also, the author noted that a major contributor to the cost escalation appeared to be delay in project start time or

construction schedule. Further, in most cases, the project contingencies were insufficient and unrealistically optimistic.

Reilly, J. J., McBride, M., Sangrey, D., MacDonald, D., and Brown, J. 2004. "The Development of CEVP – WSDOT's Cost-risk Estimating Process." *Civil Engineering Practice*, Vol. 19, No. 1, Spring/Summer.

The paper discusses a proposed methodology used by the Washington Department of Transportation to identify and quantify project risks and uncertainties using probabilistic methods.

Richmond, J. 2001. "A Whole-System Approach to Evaluating Urban Transit Investments." *Transport Reviews*. UK: 21(2), 141-179.

Saaty, T. L. 1980. "The Analytic Hierarchy Process." McGraw-Hill, Inc., USA.

Saaty, T. L., and L. G. Vargas. 2001. "Models, Methods, Concepts and Applications of the Analytic Hierarchy Process." Kluwer's International Series. Boston: Kluwer Academic Publishers.

Schexnayder, C. J., S. L. Weber, and C. Fiori. 2003. "Project Cost Estimating: A Synthesis of Highway Practice." Part of NCHRP Project 20-7, Task 152. Washington DC: Transportation Research Record.

This report presents the current practices in project cost estimating in the Departments of Transportation (DOTs) of various states in the U.S. The authors conducted a survey of all 50 DOTs and presented examples from some of them. The survey results give a breakdown of the agencies using certain practices. The authors describe in detail the number of agencies using the detailed estimating method versus the ones using the historic bid average method. They also discussed the challenges of estimating mega projects. They suggested that estimates should be in a format that can be understood, checked, verified, and corrected.

Schneck, D. C. 1997. "Project Management Control Resource Paper." *Lessons Learned: Turnkey Applications in the Transit Industry*. FTA-MA-90-8005-97-1. II-1-II-63. Washington, DC: U.S. Department of Transportation.

Schneck, D. C., R. M. Amodei, and R. S. Laver. 1994. "Improvements to the Estimation and Projection of Transit Fixed Guideway Capital Costs." Sacramento, CA: APTA Rapid Transit Conference.

Schneck, D. C., and R. S. Laver. 1995. "Transit Capital Cost Index." Washington, DC: Annual Meeting of the TRB.

Schneck, D. C., and R. S. Laver. 1997. "Estimation of Capital Funding Needs." Washington, DC: Annual Meeting of the TRB.

Schneck, D. C., and R. A. Stross. 1997. "Project Management Control Resource Paper." *Lessons Learned: Turnkey Applications in the Transit Industry*. *FTA-MA-90-8005-97-1*. II-1-II-63. Washington, DC: U.S. Department of Transportation.

The paper looks at project management controls that a transit owner employs to implement a successful project. Schedule management, cost control, payment mechanisms, and QA/QC are among topics that are covered. A comparative analysis is performed by looking at several projects that used a traditional or turnkey procurement approaches, and their differences are highlighted.

Schneck, D. C., et al. 2000. "A White Paper for the Turnkey Demonstration Program, Interim Report: Cost and Schedule Status of Transit Turnkey Projects." Washington, DC: Annual Meeting of the TRB.

Schumann, J. W. 1988. "RT Metro: From Sacramento's Community Dream to Operating Reality." *Proc. National Conference on Light Rail Transit*. 387-407. San Jose, CA: Transportation Research Board.

The author describes the planning and design approaches for the Sacramento RT Metro, an LRT project that at the time was the lowest capital cost per route mile of a new federally funded rail system. The paper shows how the design was based on the principle of using available right-of-way (ROW) and using vehicles and other systems that have been proven to work elsewhere. It presents the comparison between the estimated and actual capital costs and ridership. The cost comparison is presented by category (ROW, stations, parking, etc).

Skamris, M. K., and B. Flyvbjerg. 1996. "Accuracy of Traffic Forecasts and Cost Estimates on Large Transportation Projects." Transportation Planning Applications. *Transportation Research Record No. 1518*. 65-69. Transportation Research Board. Washington, DC: National Academy Press.

The authors compare cost and traffic data on seven bridge and tunnel projects in Denmark to show the inaccuracy of both types of forecasts. They provide a literature overview of other sources that had looked into transportation projects' forecast data. In general, they have concluded that highway projects have fared better compared to rail projects in terms of meeting forecasts.

T&T North America. 2003. "Silverline Boston." 9-11.

Thomas, H. R., et al. 1985. "Comparative Analysis of Time and Schedule Performance on Highway Construction Projects Involving Contract Claims." Washington, DC: Federal Highway Administration (FHWA).

Touran, A., P. Bolster, and S. Thayer. 1994. "Risk Assessment in Fixed Guideway Construction." *FTA-MA-26-0022*. Washington, DC: U.S. Department of Transportation.

> The authors lay out a framework for managing risk in the design and construction of fixed guideway transit projects. Risks are categorized into two: design and construction risks, and financial risks. The risk management process was presented as having three phases: risk identification, risk measurement, and risk allocation and mitigation. The authors described the process of risk modeling with analytical and probabilistic models and reviewed software available for risk management.

Wachs, M. 1990. "Ethics and Advocacy in Forecasting for Public Policy," *Business and Professional Ethics Journal,* Vol. 9, No. 1-2, pp. 141-157.

Wachs, M. 1989. "When Planners Lie With Numbers," *Journal of the American Planning Association,* Vol. 55, No.4, pp. 476-479.

Washington State Department of Transportation (WSDOT). 2003. "Cost Estimating Validation Process." Water Washington Resources Board; representatives from the University of Colorado. KJM Associates.
http://www.wsdot.wa.gov/projects/cevp/SDJC_Aug1203.htm

> WSDOT is committed to constant cost evaluation as a means to better manage projects and to respond to public skepticism and concern about project estimates and actual costs. WSDOT has been tackling this issue since February 2002, when they developed CEVP, a groundbreaking effort to identify and quantify potential risks that can impact a project's budget or schedule.

Washington State Department of Transportation (WSDOT). 2003. "Cost Estimate Validation Process Update." Water Washington Resources Board; representatives from the University of Colorado. KJM Associates.

> In 2003, WSDOT updated several project estimates to maintain project cost integrity. CEVP is helping to communicate to the public the risks identified and their potential cost impacts so that the public can understand the limits and

assumptions of an estimate and better understand what people will actually see as the project proceeds.

Willamson, L. A. 1994. "Boston's Commuter Comeback." *Civil Engineering*. New York: 64(1), pp. 66-69.

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Federal Transit Administration (FTA). undated. "Project Development Process for Major Transit Investments." Washington, DC: U.S. Department of Transportation.

Federal Transit Administration (FTA). 2003. "Risk Management Workshop." Washington, DC: U.S. Department of Transportation.

Federal Transit Administration (FTA). 2003. "Risk Assessment and Mitigation Procedures," *Guidance 22*, December, 17 pp.

Federal Transit Administration (FTA). 1999. "FY 2000 New Starts Criteria Financial Assessment Profiles." Washington, DC: Office of Planning, U.S. Department of Transportation.

Federal Transit Administration (FTA). 2003. "Annual Report on New Starts, Proposed Allocations of Funds for Fiscal Year 2004." FTA-TBP10-2003-02. Washington, DC: U.S. Department of Transportation.

Federal Transit Administration (FTA) and Government of Puerto Rico. 1995. "Tren Urbano Final Environmental Impact Statement." Washington, DC: U.S. Department of Transportation.

Federal Transit Administration (FTA) and Government of Puerto Rico. 1995. "Tren Urbano Environmental Assessment, Villa Nevarez Modified Alternative Alignment and Station." Washington, DC: U.S. Department of Transportation.

Federal Transit Administration (FTA) and Government of Puerto Rico. 1996. "Tren Urbano Environmental Assessment, University of Puerto Rico Station Technical Report." Washington, DC: U.S. Department of Transportation.

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United States General Accounting Office (GAO). 1992-2004. "Annual Report on New Starts." Washington, DC: New Starts Transit Projects.

United States General Accounting Office (GAO). 1999. "Report to Congressional Requesters, Mass Transit: Status of New Starts Transit Projects with Full Funding Grant Agreements." GAO/RCED-99-240. Washington, DC: New Starts Transit Projects.

Virginia Department of Rail and Public Transportation (DRPT). 2003. "The Capital Cost Estimate for the Dulles Corridor Project." …will be further refined as engineering and design is extended. http://www.dullestransit.com/pdf/reports/sdeis/08-sdeis-chp8.pdf

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Massachusetts Bay Transportation Authority (MBTA). Silverline. 2003. "Project Update." <http://www.allaboutsilverline.com/update.asp> (November 14, 2003)

Minnesota Department of Transportation. 2003. "Basic Facts: Hiawatha Light Rail Transit Line." <http://www.dot.state.mn.us/metro/lrt/info.html> (November 1, 2003)

NCHRP Project 8-49, "Procedures for **Cost Estimation** and Management **...**" http://www4.trb.org/trb/crp.nsf/All+Projects/NCHRP+8-49

NCTR Journal of **Public Transportation** Vol. 6 No. 2, 2003 http://www.nctr.usf.edu/jpt/jptv6n2.htm

NW Virtual Transit Center. 1998. "Westside MAX." <http://www.nwvirtualtransit.com/projects/portland/westside.html> (November 4, 2003)

Reilly, J. "New Cost Estimate Validation Process – CEVP." www.johnreillyassociates.com

> CEVP is a new, developing process to responsibly evaluate cost and risk for complex, urban, infrastructure projects. These processes are a direct outcome of a critical need to ensure that we carefully and responsibly manage cost and risk for complex, urban, infrastructure transportation projects.

Ristine, J. 2003. "New Jump in Price of Trolley Extension, 5.8-mile Project Grows by Additional $35 Million." The San Union Tribune.

<http://advancement.sdsu.edu/marcomm/news/clips/Archive/Apr2003/042503/042503trolley.html> (November 4, 2003)

Rosta, P. 2003. "Pasadena Goes for the Gold." <http://designbuild.construction.com/March2003/PasadenaMarch03.asp>

RTID **cost estimate** review
http://www.wsdot.wa.gov/publications/RTID_Cost_Review.pdf

Seattle/King Co. HistoryLink.org. 1993a. "Bus Service Begins in Downtown Seattle Transit Tunnel on September 15, 1990."
<http://www.historylink.org/_output.CFM?file_ID=2702> (November 4, 2003)

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Appendix B: Hypothesis Testing for Project Selection

The selection criteria for the case study projects are availability of data and willingness of project contacts to support the research, ability of a project to support or refute the hypotheses developed, geographic location of projects, modal characteristics, procurement type, and project setting. This makes project selection a multi-criteria decision-making problem.

The selection process is modeled as a combination of the Total Sum (TS) Multi-criteria Scoring Model (MSM) and the Analytic Hierarchy Process (AHP). Multi-criteria Analysis (MA) allows for quantitative decision-making. The AHP is a decision-making tool used to select among several alternatives based on several criteria and the importance of these criteria to the decision maker (Saaty 1980; Saaty and Vargas 2001).

As a first step, the model hierarchy is developed as shown in **Figure B-1**. It shows the overall goal of the process at the 0th level, which is to select the case study projects. At the 1st level, the projects are characterized into three groups (low, medium, or high) based on the availability of the data and access to project information. Although the project team have included the results of analyses for all 28 projects, projects with low data availability were automatically eliminated from the list of prospective alternatives. There are 15 projects with medium to high data availability. Medium to high data availability is defined as having 70 percent or more of the data needed to make a selection decision (please refer to **Table B-1** for a list of data requirements). Priority was given to projects with high data availability. At the 2nd level, modeled in **Figure B-2**, the goal was to select 8 to 10 projects out of the 28, giving priority to those that fit best in testing the hypotheses developed. Eight to ten projects are sufficient to provide insight into the tools and techniques used for successful project management, the information this research seeks given research resources. Out of the selected projects, it was hoped that six to eight should represent projects that experienced cost overruns, and the other two to four should represent projects with little or no cost overruns (successful projects). The goal was to have a basis for comparison between projects that experienced significant cost growth and those that apparently did not exhibit such problem, while keeping the emphasis on the projects with cost overruns.

In order to select projects that meet the criteria, a scoring system was developed to assign a quantitative value to the projects for each hypothesis, and rank the projects in terms of their suitability for testing the hypotheses. These projects were ranked using the TS MSM. In the proposed TS method, each project gets a score from zero (0) to the maximum of two (2), four (4), or six (6) depending on the relevance and maximum value possible for that factor as shown in **Table B-1**. Then the scores are added up to get a value for the project for each hypothesis. The TS method has been shown to produce results similar to those of more complex MA methods. Projects that score higher on a hypothesis are more qualified to test that hypothesis. For each hypothesis, the score for each project depends on certain factors that affect that hypothesis.

Factors Affecting The Hypotheses

For each hypothesis, two to seven factors that are relevant in supporting or refuting the hypothesis are listed. The factors are classified into three categories (high, medium, and low) in terms of their relevance and impact to the hypothesis. The high, medium, and low relevancy factors have a maximum score of six (6), four (4), and two (2) respectively. These numbers allow for a quantitative comparison between the projects based on quantitative and qualitative factors. Judgment is used in the scoring of each project.

Table B-1 shows a list of factors relevant to each hypothesis and their degree of relevance. It should be noted that some factors are relevant in more than one hypothesis. The important issue about the scoring is not the score for one project but the consistency of scoring for each factor across all projects.

Figures B-3 through **B-8** show the factors affecting the various hypotheses. Among the projects scored, 21 are or were executed under DBB, six under DB, and two under the DBOM delivery methods. For the DB and DBOM projects, the contractors usually finish the final design after the start of construction, while the final design is done before the projects are bid for the DBB projects. Because of this difference, we use the bid value or estimates at the PE/FFGA for the DB and DBOM projects, and the FD estimate or bid values for the DBB projects when calculating the cost differences for the factors. In the planning phase for all projects, the AA and DEIS estimates are considered the same and the PE, FEIS, and FFGA estimates are considered the same. This is because the time of these estimates is close. In the following sections, each factor and examples of projects where the factor played a role in cost growth are described.

One issue to remember is that although some factors appear in more than one hypothesis, their context is not always the same. For example, political issues affecting hypothesis 1 are issues that arise during the planning of a project, which may influence the planners to underestimate costs so that funding for the project can be secured. However, political issues affecting hypothesis 3a relate to local politics exerting pressure on the project planners to add to or modify the project in a way that will add to the costs. For example, local political pressure may call for realignment so that a project passes through a certain area.

Table B-1. Hypothesis Factors and Their Weights

Hypotheses and Factors Affecting Them	Max Score
Hypothesis 1: Project costs are minimized at the planning phase to maximize the probability of approval.	**22**
A – Cost difference between the AA/DEIS and bidding/start of construction (or FD) estimates	6
B – Political issues	6
C – Contingencies	4
D – Scope definition	4
E – Basis of estimation	2
Hypothesis 2: Project costs are increased at the preliminary engineering stage to account for: **a. Many project elements that are excluded at the earlier planning phase** **b. Unrealistically low unit-cost estimates**	**26**
A – Cost difference between AA/DEIS and FEIS/PE/FFGA	6
B – Contingencies	6
C – Basis of estimation	6
D – Scope definition	4
E – Political issues	4
Hypothesis 3A: Project costs are increased at the final design and construction stages due to the incremental project modifications to improve and enhance the project definition (scope creep).	**22**
A – Cost difference between bid (or FD) and actual costs	6
B – Community demands and political issues	6
C – Scope changes	6
D – Contingencies	4
Hypothesis 3B: Project costs are increased at the final design and construction stages due to the addition of elements that are often excluded from the prior cost estimates due to causes ranging from simple omission to the underestimation of some project components.	**12**
A – Cost difference between PE and actual costs (or bid values)	6
B – Basis of estimation	6
Hypothesis 4: Project costs are increased at the start of construction to account for the inflationary effects of project schedule delays during all of the project development phases leading up to construction.	**24**
A – Length of time between various phases of project development	6
B – Cost difference between AA/DEIS and final design/bid	6
C – Construction market condition	6
D – Inflation	6
Hypothesis 5: Projects with high degree of complexities experience cost escalation.	**36**
A – Contingencies	6
B – Extent of tunnel work	6
C – Underground stations/complexity of stations	6
D – Utilities relocation	6
E – Unforeseen soil conditions/hazardous materials	6
F – Contractors claims or change orders	4
G – Elevated structures/guideway	2

Hypothesis 1 - Project costs are minimized at the planning phase to maximize the probability of approval.

The factors that are relevant to this hypothesis play a role during the planning phase, prior to approval by the FTA and/or any other funding source. These factors, described below, are used to make the project look more attractive and, therefore, to have a better chance of approval.

A - Cost difference between the AA/DEIS and bidding/start of construction (or FD) estimates **(high relevance to the hypothesis)**

If the cost estimate at AA or DEIS is significantly lower than the bid value or the estimate at the end of the FD phase, then it is likely that the project cost estimate was lowered at the AA or DEIS phase to make the project look more attractive. For example, the Boston Old Colony Commuter Rail Project had an increase of 23 percent from DEIS to FD. This large difference does not in itself mean that the cost estimates were lowered intentionally, but it does signal the possibility. The scoring guide for this and all subsequent cost differences is as follows:

- Cost increase of less than 3 percent (including decreases) – score 0
- Cost increases of 3 to 10 percent – score 2
- Cost increases of 10 to 20 percent – score 4
- Cost increases of more than 20 percent – score 6.

B - Political issues **(high relevance to the hypothesis)**

Politics play a critical role for many projects especially in the planning phase and can influence how a project is valued. When politicians are pushing for a project in their localities, they will promote it and support its approval. Politicians have the ability to gather support for a project both within the community and in the owner agency. They can affect the project budget, through the local share of the project, by increasing or reducing the transit agency's budget. For example, politicians were highly involved in the planning and execution of the Boston Old Colony Commuter Rail Project, which experienced high public demands and a lengthy approval process. This is a very sensitive issue (factor) and is hard to prove or disprove; it requires information from inside the agency that project sponsors are not willing to share. However, some projects appear to have more politics involved than others.

***C - Contingency* (medium relevance to the hypothesis)**

Contingency is a reserve amount added to the estimated or budgeted project cost for anticipated or possible cost growth due to minor project uncertainties for which costs cannot be determined but are likely to occur (Schexnayder, Weber, and Fiori 2003). It is estimated as a percentage of total project cost or as a percentage or dollar value for all or some of the project components. An Urban Mass Transportation Authority (UMTA) study of 10 transit projects showed that contingencies provided are often inadequate (Pickrell 1990). The level of contingency needed depends on a project's complexity and the uncertainty of the assumptions used in the estimation. When the project scope is clearly defined and major changes are not expected, then the estimator is confident with the assumptions of the estimate and a small contingency may be used. However, when a project is not well defined or not finalized, or some of the assumptions used in the estimation have a high degree of uncertainty, then a higher contingency should be used. Contingency is estimated for each project component because different components have different levels of uncertainty. For example, tunnel work would be more complex and harder to estimate than the cost of fare collection equipment. The amount of contingency varies from phase to phase; it should reduce as the project progresses through the planning and design phases and is more clearly defined.

The contingency factor looks at whether sufficient contingencies were included in the estimates. Contingency is a cost item that should be justified based on the perceived risks and complexity of the project as described above. However, project sponsors can choose to use a low contingency to keep total costs low and increase the chance of approval—not fully acknowledging the project's uncertainty and complexity. An example of a project where sufficient contingency was provided is the Portland Interstate MAX LRT extension where 10 percent unallocated contingency and about 6 percent allocated contingency were budgeted. On the other hand, the contingency in the Boston Old Colony Commuter Rail and the Boston Silver Line Busway were insufficient.

***D - Scope definition* (medium relevance to the hypothesis)**

Scope definition refers to how well the project was defined during early estimates compared to the project built, and whether the planned project solved the (transportation) problem for which it was created. Projects that are well defined will have little or no changes while poorly defined projects will experience major changes or additions that will add to the project cost. In some cases, elements are omitted in the planning stages only to be added later to the project. For example, the San Juan Tren Urbano Project experienced cost growth due to the addition of two stations and a major realignment to a section of the route.

E - Basis of estimation **(low relevance to the hypothesis)**

The basis of estimation refers to the type of technique used for estimating, the assumptions made, and the elements that are included or excluded from the estimate. A full estimate will contain the costs of all elements associated with the project. Estimates can be conceptual or detailed and based on historical costs or unit prices. In the planning phase, the detailed design is not available and project sponsors use a variety of methods; including, but not limited to, historical costs from past projects within the agency or elsewhere, and unit costs from sources such as the RS Means. No matter what method is used, an estimate must be adjusted to fit the project's time, location, and other factors such as the economy and complexity of the project. Other parameters that affect the accuracy of estimates include experience with similar projects and the effort put into the estimation process. The Baltimore, Maryland MTA Central Light Rail Phase II Project was estimated using the actual cost of Phase I, which was recently completed at the time. This was a reasonable basis for the estimate because the Phase I and Phase II projects were similar in location, complexity, and time (Chaney et al. 1996). On the other hand, for the San Diego Mission Valley East Project, the agency had little experience in the type of project and, thus, underestimated some costs, such as the CM costs (Federal Transit Administration 2003).

Hypothesis 2 - Project costs are increased at the preliminary engineering (PE) stage to account for many project elements that were excluded at the earlier planning phase, and unrealistically low unit-cost estimates.

The FTA approves projects into PE after evaluation of the Locally Preferred Alternative (LPA). The PE stage is about 30 to 40 percent of the total design. For DBB projects, final design commences at the end of PE while for most DB projects the DB contract is awarded at the end of PE. In many projects the PE corresponds to the FEIS phase. This hypothesis seeks to uncover the reasons for cost growth at the PE stage. The following factors are relevant to this hypothesis.

A - Cost difference between AA/DEIS and FEIS/PE/FFGA **(high relevance to the hypothesis)**

This factor has a high relevance to the hypothesis because it raises the flag that the cost estimates have increased. The first indication that project elements were excluded at earlier estimates or low unit-cost estimates were used is an increase in the estimate at the PE stage. For example, the cost growth between DEIS and FFGA was 19 percent for the San Diego Mission Valley East Project.

***B – Contingencies* (high relevance to the hypothesis)**

See Factor C in Hypothesis 1 for explanation.

***C – Basis of estimation* (high relevance to the hypothesis)**

This factor is especially critical when the unit-costs method of estimating was used and the unit costs needed to be revised. Lack of experience or optimistic bias can cause a low unit-cost estimate. See Factor E in Hypothesis 1 for more on this factor.

***D - Scope definition* (medium relevance to the hypothesis)**

See Factor D in Hypothesis 1.

***E - Political issues* (medium relevance to the hypothesis)**

Projects are approved for final design and construction after the PE phase, so political pressure to lower cost estimates during AA will remain through PE up to the approval. See Factor B in Hypothesis 1 for more on this factor.

Hypothesis 3A - Project costs are increased at the final design and construction stages due to the incremental project modifications to improve and enhance the project scope (scope creep).

This hypothesis seeks to explain cost growth at the FD and construction stages due to pressure from various parties, such as local authorities, communities, etc., to enhance and embellish the project. The following factors are relevant to this hypothesis.

***A - Cost difference between bid (or FD) and actual costs* (high relevance to the hypothesis)**

This factor is the basic indication that costs were increased at the FD and/or construction stages. For example, the Minnesota Department of Transportation reported that the Hiawatha LRT Project experienced a cost growth of $40 million during construction due to realignment of the line at the Mall of America. The cost difference does not in itself mean that there was scope creep in a project; it could be due to other factors such as project complexities (Hypothesis 5), etc.

***B - Community Demands and Political Issues* (high relevance to the hypothesis)**

Community and municipality's demands can gradually add to project scope and cost. For example, the Hiawatha LRT project experienced a $3.8 million cost increase due to community betterments, and the San Francisco Airport extension was redesigned because of community concerns about the environmental impact of the project.

Political issues relating to this hypothesis include the politician's demands in executing the project such as realignment or other changes that add to the cost of the project. For example, political considerations prompted the realignment of the Hudson-Bergen MOS II Project. In many cases, the politician's demands and the community's demands are the same, since the politician is trying to do something good for the community. In any case, the two factors are grouped as one for this hypothesis because they are highly correlated and have the same effect—to call for a change or modification—which results in additional costs.

***C - Scope changes* (high relevance to the hypothesis)**

Scope changes add to the scope of the project. Transit projects often experience scope changes such as realignment and addition or reduction of stations and/or vehicles. For example, the San Juan Tren Urbano Project experienced cost growth because of the addition of two stations, and the Boston Old Colony Commuter Rail Project experienced cost growth because of the addition of a station and noise walls and changes to the systems. On the other hand, the Baltimore, Maryland MTA Central Light Rail Phase II Project experienced only minor changes.

***D - Contingencies* (medium relevance to the hypothesis)**

The relevance is medium here because contingency is expected to play a smaller role as the project advances in the final design and construction phases. See Factor C in Hypothesis 1.

Hypothesis 3B - Project costs are increased at the final design and construction stages due to the addition of elements that are often excluded from the prior cost estimates due to causes ranging from simple omission to the underestimation of some project components.

This hypothesis seeks to explain cost growth at the FD and construction stages where the earlier estimates did not cover the entire project scope. The following factors are relevant to this hypothesis.

***A - Cost difference between PE/FFGA and actual costs (or FD and bid values)* (high relevance to the hypothesis)**

As in Factor A in Hypothesis 3A, this factor indicates that costs have increased at the FD and/or construction stages. This could be due to underestimation during an earlier phase (e.g., PE) because of lack of sufficient detail on some components (e.g., finishes) when the estimate was made. For example, the actual cost of the Sacramento RT Metro Stage I is 38 percent higher than the FEIS/PE estimate.

B - Basis of estimation **(high relevance to the hypothesis)**

In some projects, the federal or state agency will ask the project sponsors not to consider some costs in the estimates during the planning process. The omission of those cost elements will make the total project cost appear low compared to the estimate at later stages when all costs are considered even if the included project components were reasonably estimated. For example, the ROW acquisition costs for the Boston Central Artery Project were not included in the initial estimates.

See Factor E in Hypothesis 1 for more on basis of estimation.

Hypothesis 4 - Project costs are increased at the start of construction to account for the inflationary effects of project schedule delays during all of the project development phases leading up to construction.

The following factors are relevant to this hypothesis.

A - Length of time between various phases of project development **(high relevance to the hypothesis)**

It is more likely that the AA estimates become irrelevant or low and would have to be modified if the PE stage and other subsequent stages experience significant delays after the AA. The assumptions used in the AA estimates such as unit-costs and bid values are valid for a period of time. Lengthy PE periods could be due to many factors such as the complexity of project, political issues, or delayed approval of the project. For most of the projects reviewed, this time is between 8 to 24 months. In the San Francisco BART airport extension project, the FEIS/PE was completed four years after the DEIS was completed. In the case of the Pasadena Gold Line, the project was suspended and restarted again during construction because of funding problems. These delays before or during construction significantly add to the project costs. Cost estimates are based on an assumed schedule for a project. Some costs elements, such as inflation, are highly dependent on this base schedule. Deviations from the schedule have been shown to cause cost overruns (Pickrell 1990).

B - Cost difference between AA/DEIS and Final Design/Bid **(high relevance to the hypothesis)**

See Factor A in Hypothesis 1.

***C - Construction market condition* (high relevance to the hypothesis)**

This factor refers to the economic condition of the construction industry during bidding (competition in bidding the project) and the inflation rates at the planning phases. A high degree of competition will likely produce lower bids as contractors lower their markup to increase the chance of winning the project. However, when there are many projects going on and contractors have their hands full, or when the number of bidders is small, the bids could end up high because the competition is small. For example, the San Francisco Airport extension received bids that were higher than the engineer's estimate partly because of the booming economy in the area. Another example is the San Juan Tren Urbano where lack of qualified labor force in the area was a factor in cost growth (United States General Accounting Office 1999).

***D - Inflation rates* (high relevance to the hypothesis)**

Inflation is considered in cost estimates where costs are usually expressed in year of expenditure (YOE) dollars, i.e., the costs are expressed in terms of what they will be when they are incurred. For example, projects typically expend construction costs and vehicle costs after design costs. The YOE depends on the project schedule and when the project is expected to be completed. Consideration of inflation rates in cost estimates is recognition of the time value of money. When inflation rates are underestimated or not considered, the project costs experience growth as the project is bid out. Inflation rates are published regularly by various sources. More specific to construction, there are cost indexes that track costs of various construction items on a monthly or yearly basis. These indexes are used to compare costs in different years and can be used to forecast costs of future projects. Current inflation rates are much lower than inflation in the 1970s and the 1980s (EconEdLink 2003.)

Hypothesis 5 - Projects with a high degree of complexities experience cost escalation.

This hypothesis looks at the correlation, if any, between project complexity and cost growth. Complex projects have higher uncertainties and require higher contingencies. Owners are usually reluctant to add sufficient contingency to the project budget for various reasons. The following factors are relevant to this hypothesis.

***A - Contingencies* (high relevance to the hypothesis)**

See Factor C in Hypothesis 1.

B - Extent of tunnel work **(high relevance to the hypothesis)**

The extent of tunnel work adds a significant uncertainty to transit projects, especially when the tunnel runs under a developed or urban area such as the case in the Boston Silver Line Busway and the San Juan Tren Urbano.

C - Underground stations/complexity of stations **(high relevance to the hypothesis)**

The uncertainty of estimates is increased for projects with underground stations. Underground stations have been a source of cost growth in many transit projects.

D - Utilities relocation **(high relevance to the hypothesis)**

This factor is most relevant in downtown areas and areas with heavy utility lines that have to be relocated. For example, some areas, such as Boston, have old utility lines that need to be relocated but their exact locations are not known beforehand because of lack of as-built drawings. In some projects, different contractors, often through third-party agreements, perform the utility relocation for private and public utilities. For example, for the Hiawatha project, a private utility company relocated its utilities and later put a claim on the project for the cost of the relocation (Loetterle 2003). In several of the Santa Clara County transit projects, utility relocation costs proved higher than expected. Utilities remain one of the hardest items to estimate in urban infrastructure projects (Touran, Bolster, and Thayer 1994).

E - Unforeseen soil conditions/hazardous materials **(high relevance to the hypothesis)**

Unforeseen soil conditions and the presence of hazardous materials can add to the project cost and cause delay. For projects that serve downtown areas and other brownfields, there is more likelihood of encountering hazardous materials and contaminated sites. For example, during tunnel excavation for the Seattle busway tunnel project, the contractor came across wet soil, which stopped the project until the site was dewatered.

F - Contractors claims or Change orders **(medium relevance to the hypothesis)**

Complex projects will likely have a high number of claims and changes. For example, the San Juan Tren Urbano had several change orders that significantly added to the project costs. Although not every claim results in a change order, a high correlation exists between claims and change orders. Because of this, we have combined both under one factor.

G - Elevated structures/guideway **(low relevance to the hypothesis)**

Elevated structures or guideway add to the complexity of projects somewhat similar to tunnels and underground stations. These structures require piling and other underground construction that adds to the uncertainty of the project estimates. Despite this complexity, elevated structures tend to pose fewer problems compared to underground structures because the uncertainty is less prevalent in these cases. The San Diego Mission Valley East LRT and many others have elevated structures.

Results of the Selection Process

Score sheets were developed for each of the 28 transit projects in the initial listing, and **Table B-2** shows the result of the project ranking model. **Table B-3** presents the composite values for each project. **Figure B-9** shows an example score sheet.

The projects were scored based on the preliminary data and information available about the project from the project facts sheets. Data gathering proved to be a challenge, and the research team was able to gather little information about some projects compared to others. As a result, a straight comparison is not fair. In order to filter out the projects with little information (from among the rated projects), the percentage of factors scored is calculated for each project. This is called the "Score Completion %" and is included in **Table B-3**. Projects with a score completion percentage of 70 percent and over were considered *high* in data availability, and projects with a score completion of less than 50 percent were considered *low*. The projects with a score completion of less than 70 percent were disqualified from the selection process. This ensured that the projects selected were based on sufficient information, and gathering more data would be feasible. However, this report presents the data for all 28 projects in case some of the projects prove to be important for further data collection.

Ranking in **Table B-3** is based on equal weights per hypothesis. The column headed "Average Rank" is simply an average of the ranks of the six hypotheses for each project. These average rankings are then scored from 1 to 28 under the "Composite Rank" column. The ranking marks the end of the 2nd level of **Figure B-1**. In a typical AHP model, a pair-wise comparison of the criteria is used to choose among alternatives. For example, in the modal characteristics criteria, the alternatives (busway, light rail, and heavy and commuter rail) will be compared to each other and a matrix of the pair-wise comparisons will be developed. The reader is advised to see Saaty (1980) and Saaty and Vargas (2001) for more information about the AHP.

The typical AHP approach is not applicable in our case because we needed to select a project from each subcategory without giving priority to any (see the 3rd level of **Figure B-1**). For example, we needed to include projects from the eastern, central, and western parts of the country; projects that were executed under the DBB, DB, and DBOM procurement methods; and projects for busway, light rail, and heavy rail.

The 3rd level of **Figure B-1** illustrates the selection process for the suggested case study projects. The top eight projects were selected to represent the projects that will allow for the testing of the hypothesis, and the last two projects were selected to represent the projects with little or no overrun to study successful projects and compare with the top eight. The diversity of the selected projects was examined using the rest of the selection criteria illustrated in the 3rd level of **Figure B-1**. **Table B-4** shows the characteristics of the projects chosen. It shows that the projects selected have satisfied the given criteria; there is at least one project in each subcategory. Note that projects with less than 70 percent (see **Table B-3**) of the scoring sheet completed are considered to have insufficient information and are disqualified from the selection process.

In the case that the projects selected did not satisfy one of the criteria, the last of the top six projects chosen would be taken out and replaced with the next ranked project that would satisfy the missing criteria without invalidating another criteria requirement. If that would not work then the 5th project would be replaced instead of the 6th. This process can be done to replace projects among the top six until all the criteria are satisfied.

Table B-2. Ranking of Projects for Each Hypothesis

S/N	Description	Year Completed	Rank by Hypothesis					
			1	2	3A	3B	4	5
	Weight of Rank -->		16.67% each					
1	San Juan Tren Urbano	2004	7	1	5	4	1	4
2	San Francisco BART Airport Extension	2003	1	9	3	11	1	2
3	Boston – Old Colony Commuter Rail	1997	2	4	5	1	4	12
4	Hiawatha Corridor	2004	2	6	3	15	3	6
5	Seattle – Busway Tunnel	1990	11	10	12	4	6	3
6	San Diego Mission Valley East	2005	10	7	7	4	15	7
7	Hudson-Bergen MOS-I	2001	2	2	10	11	9	16
8	Portland Westside/Hillsboro MAX	1998	8	8	2	20	7	9
9	Boston – Silver Line Busway	2004	23	23	11	8	9	4
10	Sacramento RT Metro (Stage I)	1987	13	13	7	8	24	21
11	Pasadena Gold Line	2003	12	13	19	20	7	9
12	Baltimore MTA Central Light Rail Phase II	1997	13	13	16	15	18	16
13	Los Angeles Long Beach Blue Line	1990	19	20	12	8	27	15
14	Chicago – Southwest Corridor Extension	2006	16	18	23	20	18	26
15	Sacramento South Corridor Phase I	2003	19	21	19	15	27	27
16	Portland Interstate MAX LRT Extension	2004	23	23	23	20	24	23
17	Salt Lake North South Corridor	1999	19	23	23	20	24	27
18	Chicago Douglas Branch Reconstruction	2005	23	23	23	20	27	23
19	Atlanta North Line Extension	2000	22	11	12	20	15	20
20	Denver Southwest	2000	9	13	12	1	15	27
21	Los Angeles – Red Line MOS 1, 2, and 3	1998	5	3	1	1	4	1
22	Baltimore John Hopkins Extension	1995	16	12	16	15	9	7
23	Dallas South Oak Cliff	1996	6	5	22	11	13	22
24	Portland Banfield	1985	16	18	19	14	9	23
25	Santa Clara – Capitol	2004	23	23	16	20	21	16
26	Santa Clara – East Tasman	2004	23	23	23	20	21	14
27	Santa Clara – Vasona	2005	23	21	7	7	13	11
28	Santa Clara – West Tasman	2000	23	23	23	20	21	12
29	St Louis – St. Clair County	2001	13	13	23	15	18	16

Table B-3. Composite Score of Projects for All Six Hypotheses

S/N	Description	Year Completed	Average Rank	Composite Rank	Score Completion %
	Weight of Rank -->			**0.00%**	**100%**
1	San Juan Tren Urbano	2004	3.67	2	85%
2	San Francisco BART Airport Extension	2003	4.50	3	89%
3	Boston – Old Colony Commuter Rail	1997	4.67	4	93%
4	Hiawatha Corridor	2004	5.83	5	89%
5	Seattle – Busway Tunnel	1990	7.67	6	96%
6	San Diego Mission Valley East	2005	8.33	7	67%
7	Hudson-Bergen MOS-I	2001	8.33	7	81%
8	Portland Westside/Hillsboro MAX	1998	9.00	9	74%
9	Boston – Silver Line Busway	2004	13.00	12	59%
10	Sacramento RT Metro (Stage I)	1987	14.33	16	85%
11	Pasadena Gold Line	2003	13.33	14	44%
12	Baltimore MTA Central Light Rail Phase II	1997	15.17	17	100%
13	Los Angeles Long Beach Blue Line	1990	16.83	21	26%
14	Chicago – Southwest Corridor Extension	2006	20.17	23	33%
15	Sacramento South Corridor Phase I	2003	21.33	26	89%
16	Portland Interstate MAX LRT Extension	2004	22.67	27	41%
17	Salt Lake North South Corridor	1999	22.67	27	89%
18	Chicago Douglas Branch Reconstruction	2005	23.17	29	33%
19	Atlanta North Line Extension	2000	16.67	20	48%
20	Denver Southwest	2000	12.83	11	70%
21	Los Angeles – Red Line MOS 1, 2, and 3	1998	2.50	1	93%
22	Baltimore John Hopkins Extension	1995	12.50	10	67%
23	Dallas South Oak Cliff	1996	13.17	13	74%
24	Portland Banfield	1985	16.50	19	52%
25	Santa Clara – Capitol	2004	19.83	22	52%
26	Santa Clara – East Tasman	2004	20.67	25	52%
27	Santa Clara – Vasona	2005	13.67	15	59%
28	Santa Clara – West Tasman	2000	20.33	24	56%
29	St Louis – St Clair County	2001	16.33	18	81%

Table B-4. Characteristics of Projects Selected for Case Studies

Rank	Description	Geographic Location				Project Type/Mode			Procurement Approach			Project Setting	
		East	Central	West	Other	Bus way	Light Rail	Heavy rail	D-B-B	D-B	DBOM	New Start	Rehabilitation
1	Los Angeles – Red Line			√				√	√			√	
2	San Juan Tren Urbano				√			√			√	√	
3	San Francisco Bart Airport Extension			√				√		√		√	
4	Boston Old Colony Commuter Rail	√						√	√				√
5	Hiawatha Corridor		√				√			√		√	
6	Seattle Busway Tunnel			√		√			√			√	
7	Hudson-Bergen MOS-I	√					√				√	√	
9	Portland Westside/Hillsboro MAX			√			√		√			√	
23	Sacramento South Corridor Phase I			√			√		√			√	
24	Salt Lake North South Corridor			√			√			√		√	
	Total for 10 projects	**2**	**1**	**6**	**1**	**1**	**5**	**4**	**5**	**3**	**2**	**9**	**1**

Figure B-1. The Hierarchy in Selecting Projects for Case Studies

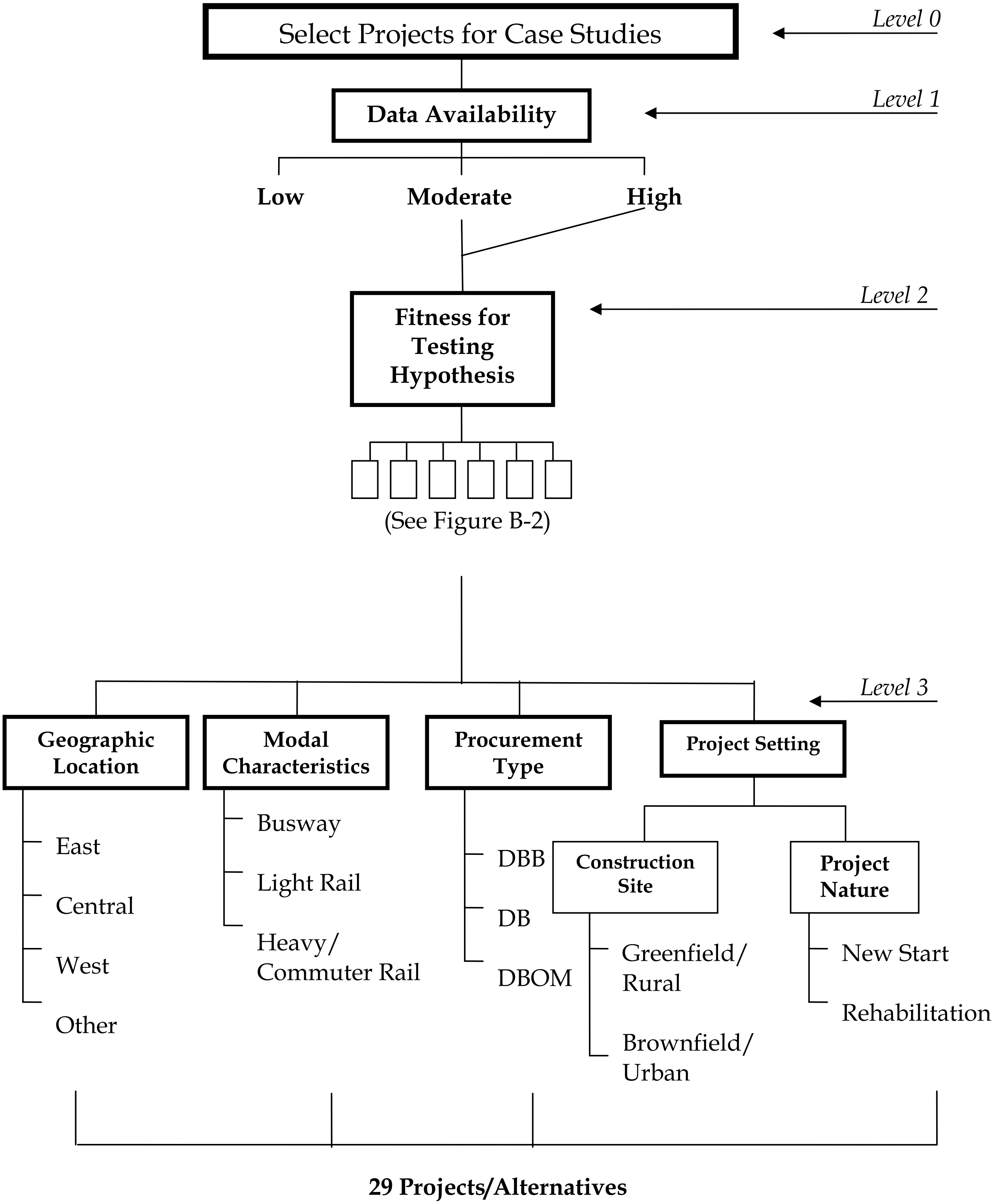

Figure B-2. Hierarchy of Hypothesis Factors

(See Table B-1 for Hypotheses)

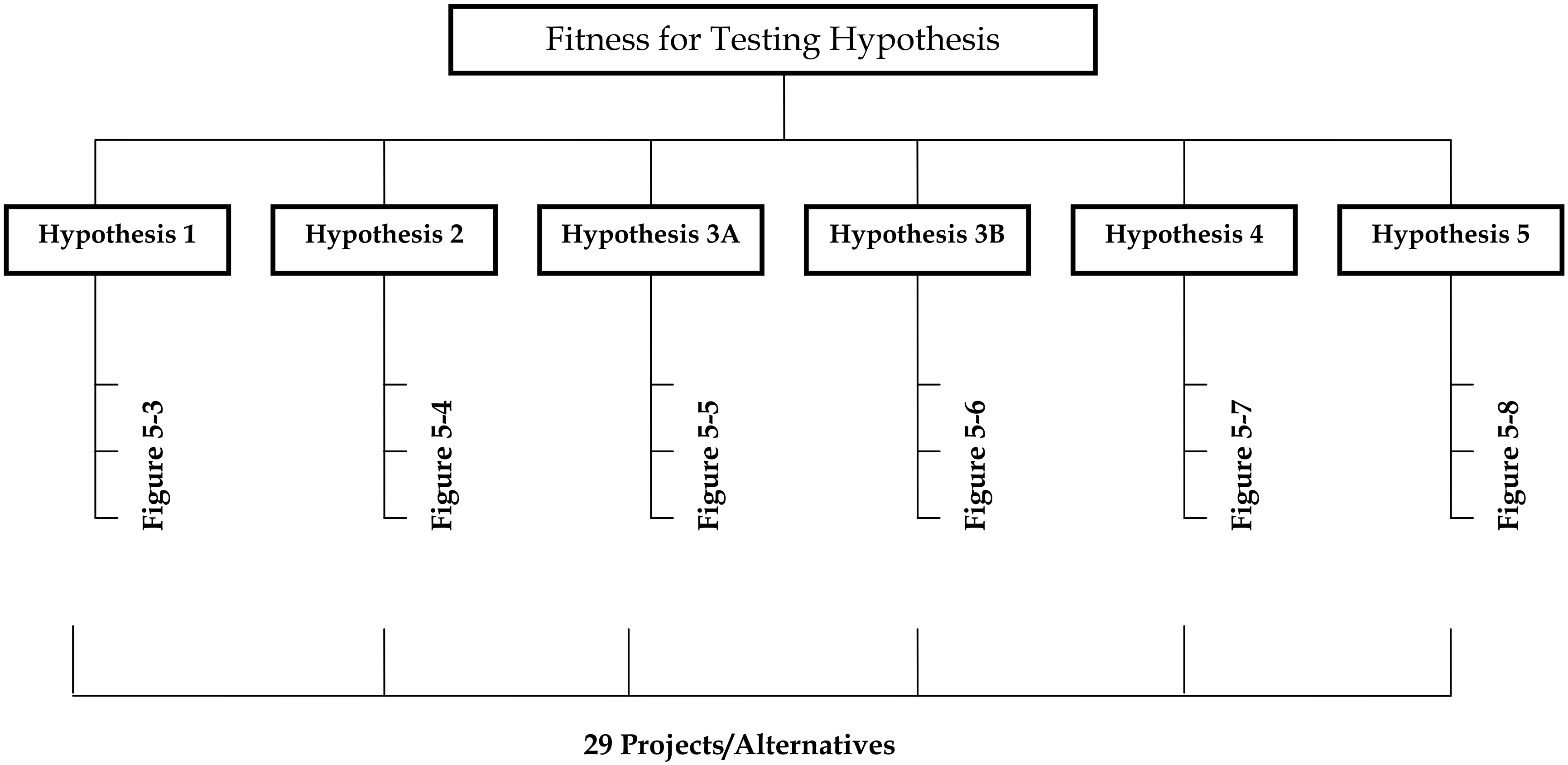

Figure B-3. Hypothesis 1 Scoring System

Hypothesis 1: Project costs are minimized at the planning phase to maximize the probability of approval

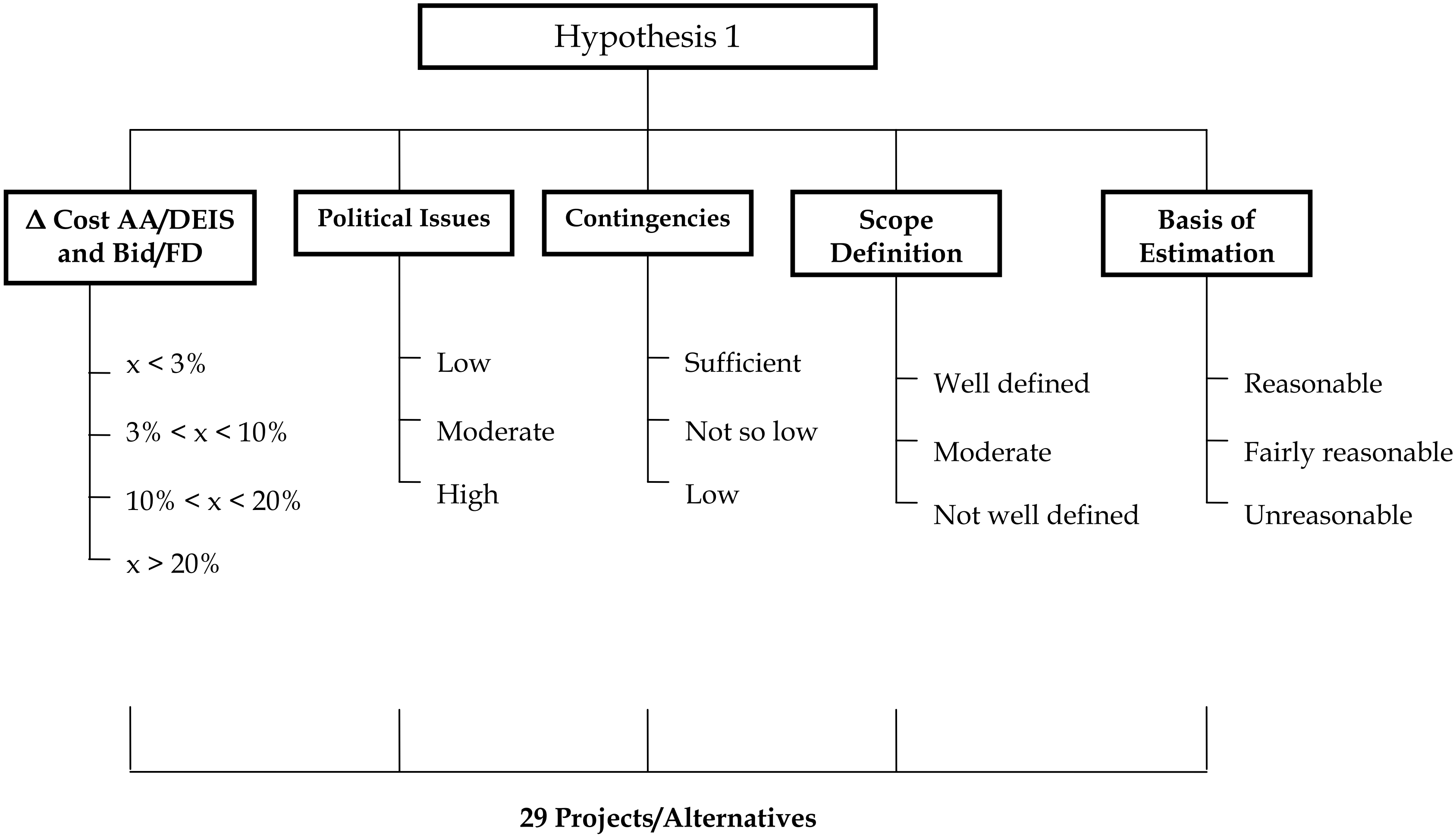

Figure B-4. Hypothesis 2 Scoring System

Hypothesis 2: Project costs are increased at the preliminary engineering stage to account for:
a. many project elements that are excluded at the earlier planning phase
b. unrealistically low unit-cost estimates

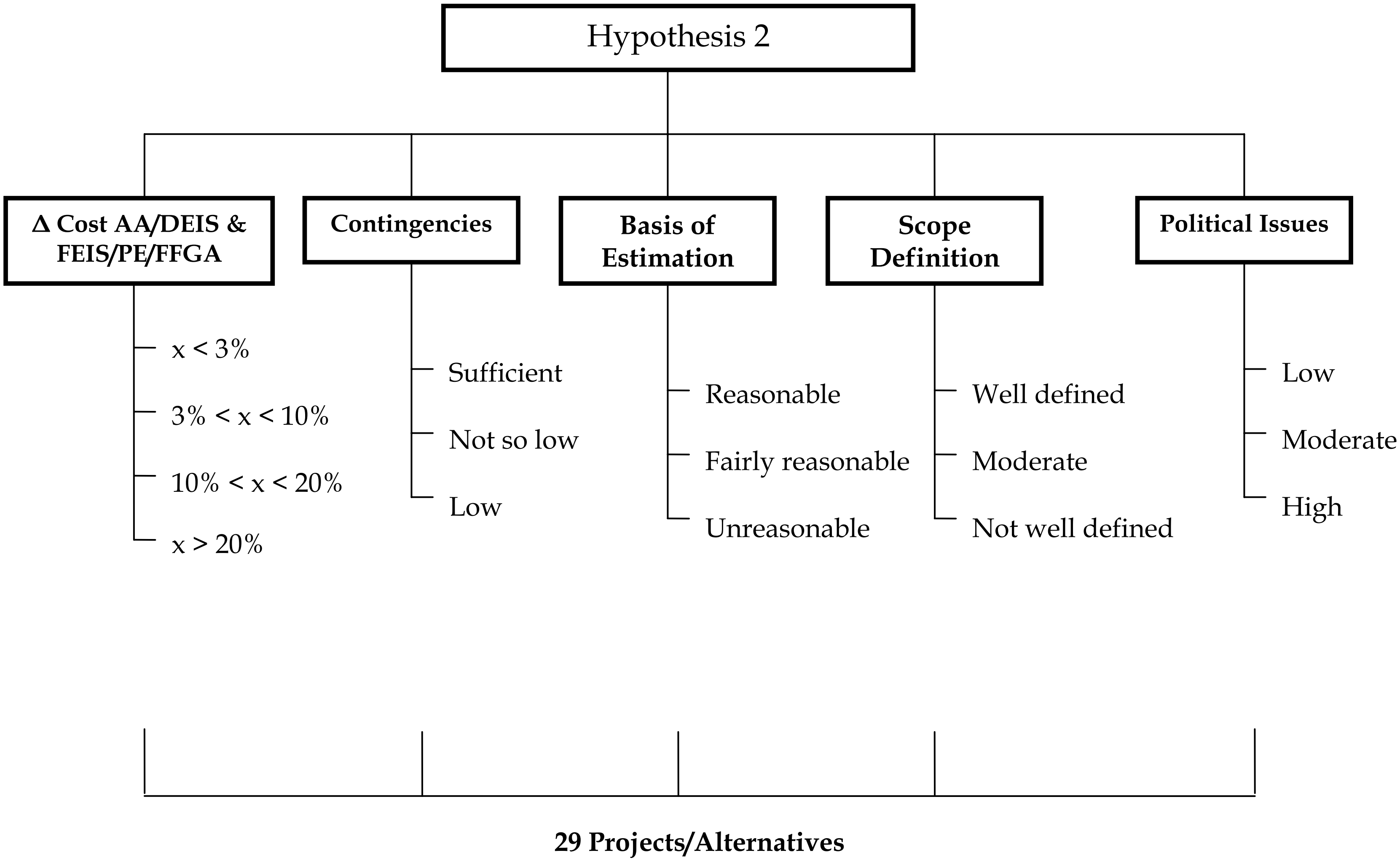

Figure B-5. Hypothesis 3A Scoring System

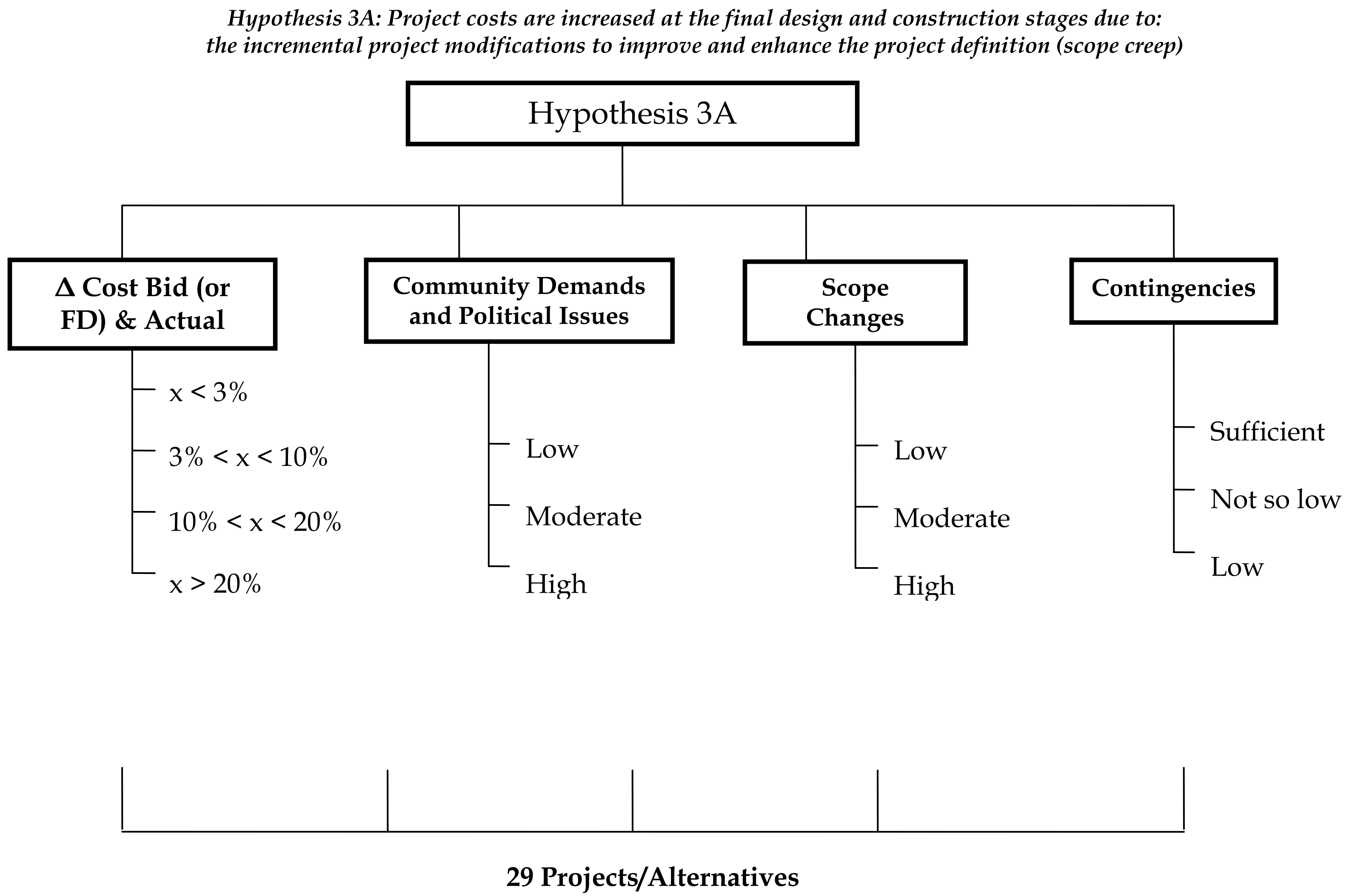

Figure B-6. Hypothesis 3B Scoring System

Hypothesis 3B: Project costs are increased at the final design and construction stages due to the addition of elements that are often excluded from the prior cost estimates due to causes ranging from simple omission to the underestimation of some project components

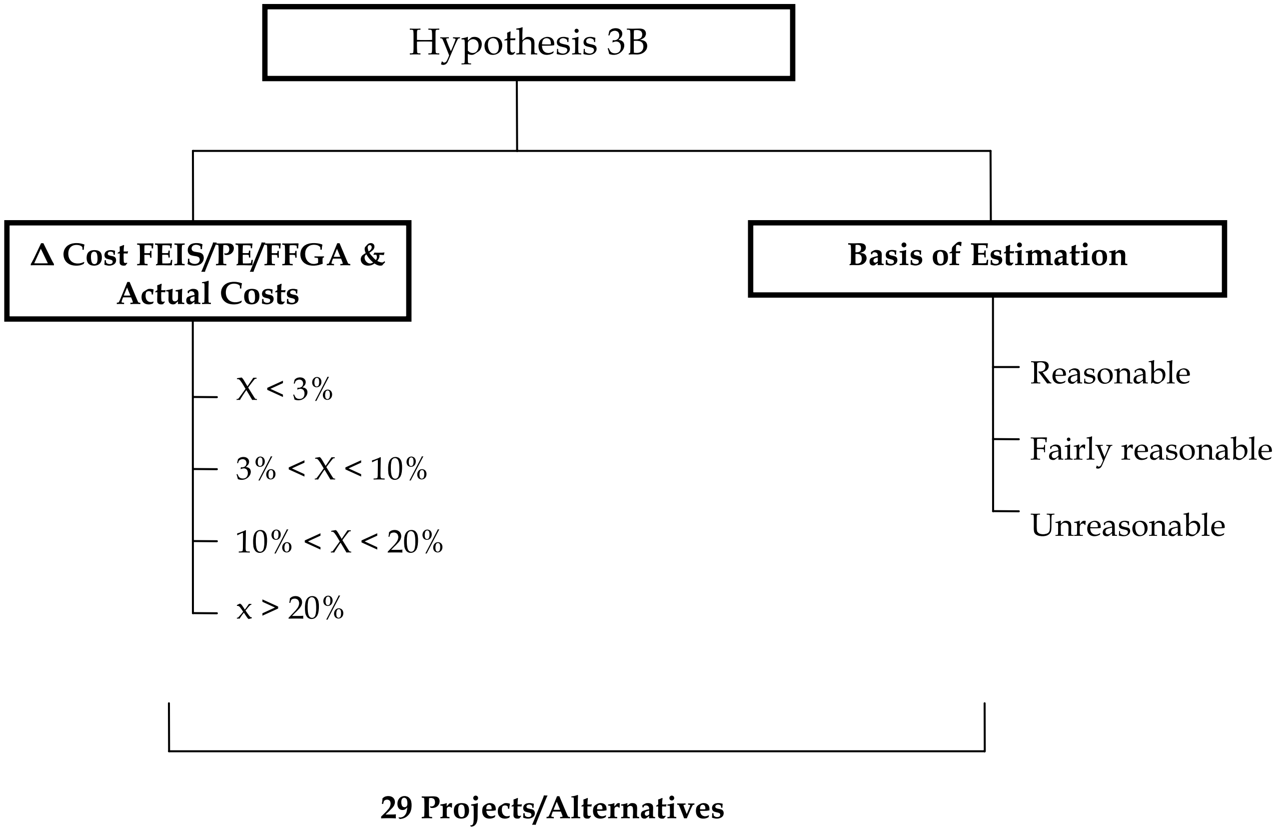

Figure B-7. Hypothesis 4 Scoring System

Hypothesis 4: Project costs are increased at the start of construction to account for the inflationary affects of project schedule delays during all of the project development phases leading up to construction.

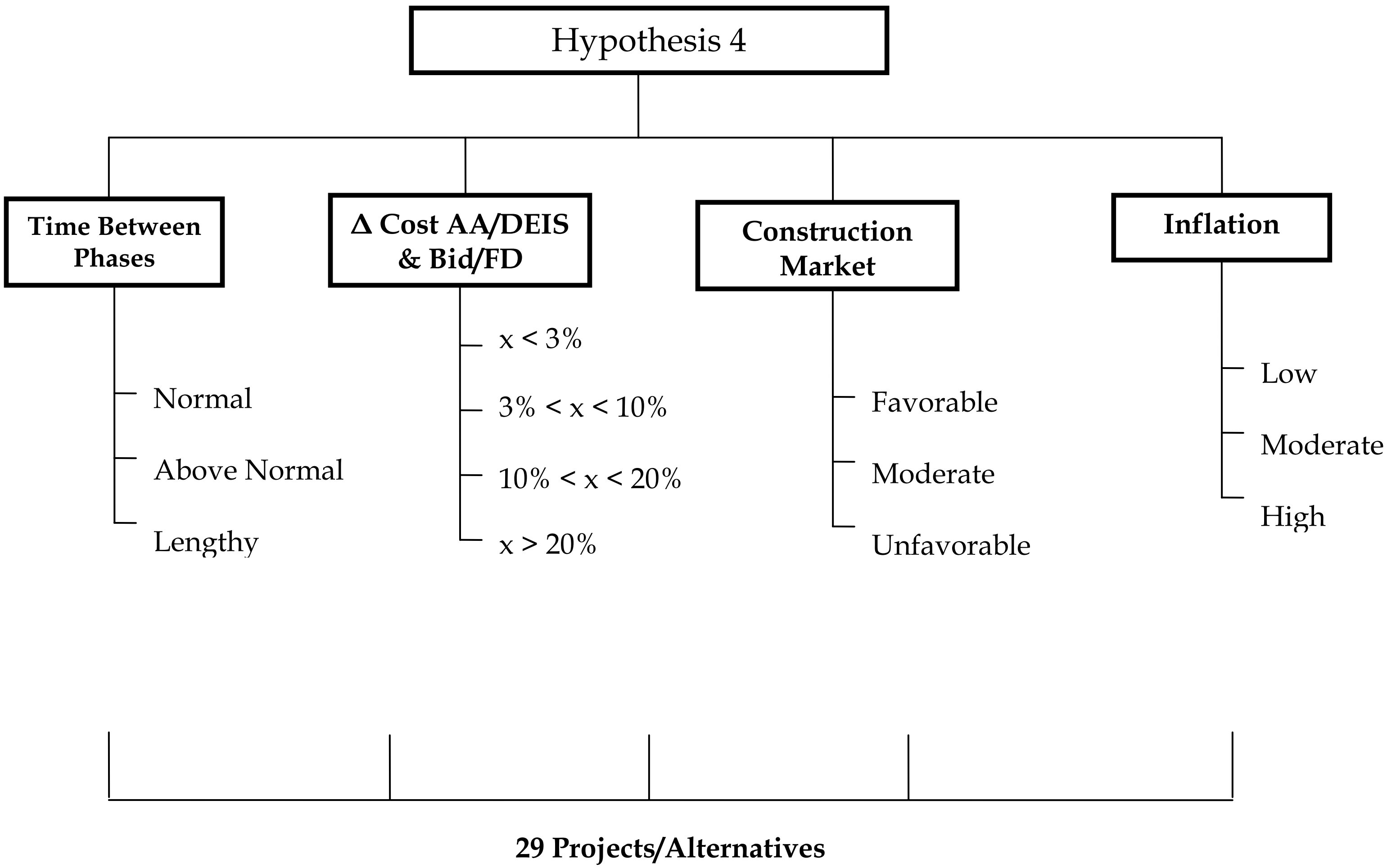

Figure B-8. Hypothesis 5 Scoring System

Hypothesis 5: Project with high degree of complexities experience cost escalation

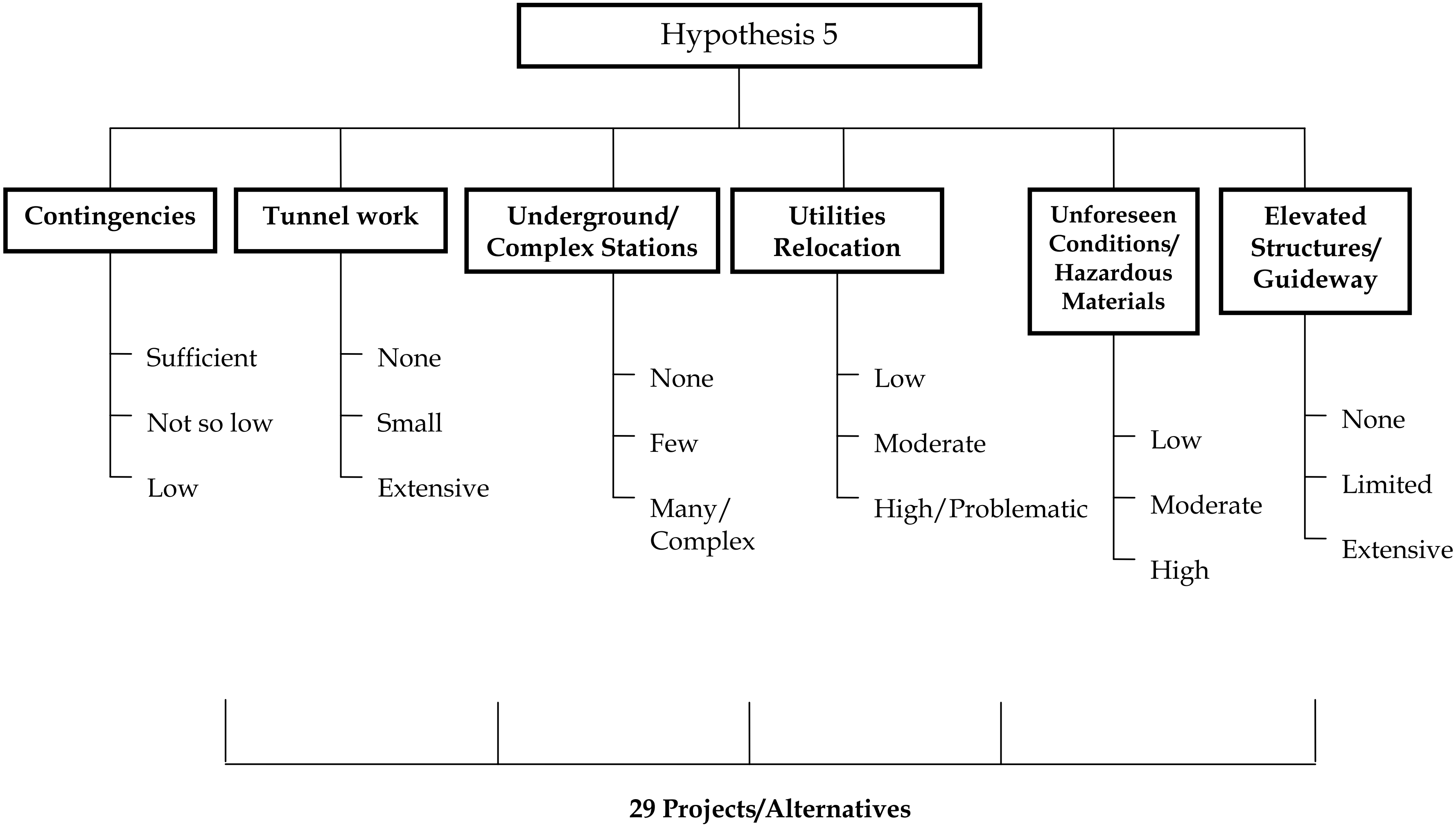

Figure B-9. Sample Project Score Sheet
Boston Old Colony Commuter Rail Project

Completed 1997	Max score	Project Score	Notes
PROJECT TOTAL	*142*	*82*	
as 100%	*100*	*57.7*	
Hypothesis 1	**22**	**16**	**73%**
Factor A	6	6	The cost difference between DEIS and FD is +23%
B	6	2	Public demands and the lengthy project phases may have prompted political issues.
C	4	4	Low contingency! The DEIS contingencies were 7.2% of the total project costs.
D	4	2	There were changes to the systems, addition of noise walls, and addition of a station.
E	2	2	The basis of estimation in DEIS and FEIS were unit costs and published cost indexes.
Hypothesis 2	**26**	**17**	**65%**
Factor A	6	2	The cost difference between DEIS and FEIS is +6%
B	6	4	Low contingency! The FEIS contingencies were 7.0% of the total project costs.
C	6	6	The basis of estimation in DEIS and FEIS were unit costs and published cost indexes.
D	4	3	The preferred alternative was modified in the FEIS.
E	4	2	Public demands and the lengthy project phases may have prompted political issues.
Hypothesis 3a	**22**	**13**	**59%**
Factor A	6	0	The cost difference between FD and actual cost is +2%.
B	6	6	The community called for relocation of stations among other things.
C	6	4	Changes include an addition of a station, addition of noise walls and changes to the systems.
D	4	3	The DEIS and FEIS contingencies were 7.2% and 7.0% of the total project costs respectively.
Hypothesis 3b	**12**	**10**	**83%**
Factor A	6	4	The cost difference between FEIS/PE and actual cost is +19%.
B	6	6	The basis of estimation in DEIS and FEIS were unit costs and published cost indexes.
Hypothesis 4	**24**	**16**	**67%**
Factor A	6	6	The feasibility study was done in 1984, DEIS in 1990, FEIS in 1992 and the project was completed in 1997. The process is long compared to many of the other projects.
B	6	6	The cost difference between DEIS and FD was +23%
C	6	---	*No information available*
D	6	4	Inflation rates were higher in the 80s when estimates were done, however for the project inflation was smaller than expected.
Hypothesis 5	**36**	**10**	**28%**
Factor A	6	4	The DEIS and FEIS contingencies were 7.2% and 7.0% of the total project costs respectively.
B	6	0	No tunnel work.
C	6	2	Stations were modified to be handicap accessible with high platforms.
D	6	0	*No information available regarding utilities, however because the alignment runs along an existing rail track we don't expect many utility relocations.*
E	6	---	*No information available regarding unforeseen or hazardous materials.*
F	4	2	Several change orders.
G	2	2	Several bridges were renovated.

* Cost differences are inflation adjusted differences, calculated using YOE and/or Cost estimates at mid point of construction dollars.

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Appendix C: Case Study Project Descriptions

The following are brief descriptions of all 28 projects in the current listing of candidate projects, including the initial indented design, the final completed investment, and descriptions of the events and modifications that drove cost changes from planning through construction for each. This information is provided for all projects specified in **Figure C-1**. **Appendix D** provides cost summary sheets for each of these projects.

Figure C-1. Candidate Projects

• Atlanta North Line Extension	• Portland Airport MAX Extension
• Boston Old Colony Rehabilitation	• Portland Banfield Corridor
• Boston Silver Line (Phase 1)	• Portland Interstate MAX
• Chicago Southwest Extension	• Portland Westside/Hillsboro MAX
• Dallas South Oak Cliff Extension	• Salt Lake North-South Line
• Denver Southwest Line	• San Francisco SFO Airport Line
• Los Angeles Red Line (MOS 1)	• San Juan Tren Urbano
• Los Angeles Red Line (MOS 2)	• Santa Clara Capitol Line
• Los Angeles Red Line (MOS 3)	• Santa Clara Tasman East Line
• Minneapolis Hiawatha Line	• Santa Clara Tasman West Line
• New Jersey Hudson-Bergen MOS1	• Santa Clara Vasona Line
• New York 63rd Street Connector	• Seattle Busway Tunnel
• Pasadena Gold Line	• St Louis – St. Clair Corridor
• Pittsburgh Airport Busway (Phase 1)	• Washington Largo Extension

Atlanta North Line Extension

The Metropolitan Atlanta Rapid Transit Authority (MARTA) constructed a 1.9-mile extension (approximately 0.7 miles at-grade, 0.4 miles elevated, 0.8 miles underground) of its heavy rail system including two stations. Originally part of the larger North Line Extension Project planned for the 1996 Atlanta Summer Olympic Games (including 3.1 miles of alignment and three stations), the project was divided into two separate segments during final design. The initial segment (1.2 miles) from Buckhead to Dunwoody stations opened in June 1996—in time for the Games, while the second segment (1.9 miles) from Dunwoody to North Springs stations did not open until December 2000. The completed project represented in this analysis is this 1.9-mile segment.

The project experienced significant changes in scope, particularly during the early phases as evidenced by the key events in **Figure C-2**. During preliminary engineering in the early 1990s, the number of vehicles procured was increased from 10 to 32—reflecting anticipated service level increases for the Olympics and the high growth in northern Atlanta. During final design in 1994, the length of the alignment was shortened from 3.1 miles to 1.9 miles and the number of stations was reduced from three to two (one at-grade and one elevated). This change ensured the completion of the Buckhead to Dunwoody segment in time for the Games, but delayed the completion of the Dunwoody to North Springs segment. Vehicle procurement was also reduced from 32 to 28 during final design, which may be a reflection of attempts to contain the budget.

The project's initial DEIS cost estimate of $370.2 million was in constant year 1990 dollars, with a planned opening in 1996 and a likely midpoint of construction in 1995. Adjusted into year-of-cost-estimate dollars to account for the project development schedule, the baseline planning estimate was $422.4 million.

In December 1994, MARTA and FTA signed an FFGA for $305.0 million in Section 5309 New Start funds for the extension from Dunwoody to North Springs. The total estimate for this project (in year-of-cost-estimate dollars) at FFGA was $381.5 million.

Total Project Cost by Phase

The upper line graph in **Figure C-2** (Project Cost by Phase) illustrates the planning estimates adjusted to the initial project schedule in year 1995 dollars, and the changes in total cost incurred by the project through construction. The planned opening of the project slipped from 1996 during the planning and preliminary engineering phases, to the year 2000 after final design as shown by the Project Schedule of **Figure C-2**. The midpoint of construction slipped accordingly from about 1995 to 1999. The inflationary cost impact of the schedule delay is represented in **Figure C-2** by the difference between the planning year estimate (dashed line) and the year-of-cost estimate (solid line).

The lower line graph (Sources of Change) in **Figure C-2** illustrates the scope and unit cost impacts of the many changes introduced throughout the development of the Atlanta North Line Extension Project. These changes in scope, noted above, are estimated to decrease costs by about $40.5 million, which would be about a 9.6-percent decrease from the planning DEIS estimate that was modified to account for the planned project development schedule (dark line). The trend of this dark line illustrates the slight increase in project scope from planning to preliminary engineering and then the reduction in scope during final design. **Figure C-2** also shows a subsequent increase in scope during construction. Most of this increase was due to increases in the parking structure capacity and the doubling of the number of vehicles procured to allow system-wide, service-level increases. Some of these changes were counterbalanced by reduction of the alignment and number of stations.

During this same project development period, unit costs for the continuing scope in the project increased by about $41.6 million (9.9 percent) from the modified planning estimate. The gray line in **Figure C-2** illustrates this declining trend in unit costs. There is generally a slow declining trend in the unit costs of the project from planning to operations.

Detailed Cost Variance by Phase

Figure C-3 illustrates the detailed project cost variance by phase. The total project change is presented in the far right columns, and the change by project phase is illustrated in the left columns. Most of the cost categories incurred unit cost decreases—totaling nearly $42 million. From planning to operations, project scope quantities increased by about $40.5 million, primarily in the cost categories of vehicles (5.00) and soft costs (8.00). The vehicle increase reflected the purchase of 56 rail cars—representing 46 more than in the planning estimate. The soft cost increases were likely due to ongoing project management costs because of significant delays and scope changes experienced during and after final design. These were offset by the cost decreases through reductions in quantities in the guideway length, stations, systems, special conditions, and right-of-way. The total variance shows the counterbalancing of the scope increases against the unit cost decreases.

Summary

The project eventually built was far different from the project first proposed in the DEIS. The 3.1-mile project's initial estimate in 1990 was $370.2 million, while the final 1.9-mile segment was completed in 2000 for $472.7 million. There were several causes for this $102.4 million (27.7 percent) difference in nominal project cost. First, adjusting the initial cost estimate into year-of-cost-estimate dollars to account for the project development schedule increased the estimate by $52.2 million (14.1 percent), resulting in a baseline planning estimate of $422.4 million. Project costs then increased from the baseline planning estimate due to changes throughout project development:

- A schedule delay during project development moved the opening from 1996 to 2000. This four-year delay shifted the estimated midpoint of construction from 1995 to 1999, and increased project costs by $49.1 million (an 11.6 percent increase from the baseline).
- The remaining $1.1 million increase (0.3 percent of the baseline) is explained by the net change in unit cost and scope. Unit costs increased by $41.6 million, while scope changes resulted in a $40.5 million decrease in costs.

Figure C-2. Atlanta North Line Extension Total Project Costs by Phase

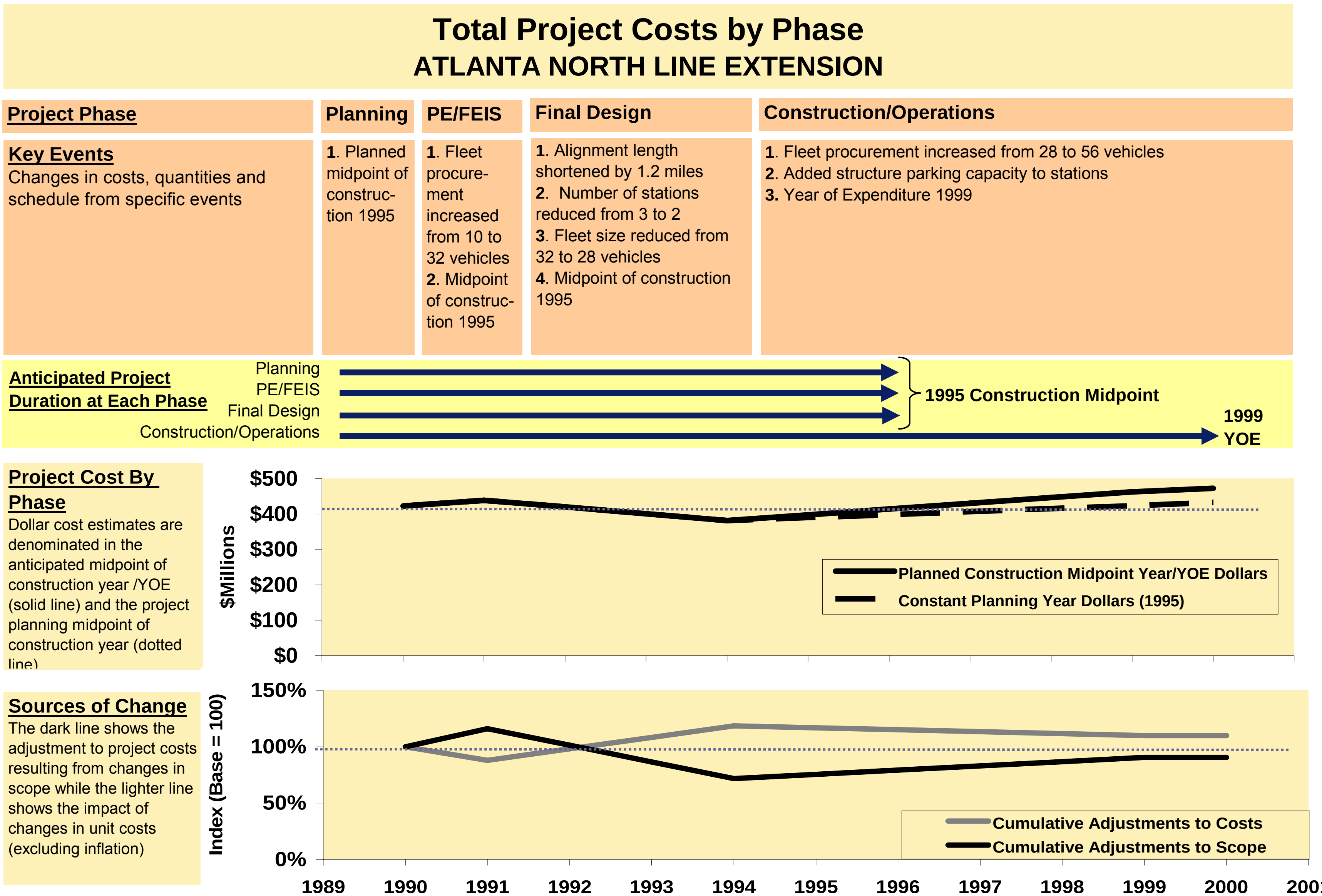
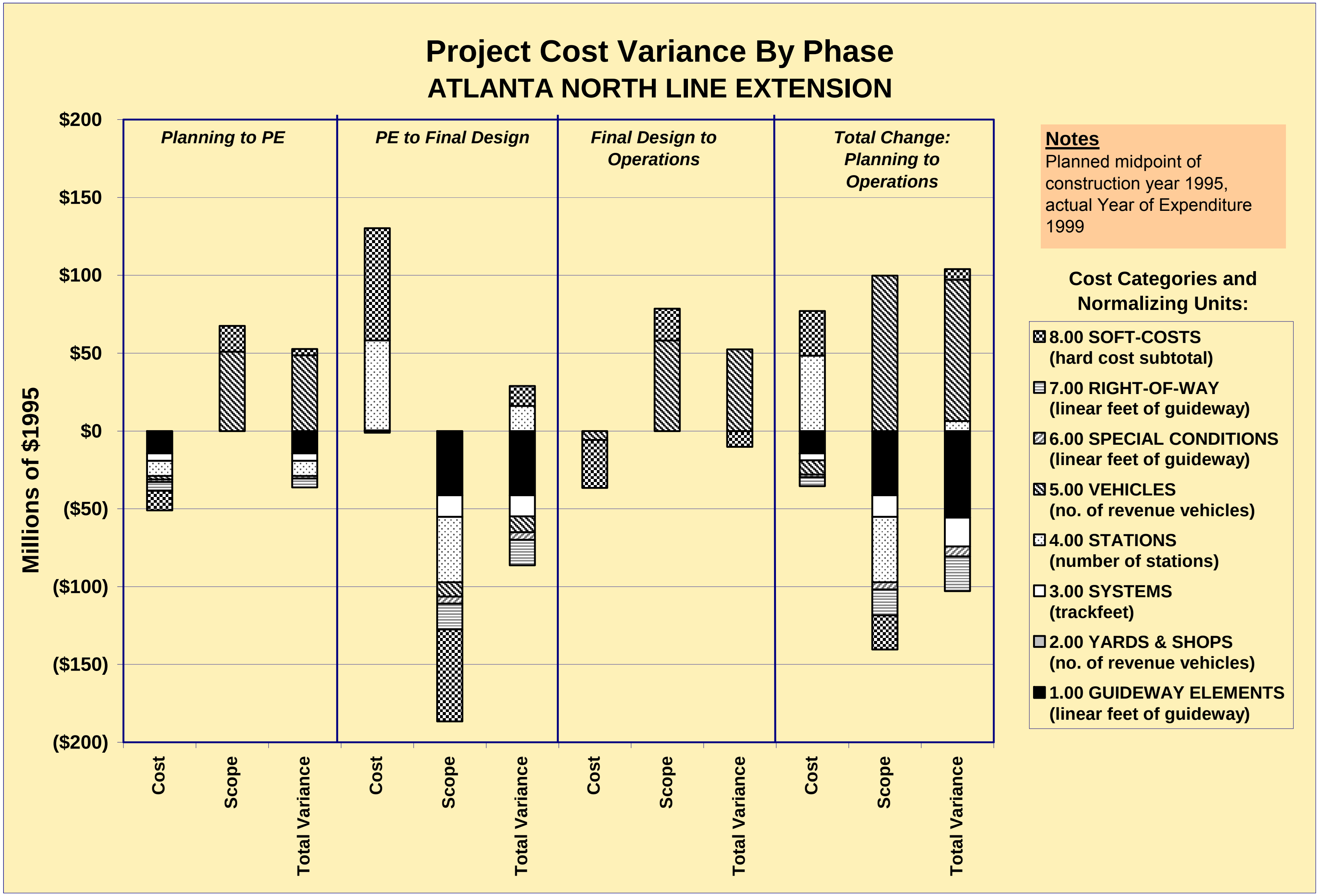


Figure C-3. Atlanta North Line Extension Project Cost Variance by Phase



Boston Old Colony Rehabilitation

The Boston Old Colony Rehabilitation project was a rehabilitation project that restored commuter rail service to the Boston South Shore area, after passenger service was stopped in 1959 for financial reasons (Faulkner and Martinez 1993). The project consisted of approximately 62 miles of ROW reconstruction along 2 routes, 14 stations, 4 park-and-ride lots, a maintenance facility, and improvements and rehabilitations of 18 road crossings and 42 bridges. The project was "packaged into 22 separate construction contracts and 5 material and equipment-procurement contracts" (Willamson 1994).

In its early stages, the project endured significant public scrutiny. Several communities called for the relocation of stations. Some parts of the line use single track. Because many of the bridges were constructed between 1896 and 1911, designers had to consider historic-preservation requirements. This included archeological excavations.

The project's initial DEIS cost estimate of $368.2 million was in 1988 dollars, while the project development schedule was planned for an opening of 1994 and a likely midpoint of construction of 1992. Adjusted into year-of-cost-estimate dollars to account for the project development schedule, the baseline planning estimate was $447.2 million.

The line graph in **Figure C-4** shows the planning estimates adjusted to the initial project schedule in year 1992 dollars, and illustrates the changes in total cost incurred by the project through construction. The planned opening of the rehabilitated Old Colony Commuter Rail was delayed from 1994 to its actual opening in 1997. The corresponding slip in midpoint of construction was from 1992 to 1995.

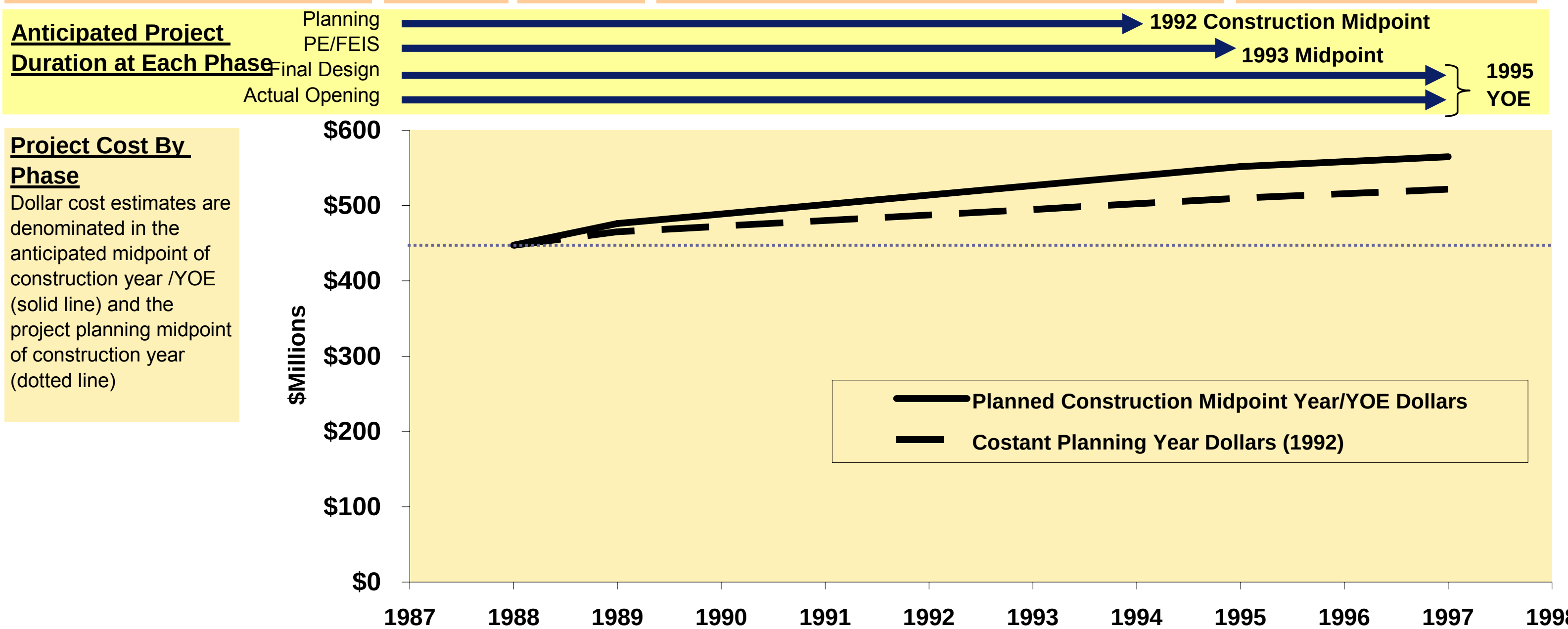
The Old Colony Commuter Rehabilitation project started out at an estimated total cost of $368.2 million, but was completed at a total cost of $565.0 million. The increase of $196.8 million (53.5 percent) is partially due to inflationary factors. Adjusting the initial cost estimate into year-of-cost-estimate dollars to account for the project development schedule increased the estimate by $79.0 million (21.5 percent), resulting in a baseline planning estimate of $447.2 million. Project costs then increased from the baseline planning estimate due to changes throughout project development:

- Due to schedule delays, the estimated midpoint of construction shifted from 1992 to 1995, which resulted in an increase in project costs of about $43.1 million (9.6 percent of the baseline).
- The remaining $74.7 million (16.7 percent of the baseline) increase is explained by the net changes in unit cost and scope. The changes primarily took place during final design—one station was added, and the vehicle fleet size was increased. The project was also delayed nine months due to design changes to the signaling systems (Middleton 1997).

Figure C-4. Boston Old Colony Rehabilitation Total Project Costs by Phase

Total Project Costs by Phase
BOSTON OLD COLONY REHABILITATION

Project Phase	**Planning**	**PE/FEIS**	**Final Design**	**Construction/Operations**
Key Events Changes in costs, quantities and schedule from specific events	**1**. Planned midpoint of construction 1992	**1**. Midpoint of construction 1993	**1.** Number of stations increased from 14 to 15 **2**. Fleet procurement increased to 26 vehicles **3**. Excludes contingencies and construction/ project management costs **4.** Midpoint of construction 1995	**1**. Significant unit cost revisions **2**. Year of Expenditure 1995



Boston Silver Line (Phase 1)

Developed by the Massachusetts Bay Transportation Authority (MBTA), the South Boston Piers Transitway project was a 1.5-mile underground transitway including five stations connecting three existing transit systems in the South Boston Piers Area. After a 1994 FFGA, the original project was reorganized. The South Boston Piers Transitway project and the locally funded Washington Street Replacement became one bus rapid transit project known as the Silver Line. Phase 1 of the project included a one-mile, three-station tunnel between South Station and the World Trade Center; the procurement of 32 vehicles; and the construction of a new vehicle maintenance facility. The project had some joint construction with the Central Artery/Tunnel project.

The line graph in **Figure C-5** shows the planning estimates adjusted to the initial project schedule in year 1995 dollars, and illustrates the changes in total cost incurred by the project through construction. The opening of the Boston Silver Line was delayed from 1996 at planning to 2004 at actual opening. The corresponding slip in midpoint of construction was from 1995 to 2002.

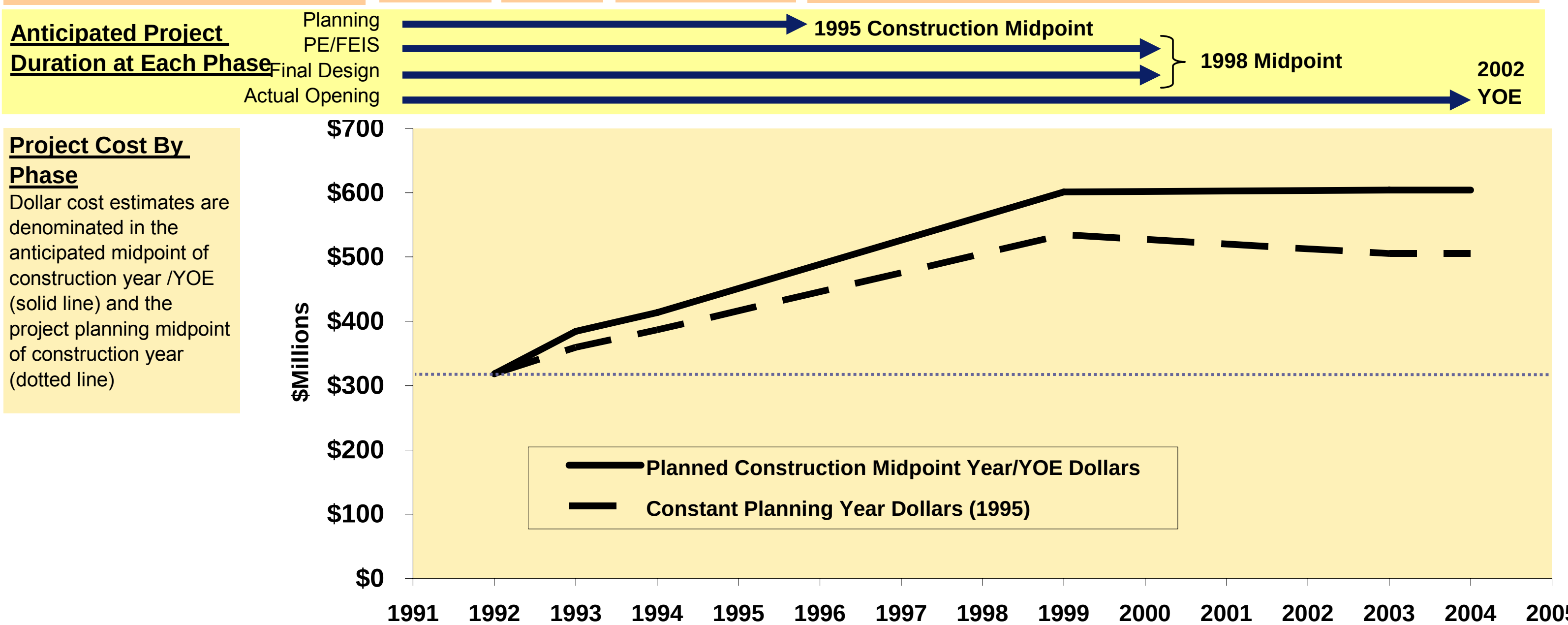
The total cost for the Silver Line project was originally estimated to be $318.1 million, but grew to $604.4 million upon completion. Because the initial DEIS cost estimate was in year-of-cost-estimate dollars, no adjustment was required to determine the baseline planning estimate. The $286.3 million (90.0 percent) increase was therefore due only to schedule delays and changes in unit cost and scope. The shift in estimated midpoint of construction from year 1995 to 2002 resulted in an increase in project costs of about $99.1 million (31.2 percent). The remaining $187.2 million (58.9 percent) increase was due to net changes in unit cost and scope.

A 2001 recovery plan was submitted to the FTA to reflect the capital cost growth due in some measure to delays in the project's implementation schedule. Factors contributing to the delays included coordination problems on the joint construction contracts with the Central Artery/Tunnel project, complications with the design for relocating utilities, and differing site conditions. Land acquisition costs were also higher than originally estimated. The escalation of the total project cost was the responsibility of local project sponsors.

Figure C-5. Boston Silver Line Total Project Costs by Phase

Total Project Costs by Phase
BOSTON SILVER LINE (PHASE 1)

Project Phase	**Planning**	**PE/FEIS**	**Final Design**	**Construction/Operations**
Key Events Changes in costs, quantities and schedule from specific events	**1**. Planned midpoint of construction 1995	**1**. Midpoint of construction 1998	**1**. The South Boston Piers Transitway project and locally funded Washington Street Replacement merged into the "Silver Line." **2**. Midpoint of construction 1998	**1.** A recovery plan was submitted to the FTA to reflect the capital cost growth due in some measure to delays in the project's implementation schedule. The escalation of the total project cost was the responsibility of local project sponsors. **2.** Year of Expenditure 2002



Chicago Southwest Extension

As initially proposed, Chicago's Southwest Extension project was a 9.3-mile extension to the Chicago Transit Authority's existing heavy rail system including 4.3 miles of elevated structure, 4 miles of embankment, and 1 mile of subway alignment. The project also included nine stations—five at-grade, three elevated, and one subway station. The project objectives were to provide service between 49th Street to Midway Airport and to ease traffic on adjacent freeways and surface streets.

Total Project Cost by Phase

The upper line graph in **Figure C-6** shows the planning estimates adjusted to the initial project schedule in year 1986 dollars, and illustrates the changes in total cost incurred by the project through construction. The planned opening of the Southwest Extension was delayed twice—from the original estimate of 1987, to 1988 during final design, and 1990 at actual opening. The corresponding slip in midpoint of construction was from 1986 to 1989.

The lower line graph in **Figure C-6** illustrates the scope and unit cost impacts of the many changes introduced throughout the development of the Southwest Extension project. Changes in scope are estimated to have reduced costs by approximately $48.6 million (10.7 percent) from the planning DEIS estimate (dark line). The trend of this line illustrates the reduction in project scope during final design, and the increase during construction. Several alignment iterations occurred, beginning in the preliminary engineering phase with a substitution of approximately 5.9 miles of at-grade guideway for subway and elevated. Also, the fleet size was reduced from 112 to 104 vehicles during the preliminary engineering phase. In final design, the overall alignment was shortened from 9.3 miles to 9.0 miles, but the share of at-grade alignment was increased. The number of stations was reduced from nine to eight (two elevated and six at-grade), and vehicle procurement was precluded. In the construction phase, fleet vehicles were added back into the cost estimates, with fleet size reduced from 104 to 88. Costs were added for utility relocation, demolitions, and additional ROW purchases. All appropriate soft costs associated with preliminary engineering, final design, project and construction management, and project initiation were accounted for.

During this project development period, unit costs for the continuing project scope increased by about $29.5 million (6.5 percent). As shown by the gray line in the lower line graph in **Figure C-6**, unit costs followed a trend similar to scope, but with a substantial increase between planning and preliminary engineering. Station costs increased during preliminary engineering, because three stations were elevated from at-grade. Alignment modifications and adjustments to soft costs, as noted in the previous paragraph, were made during all phases.

Detailed Cost Variance by Phase

Figure C-7 illustrates the detailed project cost variance by phase**.** Both costs and scope fluctuated between phases. From planning to operations, project scope quantities decreased by nearly $50 million, primarily in the cost categories of vehicles (5.00) and stations (4.00). These were offset by about $30 million in cost increases resulting from adjustments to soft costs (8.00) and modifications to stations (4.00). The total variance shows the counterbalancing of the scope decreases against the unit cost increases.

Summary

The Southwest Extension project started out at an estimated total cost of $453.0 million, but was completed at a total cost of $474.6 million—a difference of $21.6 million (4.8 percent). Because the initial DEIS cost estimate was in year-of-cost-estimate dollars, no adjustment was required to determine the baseline planning estimate. Significant fluctuation in total cost estimates occurred from planning to operations, resulting in a $19.1 million (4.2-percent) decrease in costs. This reduction was offset, however, by the impact of the two schedule delays, which increased project costs by about $40.7 million (9.0 percent).

Figure C-6. Chicago Southwest Extension Total Project Costs by Phase

Total Project Costs by Phase
CHICAGO SOUTHWEST EXTENSION

Project Phase	**Planning**	**PE/FEIS**	**Final Design**	**Construction/Operations**
Key Events Changes in costs, quantities and schedule from specific events	**1**. Planned midpoint of construction 1986	**1**. At-grade alignment substituted for subway/ elevated alignment **2**. 3 at-grade stations elevated **3**. Fleet size reduced from 112 to 104 vehicles **4**. Midpoint of construction 1986	**1**. Guideway elements modified: alignment length shortened from 9.3 to 9.0 miles; increased share of at-grade alignment; 1 subway station added **2**. Excludes vehicles **3**. Midpoint of construction 1987	**1**. Vehicle purchases included, with fleet size reduced from 104 to 88 **2**. Number of stations reduced from 10 to 8 **3**. Added soft costs for PE, Final Design, construction and project management/ initiation **4**. Year of Expenditure 1989

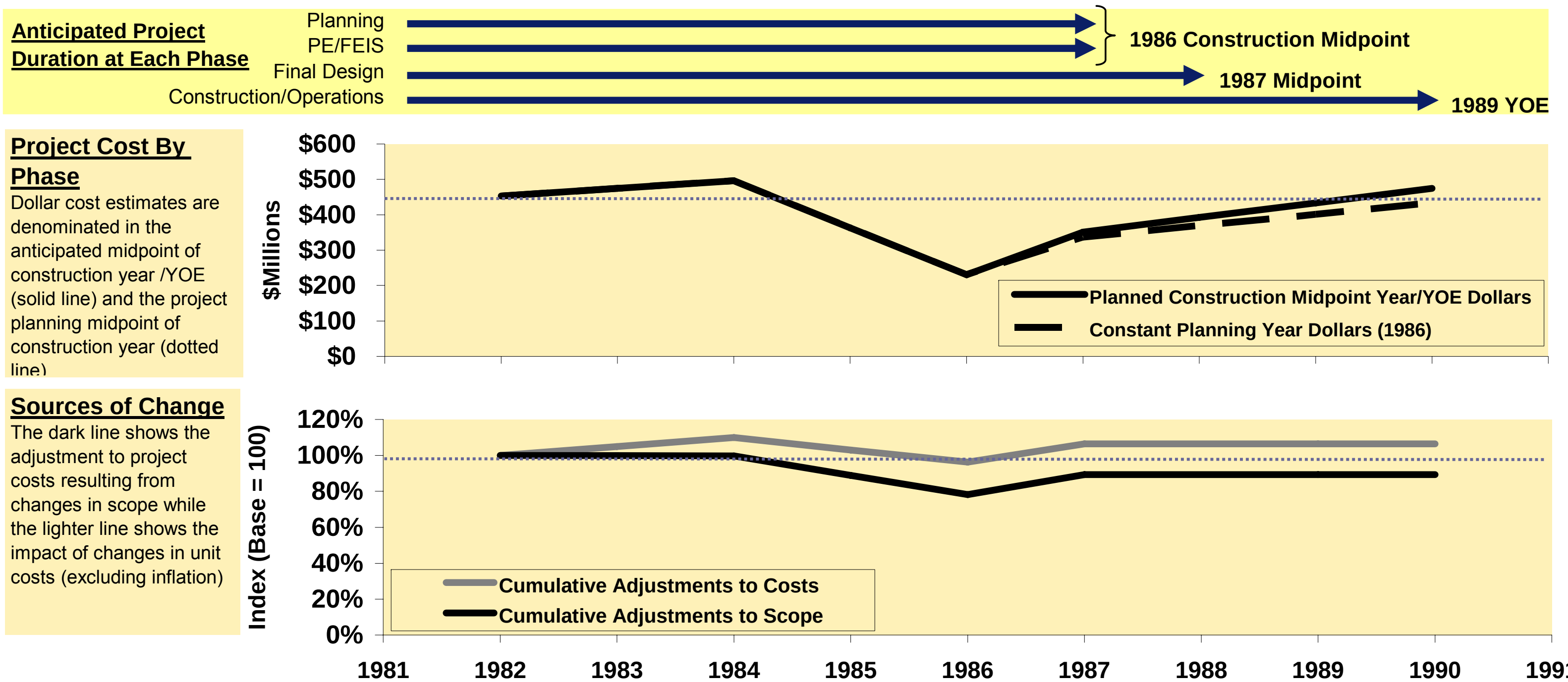
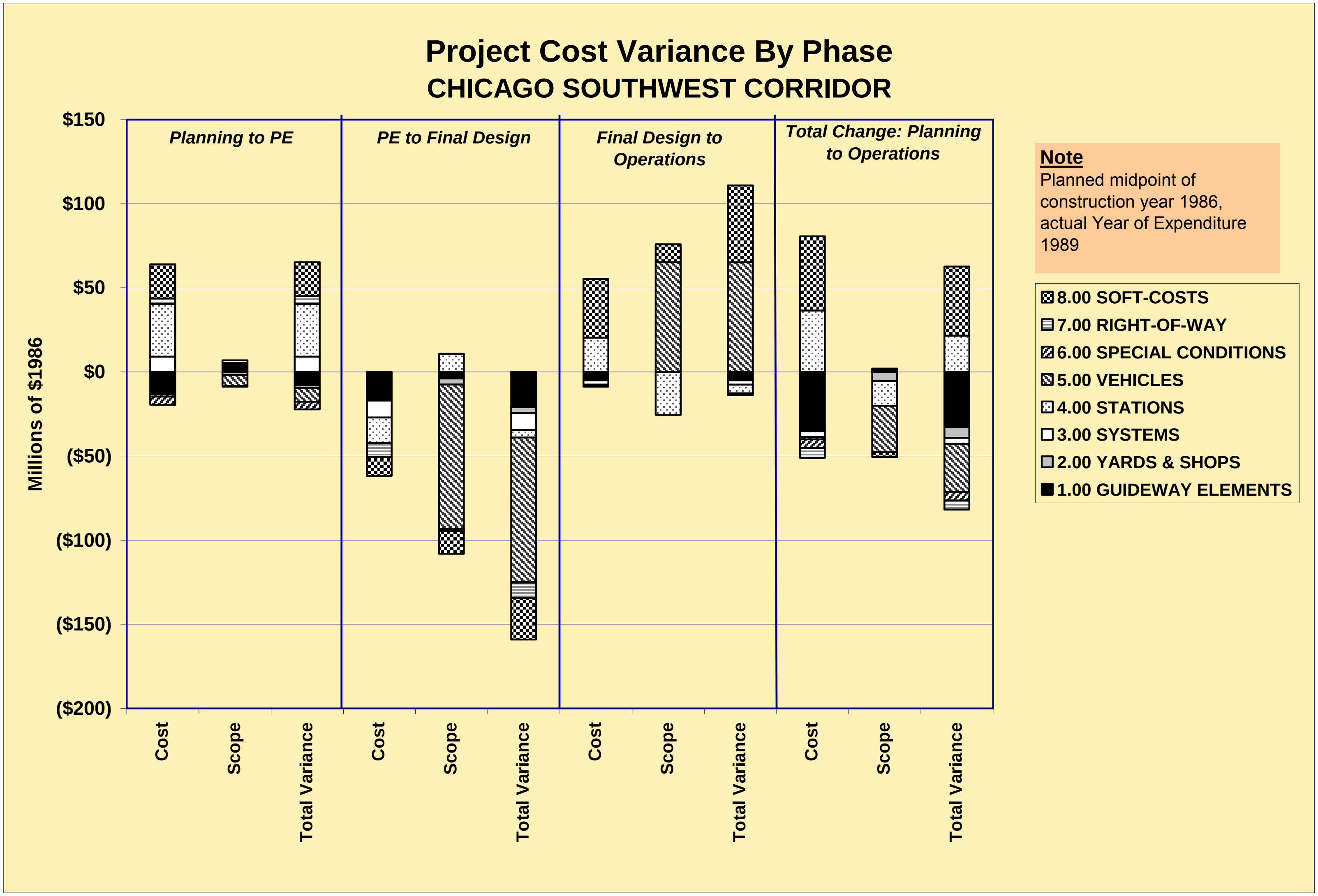


Figure C-7. Chicago Southwest Extension Project Cost Variance by Phase



Dallas South Oak Cliff Extension

The South Oak Cliff Extension is a 12.5-mile, 9-station extension of the Dallas Area Rapid Transit (DART) North Central Corridor light rail system from the Park Lane Station north to the City of Plano.

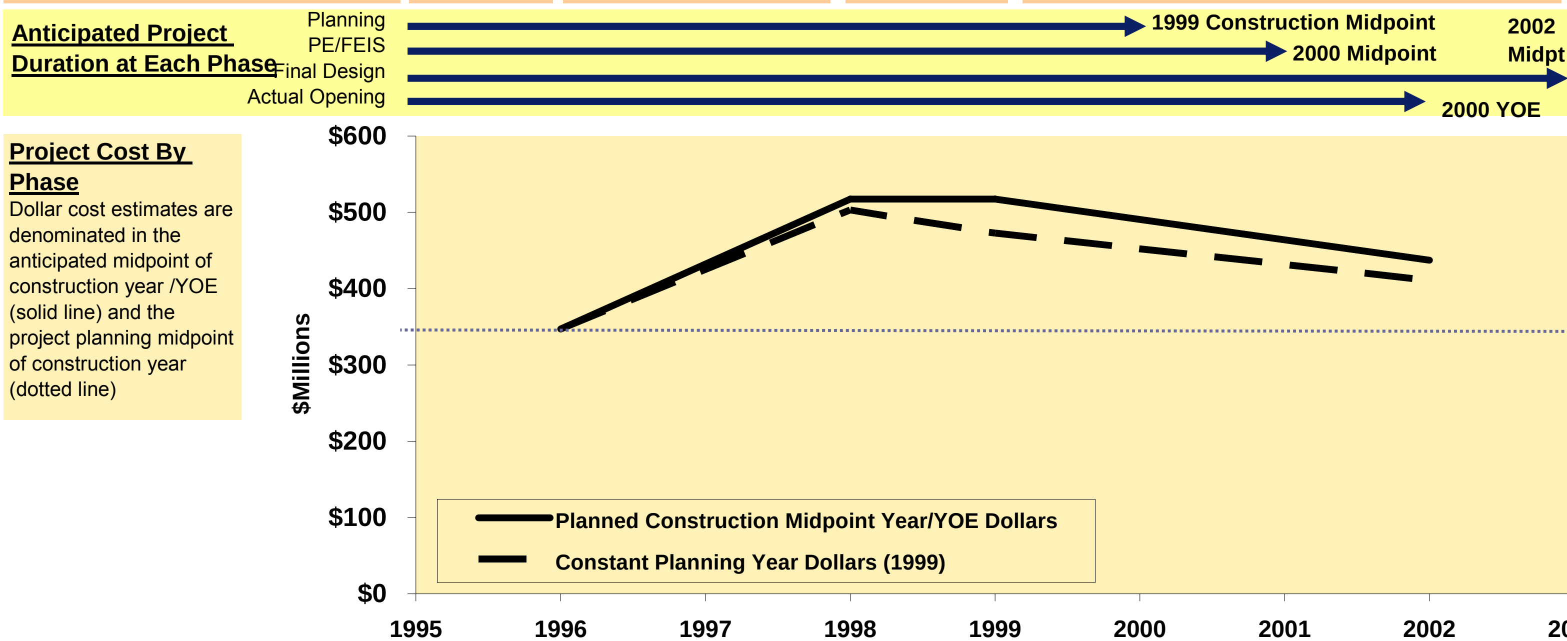
The line graph in **Figure C-8** shows the planning estimates adjusted to the initial project schedule in year 1999 dollars, and illustrates the changes in total cost incurred by the project through construction. The planned opening of the South Oak Cliff Extension was delayed during final design from 2000 to 2003, but then opened a year ahead of schedule in 2002.

The South Oak Cliff Extension project started out at a $347.1 million total cost, and was completed for $437.2 million, experiencing an increase of $90.1 million (26.0 percent). Because the initial DEIS cost estimate was in year-of-cost-estimate dollars, no adjustment was required to determine the baseline planning estimate. The estimated midpoint of construction slipped from 1999 to 2001 due to schedule changes, which increased project costs by about $26.2 million (7.6 percent). The remaining $63.9 million (18.4 percent) increase was due to the net changes in unit cost and scope. In 1997, the DART Board of Directors approved the double tracking of the entire project (five additional miles of track). Favorable bid conditions reportedly allowed DART to realize $80 million in cost savings on this project. DART requested an amendment to the FFGA to use the savings to add an additional station, parking, and the purchase of 20 additional railcars.

Figure C-8. Dallas South Oak Cliff Extension Total Project Costs by Phase

Total Project Costs by Phase
DALLAS SOUTH OAK CLIFF EXTENSION

Project Phase	**Planning**	**PE/FEIS**	**Final Design**	**Construction/Operations**
Key Events Changes in costs, quantities and schedule from specific events	**1**. Planned midpoint of construction 1999	**1**. Double tracking of entire project approved (five additional miles of track) **2.** Midpoint of construction 2000	**1.** Midpoint of construction 2002	**1**. Favorable bid conditions reportedly allowed DART to realize $80M in cost savings; DART had requested an amendment to the FFGA to use the savings to add an additional station, parking, and the purchase of 20 additional railcars. **2.** Year of Expenditure 2001



Denver Southwest Line

The Denver Southwest Line is an 8.7-mile light rail extension between Denver and Littleton. The double-track line extends from the I-25/Broadway Station on the existing Central Corridor line to Mineral Avenue in Littleton, running parallel to Santa Fe Drive over an exclusive, grade-separated right-of-way. The line includes five stations.

The project's initial DEIS cost estimate of $127.5 million was in year 1992 dollars, while the project development schedule was planned for an opening of 1996 and a likely midpoint of construction of 1995. Adjusted into year-of-cost-estimate dollars to account for the project development schedule, the baseline planning estimate was $138.0 million.

Total Project Cost by Phase

The upper line graph in **Figure C-9** shows the planning estimates adjusted to the initial project schedule in year 1995 dollars, and illustrates the changes in total cost incurred by the project through construction. The planned opening of the Southwest Line was delayed only between planning and preliminary engineering, from the initial plan of 1996 to the actual opening of 2000. The corresponding slip in midpoint of construction was from 1995 to 1999.

The lower line graph in **Figure C-9** illustrates the scope and unit cost impacts of the changes introduced throughout the development of the Southwest Line project. Changes in scope are estimated to have increased costs by approximately $2.3 million (1.7 percent) from the planning DEIS estimate that was modified to account for the planned project development schedule (dark line). The major change in scope was during final design, when the fleet size was increased.

During this same project development period, unit costs for the continuing scope in the project increased more significantly, by about $21.7 million (15.8 percent of the adjusted planning estimate). The gray line in Figure 5-15's lower line graph shows the upward trend in the second half of the project. Costs were underestimated for guideway, ROW, track, facilities, and soft costs because of changes to station design and railroad relocation plans.

Detailed Cost Variance by Phase

Figure C-10 illustrates the detailed project cost variance by phase. Both costs and scope increased during final design and construction. From planning to operations, project scope quantities increased by a little over $2 million, primarily in the cost category of vehicles (5.00). The nearly $22 million in cost increases resulted from stations adjustments (4.00) and ROW acquisitions (7.00), as well as alignment modifications (1.00).

Summary

At planning, the total cost estimate for the Southwest Line was $127.5 million, but project cost increased by $49.6 million (38.9 percent) to $177.1 million at completion. A portion of the increase can be attributed to inflationary factors. Adjusting the initial cost estimate into year-of-cost-estimate dollars to account for the project development schedule increased the estimate by $10.5 million (8.2 percent), resulting in a baseline planning estimate of $138.0 million. Project costs then increased from the baseline planning estimate due to changes throughout project development:

- The Southwest Line experienced one major schedule delay, shifting the estimated midpoint of construction from 1995 to 2000. This increased project costs by about $15.1 million (10.9 percent of the baseline).
- The remaining $24.0 million increase (17.4 percent of the baseline) was due to scope and unit cost changes introduced into the project over the developmental period.

Figure C-9. Denver Southwest Line Total Project Costs by Phase

Total Project Costs by Phase
DENVER SOUTHWEST LINE

Project Phase	Planning	PE/FEIS	Final Design	Construction/Operations
Key Events Changes in costs, quantities and schedule from specific events	**1**. Planned midpoint of construction 1995	**1**. Facilities expanded to accommodate new equipment **2**. Added park-n-ride facilities to 4 of 5 stations **3**. Right-of-way costs increased **4**. Start-up costs added to Soft-Costs **5**. Midpoint of construction 1999	**1**. Alignment adjustments **2.** Fleet size and facility capacity increased **3**. Increased ROW costs 4. Midpoint of construction 1999	**1**. Minor cost reductions for systems and facilities **2.** Year of Expenditure 1999

Anticipated Project Duration at Each Phase

- Planning → 1995 Construction Midpoint
- PE/FEIS → 1999 YOE
- Final Design → 1999 YOE
- Construction/Operatations → 1999 YOE

Project Cost By Phase
Dollar cost estimates are denominated in the anticipated midpoint of construction year /YOE (solid line) and the project planning midpoint of construction year (dotted line)

Sources of Change
The dark line shows the adjustment to project costs resulting from changes in scope while the lighter line shows the impact of changes in unit costs (excluding inflation)

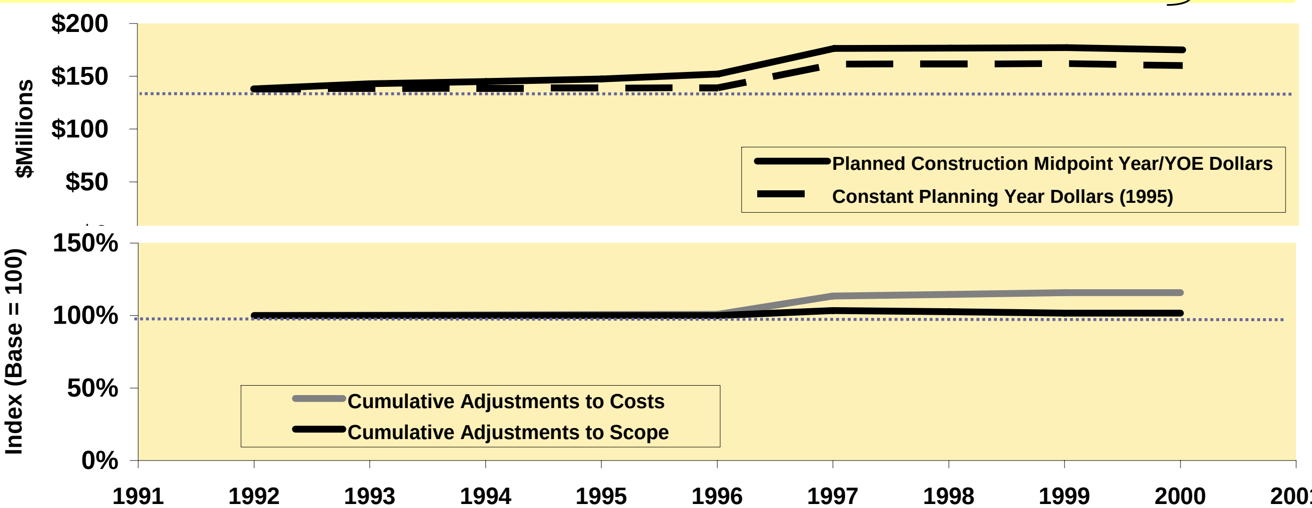
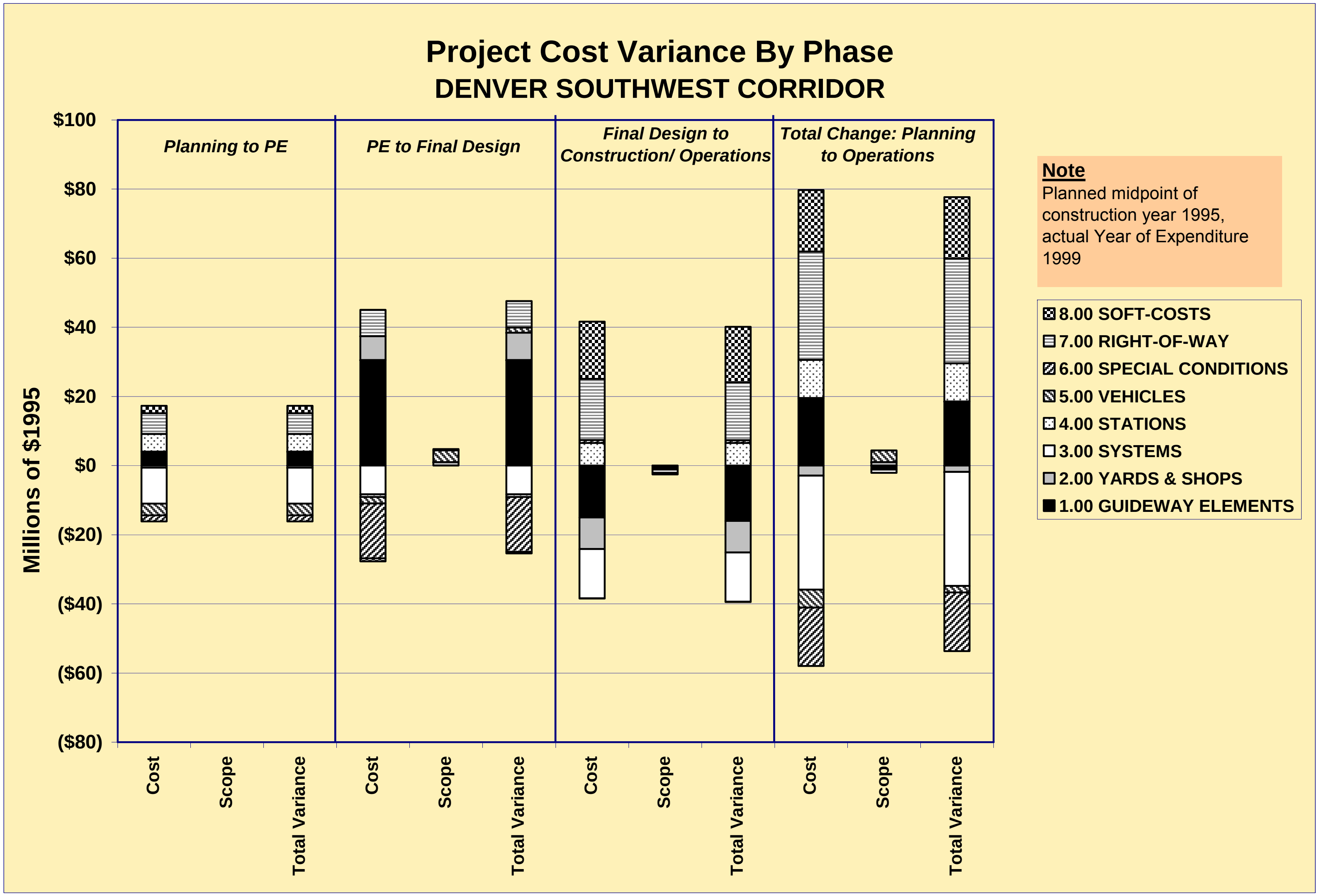


Figure C-10. Denver Southwest Line Project Cost Variance by Phase



Los Angeles Red Line MOS 1, 2, and 3

As initially proposed, Los Angeles' Red Line was an 18.6-mile, 18-station subway system heavy rail investment—the first heavy rail investment in the Los Angeles basin. The project objectives were to connect Los Angeles Union Station (LAUS) with Mid-Cities and North Hollywood and to ease traffic on adjacent freeways and surface streets.

Over the life of the project, the proposed alignment was reduced from 18.6 miles to 17.5 miles, and the number of stations was reduced from 18 to 16. The planning estimate for the full project was completed in 1983. The subway system was then designed and built in three segments: MOS 1, 2, and 3.

MOS 1

MOS 1 was a 4.5-mile segment with 5 stations. The project's initial DEIS cost estimate of $620.7 million was in 1983 dollars, while the project development schedule was planned for an opening of 1990 and a likely midpoint of construction of 1988. Adjusted into year-of-cost-estimate dollars to account for the project development schedule, the baseline planning estimate was $695.8 million.

Total Project Cost by Phase

The upper line graph in **Figure C-11** shows the planning estimates adjusted to the initial project schedule in year 1988 dollars, and illustrates the changes in total cost incurred by the project through construction. MOS 1 experienced further delay after the splitting of the Red Line, with the planned opening changing from 1990 to 1991 at final design, and to 1993 at actual opening. The corresponding slip in midpoint of construction was from 1988 to 1991.

The lower line graph in **Figure C-11** illustrates the scope and unit cost impacts of the many changes introduced throughout the development of MOS 1. Scope changes resulted in a total cost decrease of approximately $126.1 million (18.1 percent) from the planning DEIS estimate that was modified to account for the planned project development schedule (dark line). Unit cost adjustments, on the other hand, more than doubled the project cost, with an increase of about $814.3 million (117.0 percent) of the adjusted planning estimate (gray line).

The biggest change for MOS 1 was a significant alignment relocation, required to avoid significant methane gas pockets that would have been encountered by the original alignment. The change in the alignment required additional ROW acquisition that resulted in increased project costs. Hazardous material removal, as a result of the change in alignment, added burden to the environmental mitigation process. Also, harder-than-expected rock formations reduced tunnel boring machine progress. The changes during construction resulted in numerous change orders, claims, and lawsuits.

Detailed Cost Variance by Phase

Figure C-12 illustrates the detailed project cost variance by phase**.** From planning to operations, project scope quantities decreased primarily in the cost categories of guideway elements (1.00) and ROW acquisition (7.00). These were offset by the massive cost increases resulting from adjustments to soft costs (8.00), as well as modifications to stations (4.00) and other categories. The total variance shows the cost increases overwhelming the scope decreases.

Summary

At planning, the total cost estimate for MOS 1 was $620.7 million, but the project was completed for $1.49 billion. The cost more than doubled, increasing by $869.4 million (140.1 percent). A portion of the increase can be attributed to inflationary factors. Adjusting the initial cost estimate into year-of-cost-estimate dollars to account for the project development schedule increased the estimate by $75.1 million (12.1 percent), resulting in a baseline planning estimate of $695.8 million. Project costs then increased from the baseline planning estimate due to changes throughout project development:

- MOS 1 experienced multiple schedule delays, shifting the estimated midpoint of construction from 1988 to 1991, which increased project costs by about $106.2 million (15.3 percent of the baseline).
- The majority of the increase, however, was due to scope and unit cost changes introduced into the project over the developmental period, which caused a $688.2 million (98.9 percent of the baseline) net increase in costs.

Figure C-11. Los Angeles Red Line (MOS 1) Total Project Costs by Phase

Total Project Costs by Phase
LOS ANGELES RED LINE (MOS 1)

Project Phase	**Planning**	**Final Design**	**Construction/Installation**
Key Events Changes in costs, quantities and schedule from specific events **Note** Planning phase costs were reported for combined project (MOS 1,2, and 3), and have been separated for comparison purposes.	1. Planned midpoint of construc-tion 1988	1. Added soft costs: initial design, project management, finance charges and significant "other soft-costs" 2. Midpoint of construction 1989	1. Alignment location revised 2. ROW acquisition costs increased 3. Hazardous materials removal 4. Change orders, claims and lawsuits 5. Midpoint of construction 1991

Anticipated Project Duration at Each Phase

- PE/FEIS → 1988 Construction Midpoint
- Final Design → 1989 Midpoint
- Construction/Installation → 1991 YOE

Project Cost By Phase
Dollar cost estimates are denominated in the anticipated midpoint of construction year /YOE (solid line) and the project planning midpoint of construction year (dotted line)

Sources of Change
The dark line shows the adjustment to project costs resulting from changes in scope while the lighter line shows the impact of changes in unit costs (excluding inflation)

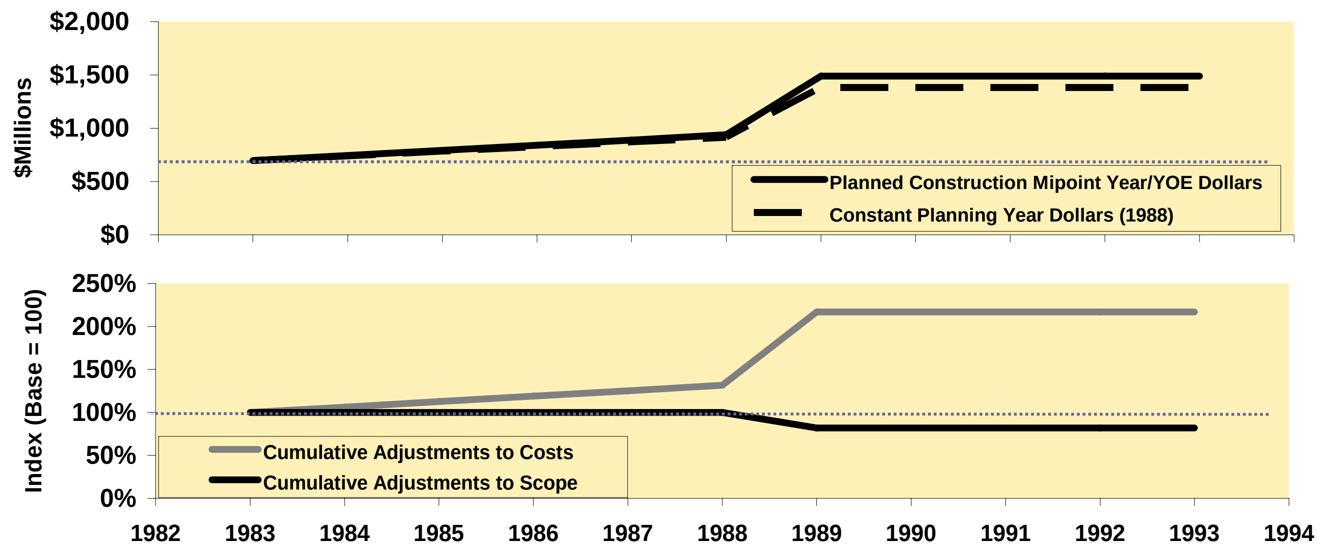
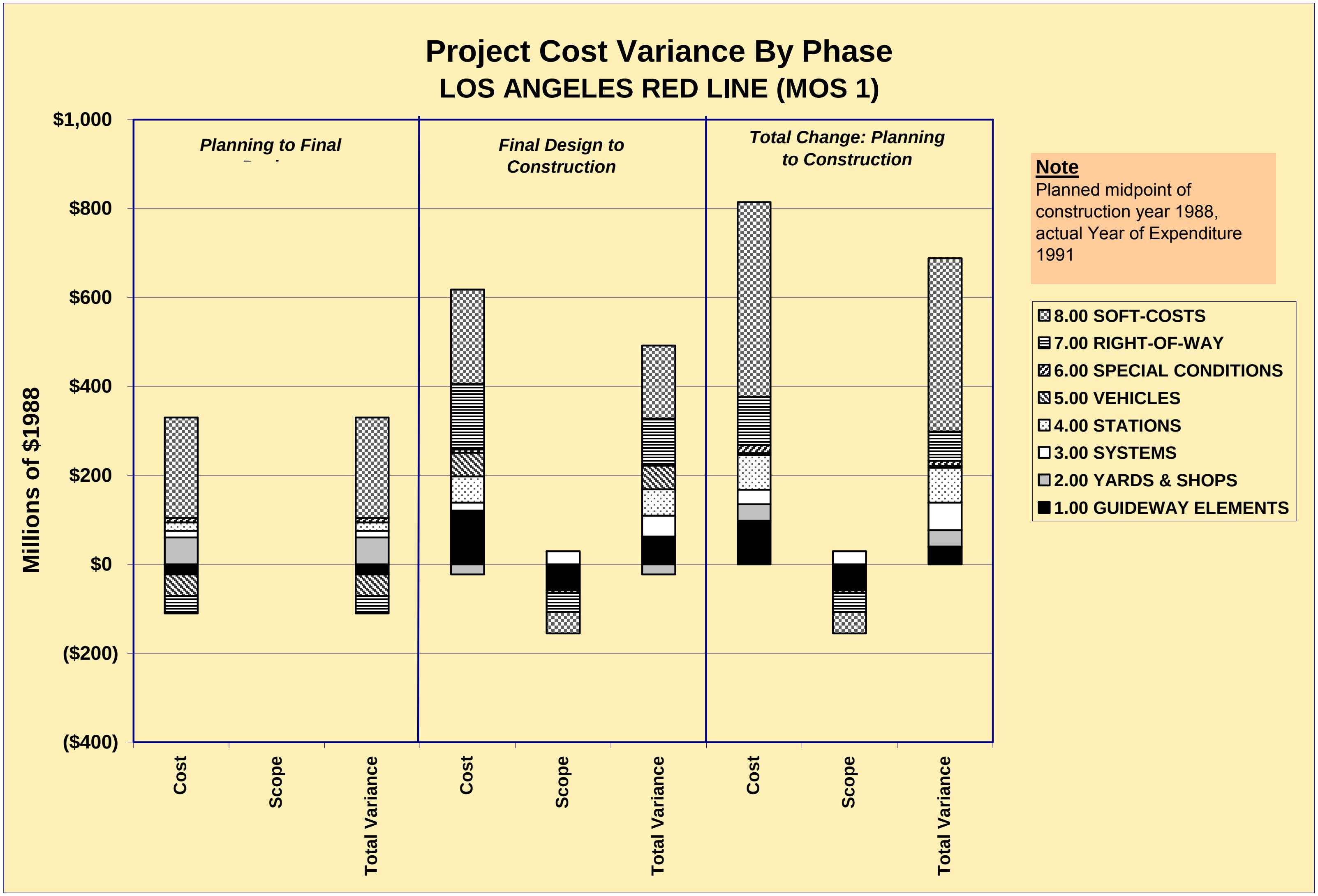


Figure C-12. Los Angeles Red Line (MOS 1) Project Cost Variance by Phase



MOS 2

MOS 2 was a 6.2-mile segment with 8 stations. The project's initial DEIS cost estimate of $949.7 million was in 1983 dollars, while the project development schedule was planned for an opening of 1992 and a likely midpoint of construction of 1990. Adjusted into year-of-cost-estimate dollars to account for the project development schedule, the baseline planning estimate was $1.12 billion.

Total Project Cost by Phase

The upper line graph in **Figure C-13** shows the planning estimates adjusted to the initial project schedule in year 1990 dollars, and illustrates the changes in total cost incurred by the project through construction. MOS 2 experienced further delay after the splitting of the Red Line, with the planned opening changing from 1992 to 1994 at final design, and to 1996 at actual opening. The corresponding slip in midpoint of construction was from 1990 to 1994.

The lower line graph in **Figure C-13** illustrates the scope and unit cost impacts of the many changes introduced throughout the development of MOS 2. Scope changes resulted in a total cost increase of approximately $63.8 million (5.7 percent) of the planning DEIS estimate that was modified to account for the planned project development schedule (dark line). Unit cost adjustments also caused an increase in total project cost—about $555.3 million (49.7 percent) of the adjusted planning estimate (gray line).

Detailed Cost Variance by Phase

Figure C-14 illustrates the detailed project cost variance by phase. From planning to operations, project scope quantities increased primarily in the systems cost category (3.00). Larger cost increases resulted from adjustments to soft costs (8.00), and in the special conditions category (6.00). The total variance shows the combination of the two increases.

Summary

At planning, the total cost estimate for MOS 2 was $949.7 million, but the project was completed for $1.92 billion. The cost nearly doubled over the life of the project, increasing by $972.0 million (102.4 percent). A portion of the increase can be attributed to inflationary factors. Adjusting the initial cost estimate into year-of-cost-estimate dollars to account for the project development schedule increased the estimate by $167.0 million (17.6 percent), resulting in a baseline planning estimate of $1.12 billion. Project costs then increased from the baseline planning estimate due to changes throughout project development:

- MOS 2 experienced multiple schedule delays, shifting the estimated midpoint of construction from 1990 to 1994. The impact was to increase project costs by about $185.9 million (16.6 percent above the baseline).
- The majority of the increase, however, was due to scope and unit cost changes introduced into the project over the developmental period, which caused a $619.1 million (55.4 percent of the baseline) net increase in costs.

Figure C-13. Los Angeles Red Line (MOS 2) Total Project Costs by Phase

Total Project Costs by Phase
LOS ANGELES RED LINE (MOS 2)

Project Phase	**Planning**	**Final Design**	**Construction/Installation**
Key Events Changes in costs, quantities and schedule from specific events **Note** Planning phase costs were reported for combined project (MOS 1,2, and 3), and have been separated for comparison purposes.	**1**. Planned midpoint of construc-tion 1990	**1**. Alignment location revised **2.** Added soft costs: initial design, project management, and significant "other soft-costs" **3.** Midpoint of construction 1992	**1**. Tunnel boring issues including harder than expected rock and oversized boring through fault zone, unexpected sinkhole **2**. Station costs increased due to additional entrances; ADA system upgrades **3**. Added Fare Collection system costs **4**. Change orders, claims and lawsuits, additional finance charges **5.** Year of Expenditure 1994

Anticipated Project Duration at Each Phase

PE/FEIS → **1990 Construction Midpoint**
Final Design → **1992 Midpoint**
Construction/Installation → **1994 YOE**

Project Cost By Phase
Dollar cost estimates are denominated in the anticipated midpoint of construction year /YOE (solid line) and the project planning midpoint of construction year (dotted line)

Sources of Change
The dark line shows the adjustment to project costs resulting from changes in scope while the lighter line shows the impact of changes in unit costs (excluding inflation)

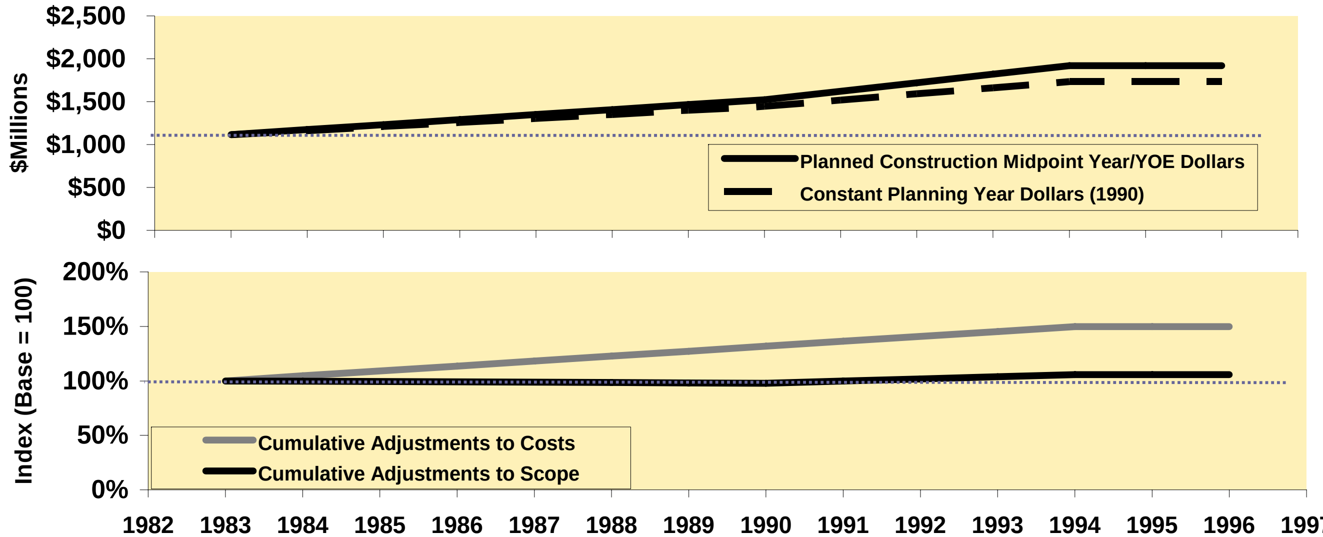
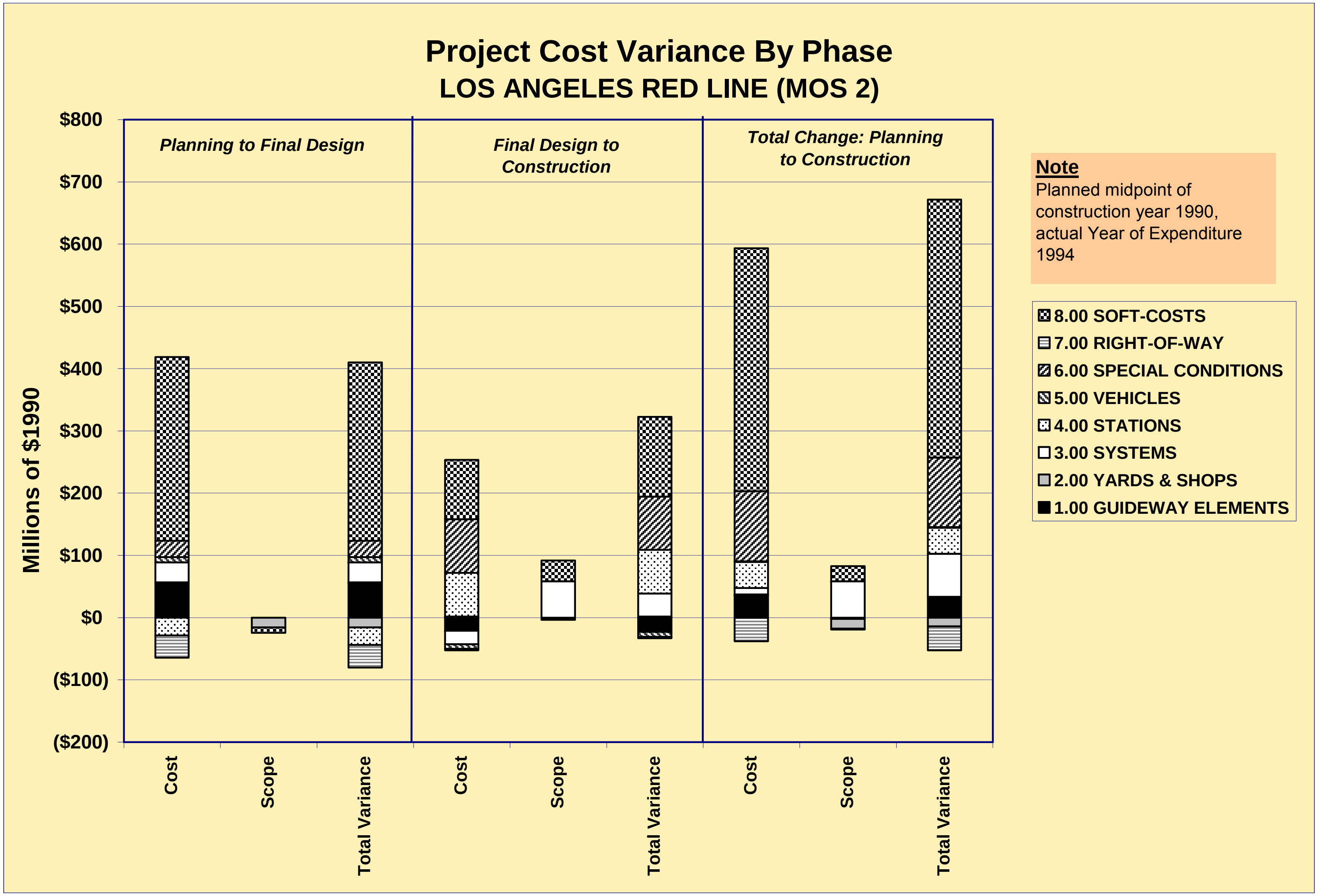


Figure C-14. Los Angeles Red Line (MOS 2) Project Cost Variance by Phase



MOS 3

MOS 3 was a 6.3-mile segment with 3 stations, which extended the Hollywood branch of MOS 2 north through the Santa Monica mountains into North Hollywood in the San Fernando Valley.

The project's initial DEIS cost estimate of $898.3 was in 1983 dollars, while the project development schedule was planned for an opening of 1994 and a likely midpoint of construction of 1992. Adjusted into year-of-cost-estimate dollars to account for the project development schedule, the baseline planning estimate was $1.11 billion.

Total Project Cost by Phase

The upper line graph in **Figure C-15** shows the planning estimates adjusted to the initial project schedule in year 1992 dollars, and illustrates the changes in total cost incurred by the project through construction. MOS 3 experienced further delay after the splitting of the Red Line, with the planned opening changing from 1994 to 1996 at final design, and to 1997 at actual opening. The corresponding slip in midpoint of construction was from 1992 to 1995.

The lower line graph in **Figure C-15** illustrates the scope and unit cost impacts of the many changes introduced throughout the development of MOS 3. Scope changes resulted in a small total cost decrease of approximately $4.6 million (0.4 percent) of the planning DEIS estimate that was modified to account for the planned project development schedule (dark line), while unit cost adjustments led to a small cost increase in the project cost of about $25.4 million (2.3 percent) of the adjusted planning estimate (gray line).

The unit cost adjustments occurred primarily in final design, in anticipation of more difficult construction conditions than originally planned. Oversize tunnel boring was required through the mountain into the North Hollywood area to overcome the position and size of a seismic fault zone and to meet Fire Services requirements regarding ventilation.

Detailed Cost Variance by Phase

Figure C-16 illustrates the detailed project cost variance by phase**.** From planning to operations, project scope quantities decreased primarily in the cost category of guideway elements (1.00). Cost adjustments included increases in categories such as soft costs (8.00), decreases in categories such as ROW acquisition (7.00), and fluctuation in categories such as guideway elements (1.00) and stations (4.00). The total variance shows the cost adjustments summing to a small increase in project cost.

Summary

At planning, the total cost estimate for MOS 3 was $898.3 million, but the project was completed for $1.23 billion. Although not as large as the cost increases for MOS 1 and MOS 2, MOS 3 experienced a cost increase of $329.4 million (36.7 percent). The increase for MOS 3 can partially be attributed to adjusting the initial project estimate into year-of-cost-estimate dollars to account for the project development schedule. This increased the estimate by $21.5 million (23.9 percent), resulting in a baseline planning estimate of $1.11 billion. Project costs then increased from the baseline planning estimate due to changes throughout project development:

- MOS 3 experienced multiple schedule delays, shifting the estimated midpoint of construction from 1992 to 1995I, which increased project costs by about $93.6 million (10.4 percent of the baseline).
- The remaining $20.8 million increase (2.3 percent of the baseline) was due to unit cost and scope changes.

Figure C-15. Los Angeles Red Line (MOS 3) Total Project Costs by Phase

Total Project Costs by Phase
LOS ANGELES RED LINE (MOS 3)

Project Phase	Planning	Final Design	Construction/Installation
Key Events Changes in costs, quantities and schedule from specific events **Note** Planning phase costs were reported for combined project (MOS 1,2, and 3), and have been separated for comparison purposes.	**1**. Planned midpoint of construc-tion 1992	**1**. Alignment location revised **2**. Added fireman's ventilation requirements **3**. Added costs for environmental mitigation, landscaping, and third party agreements **4**. Added soft costs: initial design, project management, and "other soft-costs" **5**. Midpoint of construction 1994	**1**. Cost adjustments to several categories: guideway, systems, stations, soft costs **2**. Landscaping costs removed from special conditions **3**. Year of Expenditure 1995

Anticipated Project Duration at Each Phase

PE/FEIS → 1992 Construction Midpoint
Final Design → 1994 Midpoint
Construction/Installation → 1995 YOE

Project Cost By Phase
Dollar cost estimates are denominated in the anticipated midpoint of construction year /YOE (solid line) and the project planning midpoint of construction year (dotted line)

Sources of Change
The dark line shows the adjustment to project costs resulting from changes in scope while the lighter line shows the impact of changes in unit costs (excluding inflation)

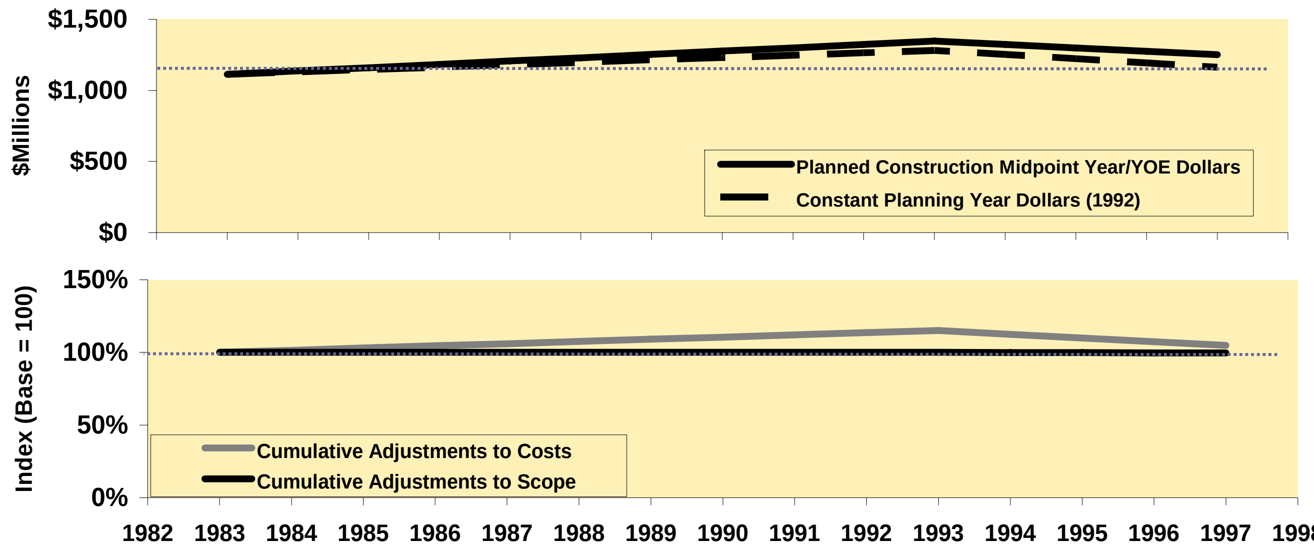
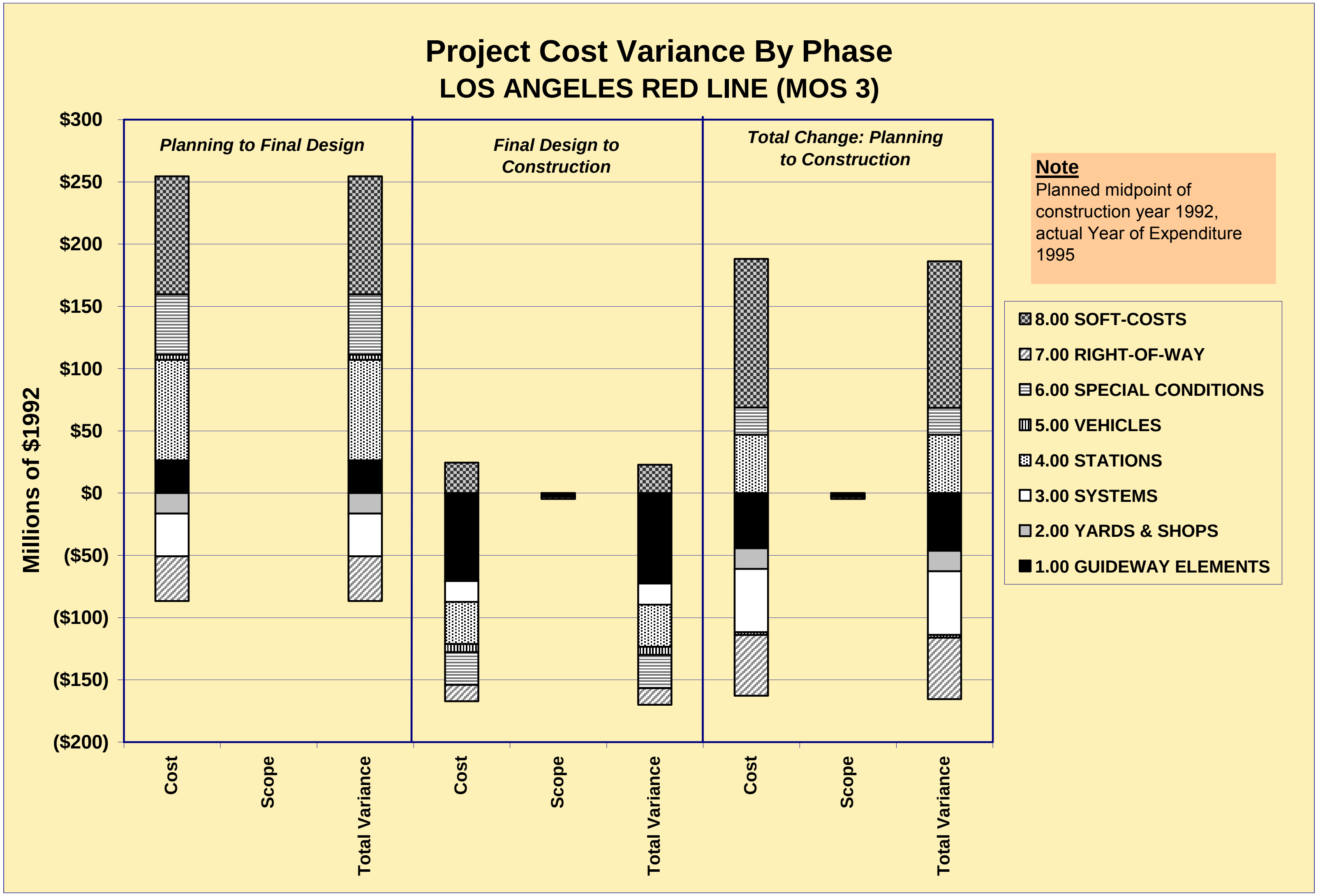


Figure C-16. Los Angeles Red Line (MOS 3) Project Cost Variance by Phase



Minneapolis Hiawatha Line

Metro Transit and the Metropolitan Council (local Metropolitan Planning Organization), in cooperation with the Minnesota Department of Transportation (MnDOT), Hennepin County, and the Metropolitan Airports Commission (MAC), constructed an 11.6-mile light rail transit (LRT) line within the Hiawatha Corridor. The line operates on the Hiawatha Avenue/Trunk Highway 55 Corridor linking downtown Minneapolis, the Minneapolis-St. Paul (MSP) International Airport, and the Mall of America in Bloomington. The project included a 1.5-mile tunnel under the MSP airport runways and taxiways, 26 light rail vehicles, and a total of 17 stations—12 stations on the Hiawatha Corridor, 3 stations in Bloomington, and a station serving the Mall of America.

The line graph in **Figure C-17** shows the planning estimates adjusted to the initial project schedule in year 1998 dollars, and illustrates the changes in total cost incurred by the project through construction. The 1999 planned opening of the South Hiawatha Line was delayed between each phase of the project to actual opening in 2004. Between planning and actual opening, the midpoint of construction thus shifted from 1998 to 2002.

The Hiawatha Line project started out at a $581.0 million total cost, and was completed for $715.3 million, experiencing an increase of $134.4 million (23.1 percent). Because the initial DEIS cost estimate was in year-of-cost-estimate dollars, no adjustment was required to determine the baseline planning estimate. Schedule delays increased project costs by $75.6 million (13.0 percent). Changes in unit cost and scope accounted for a $58.7 million (10.1 percent) net increase.

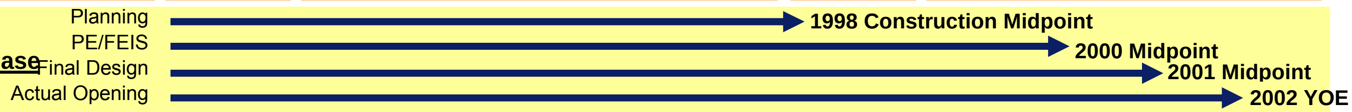
In August 1999, Metro Transit completed a re-evaluation of the FEIS on a segment of the alignment extending from the Minneapolis CBD to Interstate 494 (I-494). An environmental assessment on the segment extending from I-494 to the Mall of America was also completed at that time. Subsequently, the alignment was shortened by 0.6 miles, a tunnel was added, and the vehicle fleet procurement increased slightly. These changes drove the revision of costs (particularly right-of-way acquisition) and ridership estimates.

Figure C-17. Hiawatha Corridor LRT Total Project Costs by Phase

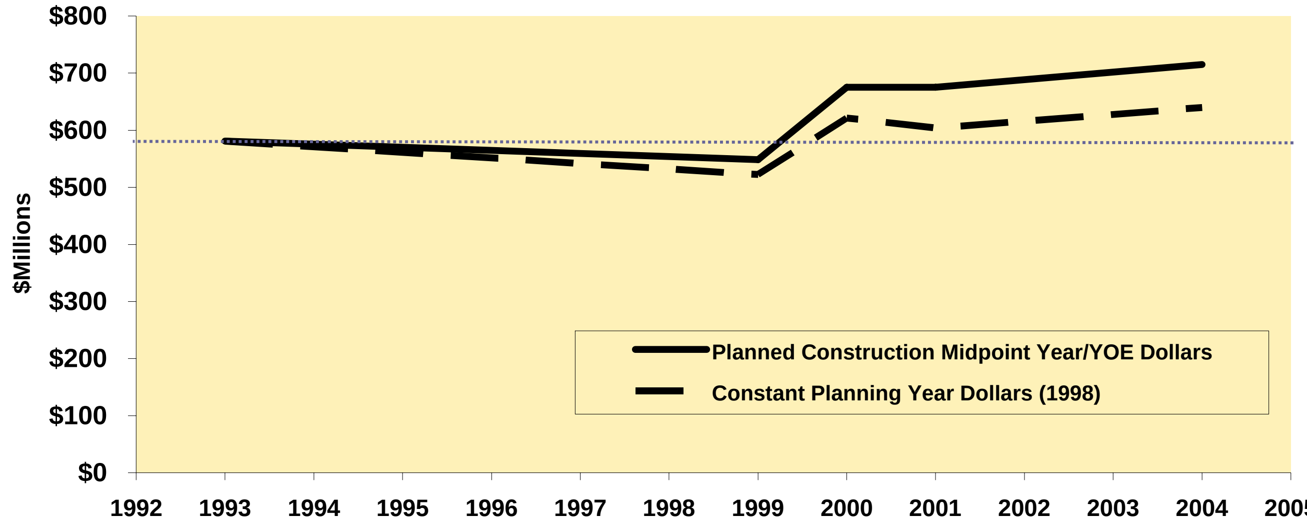
Total Project Costs by Phase
MINNEAPOLIS HIAWATHA LINE

Project Phase	**Planning**	**PE/FEIS**	**Final Design**	**Construction/Operations**
Key Events Changes in costs, quantities and schedule from specific events	**1**. Planned midpoint of construction 1998	**1**. Alignment length reduced from 12.2 to 11.6 miles; added 1.5 mile tunnel **2**. Number of stations reduced from 18 to 17 **3**. Vehicle fleet size increased from 60 to 64 **4**. Midpoint of construction 2000	**1.** 4 vehicles added **2**. Cost of ROW revised **3**. Midpoint of construc-tion 2001	**1**.Year of Expenditure 2002

Anticipated Project Duration at Each Phase



Project Cost By Phase
Dollar cost estimates are denominated in the anticipated midpoint of construction year /YOE (solid line) and the project planning midpoint of construction year (dotted line)



New Jersey Hudson-Bergen MOS 1

The Hudson-Bergen Waterfront MOS 1 is a 9.6-mile, 16-station light rail line along the Hudson River Waterfront in Hudson County, from the Hoboken Terminal to 34th Street in Bayonne and Westside Avenue in Jersey City. This line was intended as the "initial operating segment" of a larger 21-mile, 30-station line extending from the Vince Lombardi park-and-ride lot in Bergen County to Bayonne, passing through Port Imperial in Weehauken, Hoboken, and Jersey City. The minimum operating segment was defined in 1996 and the alignment was shortened; although, an alignment shift in Hoboken increased the number of stations. New Jersey Transit used a turnkey procurement to implement the project. A design-build-operate-maintain contract was signed in October 1996, and notice to proceed was given to the contractor in November 1996. Revenue operations were phased over two years with the segment to Exchange Place (Phase A) opening in April 2000, three additional stations in November 2000, and full service to the Hoboken Terminal in the Spring of 2002.

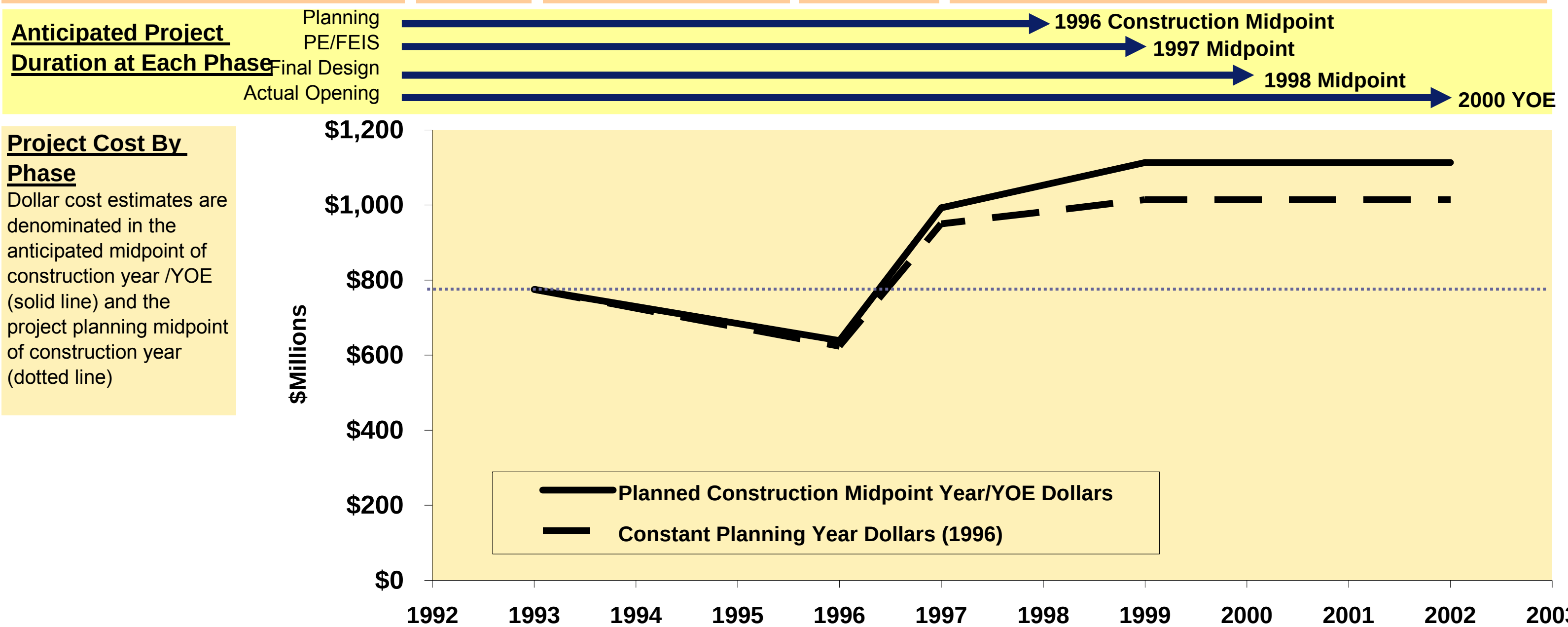
The line graph in **Figure C-18** shows the planning estimates adjusted to the initial project schedule in year 1996 dollars, and illustrates the changes in total cost incurred by the project through construction. The opening of the Hudson-Bergen line was delayed multiple times during its planned opening in 1998 to actual opening in 2002. The corresponding slip in midpoint of construction was from 1996 to 2000.

The total cost of the Hudson-Bergen LRT project was originally estimated to be $775.0 million, but increased by $338.0 million (43.6 percent) to $1.11 billion. Because the initial DEIS cost estimate was in year-of-cost-estimate dollars, no adjustment was required to determine the baseline planning estimate. The project cost increase was partially due to the many changes to project schedule, which increased project costs by about $98.5 million (12.7 percent). The remaining $239.5 million (30.9 percent) increase was due to net changes in unit cost and scope.

Figure C-18. New Jersey Hudson-Bergen MOS 1Total Project Costs by Phase

Total Project Costs by Phase
NEW JERSEY HUDSON-BERGEN (MOS-1)

Project Phase	**Planning**	**PE/FEIS**	**Final Design**	**Construction/Operations**
Key Events Changes in costs, quantities and schedule from specific events	**1**. Planned midpoint of construc-tion 1996	**1**. Alignment reduced by 1.5 miles **2**. Planned midpoint of construction 1997	**1**. Major revisions to alignment location **2**. Midpoint of construction 1998	**1**. Revenue operations were phased over two years with the segment to Exchange Place (Phase A) opening in April 2000, three additional stations in November 2000, and full service to the Hoboken Terminal in the Spring of 2002 **2.** Year of Expenditure 2000



New York 63rd Street Connector

The New York 63rd Street Connector runs from the 63rd Street tunnel to the existing express and local tracks of the Queens Boulevard subway lines, through a new short tunnel segment. The Queens Connector consists of approximately 1/3-mile of new tunnel, with corresponding track, signal work, and real estate acquisition. The goal of the project was to relieve severe overcrowding on the Queens Boulevard subway lines by diverting service from the existing bottleneck in the 53rd Street tunnel to the 63rd Street tunnel, allowing the operation of an additional 15 trains per hour between Manhattan and Queens.

The line graph in **Figure C-19** shows the planning estimates adjusted to the initial project schedule in year 1995 dollars, and illustrates the changes in total cost incurred by the project through construction. The 1997 planned opening of the 63rd Street Connector was delayed to actual opening in 2001. The corresponding slip in midpoint of construction was from 1995 to 1998.

The 63rd Street Connector project started out at a $488.4 million total cost, and was completed for $632.3 million. Because the initial DEIS cost estimate was in year-of-cost-estimate dollars, no adjustment was required to determine the baseline planning estimate. The increase of $143.9 million (29.5 percent) is partially due to schedule delays, which escalated project costs by about $41.2 million (8.4 percent). The remaining $102.7 million (21.0 percent) increase was due to net changes in unit cost and scope. Early estimates were affected by New York City labor costs, working around active roadway and railroad, and limited allowable work hours.

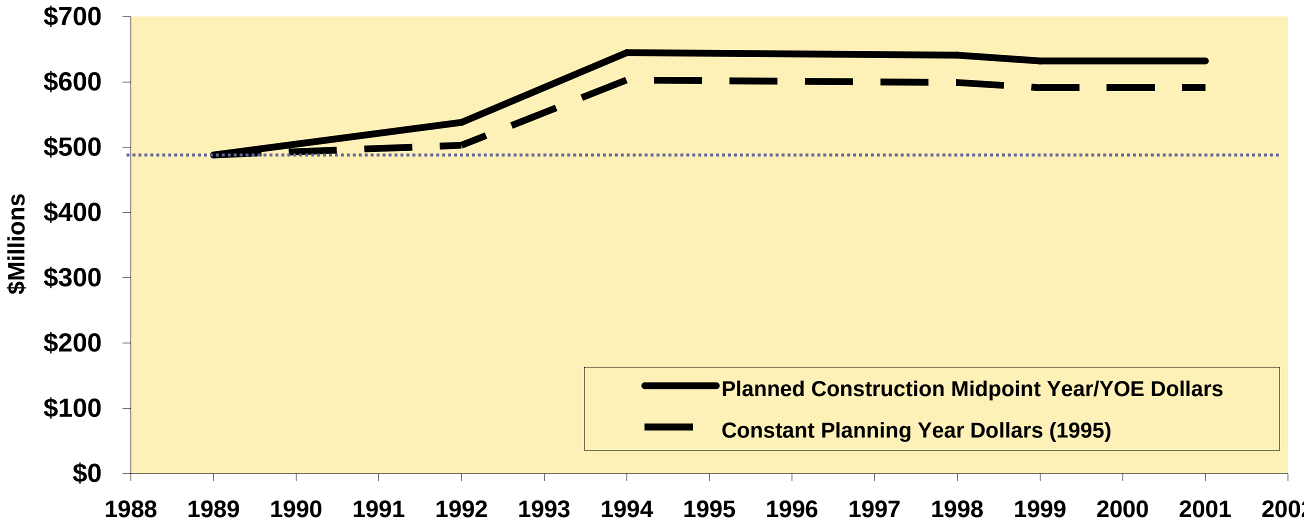
Figure C-19. New York NYCT 63rd St. Connector Total Project Costs by Phase

Total Project Costs by Phase
NEW YORK 63RD SREET CONNECTOR

Project Phase	**Planning**	**PE/FEIS**	**Final Design**	**Construction/Operations**
Key Events Changes in costs, quantities and schedule from specific events	**1**. Planned midpoint of construction 1995	**1.** Midpoint of construction 1998	**1.** Early estimates were affected by NYC labor costs, working around active roadway and railroad, and limited allowable work hours **2**. Midpoint of construction 1998	**1**. Year of Expenditure 1998

Anticipated Project Duration at Each Phase

Project Cost By Phase
Dollar cost estimates are denominated in the anticipated midpoint of construction year /YOE (solid line) and the project planning midpoint of construction year (dotted line)



Pasadena Gold Line

The Pasadena Gold Line is Los Angeles County's latest light rail project to open. In 1994, the agency purchased the Atchison, Topeka, and Santa Fe railroad rights-of-way to be used for the alignment. After the budget began to escalate, the agency requested a cost containment study to be completed in 1996, and the budget was reduced while the revenue operation date (ROD) was extended to May 2001. Shortly thereafter, the Los Angeles County Metropolitan Transportation Authority (Metro) continued with the constrained design and began minimal construction of the project. By 1998, Metro had expended over $200 million on design and construction, and the ROD was again extended to July 2002. Metro then decided to suspend the project due to budget concerns. The project was eventually restarted in 1999 under the Metro Gold Line Construction Authority with a new name—the Gold Line.

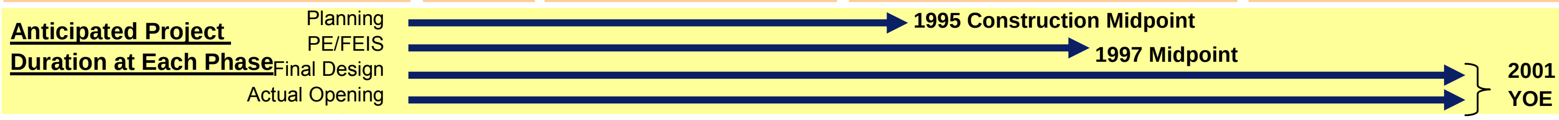
The line graph in **Figure C-20** shows the planning estimates adjusted to the initial project schedule in year 1995 dollars, and illustrates the changes in total cost incurred by the project through construction. The planned opening of the Gold Line was delayed from 1997 to actual opening in 2003. The corresponding slip in midpoint of construction was from 1995 to 2001.

The original budget forecast in 1993 was $997.5 million with a ROD of November 1997. The project was completed for $677.6 million—a $320.1 million (32.1 percent) decrease. Because the initial DEIS cost estimate was in year-of-cost-estimate dollars, no adjustment was required to determine the baseline planning estimate. Schedule delays caused a project cost increase of $94.8 million (9.5 percent). However, the schedule was also delayed to allow for many changes in scope and unit cost, resulting in a reduction in project costs of $414.7 million (41.6 percent). Significant changes were made to the scope of the stations and maintenance facilities. The key cost drivers identified were systems, trackwork, stations, elevated structures, differing site conditions, and third-party influence on scope.

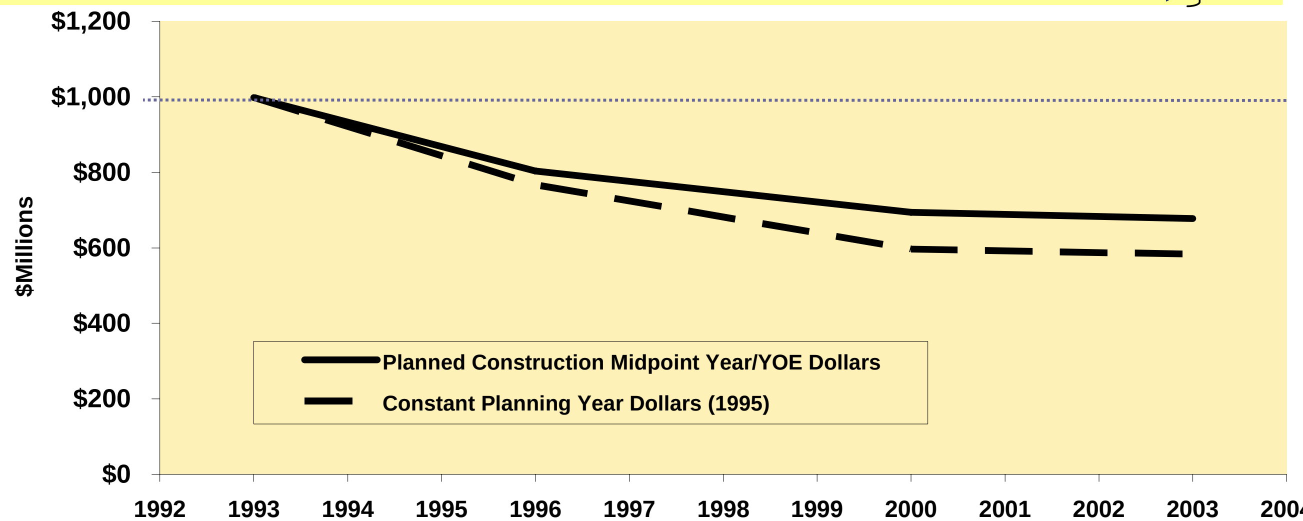
Figure C-20. Pasadena Gold Line Total Project Costs by Phase

Total Project Costs by Phase
PASADENA GOLD LINE

Project Phase	**Planning**	**PE/FEIS**	**Final Design**	**Construction/Operations**
Key Events Changes in costs, quantities and schedule from specific events	1. Planned midpoint of construction 1995	1. Number of stations decreased from 14 to 13 2. Number of traction power substations decreased from 15 to 13 3. Midpoint of construction 1997	1. Significant reductions in unit costs for several cost categories 2. Project suspended in 1998, restarted under Metro Gold Line Construction Authority in 1999 3. Midpoint of construction 2001	1. Minor cost revisions 2. Year of Expenditure 2001



Project Cost By Phase
Dollar cost estimates are denominated in the anticipated midpoint of construction year /YOE (solid line) and the project planning midpoint of construction year (dotted line)



Pittsburgh Airport Busway (Phase 1)

The Pittsburgh Airport Busway consists of five miles of exclusive bus right-of-way and an exclusive interchange for buses along the Parkway West (I-279) in the Borough of Carnegie. Via direct bus service that extends beyond the busway, the Airport Busway connects the Pittsburgh International Airport and businesses surrounding the Airport and along Parkway West, with downtown Pittsburgh and other employment and activity centers in the area. The following BRT components are demonstrated in this system: exclusive busway, enhanced stations, simplified route structure, limited stops, signal priority, high operating speed, and multi-modal interfaces. The goal of the Port Authority for the West Busway was to improve mobility within the increasingly congested Parkway West corridor.

The line graph in **Figure C-21** shows the planning estimates adjusted to the initial project schedule in year 1993 dollars, and illustrates the changes in total cost incurred by the project through construction. The planned opening of the Pittsburgh Airport Busway was delayed multiple times from the estimate of 1994. The actual opening occurred in two phases, with the full system opening in 2002. The corresponding slip in midpoint of construction was from 1993 to 2001.

The Pittsburgh Airport Busway project had an estimated total cost of $170.2 million, but experienced an increase of $156.6 million (92.0 percent) in total costs to be completed for $326.8 million. Because the initial DEIS cost estimate was in year-of-cost-estimate dollars, no adjustment was required to determine the baseline planning estimate. The many changes to project schedule shifted the estimated midpoint of construction from 1993 to 2001, which increased project costs by about $61.1 million (35.9 percent). The remaining $95.5 million (56.1 percent) increase was due to net changes in unit cost and scope. In 1997, the FTA asked the agency for a recovery plan because of significant cost and schedule overruns. Under the FFGA, any overruns were the responsibility of the agency. As a result, the Mon River Bridge and Conrail shelf portions of the Airport Busway/Wabash HOV Project were dropped in the recovery plan. The principal cost drivers were the purchase of rail rights-of-way, elevated structures and tunnels, and higher than expected property and acquisition costs.

Figure C-21. Pittsburgh PAAC Airport Busway Total Project Costs by Phase

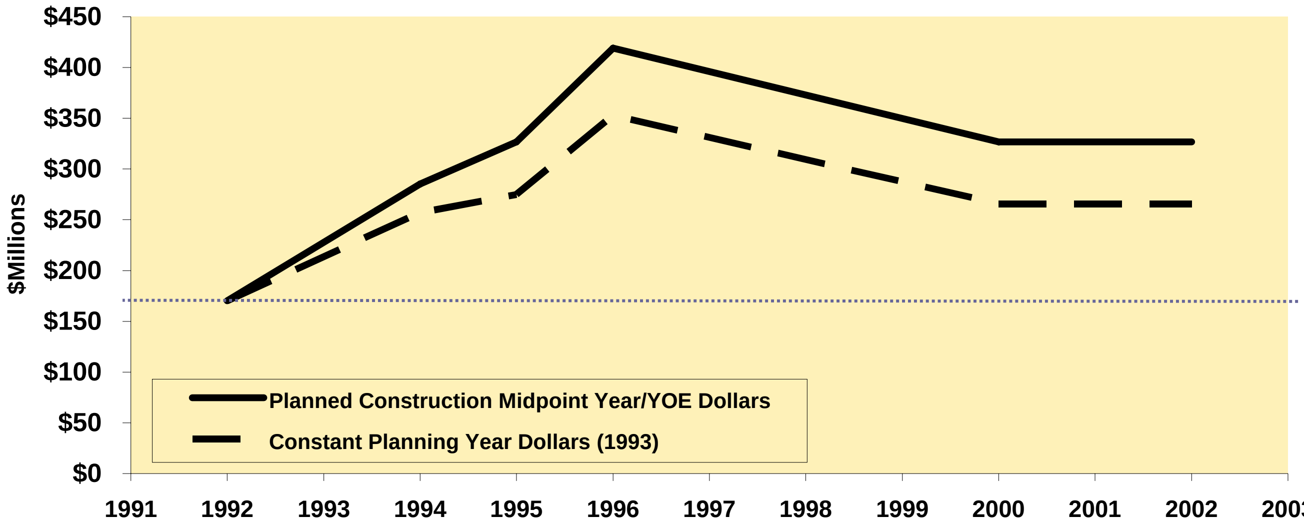
Total Project Costs by Phase
PITTSBURGH AIRPORT BUSWAY (PHASE 1)

Project Phase	**Planning**	**PE/FEIS**	**Final Design**	**Construction/Operations**
Key Events Changes in costs, quantities and schedule from specific events	**1**. Planned midpoint of construc-tion 1993	**1**. Midpoint of construc-tion 1996	**1.** Midpoint of construc-tion 1996	**1**. In 1997, the FTA asked the agency for a recovery plan because of significant cost and schedule overruns. Under the FFGA, any overruns were the responsibility of the agency. The result was that the Mon River Bridge and Conrail shelf portions of the Airport Busway/Wabash HOV Project were dropped from the project in the recovery plan. The principal cost drivers were the purchase of rail rights-of-way, elevated structures and tunnels, higher than expected property acquisition costs, design changes, and inflationary factors due to schedule delay. **2.** Year of Expenditure 2001

Anticipated Project Duration at Each Phase

- Planning → 1993 Construction Midpoint
- PE/FEIS → 1996 Midpoint
- Final Design → 1996 Midpoint
- Actual Opening → 2001 YOE

Project Cost By Phase
Dollar cost estimates are denominated in the anticipated midpoint of construction year /YOE (solid line) and the project planning midpoint of construction year (dotted line)



Portland Airport MAX Extension

Light rail to Portland International Airport (PDX) had been part of regional and airport master planning since the mid-1980s. The design of Interstate 205 included a future transitway in the median, including a tunnel beneath the northbound lanes. While a preliminary light rail alignment to the airport terminal was established in the late 1980s, regional plans placed development closer to 2010. In 1997, Bechtel Enterprises approached the region with a proposal to design and construct a TriMet Metropolitan Area Express (MAX) extension to the airport under a public-private partnership. Bechtel would contribute a quarter of the project's funding and be contracted to build the light rail extension. In return, Bechtel would receive development rights to a 120-acre, mixed-use commercial site near the entrance to the airport. This innovative cost-sharing venture meant no federal appropriations, state general funds, or additional property taxes were needed to build the line.

The line graph in **Figure C-22** shows the planning estimates adjusted to the initial project schedule in year 2000 dollars, and illustrates the changes in total cost incurred by the project through construction. The project schedule remained constant throughout project development, and the project was completed on time. **Figure C-22** illustrates this in the absence of any difference between the planning year estimate (dashed line) and the year-of-cost estimate (solid line).

The Airport MAX project started out at a total cost of $125.0 million, and was completed for $127.0 million. Because the initial DEIS cost estimate was in year-of-cost-estimate dollars, no adjustment was required to determine the baseline planning estimate. Since there were no schedule delays, the $2.0 million (1.6 percent) increase was completely due to changes in scope and unit cost over the project developmental period. Although the project was delivered close to budget, early cost estimation was influenced by insurance, the start of construction, and management overhead.

Figure C-22. Portland Airport MAX Extension Total Project Costs by Phase

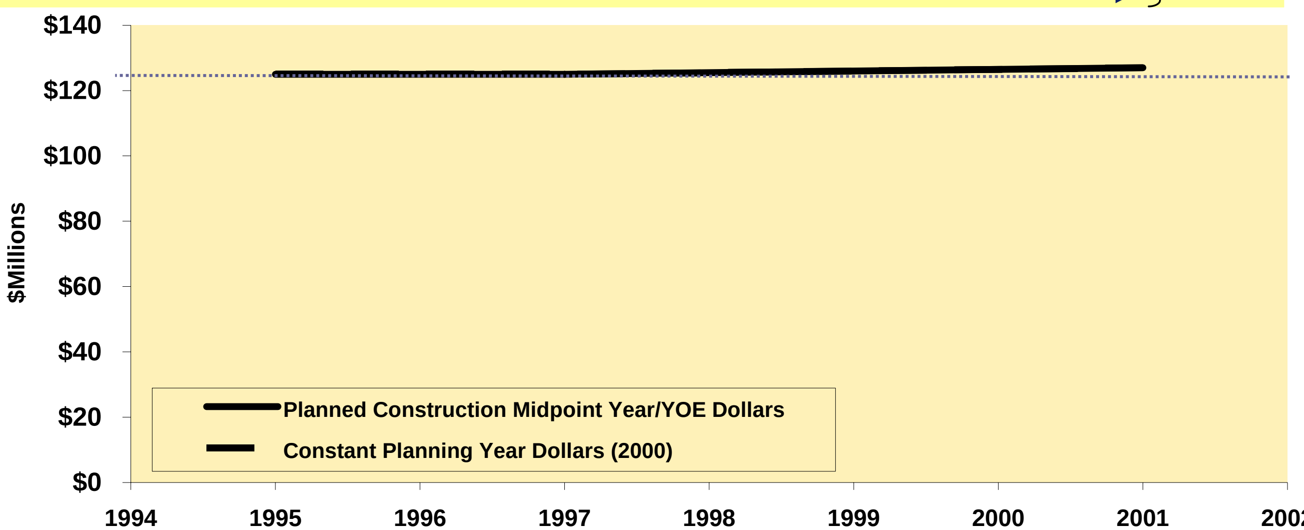
Total Project Costs by Phase
PORTLAND AIRPORT MAX EXTENSION

Project Phase	**PE/FEIS**	**Final Design**	**Construction/Operations**
Key Events Changes in costs, quantities and schedule from specific events	**1**. Planned midpoint of construction 2000	**1.** Midpoint of construction 2000	**1**. Early estimates influenced by insurance and management overhead. **2**. Year of Expenditure 2000

Anticipated Project Duration at Each Phase

PE/FEIS
Final Design
Actual Opening
2000 YOE

Project Cost By Phase
Dollar cost estimates are denominated in the anticipated midpoint of construction year /YOE (solid line) and the project planning midpoint of construction year (dotted line)



Portland Banfield Corridor

The Portland Banfield Corridor is a 15.1-mile initial LRT investment with 13 miles of double-track, 2.1 miles of single track with two-way traffic, and 25 at-grade stations. The project objectives were to provide rail service between Portland and Gresham and to create intermodal convenience for the public and reduce traffic congestion on adjacent freeways.

Total Project Cost by Phase

The upper line graph in **Figure C-23** shows the planning estimates adjusted to the initial project schedule in year 1981 dollars, and illustrates the changes in total cost incurred by the project through construction. The planned opening of the Banfield Corridor was delayed from 1982 to an actual opening in 1984. The corresponding slip in midpoint of construction was from 1981 to 1983.

The lower line graph in **Figure C-23** illustrates the scope and unit cost impacts of the many changes introduced throughout the development of the Banfield Corridor project. Changes in scope are estimated to have increased costs by approximately $9.1 million (4.3 percent) from the planning DEIS estimate (dark line). The trend of this line illustrates the small changes overall to project scope. In the final design phase, some minor modifications to the alignment position occurred. The number of vehicles to be procured increased from 29 to 33, and the number of stations decreased from 27 to 25. In the construction phase, the vehicle fleet procurement was reduced from 33 vehicles to 26, while the quantity of maintenance facilities increased.

During this project development period, unit costs for the continuing project scope decreased by about $7.8. million (3.6 percent). As shown by the gray line in the lower line graph in **Figure C-23**, unit costs fluctuated—increasing during design and decreasing during construction. In the final design phase, some minor modifications to the alignment position occurred, and soft costs were increased to account for planning and feasibility studies, preliminary engineering, final design, project initiation, and insurance. In the construction phase, alignment modifications led to a significant reduction in guideway unit costs. Maintenance facilities costs were also reduced, while soft costs were increased for added project management, training, and start-up testing.

Detailed Cost Variance by Phase

Figure C-24 illustrates the detailed project cost variance by phase**.** Both costs and scope fluctuated between phases. From planning to operations, project scope quantities increased by just over $9 million, primarily in the cost categories of yards and shops (2.00). These were offset with close to $8 million in cost decreases through adjustments to soft costs (8.00) and alignment modifications (1.00). The total variance shows the counterbalancing of the cost decreases against the scope increases.

Summary

The Portland Banfield project started out at an estimated total cost of $214.0 million, but was completed for a total cost of $246.8 million—a difference of $32.7 million (15.3 percent). Because the initial DEIS cost estimate was in year-of-cost-estimate dollars, no adjustment was required to determine the baseline planning estimate. The net effect of the scope and unit cost changes introduced into the project over the developmental period was a $1.4 million (0.6 percent) net increase in costs. This increase was small in comparison to the impact of the schedule delay, which shifted the midpoint of construction from 1981 to 1983, and increased project costs by about $31.4 million (14.7 percent).

Figure C-23. Portland Banfield Corridor Total Project Costs by Phase

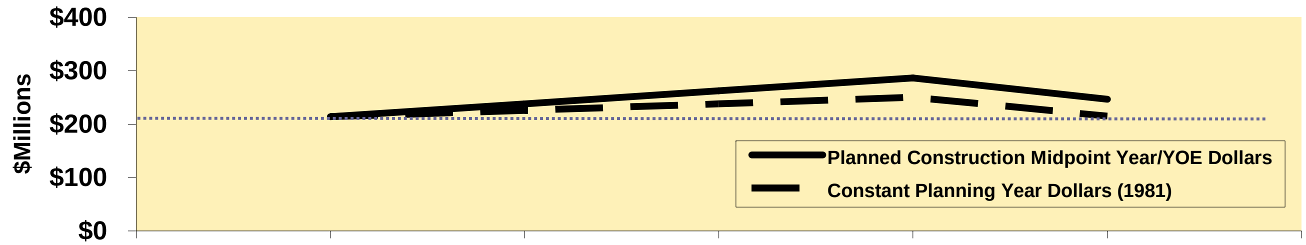
Total Project Costs by Phase
PORTLAND BANFIELD CORRIDOR

Project Phase	PE/FEIS	Final Design	Construction/Operations
Key Events Changes in costs, quantities and schedule from specific events	**1**. Planned midpoint of construction 1981	**1**. Minor modifications to alignment position **2**. Fleet size increased from 29 to 33 vehicles **3**. Soft Costs increased **4**. Midpoint of construction 1983	**1**. Alignment modifications and significant reduction in guideway unit costs **2.** Reduced facility costs **3**. Fleet procurement reduced from 33 to 26 vehicles **4.** Additional RR ROW acquisitions **5.** Soft Costs increased – added Project Management, Construction Management, and Training/Start-up Testing **6**. Year of Expenditure 1983

Anticipated Project Duration at Each Phase

- PE/FEIS → **1981 construction midpoint**
- Final Design → **1983 YOE**
- Construction/Operations → **1983 YOE**

Project Cost By Phase
Dollar cost estimates are denominated in the anticipated midpoint of construction year /YOE (solid line) and the project planning midpoint of construction year (dotted line)



Sources of Change
The dark line shows the adjustment to project costs resulting from changes in scope while the lighter line shows the impact of changes in unit costs (excluding inflation)

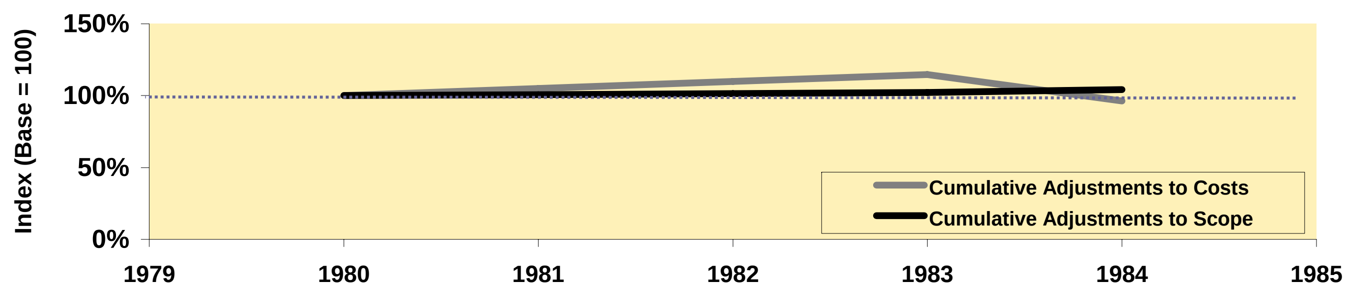
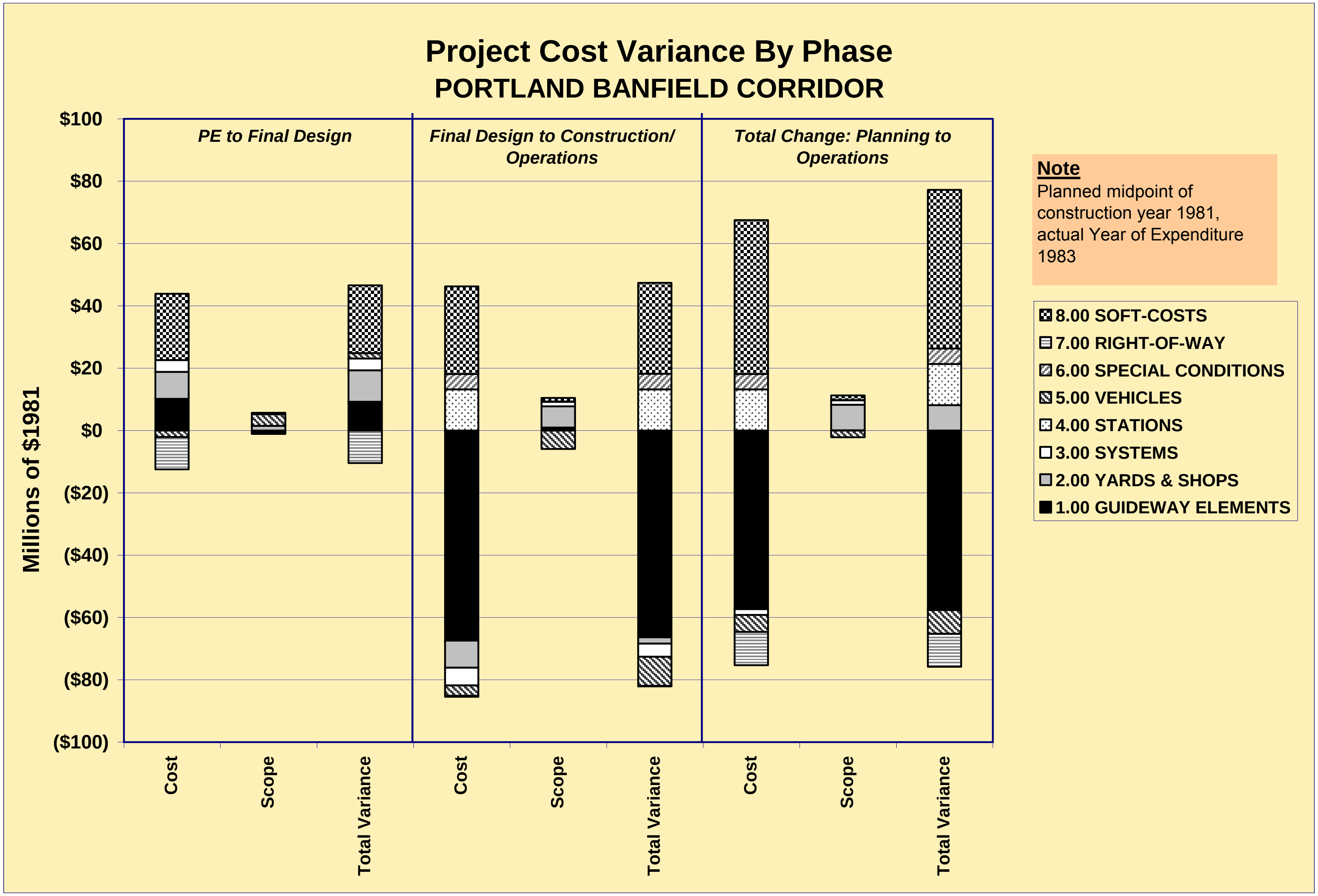


Figure C-24. Portland Banfield Corridor Project Cost Variance by Phase



Portland Interstate MAX

The Interstate MAX light rail project emerged from the former South-North light rail project. In November 1998, voters rejected an affirmation of a $475 million General Obligation bond measure previously approved to fund construction of the South-North LRT. Consequently, TriMet evaluated alternative alignments and funding strategies to implement the system. A 5.8-mile Interstate MAX line emerged that would serve North and Northeast Portland along Interstate Avenue, terminating at the Expo Center. It would tie into the existing MAX Blue Line at Rose Quarter. A design priority was to transform Interstate Avenue into a pedestrian-friendly, multi-modal urban street. Interstate MAX would serve long-established, diverse neighborhoods with a strong sense of community. Station placement and design and art elements reflected the adjacent communities. Since the project would be constructed at grade within the existing street right-of-way, it was also crucial to integrate safety, lighting, and aesthetics into the alignment design.

Interstate MAX used innovative, green construction practices not previously widely applied to light rail construction. Examples include:

- Using 6,000 recycled plastic railroad ties in embedded trackway
- Employing recycled plastic bollards and chains to discourage trespassing
- Creating art elements for storm water management
- Recycling asphalt and concrete as base materials for roadways, trackway, and sidewalks
- Expanding wetlands and tripling the number of trees along the alignment
- Reusing excavated soils in sewer trenches and planters, saving on hauling and disposal
- Recycling excavated old trolley rails
- Designing system support buildings to shed rainwater into the ground rather than into the storm sewer system

The project's initial DEIS cost estimate of $278.9 million was in 1999 dollars, while the project development schedule was planned for an opening of 2004 and a likely midpoint of construction of 2003. Adjusted into year-of-cost-estimate dollars to account for the project development schedule, the baseline planning estimate was $313.4 million.

Total Project Cost by Phase

The upper line graph in **Figure C-25** shows the planning estimates adjusted to the initial project schedule in year 2003 dollars, and illustrates the changes in total cost incurred by the project through construction. The project schedule remained constant throughout project development, and the project was completed on time. **Figure C-25** illustrates this in the absence of any difference between the planning year estimate (dashed line) and the year-of-cost estimate (solid line).

The lower line graph in **Figure C-25** illustrates the scope and unit cost impacts of the changes introduced throughout the development of the Interstate MAX project. Changes in scope are estimated to have decreased costs by approximately $20.8 million (6.6 percent) from the planning DEIS estimate that was modified to account for the planned project development schedule (dark line). Despite an increase in the fleet size during final design, scope reduction during construction was made possible by value engineering, utilizing the construction management/general contractor delivery method, bringing the construction contractor early into the design phase, and using innovative construction practices and materials.

During this same project development period, unit costs for the continuing project scope increased by about $56.8 million (18.1 percent of the adjusted planning estimate). As shown by the gray line in the lower line graph in **Figure C-25**, the unit cost trend mirrored the scope trend. Alignment costs went down during final design, but up again during construction. Construction costs were also impacted by the need to close the MAX Blue Line for a brief period while existing tracks were raised and realigned. During the closure, buses shuttled MAX riders around the area. In addition, in the Kenton neighborhood, a 37-foot, 6-ton statue of Paul Bunyan served as a community icon for more than 40 years—and stood in the middle of the planned alignment. In a community event, the statue was moved 59.2 feet to a new plaza.

Detailed Cost Variance by Phase

Figure C-26 illustrates the detailed project cost variance by phase. From planning to operations, project scope quantities fluctuated, but decreased overall by almost $21 million. The primary changes were in the cost categories of guideway elements (1.00), systems (3.00), and soft costs (8.00). The fleet size was also increased during final design (5.00). The decrease from scope was offset with about $57 million in cost increases through adjustments to soft costs (8.00), alignment modifications (1.00), and impacts of special conditions (6.00). The total variance shows the counterbalancing of the cost increases against the scope reductions.

Summary

The Interstate MAX project started out at an estimated total cost of $278.9 million, but was completed for $349.4 million. The $70.5 million increase (25.3 percent) was due partially to adjusting the initial cost estimate into year-of-cost-estimate dollars. This increased the project cost estimate by about $34.5 million (12.4 percent), to a baseline planning estimate of $313.4 million. Since there were no schedule delays, the remainder of the increase was completely due to changes in scope and unit cost over the project developmental period. Scope changes and cost adjustments resulted in a $36.0 million (11.5 percent) increase to the baseline planning estimate.

Figure C-25. Portland Interstate MAX Total Project Costs by Phase

Total Project Costs by Phase
PORTLAND INTERSTATE MAX

Project Phase	**Planning**	**PE/FEIS**	**Final Design**	**Construction/Operations**
Key Events Changes in costs, quantities and schedule from specific events	**1**. Planned midpoint of construc-tion 2003	**1**. Facilities expanded **2**. Added costs for central control facility and increased electrification **3**. Added start-up costs to soft costs **4.** Midpoint of construction 2003	**1.** Minor alignment modifications **2.** Fleet procurement increased from 17 to 24 vehicles **3.** Added costs of demolitions **4**. Midpoint of construction 2003	**1.** Changes to alignment and structures yielding significant increase in guideway costs **2**. Addition of significant costs for utility relocation, environmental mitigation and landscaping **3**. Major reduction in project soft-costs relative to prior estimates **4.** Year of Expenditure 2003

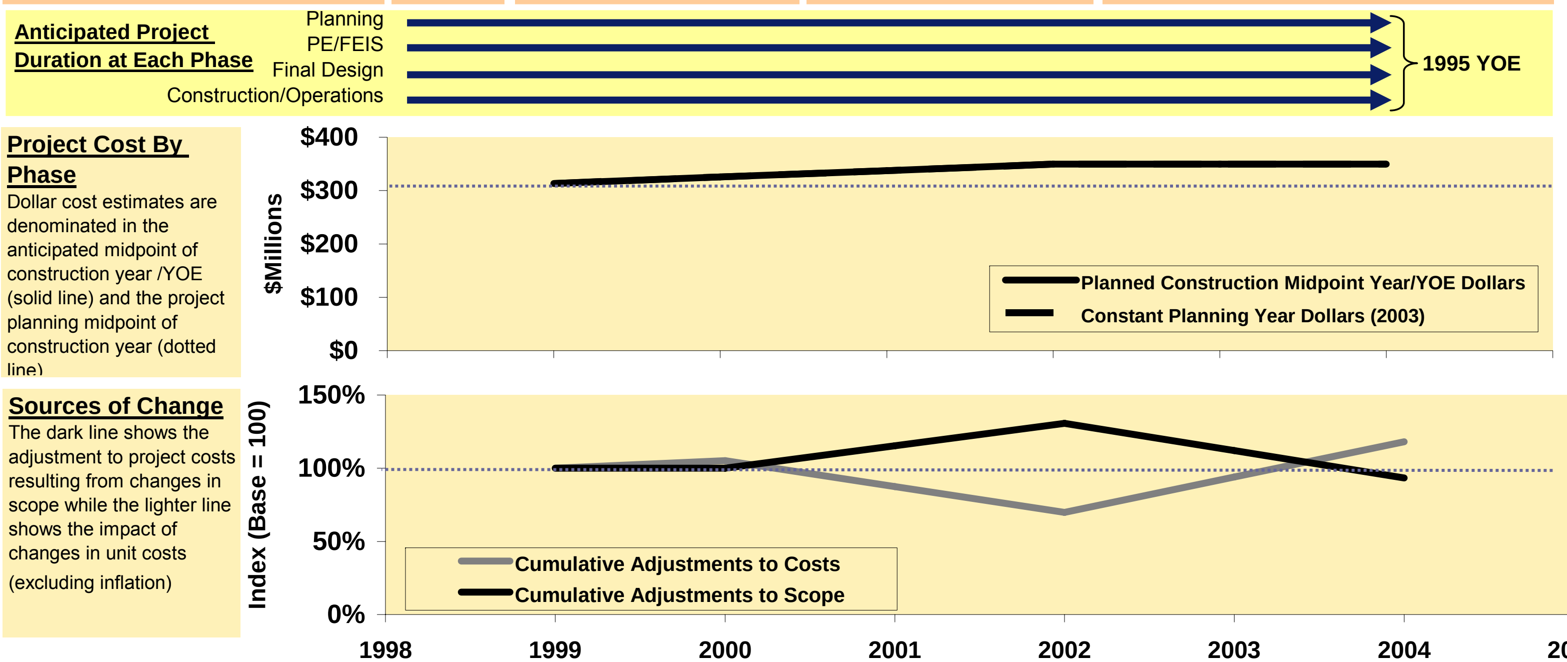
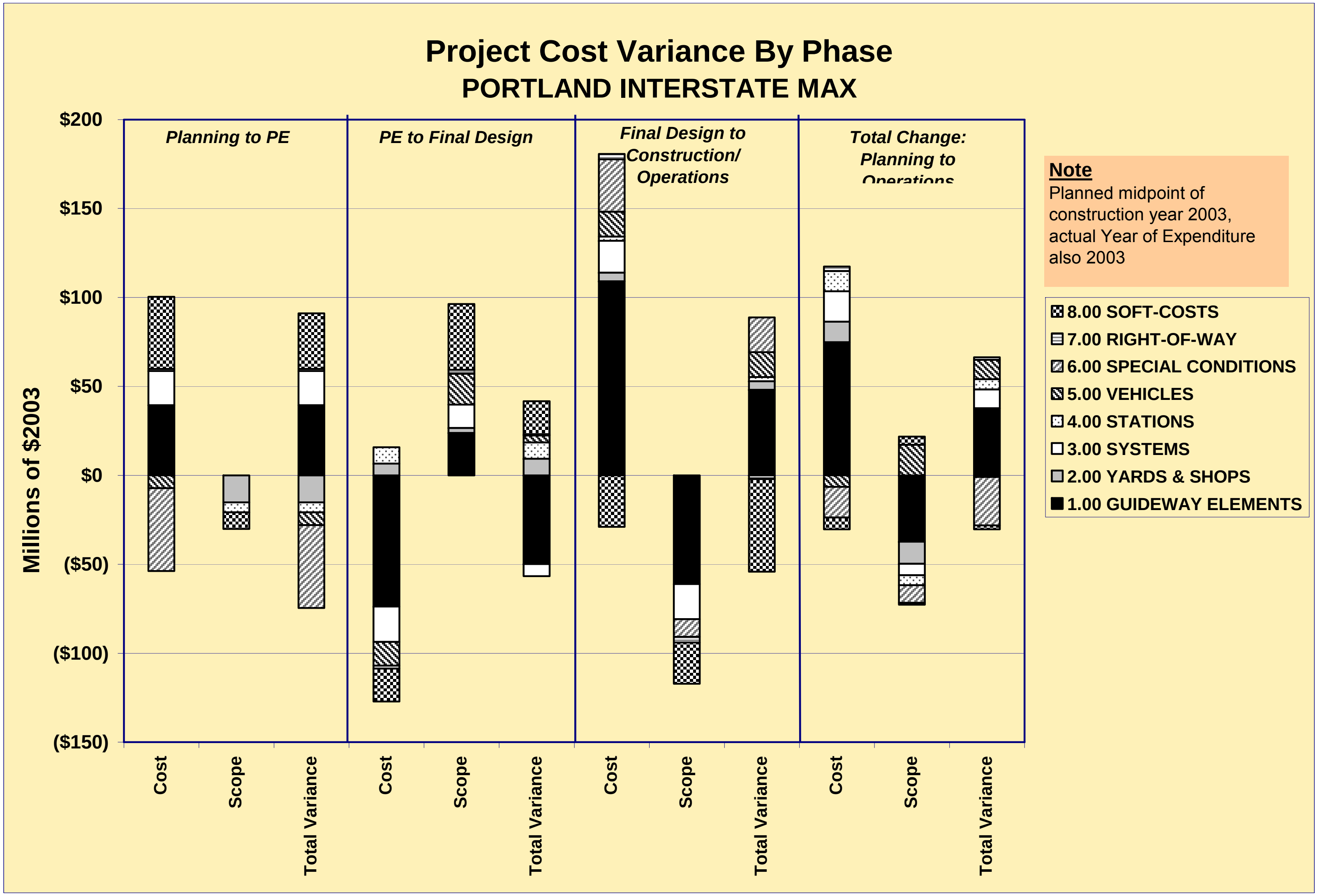


Figure C-26. Portland Interstate MAX Project Cost Variance by Phase



Portland Westside/Hillsboro MAX

This was an extension of Portland's MAX light rail line. The Westside MAX connects Downtown Hillsboro to Downtown Portland and to Gresham. The extension is 18 miles and includes 20 new stations and 52 light rail vehicles supplied by Siemens Transportation Systems (NW Virtual Transit Center 1998). The low-floor light rail vehicles were the first of their kind in North America, and are easily accessible to handicapped persons without the need for lifts on the platforms.

The extension runs along dedicated ROW, city streets, and a three-mile tunnel. The 6.2-mile Hillsboro side was added to the 12-mile Westside project after the FEIS. There is one station in the tunnel; at 260 feet, it was the deepest station in North America at the time it was built (Elcon Associates Inc. undated). The community was heavily involved in choosing the alignment, other project features, and the construction plan, demanding an additional station during the planning (Hastings 2003).

The project's initial DEIS cost estimate of $479.8 million was in 1988 dollars, while the project development schedule was planned for an opening of 1994 and a likely midpoint of construction of 1992. Adjusted into year-of-cost-estimate dollars to account for the project development schedule, the baseline planning estimate was $531.9 million.

The line graph in **Figure C-27** shows the planning estimates adjusted to the initial project schedule in year 1992 dollars, and illustrates the changes in total cost incurred by the project through construction. The 1994 planned opening of the Westside/Hillsboro MAX was delayed to an actual opening in 1998. The corresponding slip in midpoint of construction was from 1992 to 1996.

The Westside/Hillsboro project started out at an estimated total cost of $479.8 million, but was completed for a total cost of $963.5 million. The majority of the $483.7 million increase (100.8 percent) was due to the addition of the Hillsboro extension to the Westside project, which impacted scope and schedule. First, however, adjusting the initial cost estimate into year-of-cost-estimate dollars to account for the project development schedule increased the estimate by $52.1 million (10.9 percent), resulting in a baseline planning estimate of $531.9 million. Project costs then increased from the baseline planning estimate due to changes throughout project development:

- Due to schedule delays, the estimated midpoint of construction shifted from 1992 to 1996. This schedule delay impact increased project costs by about $94.4 million (17.8 percent of the baseline).
- Scope changes and cost adjustments resulted in a $337.1 million (63.4 percent of the baseline) increase to total cost. This reflects the combination of the Westside and Hillsboro segments into a single project. Other cost increases included a $13 million

claim on a $29 million contract during construction, a $75 million increase on a $104 million tunnel segment, and an additional $2.5 million for utility relocation work (Irwin 2003). Issues during construction included work (blasting noise) in the tunnel that elicited resident complaints. In response, Tri-Met had to limit construction during the night hours (Grodner 1998).

Figure C-27. Portland Westside/Hillsboro MAX Total Project Costs by Phase

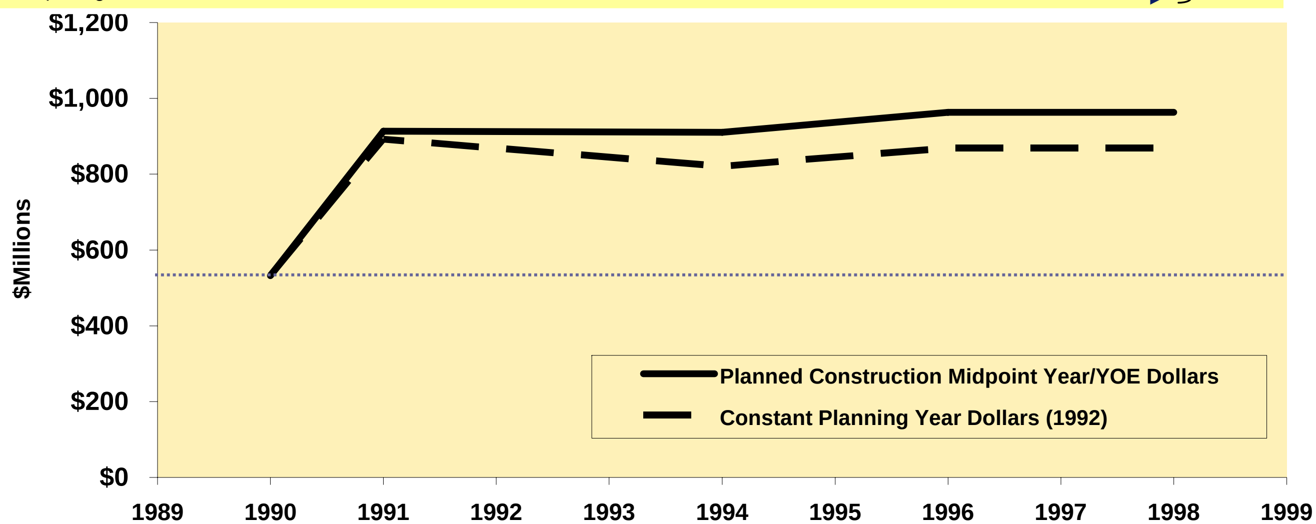
Total Project Costs by Phase
PORTLAND WESTSIDE/HILLSBORO MAX

Project Phase	**Planning**	**PE/FEIS**	**Final Design**	**Construction/Operations**
Key Events Changes in costs, quantities and schedule from specific events **Note** Planning phase costs were reported in $1980 and $1990 for Westside and Hillsboro respectively. Cost and schedule were derived for the combined project, in order to compare with later phases.	**1**. Planned midpoint of construction for combined projects 1992	**1**. Westside and Hillsboro projects combined **2**. Three-mile tunnel added **3**. Station number increased to 20 **4**. Midpoint of construction 1993	**1.** Minor cost reductions for several cost categories **2.** Midpoint of construction 1996	**1**. Minor cost revisions **2**. Fleet size increased to 52 vehicles **3.** Year of Expenditure 1996

Anticipated Project Duration at Each Phase

- Planning → **1992 Construction Midpoint**
- PE/FEIS → **1993 Midpoint**
- Final Design → **1996 YOE**
- Actual Opening → **1996 YOE**

Project Cost By Phase
Dollar cost estimates are denominated in the anticipated midpoint of construction year /YOE (solid line) and the project planning midpoint of construction year (dotted line)



Salt Lake North-South Line

The North-South Line project is a 15-mile light rail line from downtown Salt Lake City to the southern suburbs. The line operates on city streets downtown (2 miles) and then follows a lightly used railroad alignment owned by the Utah Transit Authority (UTA) to the suburban community of Sandy (13 miles). The project was part of Interstate 15 (I-15) corridor improvements, which included reconstruction of a parallel segment of I-15.

The project's initial DEIS cost estimate of $256.3 million was in 1994 dollars, while the project development schedule was planned for an opening of 1998 and a likely midpoint of construction of 1997. Adjusted into year-of-cost-estimate dollars to account for the project development schedule, the baseline planning estimate was $276.9 million.

Total Project Cost by Phase

The upper line graph in **Figure C-28** shows the planning estimates adjusted to the initial project schedule in year 1997 dollars, and illustrates the changes in total cost incurred by the project through construction. The planned opening of the North-South project was delayed at preliminary engineering from 1998 to 2000, but the project then opened a year early in 1999. The corresponding change in midpoint of construction was from 1997 to 1998.

The lower line graph in **Figure C-28** illustrates the scope and unit cost impacts of the changes introduced throughout the development of the North-South project. Changes in scope are estimated to have increased costs by approximately $23.5 million (8.5 percent) from the planning DEIS estimate that was modified to account for the planned project development schedule (dark line). The major change in scope was an increase in fleet size occurring during final design. Scope growth early in project development included changes to a maintenance facility, stations, and park-and-ride centers.

During this project development period, unit costs for the continuing project scope increased by about $5.1 million (1.8 percent of the $28.6 million adjusted planning estimate). The gray line in the lower line graph in **Figure C-28** shows the less steep upward trend in unit costs. The principal cost drivers were right-of-way and track elements, LRT vehicles, systems, stations, and parking.

Detailed Cost Variance by Phase

Figure C-29 illustrates the detailed project cost variance by phase. Both costs and scope increased during final design and construction. From planning to operations, project scope quantities increased by about $23.5 million, primarily in the cost category of vehicles (5.00). The increase from unit costs was just over $5 million, resulting from adjustments for stations (4.00) and soft costs (8.00), as well as alignment modifications (1.00).

Summary

At planning, the total cost estimate for the North-South Line was $256.3 million, but the project cost increased by $55.5 million (21.7 percent) to $311.8 million at completion. A portion of the increase can be attributed to inflationary factors. Adjusting the initial cost estimate into year-of-cost-estimate dollars to account for the project development schedule increased the estimate by $20.6 million (8.0 percent), resulting in a baseline planning estimate of $138.0 million. Project costs then increased from the baseline planning estimate due to changes throughout project development:

- The North-South Line experienced some schedule changes, shifting the estimated midpoint of construction from 1997 to 1998. The impact was to increase project costs from the baseline by about $6.2 million (2.2 percent).
- The remaining $28.6 million increase (10.3 percent of the baseline) was due to scope and unit cost changes introduced into the project over the developmental period.

Figure C-28. Salt Lake South-North Line Total Project Costs by Phase

Total Project Costs by Phase
SALT LAKE NORTH-SOUTH LINE

Project Phase	**Planning**	**PE/FEIS**	**Final Design**	**Construction/Operations**
Key Events Changes in costs, quantities and schedule from specific events	**1.** Planned midpoint of construction 1996	**1.** Midpoint of construction 1999	**1.** Minor alignment modifications **2.** Fleet size increased from 18 to 23 **3.** Increased ROW costs **4.** Added soft Costs **5.** Midpoint of construction 1999	**1.** Reduced requirements for roadway changes **2.** Reduced number of stations from 17 to 16, although total station cost did not decrease substantially **3.** Reduced schedule to open a year early in 1999 **4.** Year of Expenditure 1998

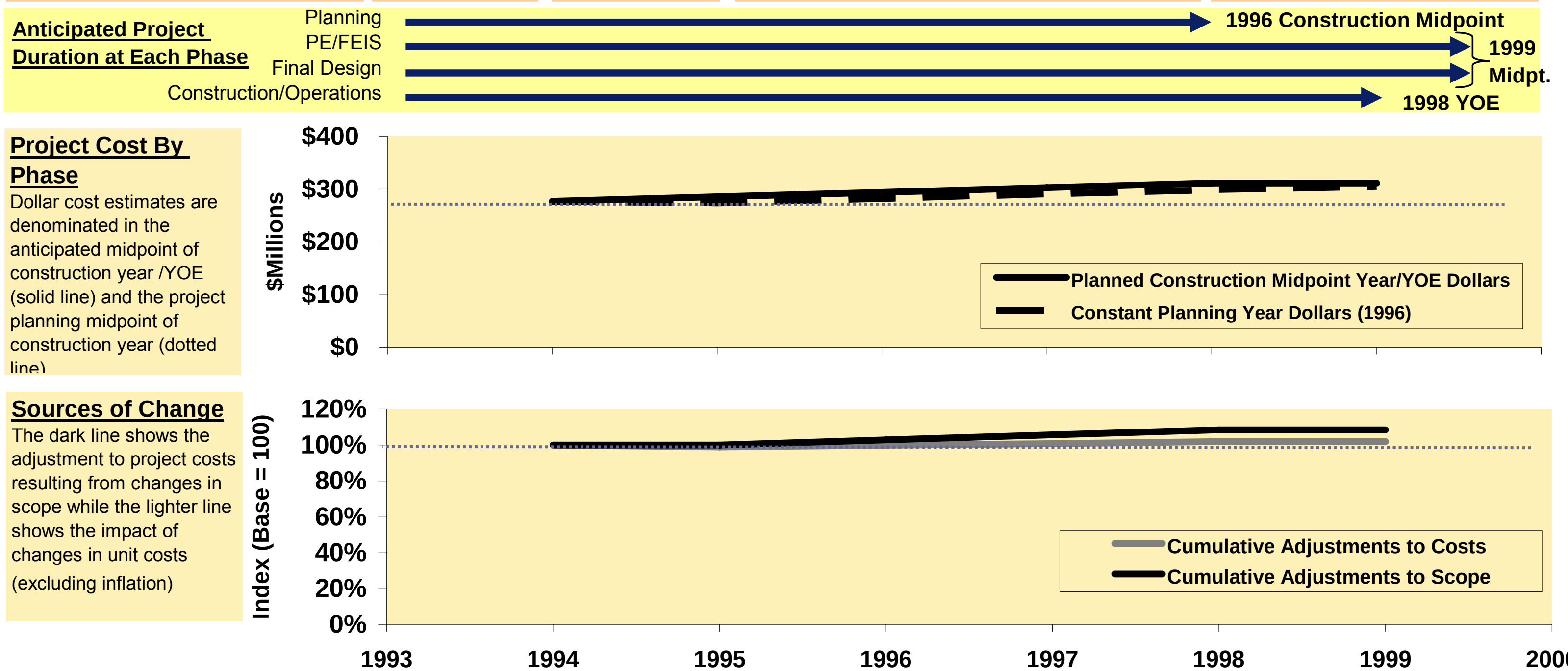
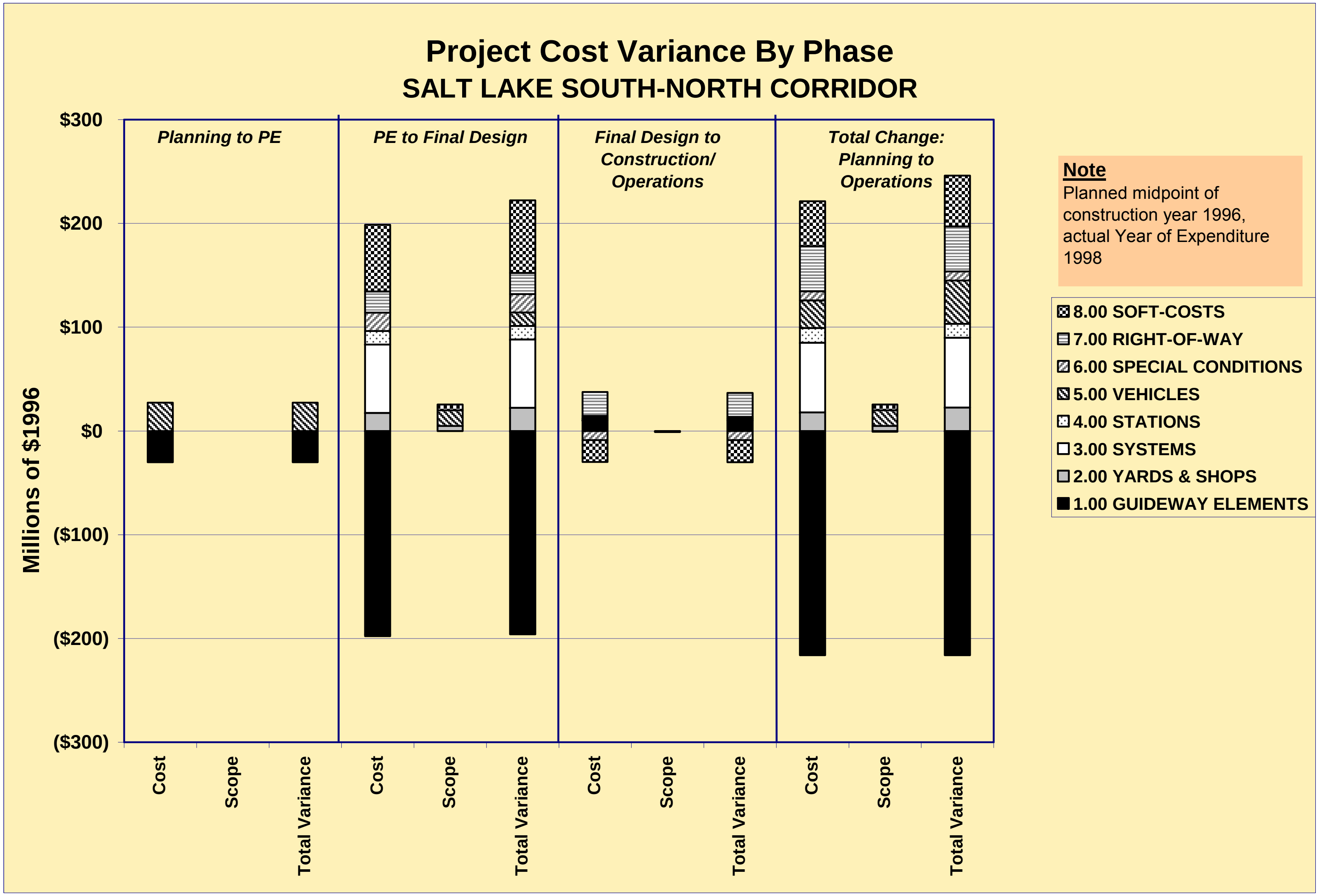


Figure C-29. Salt Lake South-North Line Project Cost Variance by Phase



San Francisco SFO Airport Extension

The San Francisco Bay Airport Extension is an 8.2-mile, 4-station extension of the BART system to provide service to San Francisco International Airport (SFO). The project consists of a mainline extension from the BART station at Colma, through Colma, South San Francisco, and San Bruno, terminating at the Millbrae Avenue BART/CalTrain Station. An additional track from the main line north of Millbrae takes BART trains directly into an airport station adjoining a new international terminal.

The project's initial DEIS cost estimate of $1.05 billion was in 1997 dollars, while the project development schedule was planned for an opening of 1999 and a likely midpoint of construction of 1997. Adjusted into year-of-cost-estimate dollars to account for the project development schedule, the baseline planning estimate was $1.18 billion.

The line graph in **Figure C-30** shows the planning estimates adjusted to the initial project schedule in year 1997 dollars, and illustrates the changes in total cost incurred by the project through construction. The planned opening of the BART Airport Extension was delayed multiple times between its estimated 1999 opening and actual 2003 opening. The corresponding slip in midpoint of construction was from 1997 to 2001.

The Airport Extension project started out at an estimated total cost of $1.05 billion, but was completed for $1.55 billion. The $504.2 million increase (48.2 percent) was due to several factors. First, adjusting the initial cost estimate into year-of-cost-estimate dollars to account for the project development schedule increased the estimate by $129.3 million (12.4 percent), resulting in a baseline planning estimate of $1.18 billion. Project costs then increased from the baseline planning estimate due to changes throughout project development:

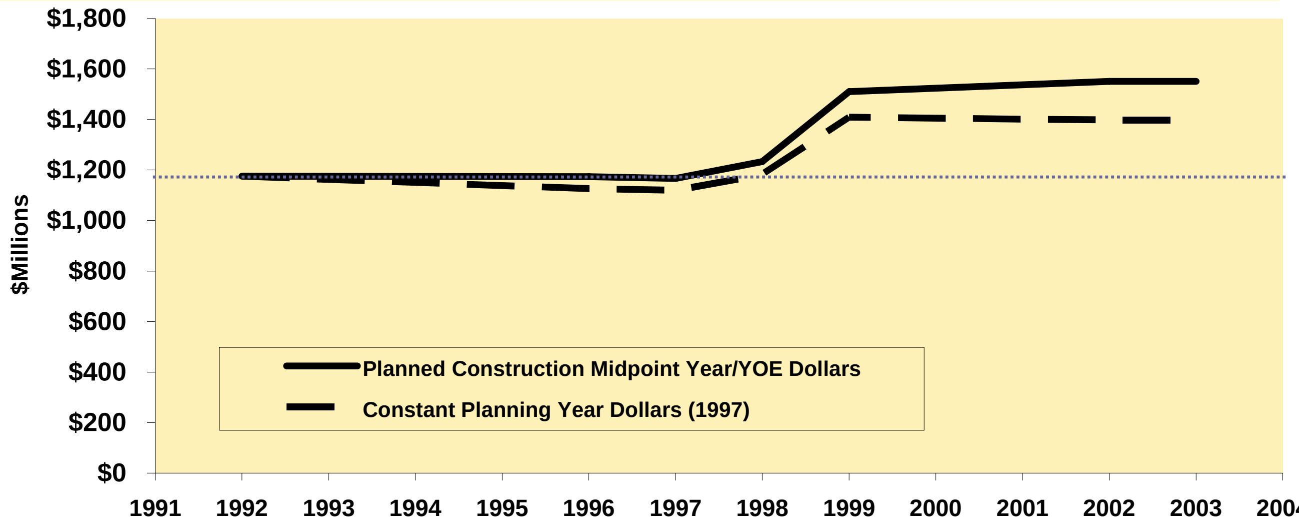
- Due to schedule delays, the estimated midpoint of construction shifted from 1997 to 2001, which increased project costs by about $152.4 million (a 13.0 percent increase from the baseline).
- Scope changes and cost adjustments resulted in a $222.5 million increase (18.9 percent of the) to total cost. Initial cost increases were due to the fact that new alignments were evaluated from 1995 to 1996, and the preferred alternative was revised to include an aerial design option (wye stub) into the airport. Later in the project's development, SFO added $113 million in civil works (new facilities) on airport property. SFO was a major partner in this extension project; although, the airport work was outside the scope of the FFGA. There was also $80 million in additional local funding for scope growth. Construction cost increases were partially attributed to higher-than-expected bids on three contracts caused by a very competitive Bay Area economy. Other cost impacts included higher-than-expected costs for right-of-way and third-party contracts, as well as additional financing costs.

Figure C-30. San Francisco SFO Airport Extension Total Project Costs by Phase

Total Project Costs by Phase
SAN FRANCISCO SFO AIRPORT EXTENSION

Project Phase	**Planning**	**PE/FEIS**	**Final Design**	**Construction/Operations**
Key Events Changes in costs, quantities and schedule from specific events	**1**. Planned midpoint of construction 1997	**1**. Midpoint of construction 1999	**1.** Guideway length increased **2.** New vehicles replaced by improvements to current fleet **3.** Midpoint of construction 1999	**1**. Unit cost revisions **2**. SFO airport added $113M in civil works (new facilities) on airport property. The SFO airport was a major partner in this extension project, although the airport work was outside the scope of the FFGA. There was also $80M in additional local funding for scope growth. **3.** Year of Expenditure 2001

Project Cost By Phase
Dollar cost estimates are denominated in the anticipated midpoint of construction year /YOE (solid line) and the project planning midpoint of construction year (dotted line)



San Juan Tren Urbano

This project is the first mass transit system in Puerto Rico. It is a 10.7-mile, 16-station, rapid rail line between Bayamon Centro and the Sagrado Corazan area in the metropolitan San Juan area. The project was selected as one of the FTA's turnkey demonstration projects. The system consists of double-track line mostly at grade (about 40 percent) and elevated with a short tunnel section that passes through a historic neighborhood (FTA 2003a). The project includes 74 vehicles and a maintenance and storage facility.

The project has experienced several schedule delays. Due to the increased cost of the Tren Urbano project, the Puerto Rico Highway and Transportation Authority (PRHTA) had to reduce its budget for other transportation projects in the area, such as a planned transportation building. During construction, the FTA withheld some of its commitments to the project until the PRHTA submitted a recovery plan to deal with the cost and schedule escalation and project management.

The project's initial DEIS cost estimate of $766.0 million was in 1992 dollars, while the project development schedule was planned for an opening of 1998 and a likely midpoint of construction of 1996. Adjusted into year-of-cost-estimate dollars to account for the project development schedule, the baseline planning estimate was $965.0 million.

The line graph in **Figure C-31** shows the planning estimates adjusted to the initial project schedule in year 1996 dollars, and illustrates the changes in total cost incurred by the project through construction. The planned opening of the Tren Urbano project was delayed from 1998 to 2005. Some of the delay was attributed to weather (hurricane) and to "the limited availability of a skilled workforce" (GAO 1999). The corresponding slip in midpoint of construction was from 1996 to 2000.

The Tren Urbano project started out at an estimated total cost of $766.0 million, but the total cost of the project was over $2.25 billion—the total cost almost tripled, with a total increase of $1.48 billion (193.7 percent). A significant portion of this was due to inflationary factors. Adjusting the initial cost estimate into year-of-cost-estimate dollars to account for the project development schedule increased the estimate by $199.0 million (26.0 percent), resulting in a baseline planning estimate of $965.0 million. Project costs then increased from the baseline planning estimate due to the many changes throughout project development:

- Multiple schedule delays shifted the midpoint of construction from 1996 to 2000, which further increased project costs by about $199.1 million (26.0 percent).

- Increases due to scope changes and unit cost adjustments alone totaled more than the baseline planning estimate. The increase was about $1.09 billion (112.5 percent of the baseline).

The DEIS called for 16 stations and 60 revenue vehicles, while the FEIS cut the stations to 14 and increased the revenue vehicles to 64. The FFGA was signed in 1996 with a total estimated project cost of $1.25 billion. In 1999, 2 stations and 10 rail cars were added to the project, the FFGA was amended accordingly, and the cost increased by $400.9 million. Furthermore, the stations and the fare collection system were enhanced. Other factors that contributed to the increase in project costs were an enhanced fare collection system, a system integration and quality assurance program, schedule delays, and engineer's low estimates (GAO 1999; OIG 2002a, 2002c). More recent increases to cost included claims and extended project management costs (FTA 2004).

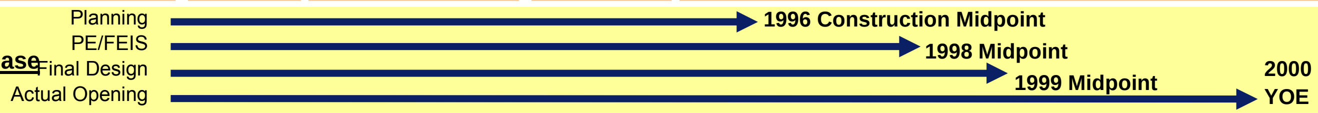
Seven DB contracts were awarded in 1996 and 1997, which covered different segments of the project. The contract awards were $129 million above the engineers estimate. The selection criterion was based on best value, which combined price, design quality, construction innovation, and the proposer's past experience (Fosbrook and Gonzalez 1997). One of the turnkey contracts awarded was for system operation and maintenance for which the contractor is responsible for the first five years of operation. Siemens Transit Team was awarded a contract for $499 million for vehicles, traction power, train control, and communications.

Figure C-31. San Juan Tren Urbano Total Project Costs by Phase

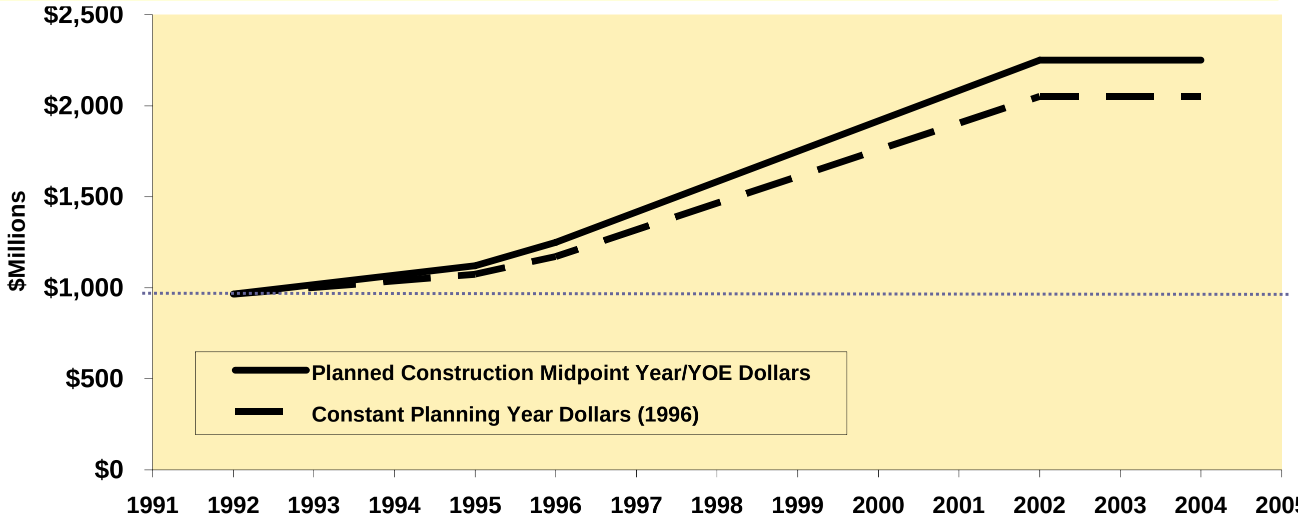
Total Project Costs by Phase
SAN JUAN TREN URBANO

Project Phase	**Planning**	**PE/FEIS**	**Final Design**	**Construction/Operations**
Key Events Changes in costs, quantities and schedule from specific events	1. Planned midpoint of construc-tion 1996	1. Third-rail replaced overhead power 2. Number of stations reduced from 16 to 14 3. Fleet size increased from 60 to 64 vehicles 4. Midpoint of construction 1998	1. Alignment length reduced 2. Midpoint of construction 1999	1. Significant unit cost revisions 2. Number of stations increased from 14 to 16 (added one elevated and one subway station) 3. Number of fleet vehicles increased from 64 to 74 4. Year of Expenditure 2000

Anticipated Project Duration at Each Phase



Project Cost By Phase
Dollar cost estimates are denominated in the anticipated midpoint of construction year /YOE (solid line) and the project planning midpoint of construction year (dotted line)



Santa Clara Capitol Line

The Santa Clara Capitol Line is a 4-station, 3.3-mile at-grade extension to Santa Clara's pre-existing LRT system. The project objectives were to extend service to the eastern side of the Santa Clara Valley from the terminus point of the Tasman East Line to Alum Rock, and to ease traffic on adjacent freeways and surface streets.

Total Project Cost by Phase

The upper line graph in **Figure C-32** shows the planning estimates adjusted to the initial project schedule in year 2003 dollars, and illustrates the changes in total cost incurred by the project through construction. The project schedule remained constant throughout project development, and the project was completed on-time. **Figure C-32** illustrates this by the absence of any difference between the planning year estimate (dashed line) and the year-of-cost estimate (solid line).

The lower line graph in **Figure C-32** illustrates the impact of changes in scope and unit costs during development of the Capitol project. Scope remained constant (dark line), but unit costs for the continuing project scope increased by about $15.4 million, or 10.5 percent (gray line).

Detailed Cost Variance by Phase

Figure C-33 illustrates the detailed project cost variance by phase**.** From planning to operations, project scope quantities remained constant, while cost increases totaled about $15.4 million. Cost increases between planning and project completion were attributed to PG&E bankruptcy, survey errors resulting in required rework of the project alignment and attendant delays, and increased need for utility relocation and ROW acquisition. Counterbalancing these cost increases were favorable bids on substation and TVM contracts coupled with change order growth below plan on systems contracts. Also, a very favorable bidding environment on station construction contracts assisted in some control of overall cost growth. Finally, fewer condemnations went to trial than contemplated in the original budget; although, significant construction management resources were required to manage utility relocations to limit schedule slippage.

Summary

The Capitol project started out at an estimated total cost of $147.1 million, and was completed for $162.5 million. Because the initial DEIS cost estimate was in year-of-cost-estimate dollars, no adjustment was required to determine the baseline planning estimate. The $15.4 million (10.5 percent) increase was due solely to changes in unit cost over the project developmental period.

Figure C-32. Santa Clara Capitol Line Total Project Costs by Phase

Total Project Costs by Phase
SANTA CLARA CAPITOL LINE

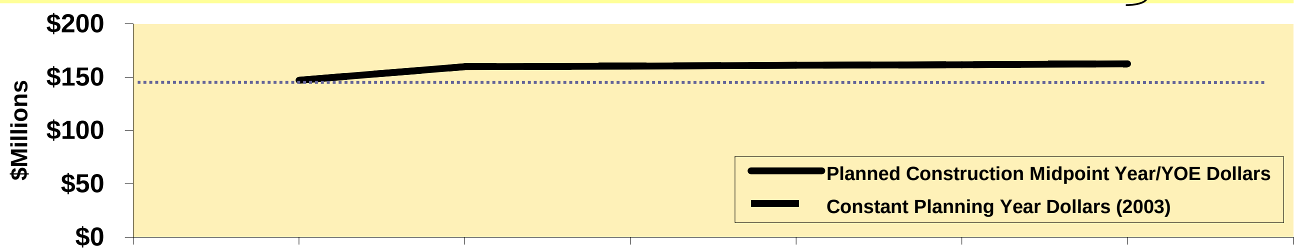
Project Phase	**PE/FEIS**	**Final Design**	**Construction**
Key Events Changes in costs, quantities and schedule from specific events	**1**. Planned midpoint of construction 2003	**1**. Minor modifications to alignment position **2**. Reductions to some unit costs resulting from a favorable bidding environment **3.** Midpoint of construction 2003	**1**. Minor alignment modifications **2.** Increased costs for utility relocation and ROW acquisition **3**. Year of Expenditure 2003

Anticipated Project Duration at Each Phase

PE/FEIS
Final Design
Construction

2003 YOE

Project Cost By Phase
Dollar cost estimates are denominated in the anticipated midpoint of construction year /YOE (solid line) and the project planning midpoint of construction year (dotted line)



Sources of Change
The dark line shows the adjustment to project costs resulting from changes in scope while the lighter line shows the impact of changes in unit costs (excluding inflation)

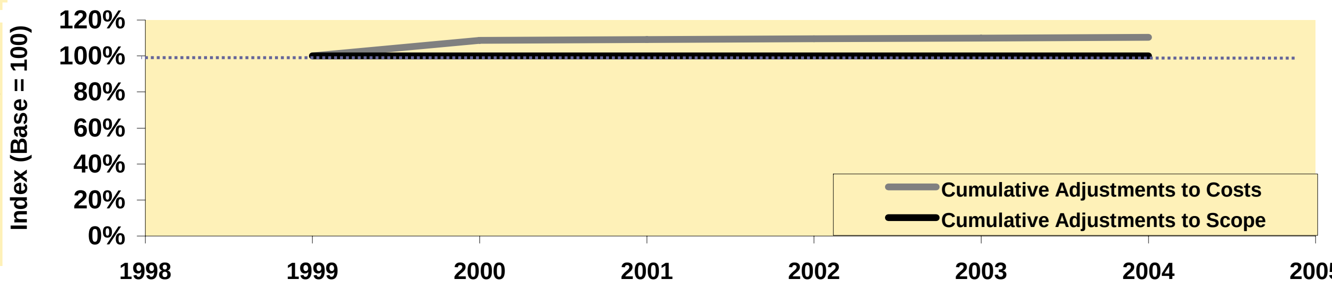
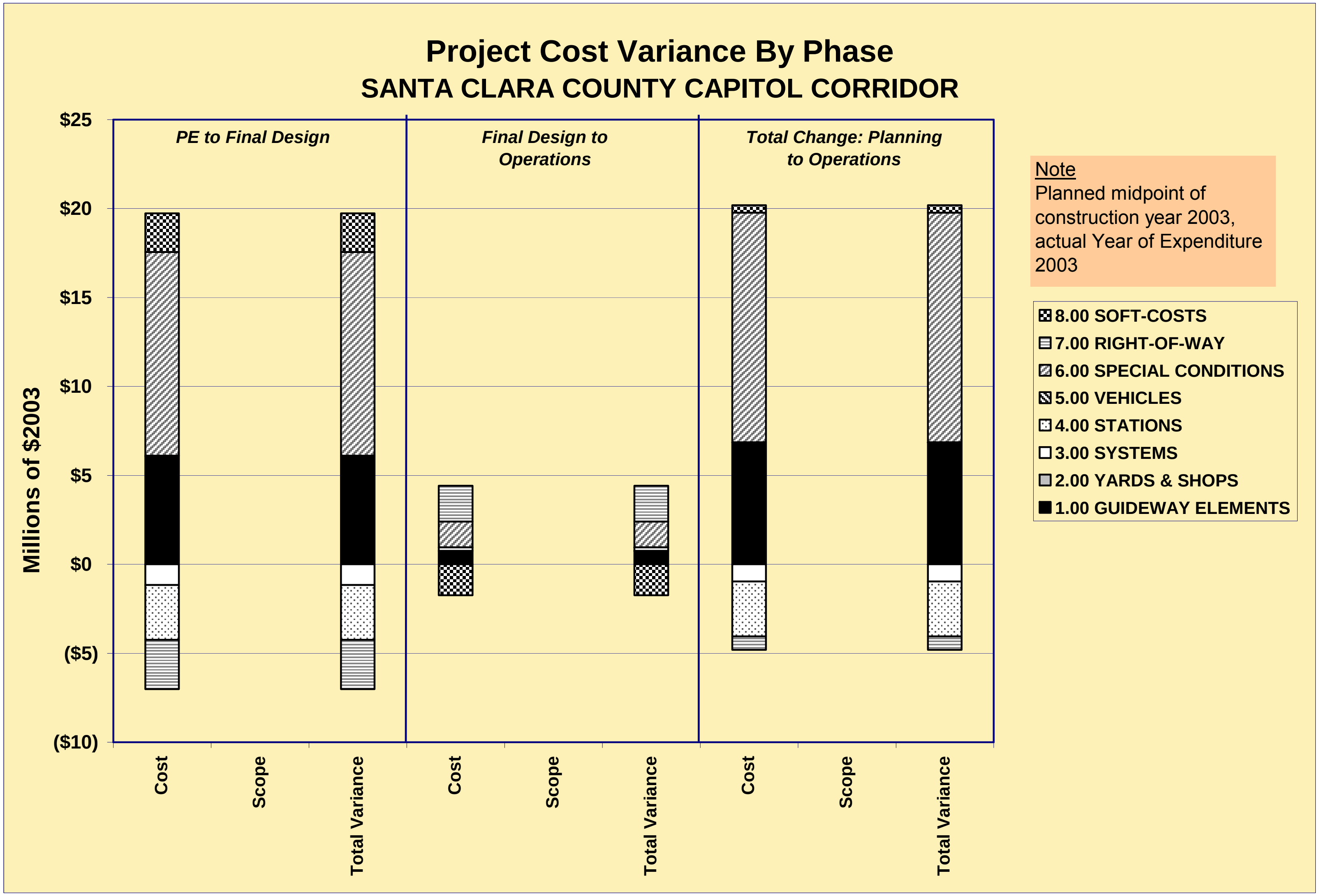


Figure C-33. Santa Clara Capitol Line Project Cost Variance by Phase



Santa Clara Tasman Line

The Santa Clara Tasman Line project was initially proposed as a 12.4-mile, at-grade extension to the existing light rail system, estimated at $480 million. At preliminary engineering, the project was divided into two lines: Tasman West and Tasman East.

<u>Tasman West</u>

The proposed Santa Clara West Tasman Line project was a 7.5-mile, at-grade light rail system with 11 at-grade stations. The project objectives were to connect North San Jose to Mountain View; to ease traffic on adjacent freeways and surface streets; and to provide the public initial leg of a modern, rapid transportation system.

Approximately $250 million of the planning estimate for the full Tasman project would have been apportioned to the Tasman West Project. Detailed scope and cost data is not available for this phase; however, it is useful to consider the project from preliminary engineering to operation. At preliminary engineering, the total cost estimate was $327.8 million, and the project was completed for $280.6 million.

Total Project Cost by Phase

The upper line graph in **Figure C-34** shows the planning estimates adjusted to the initial project schedule in year 1995 dollars, and illustrates the changes in total cost incurred by the project through construction. Aside from the delay caused by splitting the Tasman project into East and West, when the planned opening changed from 1998 to 2000 (shifting the estimated midpoint of construction from 1995 to 1999), the Tasman West project was actually completed ahead of schedule in 1999.

Considering the period from definition of the Tasman West project (preliminary engineering) through project completion, the midpoint of construction remained constant. During this period, there were no cost impacts due to schedule. Rather, the reduction in total cost of about $47.2 million (14.4 percent) is attributable to unit cost adjustments. The lower line graph in **Figure C-34** illustrates how the scope remained constant (dark line), while the unit costs for the continuing project scope decreased (gray line).

Detailed Cost Variance by Phase

Figure C-35 illustrates the detailed project cost variance by phase**.** From preliminary engineering to operations, project scope quantities remained constant, while unit cost reductions totaled about $47.2 million. Sources of cost reductions included the favorable bids on substations, TVMs, communications and signal contracts, and lower soft costs for project design and project management than initially estimated.

Partially offsetting these savings were numerous underground utilities that were not discovered during design. Also, greater-than-anticipated groundwater inflow through a depressed section required additional expenditures for mitigation. Construction also suffered from a record rainy season during the trackway earthwork phase. While third-party utility relocation was more significant than envisioned in the original budget, ROW acquisition was completed in 1996, just before a steep increase in Silicon Valley land prices.

Summary

The first cost estimate for the separated Tasman West was for $327.8 million at preliminary engineering, and the project was completed for $280.6 million. Because the PE cost estimate was in year-of-cost-estimate dollars, no adjustment was required to determine the baseline estimate. The $47.2 million (14.4 percent) decrease was due solely to changes in unit cost over the project developmental period.

Figure C-34. Santa Clara Tasman West Line Total Project Costs by Phase

Total Project Costs by Phase
SANTA CLARA TASMAN WEST LINE

Project Phase	Planning	PE/FEIS	Final Design	Construction
Key Events Changes in costs, quantities and schedule from specific events	**1**. Planned midpoint of construction for combined Tasman project 1995	**1**. Project separated into Tasman West and East **2**. Planned midpoint of construction 1999	**1**. Minor revisions to unit cost estimates **2**. Midpoint of construction 1999	**1**. Minor revisions to unit cost estimates **2**. Higher than expected costs for third party utility relocation **3**. Lower soft-costs for project design and project management than initially estimated **4**. Year of Expenditure 1999

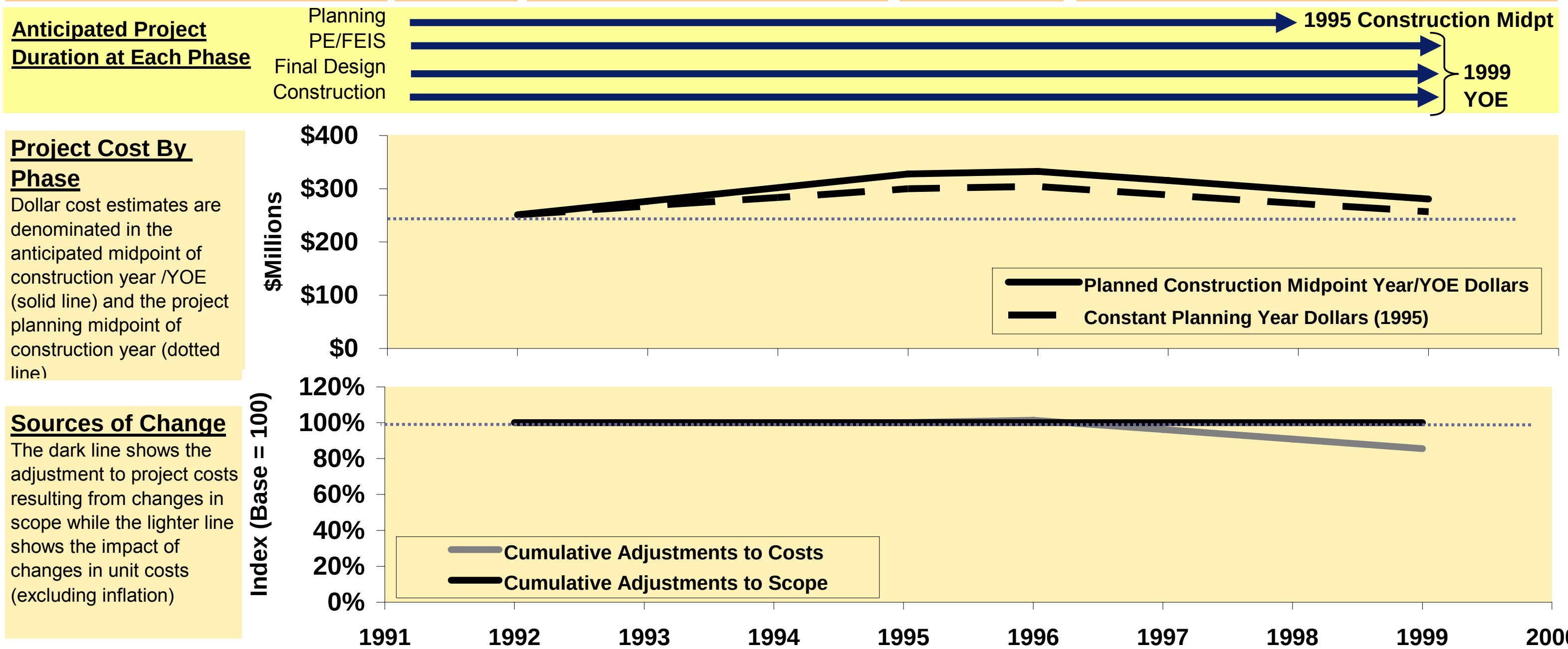
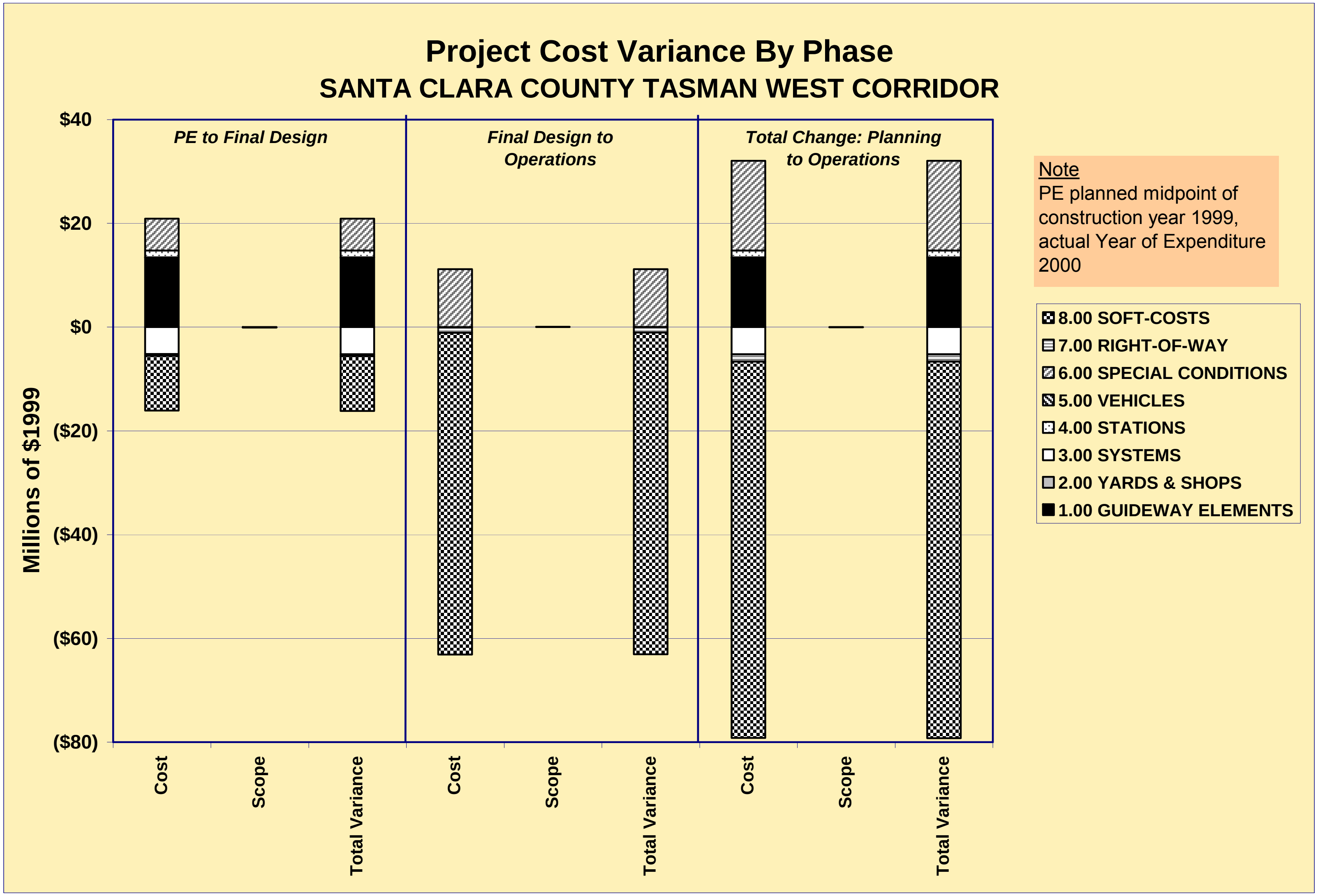


Figure C-35. Santa Clara Tasman West Line Project Cost Variance by Phase



Tasman East

The Santa Clara East Tasman Line is a 4.9-mile extension to Santa Clara County's existing light rail system. The proposed project included 3.6 miles at-grade and 1.3 miles elevated alignment and 7 stations (5 at-grade and 2 elevated). The project objectives were to connect North First Street to the Capitol Avenue and Hostetter, to provide service to the Great Mall, and to ease traffic congestion on adjacent freeways and surface streets.

Approximately $200 million of the planning estimate for the full Tasman project would have been apportioned to the Tasman East Project. Since detailed scope and cost data is not available for this phase, it is useful to consider the project from preliminary engineering to operation. At preliminary engineering, the total cost estimate was $275.9 million, and the project was completed for $276.2 million.

Total Project Cost by Phase

The upper line graph in **Figure C-36** shows the planning estimates adjusted to the initial project schedule in year 1995 dollars, and illustrates the changes in total cost incurred by the project through construction. In addition to the delay caused by splitting the Tasman project into East and West, when the planned opening changed from 1998 to 2000, the Tasman East project was delayed during final design to open in 2001. The estimated midpoint of construction thus shifted from 1995 to 2000.

However, considering the period from definition of the Tasman East project (preliminary engineering) through project completion, the midpoint of construction shifted only from 1999 to 2000. The impact of this delay was a $7.5 million (2.7 percent) increase in total project cost.

The schedule delay was offset by unit cost adjustments, which reduced total project cost by about $7.2 million (2.6 percent). The lower line graph in **Figure C-36** illustrates how the scope remained constant (dark line), while the unit costs for the continuing project scope decreased slightly (gray line).

Detailed Cost Variance by Phase

Figure C-37 illustrates the detailed project cost variance by phase**.** Several factors contributed to the small overall change in costs, including construction bid savings and a claim-free closeout. Also, favorable bids were received on the signals contract coupled with change order growth below plan on substations, TVMs, and completed system contracts. In addition, the project experienced a very favorable bidding environment on its station construction contract, and there were only minor changes to cost estimates for most cost elements.

Utility relocation was more significant than envisioned in the original budget, resulting in additional construction management resources. But, the overall lower costs associated with other contracts balanced out the higher utility relocation costs. Finally, the project received a favorable ruling on a large condemnation case in the Baypointe Segment.

Summary

The first cost estimate for the separated Tasman East was for $275.9 million at preliminary engineering, and the project was completed for $276.2 million. Because the PE cost estimate was in year-of-cost-estimate dollars, no adjustment was required to determine the baseline estimate. The $0.3 million (0.1 percent) increase, was the result of the following:

- Schedule delay caused an increase of $7.5 million (2.7 percent).
- Changes in unit cost over the project developmental period caused a decrease of $7.2 million (2.6 percent).

Figure C-36. Santa Clara Tasman East Line Total Project Costs by Phase

Total Project Costs by Phase
SANTA CLARA TASMAN EAST LINE

Project Phase	**Planning**	**PE/FEIS**	**Final Design**	**Construction**
Key Events Changes in costs, quantities and schedule from specific events	1. Planned midpoint of construction for combined Tasman project 1995	1. Project separated into Tasman East and West 2. Planned midpoint of construction 1999	1. Overall reductions in project unit cost estimates 2. Added environmental mitigation 3. Increased provisions for utility relocations/betterments and third party agreements 4. Midpoint of construction 2000	1. Minor changes to cost estimates for many cost elements 2. Year of Expenditure 2000

Anticipated Project Duration at Each Phase

Project Cost By Phase
Dollar cost estimates are denominated in the anticipated midpoint of construction year /YOE (solid line) and the project planning midpoint of construction year (dotted line)

Sources of Change
The dark line shows the adjustment to project costs resulting from changes in scope while the lighter line shows the impact of changes in unit costs (excluding inflation)

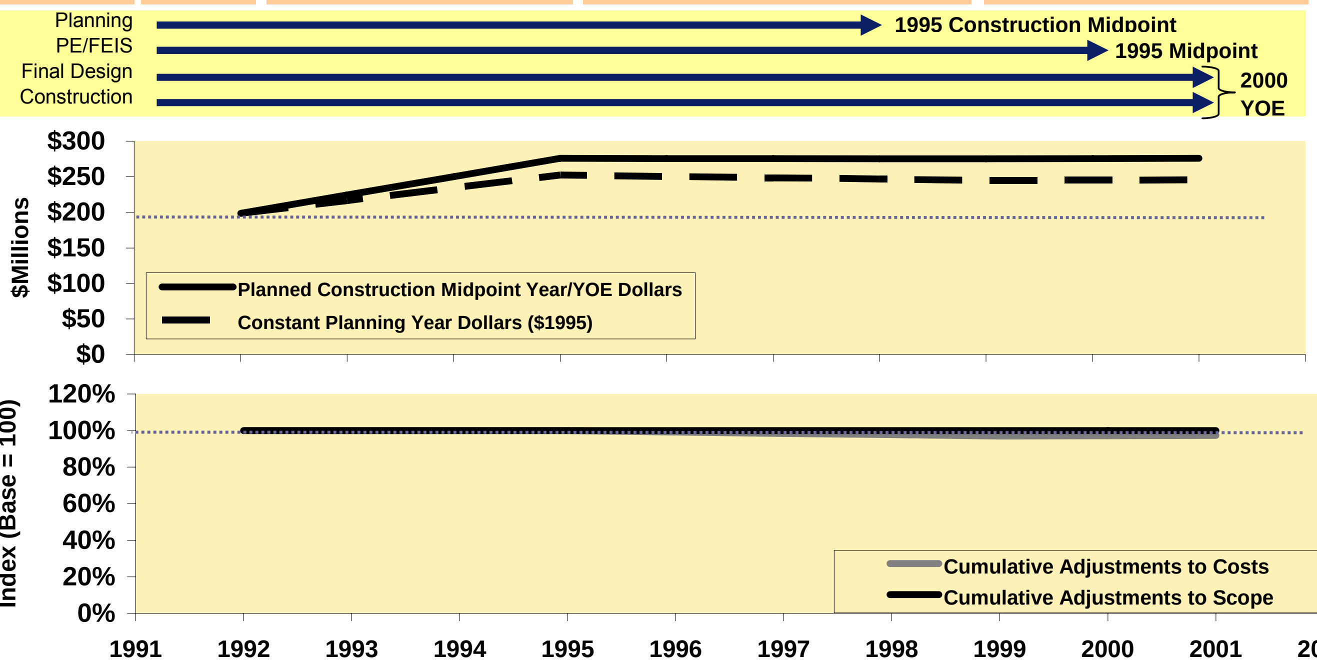
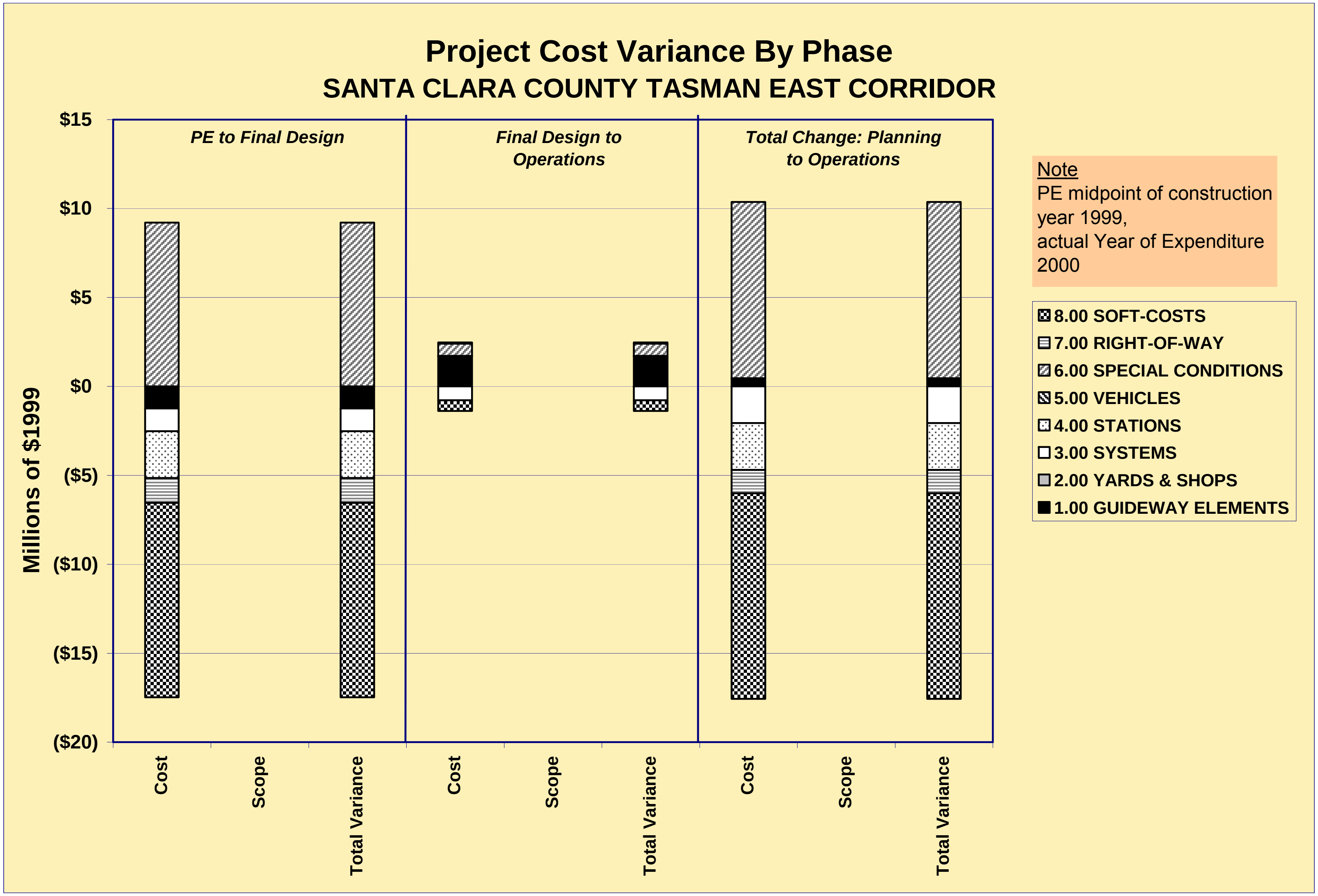


Figure C-37. Santa Clara Tasman East Line Project Cost Variance by Phase



Santa Clara Vasona Line

The Santa Clara Vasona Line represents a 5.2-mile extension to Santa Clara County's existing light rail system. The completed project includes 0.18 miles of subway alignment, 0.1 miles elevated and the remainder at-grade. There are eight stations, including seven at-grade stations and one elevated station. The project objectives were to provide service between downtown San Jose and the town of Campbell and to ease traffic on adjacent freeways and surface streets.

Total Project Cost by Phase

The upper line graph in **Figure C-38** shows the planning estimates adjusted to the initial project schedule in year 2003 dollars, and illustrates the changes in total cost incurred by the project through construction. The project schedule remained constant throughout project development, and the project was completed on time. This is illustrated in that there is no difference between the planning year estimate (dashed line) and the year-of-cost estimate (solid line).

The lower line graph in **Figure C-38** illustrates the impact of changes in scope and unit costs during development of the Vasona project. Scope remained constant (dark line), but unit costs for the continuing project scope increased by about $47.8 million, or 17.7 percent (gray line).

Detailed Cost Variance by Phase

Figure C-39 illustrates the detailed project cost variance by phase**.** From planning to operations, project scope quantities remained constant, while cost increases totaled about $47.8 million. The growth is attributed in part to several requirements imposed by third parties, such as additional requirements by Union Pacific Railroad (UPRR) as part of the ROW purchase for existing freight track relocation and reconstruction. ROW purchase cost from UPRR was also higher than the original budget. Similarly, 496 feet of guideway required elevation after the California Public Utilities Commission (CPUC) disapproved of at-grade crossing at Hamilton Avenue. In addition, the Hamilton station had to be elevated as a result of the guideway being elevated. Utility relocation was more significant than envisioned in the original budget and required additional construction management resources to limit schedule slippage.

Summary

The Vasona project started out at an estimated total cost of $269.1 million, and was completed for $316.8 million. Because the initial DEIS cost estimate was in year-of-cost-estimate dollars, no adjustment was required to determine the baseline planning estimate. The $47.8 million (17.7 percent) increase was due solely to changes in unit cost over the project developmental period.

Figure C-38. Santa Clara Vasona Line Total Project Costs by Phase

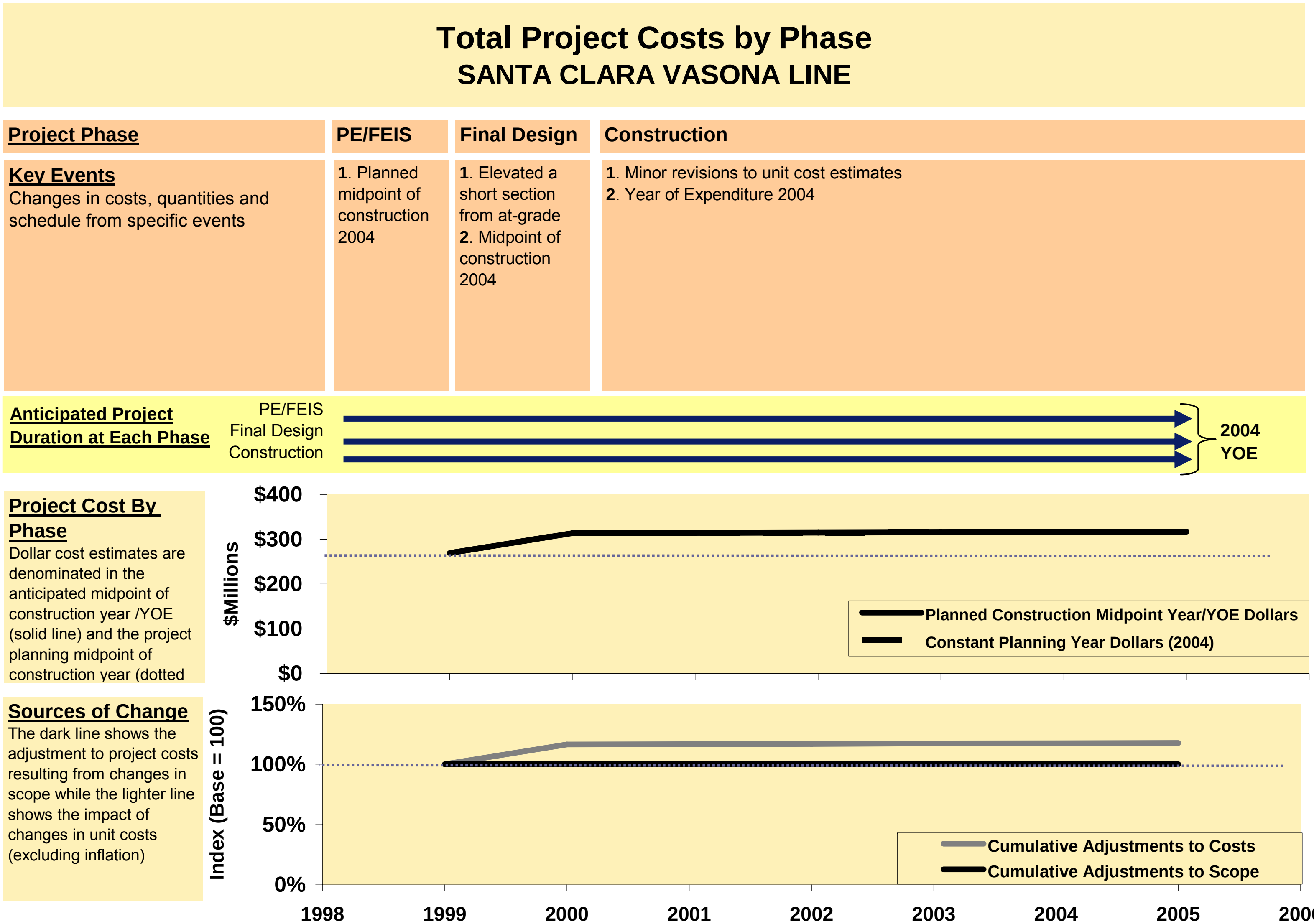
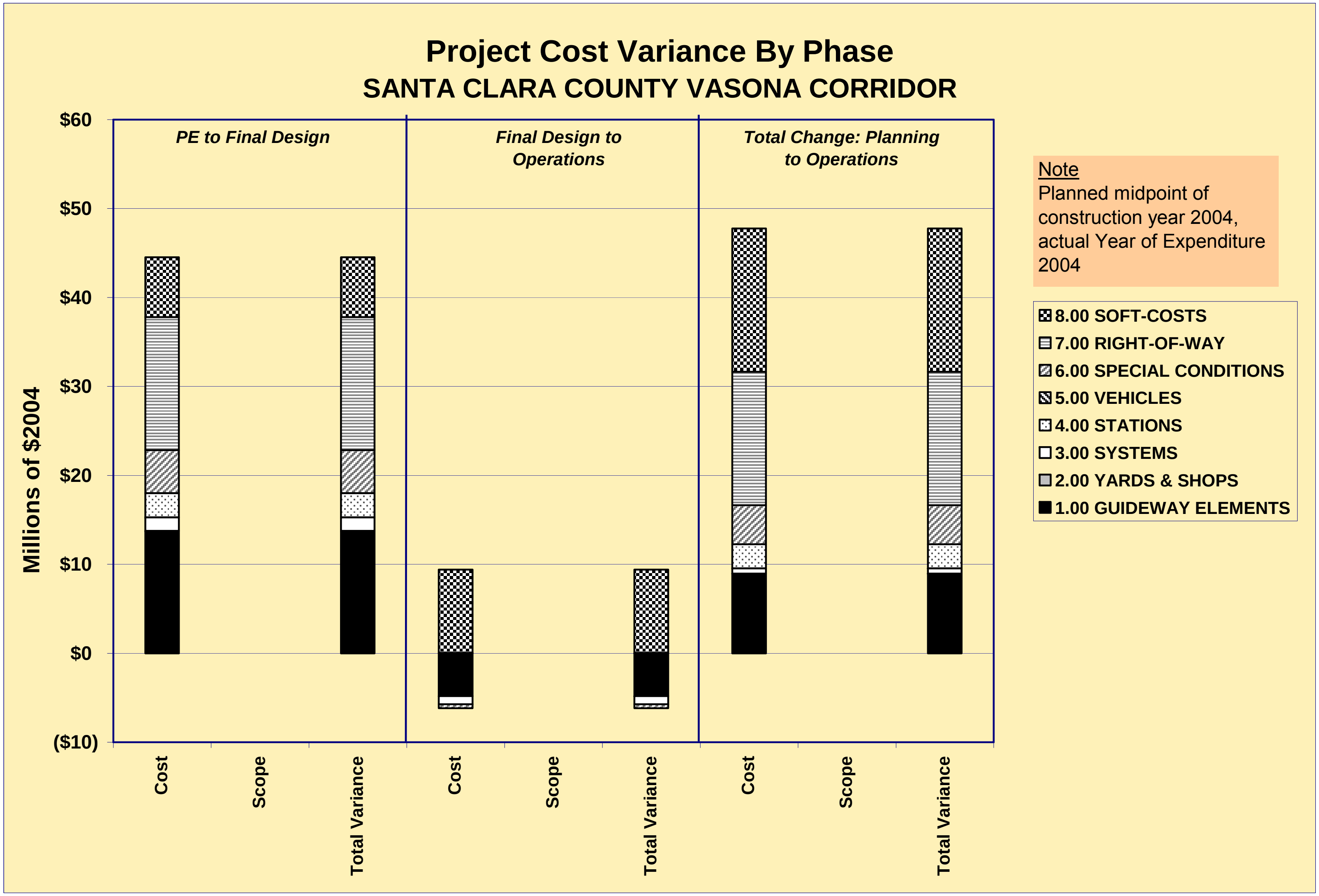


Figure C-39. Santa Clara Vasona Line Project Cost Variance by Phase



Seattle Busway Tunnel

The Downtown Seattle Transit Project (DSTP) is a 1.3-mile busway tunnel, which includes three underground stations and two other stations in the downtown Seattle area. The tunnel was designed to accommodate future light rail trains. The alignment is 5,000-foot, twin-bored tunnel, and the rest is cut-and-cover construction. The work was executed with more than 20 separate contracts (Brodberg 1999). The project included the procurement of 236 dual-mode buses that run on electricity in the tunnel and on diesel fuel outside the tunnel.

The project's initial DEIS cost estimate of $288.3 million was in 1983 dollars, while the project development schedule was planned for an opening of 1986 and a likely midpoint of construction of 1985. Adjusted into year-of-cost-estimate dollars to account for the project development schedule, the baseline planning estimate was $314.1 million.

The upper line graph in **Figure C-40** shows the planning estimates adjusted to the initial project schedule in year 1985 dollars, and illustrates the changes in total cost incurred by the project through construction. A four-year schedule delay was encountered during project development, with the actual opening occurring in 1990 rather than 1986. The corresponding slip in midpoint of construction was from 1985 to 1988.

The DSTP started out at an estimated total cost of $288.3 million, but was completed for a total cost of $468.7 billion. Inflationary factors contributed to a portion of the $322.8 million (112.0 percent) increase. Adjusting the initial cost estimate into year-of-cost-estimate dollars to account for the project development schedule increased the estimate by $25.8 million (9.0 percent), resulting in a baseline planning estimate of $314.1 million. Project costs then increased from the baseline planning estimate due to the many changes throughout project development:

- The impact of the four-year schedule delay was to increase project costs by about $49.6 million (17.2 percent of the baseline).
- Cost adjustment and scope changes accounted for a $247.4 million (85.8 percent of the baseline) increase in cost. With scope remaining constant throughout the project, the increase is due solely to changes in unit costs. During construction in 1988, work was temporarily stopped because the construction team hit wet sand. Because of concerns for the buildings above, wells were drilled and water pumped out of the area before work resumed (Foster 2000).

Figure C-40. Seattle Busway Tunnel Total Project Costs by Phase

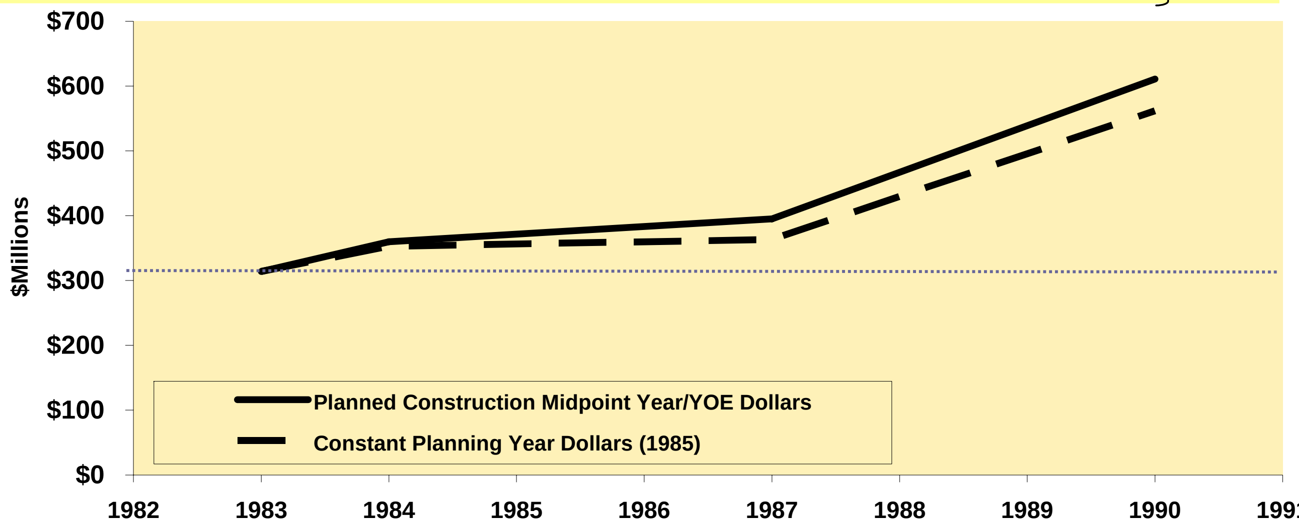
Total Project Costs by Phase
SEATTLE BUSWAY TUNNEL

Project Phase	**Planning**	**PE/FEIS**	**Final Design**	**Construction/Operations**
Key Events Changes in costs, quantities and schedule from specific events	**1**. Planned midpoint of construction 1985	**1**. Midpoint of construction 1986	**1.** Midpoint of construction 1988	**1**. Obstructions encountered during tunnel excavation, especially relating to soil condition, caused substantial cost increases. **2**. Year of Expenditure 1988

Anticipated Project Duration at Each Phase

- Planning → **1985 Construction Midpoint**
- PE/FEIS → **1986 Midpoint**
- Final Design → **1988 YOE**
- Actual Opening → **1988 YOE**

Project Cost By Phase
Dollar cost estimates are denominated in the anticipated midpoint of construction year /YOE (solid line) and the project planning midpoint of construction year (dotted line)



St. Louis – St. Clair Corridor

The St. Clair Corridor is a 17.4-mile extension to St. Louis's existing LRT system. The alignment is entirely at-grade and includes eight at-grade stations. The project objectives were to provide service from 5th Street/Missouri Avenue to Mid-America Airport and to ease local traffic congestion.

Total Project Cost by Phase

The upper line graph in **Figure C-41** shows the planning estimates adjusted to the initial project schedule in year 2000 dollars, and illustrates the changes in total cost incurred by the project through construction. The project schedule remained constant throughout project development, and the project was completed on time. This is illustrated in that there is no difference between the planning year estimate (dashed line) and the year-of-cost estimate (solid line).

The lower line graph in **Figure C-41** illustrates the scope and unit cost impacts of the many changes introduced throughout the development of the St. Clair Corridor project. Changes in scope are estimated to have decreased costs by approximately $95.2 million (28.2 percent) from the planning DEIS estimate (dark line). The trend of this line illustrates a minor increase during preliminary engineering, and a more significant decrease during final design. During the preliminary engineering phase, fleet size increased from 16 to 24 vehicles, while station quantities were reduced from 13 to 11. Soft costs were also added for project design, construction and project management, and project initiation. At final design, the alignment was reduced from 24 miles to 17.4 miles. This reduced costs in most categories and eliminated the need to make roadway changes. The number of stations was further reduced from 11 to 8. A significant increase in soft costs at this phase was due mainly to the significant design changes to the project.

During this project development period, unit costs for the continuing scope in the project increased by about $94.4. million, or 28.0 percent (gray line). Costs increased substantially for utility relocation, ROW acquisition, and "other" soft costs.

Detailed Cost Variance by Phase

Figure C-42 illustrates the detailed project cost variance by phase**.** From planning to operations, project scope quantities decreased by nearly $95.2 million, primarily in the cost categories of guideway (1.00) and systems (3.00). These were offset by about $94.4 million in cost increases. The total variance shows the counterbalancing of the scope decreases against the unit cost increases.

Summary

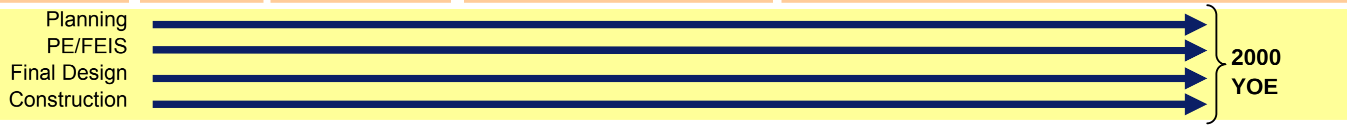
The St. Clair Corridor project started out at an estimated total cost of $337.3 million, and was completed for $336.5 million. Because the initial DEIS cost estimate was in year-of-cost-estimate dollars, no adjustment was required to determine the baseline planning estimate. The small reduction of $0.8 million (0.2 percent) was due solely to changes in scope and unit cost over the project developmental period.

Figure C-41. St. Louis – St. Clair Corridor Total Project Costs by Phase

Total Project Costs by Phase
ST LOUIS - ST CLAIR CORRIDOR

Project Phase	**Planning**	**PE/FEIS**	**Final Design**	**Construction**
Key Events Changes in costs, quantities and schedule from specific events	**1**. Planned midpoint of construc-tion 2000	**1**. Fleet size increased from 16 to 24 vehicles **2**. Number of stations reduced from 13 to 11 **3**. Midpoint of construction 2000	**1**. Alignment reduced from 26 to 17.4 miles **2**. Number of stations reduced from 11 to 8 3. Substantial increase in "other" soft-costs **4**. Midpoint of construction 2000	**1.** Minor adjustments to unit costs **2**. Year of Expenditure 2000

Anticipated Project Duration at Each Phase



Project Cost By Phase
Dollar cost estimates are denominated in the anticipated midpoint of construction year /YOE (solid line) and the project planning midpoint of construction year (dotted line)

Sources of Change
The dark line shows the adjustment to project costs resulting from changes in scope while the lighter line shows the impact of changes in unit costs (excluding inflation)

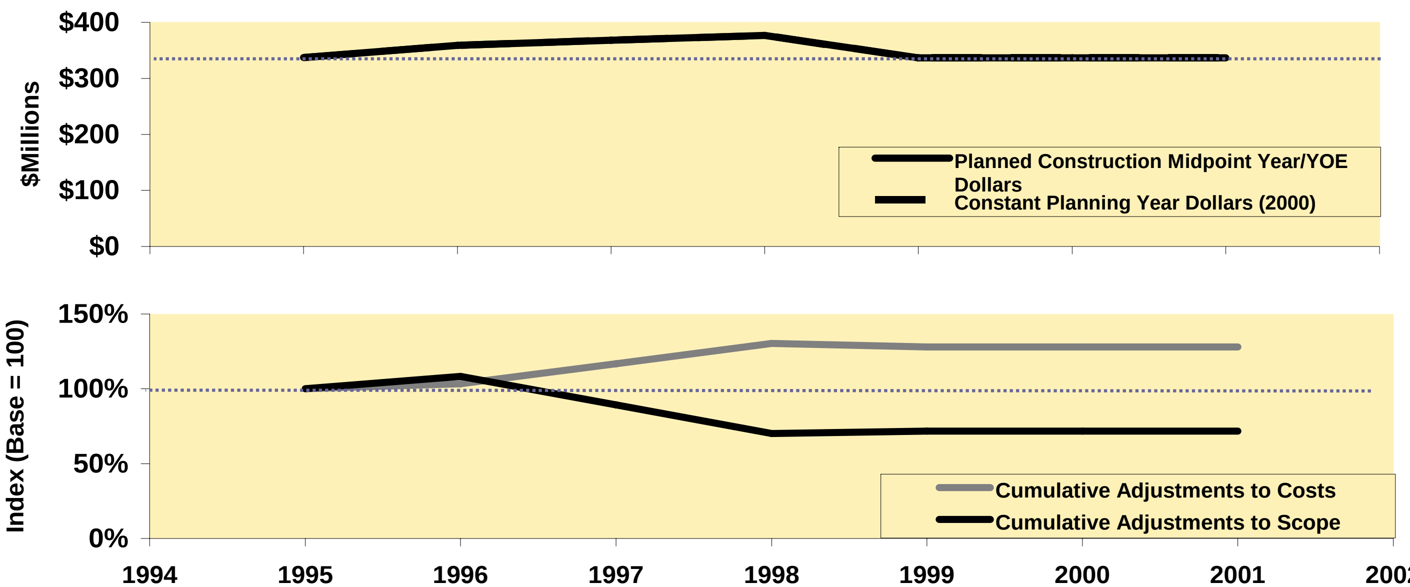
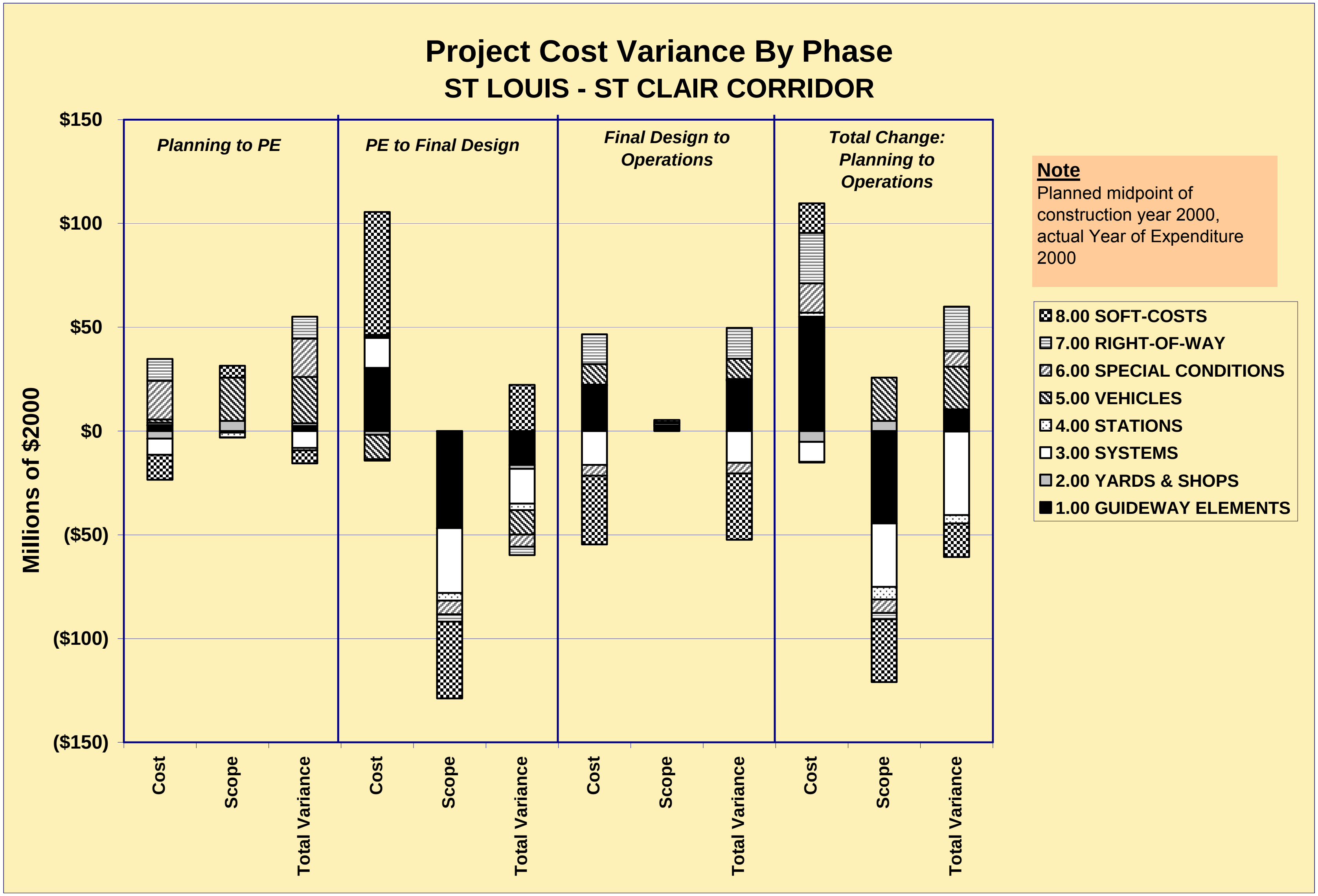


Figure C-42. St. Louis – St. Clair Corridor Project Cost Variance by Phase



Washington Largo Extension

The Maryland Transit Administration (MTA) and the Washington Metropolitan Area Transit Authority (WMATA) were joint lead agencies in the construction of the 3.1-mile heavy rail extension of WMATA Metro's Blue Line. The extension extends the Blue Line from its current terminus at the Addison Road Station to Largo Town Center, located just beyond the Capital Beltway in Prince George's County, Maryland. The 3.1-mile alignment included tunnel and surface segments, 2 new stations at Morgan Boulevard and Largo Town Center, and the purchase of 14 heavy rail vehicles. The stations provide a total of 2,700 park-and-ride spaces, including "kiss-and-ride" spaces and bus bays. The project provides direct service to a new Boulevard Cap Center retail development, and shuttle bus service to the sports complex at FedEx Field. The MTA managed the project through preliminary engineering, and WMATA assumed responsibility for managing the final design and construction activities, using a design-build construction method.

The line graph in **Figure C-43** shows the planning estimates adjusted to the initial project schedule in year 2002 dollars, and illustrates the changes in total cost incurred by the project through construction. The planned opening of the Washington Largo Extension moved multiple times, from 2003 during planning, to 2005 during preliminary engineering, and to 2004 during final design through actual opening. The corresponding movement in midpoint of construction was from 2002 to 2003.

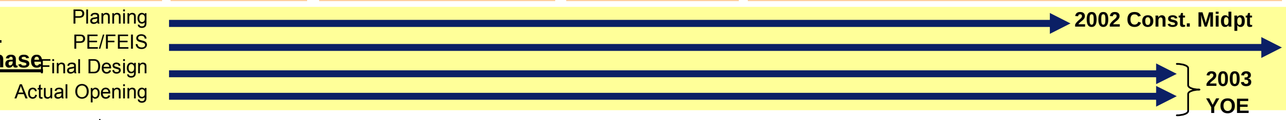
The Largo Extension project started out at an estimated total cost of $397.1 million, and experienced an increase of $58.9 million (14.8 percent) to be completed at a total cost of $456.0 million. Because the initial DEIS cost estimate was in year-of-cost-estimate dollars, no adjustment was required to determine the baseline planning estimate. The changes to project schedule shifted the estimated midpoint of construction by one year, increasing project costs by about $11.9 million (3.0 percent). The remaining $47.0 million (11.8 percent) increase was due to net changes in unit cost and scope. In 1998, capital cost estimates were updated based on the continuing development of preliminary engineering plans and the FEIS. A 10-percent cost contingency was built into the cost estimate. In September 2002, Prince George's County and the Maryland Department of Transportation authorized an additional $13.6 million for the project to add a parking structure and day care center at the Largo station. In the same month, WMATA's Board approved $9 million from its Transit Infrastructure Investment Fund for the increase in scope.

Figure C-43. Washington Largo Extension Total Project Costs by Phase

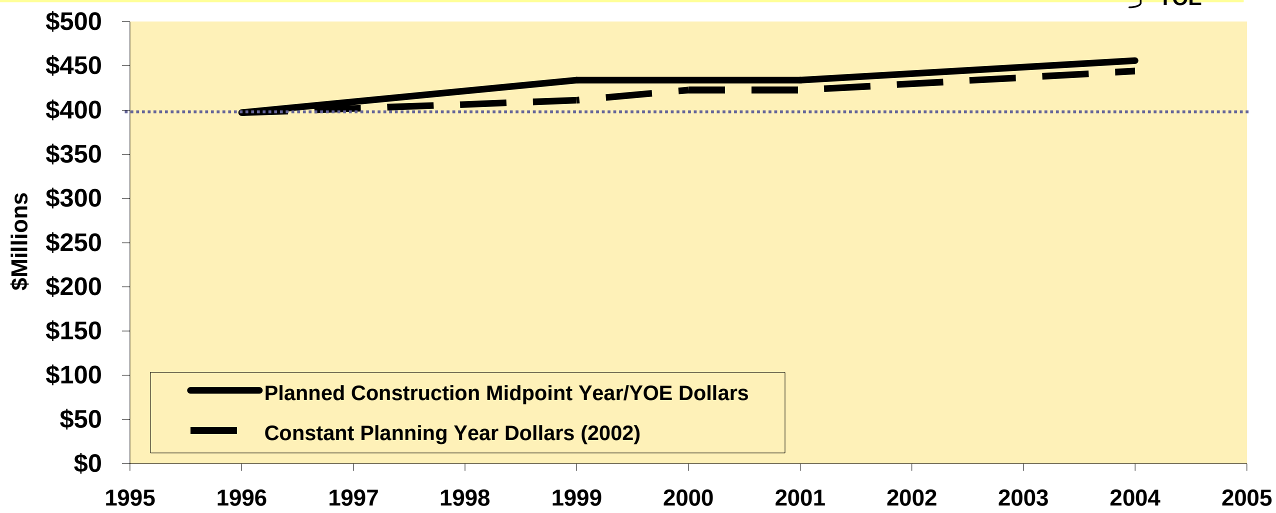
Total Project Costs by Phase
WASHINGTON LARGO EXTENSION

Project Phase	**Planning**	**PE/FEIS**	**Final Design**	**Construction/Operations**
Key Events Changes in costs, quantities and schedule from specific events	**1**. Planned midpoint of construction 2002	**1**. 10-percent contingency added **2.** Midpoint of construction 2004	**1.** Management responsibilities transferred from Maryland Transit Administration to WMATA **2.** Midpoint of construction 2003	**1**. In 2002, $13.6M authorized by Prince George County and Maryland DOT to add a parking structure and day care center at the Largo station. WMATA's Board approved $9M from its Transit Infrastructure Investment Fund for the increase in scope. **2.** Year of Expenditure 2003

Anticipated Project Duration at Each Phase



Project Cost By Phase
Dollar cost estimates are denominated in the anticipated midpoint of construction year /YOE (solid line) and the project planning midpoint of construction year (dotted line)



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Appendix D: Summary of Responses to Interview Guide

Respondents	***Atlanta MARTA North Line Extension***	***New York NYCT 63rd Street Connector***	***Pasadena LACMTA Gold Line***	***Pittsburgh PAAC Airport Busway***	***Portland TriMet Interstate Max Extension***	***Portland TriMet Airport Extension***	***Salt Lake City UTA North South Line***	***Denver RTD Southwest Line***	***Washington WMATA Largo Extension***
General Manager									
Asst. General Mgr. for Engineering & Construction		x					x		
Environmental and Planning Manager									
Environ. and Planning Consulting Project Manager							x		
Engineering Design Manager	x	x					x	x	
Engineering & Design Consulting Project Manager				x			x	x	
Construction Project Manager		x	x	x	x	x		x	X
Construction Contractor Manager - Winning		x			x	x			
Construction Contractor Manager - Losing									
Construction Management Consulting Manager									
Project Chief Estimator		x							
Project Quality Director		x							

I.	Alternatives Selection	Atlanta MARTA North Line Extension	New York NYCT 63rd Street Connector	Pasadena LACMTA Gold Line	Pittsburgh PAAC Airport Busway	Portland TriMet Interstate Max Extension	Portland TriMet Airport Extension	Salt Lake City UTA North South Line	Denver RTD Southwest Line	Washington WMATA Largo Extension
1	What was the basis for selecting the LPA?	Alternative Analysis/EIS	Alternative Analysis (Queens Subway Options Study)	Corridor congestion	Technical evaluation during the AA/DEIS, comments received at public hearings.		Unsolicited proposal by a DB contractor was accepted	An alternatives analysis was conducted that evaluated a wide variety of both highway and transit alternatives.	Detailed alternative analysis	ROW set aside by the jurisdictional agencies The alignment was previously reserved by regional planning agencies. Short sections had to be designed to get to and fit in the reserve. Local hearings forced the alignment below grade as opposed to the above and at grade design prepared for NEPA
2	Who was involved in the alternatives analysis?	The public, the MARTA Staff, the MARTA Board, stakeholders and FTA	NYCT, FTA, public	LACMTA, Caltrans, cities along alignment (Los Angeles, Pasadena, and South Pasadena), and public	Federal, state and county government, municipalities, environmental agencies, local interest groups, general public		Tri-Met, Port, City of Portland	UDOT, WFRC (MPO), UTA, FTA, FHWA	RTD, FTA, DRCOG (MPO), Colorado DOT	Public comment and review was a primary driving force. Most of the alignment was reserved. Regional planning agencies also played a part in identifying alternatives
3	What was the basis for choosing alternatives? How are they ranked?	Capital and operating costs; financial feasibility; ridership; user and non-user benefits; cost	Adding system capacity, improving service, cost effectiveness, but the deciding factor were ultimately price and least	--	Cost effectiveness, ridership, transportation improvement, environmental considerations	--	--	(1) Capital costs; (2) Operating and Maintenance costs; (3) Financial Feasibility; (4) Attainment of Local Goals and	Costs, mobility, economic development, social and environmental impact, station access and	Regional planning and public comment.

I.	Alternatives Selection	Atlanta MARTA North Line Extension	New York NYCT 63rd Street Connector	Pasadena LACMTA Gold Line	Pittsburgh PAAC Airport Busway	Portland TriMet Interstate Max Extension	Portland TriMet Airport Extension	Salt Lake City UTA North South Line	Denver RTD Southwest Line	Washington WMATA Largo Extension
		effectiveness; and assessment of environmental impacts	adverse impact or disruption to communities during construction.					Objectives including Transportation Effectiveness, Overall Environmental Assessment, and Equity; (5) Cost-Effectiveness; and (6) Comparison of the Significant Trade-Offs Between Alternatives	ridership	
4	What was the role and reaction of the community and politicians on the alternatives analysis and choosing the LPA or any modification?		Politicians (particularly a Senator) were influential in the adoption of the project.	Project was suspended in 1998 due to budget concerns and a project construction authority was created	--	After a lengthy public planning process in the 1990's and the defeat of a local funding ballot, the project was shortened and advanced	--	A public debate extended over 7 years and involved a public referendum.	Public and politicians helped define the selection criteria and provided input to state mandated process lead by DRCOG	ROW was set aside by the jurisdictional agencies. The Community and local Politicians were very active in ensuring that the alignment fit into the expectations of the communities along the alignment. They addressed noise, vibration, aesthetics and other issues at various meetings.

II.	Estimation	Atlanta MARTA North Line Extension	New York NYCT 63rd Street Connector	Pasadena LACMTA Gold Line	Pittsburgh PAAC Airport Busway	Portland TriMet Interstate Max Extension	Portland TriMet Airport Extension	Salt Lake City UTA North South Line	Denver RTD Southwest Line	Washington WMATA Largo Extension
1	What was the basis of estimate at each phase?	The scope and schedule of work as defined by the agency in the form of design or construction documents	Actual site and field conditions for all trades	Authority defined project scope and provided some design drawings as reference; Joint Venture DB contractor made hard bid	Construction estimates were prepared at each phase of design development and were based on prevailing labor and material rates in effect at		Agency experience and data, TriMet design standards, design plans and specs, input from local contractors and	Bottom-up, cross-section estimates at all phases (e.g. 30%, 60%, 90%) were used with estimated quantities and local unit costs		The completed documents that were prepared as the project advanced. This was based on the costs experienced in constructing the

II.	Estimation	Atlanta MARTA North Line Extension	New York NYCT 63rd Street Connector	Pasadena LACMTA Gold Line	Pittsburgh PAAC Airport Busway	Portland TriMet Interstate Max Extension	Portland TriMet Airport Extension	Salt Lake City UTA North South Line	Denver RTD Southwest Line	Washington WMATA Largo Extension
				at project inception	the time.		suppliers, economic indicators, labor conditions	where applicable. For LRT components, unit costs were used from similar projects and adjusted, if needed, to Salt Lake labor conditions and local experience.		103 Mile system
2	Who did the estimate, in-house or consultant?	Both, depending on engineer-of-record	Both	Consultant	Consultant	Both	Consultant (in-house to DB contractor)	Consultant	Consultant at PE, in-house at Final Design	Both
3	Does your agency have an estimating manual or guide? Is there a formalized estimating process? If so, was it used for this project at any time? At what phases?	Yes, for all phases	Yes, for all phases	Yes, project used a formulized Joint Venture (JV) estimating process and bid	No formal estimating manual but estimates are developed and presented in accordance with the contract bid form	There is an established process but no formal estimating manual	Yes, agency had an established process (including a database and RS Means) that was used for all phases	No, but there was a design criteria manual that has since been developed into an estimating manual	No	Not sure if the agency has an estimating manual or guide. There is there a formalized estimating process it is used throughout the project. All estimates were prepared in accordance with our standards
4	Was the cost estimate reviewed? Internal or external? Frequency? By phase?	Yes, internally for all phases	Both internally and externally for all phases	Yes, internally by JV	Yes, reviewed internally for each phase (30%,60%,90% and final design) and updated on a quarterly basis	--	Both internally and externally	Both internally and externally at bi-monthly reviews	Yes, internally several times between PE and FD	The cost estimate was reviewed internally by phase as it progressed and on completion before being finalized
5	Was there a formal independent cost estimate completed? When? At what phases?	Yes, at each phase of the project	Yes, prior to sign-off at each phase	No, both companies in joint venture produced bid	No	--	Yes, at conceptual and PE phases	No	Yes at 50% and 90% design	Yes, completed during design development and prior to RFP

II.	Estimation	Atlanta MARTA North Line Extension	New York NYCT 63rd Street Connector	Pasadena LACMTA Gold Line	Pittsburgh PAAC Airport Busway	Portland TriMet Interstate Max Extension	Portland TriMet Airport Extension	Salt Lake City UTA North South Line	Denver RTD Southwest Line	Washington WMATA Largo Extension
6	What were the major cost drivers?	Scope of work and scope growth (material and system with a longer functional life), design and construction change orders, difficult and unexpected field conditions (heavy traffic, excavations)	NYC labor costs, working around active roadway and railroad, limited allowable work hours	Systems, trackwork, stations, elevated structures, differing site conditions, 3rd party influence on scope	Elevated structures, ROW, and tunnels	--	Insurance, start of construction, management overhead	Right of way and track elements, LRT vehicles, systems, stations and parking	Station design and railroad relocation	Cost of materials – metals, concrete. Specialty equipment to meet WMATA standard. Uncertainty of utility relocations, regulatory compliance – storm water management, Water & Sewer installations, Power supply to meet WMATA Criteria
7	How much experience do the estimators have on similar projects?	Very experienced	10-15 years	Very experienced	Very experienced	--	>25 years	Very experienced	>10 years	Moderate experience on similar projects. Average service is over 10 years
8	If unit costs were used, how were they gathered-from past projects or other agencies' data?	Historical data files, other agency costs, differences between new situations and past averages, unusual project features and variations from past projects	Past projects and some previous bids; contractor's crew size production rates	Past project history	Past project history	Unit costs gathered from past projects and from RS Means	TriMet maintains an extensive database of submitted bids for previous projects, uses RS Means, and calls local and regional suppliers to confirm current market trends.	Both types of sources, past project history and other agency data	From past projects as well as Colorado DOT cost data, RS Means, and various supplier quotes	Unit costs were used from past projects and other agencies' data but more from past projects
9	How are contingencies estimated? How are they subsequently managed, approved and authorized for use?	Project contingency is estimated as a percentage of the base estimate at each phase of the project. Contingencies are	Contingencies were built into contractor's reduced production rates	Contingencies based on project risk	Agency standard contingencies range from 10% to 30% during design development and are applied to the total construction	Contingencies are estimated as a percentage of the hard costs. For management purposes, contingency is	The owner had zero contingency on the books because of budget constraints. All parties knew	Standard contingencies and soft costs recommended by FTA and FHWA	The contingency per contract package was adjusted at each phase according to complexity, potential of unforeseen	Contingencies are estimated based on past projects. They were segregated in line items that were monitored

II.	Estimation	Atlanta MARTA North Line Extension	New York NYCT 63rd Street Connector	Pasadena LACMTA Gold Line	Pittsburgh PAAC Airport Busway	Portland TriMet Interstate Max Extension	Portland TriMet Airport Extension	Salt Lake City UTA North South Line	Denver RTD Southwest Line	Washington WMATA Largo Extension
		distributed over contract packages and limited portions thereof are appropriated for use by authorized project representatives at various levels of management.			cost.	divided into "owner's contingency" and construction contingency	that any change that would increase costs would have to be offset by cost savings to move forward.		conditions, and type of work.	monthly and each time a change or revision was issued
10	Were the estimates reviewed by any one other than the estimator(s)?	Yes, by the manager of the estimating department, the project managers, engineering and construction managers, department directors and MARTA Assistant General Managers	Yes, design managers, construction managers, MTA and FTA oversight	Yes, senior JV board	Yes, by Port Authority staff and its GEC	Yes, by PMO team	Yes, all key project and technical staff	Yes, PMO and VE consultant	Yes, other in-house staff and PMO	Yes, Project Manager and the Contract Administrator (procurement staff) and the Department of Planning and Strategic Programs
11	Were contractors or suppliers involved in the cost estimation during any of the phases?	Yes, contractors and suppliers were routinely contacted during the design phase of the project to verify availability, feasibility of materials, latest technology and industry trends.	Yes, suppliers provided vendor quotes to agency	Yes	Yes	No	Yes	No	Yes, when resources not available internally	Yes, RFP
12	What was the role of the designer/CM/PM in the cost estimation process?	The designer/CM/PM provided the design, constructability reviews and the coordination of the drawings and specifications and assisted in researching cost efficient means and methods of	Estimates and constructability reviews; administering bid process, answering pre-bid questions	Designer was consulted	The CM had primary responsibility to prepare the estimate. The Designer/PM provided review and oversight.	Pricing and estimate validation		Estimates and review	Review and contingency assignment	The designer consultant prepared the RFP documents and an independent cost estimate. Also developed a formal independent Risk Analysis (TVO) using Monte Carlo

II.	Estimation	*Atlanta MARTA North Line Extension*	*New York NYCT 63rd Street Connector*	*Pasadena LACMTA Gold Line*	*Pittsburgh PAAC Airport Busway*	*Portland TriMet Interstate Max Extension*	*Portland TriMet Airport Extension*	*Salt Lake City UTA North South Line*	*Denver RTD Southwest Line*	*Washington WMATA Largo Extension*
		construction.								simulation. The Design-Build teams – helped to identify cost drivers and areas where costs may be reduced
13	Were any changes made to the estimation process because of the lessons learned on this project?	Yes	No	No	No	Yes, earlier involvement of contractors to take advantage of current market information and construction techniques	No, but added this project data to Tri-Met's database	No	No	Yes the Data base maintenance was revised
14	What risk assessment approaches were used to develop and/or evaluate the cost estimate? Describe the mitigation process…how was it implemented through the project development process?	No formal risk assessment approach-- placed contingency values on estimated quantities to account for potential overruns	Line by line contingency allocation; anticipation of known risks such as support of excavation and groundwater control	Risk was evaluated and allocated on 3rd party influence, differing site conditions, environmental and hazardous waste mitigation, QA/QC, and relocation of utilities to minimize the necessary project contingencies	No formal risk assessment process	--	Agency used it's extensive cost database for light rail projects and a highly-experienced consultant	No formal risk assessment process, but risk management is part of UTA's philosophy and functions	No formal risk assessment process but a Phase II Hazard Analysis as well as other "intuitive" analyses was done	All risk real and perceived were reviewed. The consequence, mitigation strategy, person responsible and status were summarized and tracked. The mitigation process was reviewed quarterly by PMs and Director.
15	Were any unique techniques used to generate the cost estimate? If so, describe.	No	Contractor based estimates were used with actual site and field conditions for all trades (as opposed to preparing a baseline engineering estimate and applying complexity	No	No	No	No	No	No	Simulation techniques used to generate the cost estimate was the Monte Carlo simulation to establish cost confidence level and identify contingency

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			factors)							
16	Was the proposed project implementation schedule reflected in the cost estimates?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	--	Yes
17	Was the estimate completed in year-of-expenditure dollars or in constant dollars? If constant dollars, why?	Both-- Constant with escalation during design phases; YOE during construction	Constant-- using current year dollars escalated to the mid-point of construction	YOE	Both	YOE (per agency's policy)	YOE (per agency's policy)	Both-- constant dollars for simplicity and for the federal evaluation cost-effectiveness index	YOE	The early estimates were escalated to mid point of construction. Final estimates escalated to mid-point of construction for several key commodities using BCS indices

III.	Procurement Strategy Questions	Atlanta MARTA North Line Extension	New York NYCT 63rd Street Connector	Pasadena LACMTA Gold Line	Pittsburgh PAAC Airport Busway	Portland TriMet Interstate Max Extension	Portland TriMet Airport Extension	Salt Lake City UTA North South Line	Denver RTD Southwest Line	Washington WMATA Largo Extension
1	What approach did you employ for procuring this project? Design-Bid-Build (DBB), Construction Management at Risk (CMR), Design-Build (DB), Design-Build-Operate-Maintain (DBOM), Super Turnkey	DBB	DBB	DB	DBB (line and stations), DB (park and ride lots), DBOM (ITS)	CMR (for most of construction), DB (bridge)	DB	DBB	DBB	DBB (for the high risk site preparation contract, including the construction of the bridge over the Capitol Beltway), DB (stations and parking facilities and the Line, Trackwork and Systems contracts)

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2	What was the basis for your chosen method of procurement?	Past experience	--	Compress schedule, save on professional services cost by contracting experienced project management consultant, minimize interfaces with fewer DB contractors	Bid environment and operational requirements	--	Unsolicited proposal	Previous experience with this conventional and proven method; federal agency acceptance; cost effectiveness	To minimize risk by providing complete design prior to bid.	The need to allow for expedited completion of the project and to utilize the innovation of experienced contractors and designers in the industry.
3	What were the criteria for selecting GEC and construction contractors? Low Bid, Best Value, Two Step	GEC by qualification; most construction on low bid	Low bid	Two Step (qualified low bid)	Low bid (construction contracts); Two step (GEC)	--	--	Low bid	Low bid (construction); RTD was GEC	Two step (1st qualifications, 2nd best value technical/cost proposal)
4	How many bidders submitted proposals?	at least 3	3 to 5 for each contract	4	2 to 12	--	--	4 to 7	4 to 5 per construction package	4
5	Did you pre-qualify each bidder?	No, except for special material procurement contractors	No	Yes	No	No	--	No	No	Yes
6	Did your agency conduct an industry review?	Yes, on the contracts deemed appropriate	No	No	No	No	--	No, but agency sponsored peer reviews and VE reviews	Some informal industry reviews and several peer reviews and	Yes
7	Were there any incentives or penalties used in the design contracts?	No	No, only liquidated damages if schedule not met	No	A performance based fee was employed but no penalties	No	--	Only liquidated damages	No	One contract had an incentive for early completion
8	What drove costs in procurement? Process, Terms, Market place, Contract size or complexity	Process, terms, marketplace, contract size and complexity	Contract size and complexity	Terms (risk allocation)	Process, terms, marketplace, contract size and complexity	Marketplace	--	Marketplace, process, terms, contract size and complexity	Contract size and complexity	Marketplace
9	Describe the risk management plan used to form the basis to the procurement. What	The Agency took on the risk of safety but reduced overall insurance cost by operating	Most of the risks were assigned to the contractor, except for the shifting of trains and	Authority had full responsibility for environmental and hazardous waste mitigation,	The owner assumed full risk of constructability. The contractors	The agency assumed the insurance, ROW delivery, NEPA delays, and	Agency: ROW delivery, NEPA delays, local land use (entitlement)	Owner controlled insurance program	RTD's philosophy was to accept all underground risks including	Agency Risks: Designating certain features of the project to conform to the

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	risks did the agency take, contractor assigned, shared? What particular risk elements challenged the contractor bids the most?	an Owner Controlled Insurance Program (OCIP). The OCIP also has a fringe benefit in allowing DBEs that may not normally have the required coverage for working on this scale of project to participate since the insurance is provided. Contractor had technical risks such as the design of the soil nail support of excavation and temporary traffic decking in the highly traveled corridor.	commuters through the active work site. The agency used periodic management and partnering meetings, and development of baseline geotech contract to manage some risks. A few unit price items were established but only for the unknown cut-off wall and contingency work quantities. The agency set caps on its contractor support services (such as flagmen and work trains) forcing discretionary usage by the contractors. The agency placed much of the "ownership of the subsurface conditions" on the contractor, causing some disputes, delays and claims. The agency also overlapped multiple contractors on the same work site, saving anticipated schedule but necessitating greater coordination by the contractors.	and quality compliance auditing; the DB contractor had responsibility for QC and relocation of utilities and city facilities; both shared the risk of differing site conditions	assumed the risk of schedule and contract completion. The contractor bids were most challenged by marketplace variability of labor and material costs.	permitting risks; the agency and the contractors shared in the safety programs and incentives; the contractor assumed site conditions, labor problems, design errors, and construction permits. The bridge challenged the contractors the most.	permitting, owner decision delays, scope growth and force majeure. Contractor: site conditions, labor problems, design errors, and construction permits		hazardous material and unidentified objects known at the EIS phase of the project after completing the Phase II Hazard Analysis. The biggest risk that the contractors took was the estimation of the railroad flagging needed to perform their activities.	existing system and in some areas fully designing specific elements, Owner Controlled Insurance Program (OCIP), Obtaining permits from jurisdictional agencies. Contractor: Design of temporary work, completing final designs, design and construction schedule, coordination with jurisdictional agencies. Shared interface coordination between the contracts. Schedule and coordination with Jurisdictional agencies challenged the contractors the most.

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10	How was the risk assessment process utilized in the project development process? What mechanisms were used? To guide the cost estimation process? The construction management process?	No formal risk assessment process	Line by line contingency allocation; anticipation of known risks such as support of excavation and groundwater control	--	No formal risk assessment, but standard engineering practices required analysis of risks as a matter of course	No formal risk assessment	No formal risk assessment but contractor performed its own risk assessment	No formal risk assessment process	Only intuitive risk analysis was conducted.	Formal Risk Assessment Analysis at the 50% completion point of the Preliminary Engineering
11	What were the key procurement lessons learned?	1) Manage high-risk projects by creating smaller job specific packages. 2) Utilize value engineering and/or new technologies (soil nailing) to mitigate impacts to the public (traffic, station location and excavation hazards), reduce costs and improve schedule performance. 3) Perform permitting, real estate acquisition and procurement ahead of construction. 4) Reinforce the belief that the Partnering Process is worthwhile.	Agency: Early involvement with outside agencies permits; Advance procurement of utilities contracts; Securing property rights (condemnation); Hazardous materials (removal & disposal) Contractor: Allowing innovation to the contractors lowers the bid cost and helps partner the project; Capping agency services to the contractor (in reasonable amounts) increases their efficient use; Overlapping contractors on the same site requires huge coordination and may have been better to speed up the acquisition and design than stack the contractors; The agency needs to "own" the	Dividing the project into 3 contracts helped to limit the amount of interaction between contractors and therefore the possibility of contractor caused delays or disruptions	A project needs continuing regional support and the buy-in of key government officials. In addition, there is a critical need for continued maintenance of individual construction package estimates through design development to help control costs.	Use of timely value engineering and constructability reviews provided schedule and budget certainty	--	Good leadership helped guide the project and gain community support	The project required the relocation of several miles of existing railroad tracks. The relocation process required phased construction and necessitated massive coordination among the contractors, RTD, railroads and other entities. This constituted a major risk and dictated the construction packaging and the organization for the construction management process. RTD managed this risk by negotiating the agreements with the two railroads prior to the	Perform minimal design but focus on the performance parameters that are acceptable. Be less prescriptive.

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			responsibility of the subsurface conditions in order to maintain competitive bidding and claims control.						onset of construction. Taking the risk of construction phasing and sequencing of the various contracts can be problematic. Care must be taken in managing several overlapping schedules.	

IV.	Project Organization Questions	Atlanta MARTA North Line Extension	New York NYCT 63rd Street Connector	Pasadena LACMTA Gold Line	Pittsburgh PAAC Airport Busway	Portland TriMet Interstate Max Extension	Portland TriMet Airport Extension	Salt Lake City UTA North South Line	Denver RTD Southwest Line	Washington WMATA Largo Extension
1	Please describe your agency's organizational unit. What were its primary responsibilities?	The MARTA Department of Development consisted of the Office of the Vice President, the Office of Systems Engineering, the Office of Facilities Engineering, the Office of Construction and Contract Administration, the Branch of Project Controls. The Department's prime responsibilities were to direct and control all activities related to new	A new Routes Division was created to manage mega project under NYCT-Capital Program Management. A Program Manager who was responsible for day to day management of the project was headed this organizational unit. He reported to the Senior Vice President of NYCT-CPM. The organization operated under a matrix where service centers provided skilled personnel to the Program Manager	Authority kept the number of its employees to a minimum by integrating into an experienced project management consultant team comprised of the design engineers, construction managers, project controls personnel, contract administrators, and quality assurance. The project also included 3 construction Design-Build	--	Projects are overseen by the Capital Projects and Facilities Division, one of 5 units of TriMet. Capital Projects develops, designs, constructs, and maintains the Agency's facilities including bus and rail infrastructure and administrative buildings. The Division is managed by an Executive Director, who reports to the General Manager.	--	--	The project organization included the following teams: planning, design, construction, project control and QA/AC. There were also support teams consisting of legal, contracts, finance and right-of-way	Quality assurance, project administration-budget and schedule management

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		development and improvements and renovations to existing rail and bus facilities.	for developing the contract documents related to their particular skills. A Design Manager who reported to the Program Manager was responsible for all Design Management activities and three Construction Managers reported directly to Program Manager who were responsible for all construction activities for the Project.	teams.						
2	What was the total number of staff in your organization?	110	105 FTE at peak	50 salary staff, 500 construction	32 in Engineering, Planning, and Construction	70-90	--	8 to 15	61 FTEs	35
3	What technical disciplines does your agency's resources cover?	Comprehensive – Civil, Structural, Electrical, Mechanical, Architectural, Train Control, Communications, Environmental	Structural, Civil, Mechanical & HVAC, Electrical, Signal and Traction Power, Support groups including Estimating, Scheduling, Procurement, Quality, and Safety	--	Architectural, Civil, Mechanical and Electrical	Capital Projects includes systems and civil engineers, architects, construction managers and administrative staff, project controls, and rail vehicle engineers.	--	--	All (agency was GEC)	Civil, structural, mechanical, electrical, systems, architecture and procurement

IV.	Project Organization Questions	*Atlanta MARTA North Line Extension*	*New York NYCT 63rd Street Connector*	*Pasadena LACMTA Gold Line*	*Pittsburgh PAAC Airport Busway*	*Portland TriMet Interstate Max Extension*	*Portland TriMet Airport Extension*	*Salt Lake City UTA North South Line*	*Denver RTD Southwest Line*	*Washington WMATA Largo Extension*
4	Were there any changes made to the organizational structure to prepare for the procurement and execution of this project?	No major changes related to the project	Yes, dedicated construction management office was set up at the job site	Yes, integration of a project management consultant team	Yes, project staff set up	Yes, before each rail project commences, a matrix organization is created from among the Division's staff to support that project. Project-specific staff were hired for owner-controlled insurance program and construction safety.	--	Yes, project staff set up	Yes, new hires for final design and construction phases	Establishment of a co-located project group which comprised of the WMATA project staff and a core group from the GEC
5	Did you rely on in-house technical resources or external consultant services?	Both	Both	Both	Both	Both	--	Both	Mostly internal (agency was GEC) except during PE and for LRT and railroad design	Both
6	If you chose external consultant support, did you have separate systems consultants? Why?	No, GEC provided both facilities and systems engineering	Yes (e.g. HVAC)	Yes, systems was subcontracted DB contractor	Yes	Yes	--	No	System final design done internally	Yes to supplement agency staff and to have wider deeper talent
7	What was the level of interagency coordination? What other agency units were involved during the procurement phase of the project?	--	Highly coordinated with NYC traffic, police, fire, building, and environmental protection	--	Extensive interagency coordination during design included Federal, State and Local agencies and governments, public utilities and railroads	Intergovernmental agreements were executed with the Portland Department of Transportation, MPO, Oregon Department of Transportation, and the Oregon Department of Environmental Quality.	--	UTA purchased LRT vehicles with San Diego as a Tag-on to their order. UTA also coordinated with Portland, Oregon.	Cities along the alignment, CDOT, FRA, FTA, and PUC	Operations (OPER), Engineering(ENGA), Communications(.COM), Safety and Security(SARP), counsel (COUN)
8	Assess the effectiveness of the overall organizational approach during									

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	the procurement of the project.									
a.	Strengths?	With DBB the Owner is assured of getting facilities that are designed to optimize the end users requirements and life cycle.	Able to respond to bidders' questions regarding schedule, construction, and alternative solutions	--	Previous experience of team members and multi-discipline backgrounds	Flexibility and sufficient depth to effectively manage the design and construction processes; Alignment of interests amongst the partners meant fewer organizational problems, clarity of communications between stakeholders helped as did simplicity of the DB agreements and related documents	--	Very good collaboration	Cost savings resulted for utilizing in-house staff throughout the design and construction phases. In addition, savings resulted from the ability of the agency to reach a timely agreement for relocation of existing railroad lines with both railroads.	Very effective organizational approach; achieved project within budget
b.	Weaknesses?	With DBB the Owner is only innovative as their design team. If DB were used the marketplace would assure the Owner got the most cost effective design. The problem with Design-Build would be that the significant up front cost will limit the number of proposers for the project.	Contractor believes that a better balance of risk sharing and responsibility was possible	--	Lack of experience of some members with FTA guidelines	TriMet lacks depth in some systems areas; consultants are retained to provide needed expertise; Complexity of the Master Agreement; coordination with Oregon DOT could have been better, especially in gaining clarity and buy-in to the design	--	Everyone was very busy and could not focus on just one task. All work was 80% of what it could have been possibly because of understaffing.	Retention of specialized technical staff was difficult due to market demands.	The procurement process took longer than planned

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9	How might the roles and responsibilities have been assigned under DBB vs. DB?		Likely more input from contractor on means and methods to speed up resolution of problems		Same way	Not much different			--	Similar, but there would have been more work done before the RFP in the DBB process and there would have been more need for contract administration and design support through the construction process. The DB process resulted in more engineering support for review or proposed schemes and fewer but larger value changes
10	What were some of the significant lessons learned in organizational approach under your chosen procurement method (i.e., DBB vs. DB)?		Preparatory phase meetings; Experienced management teams on both sides; Timely problem-solving; Weekly schedule and program meetings; Open communication with contractors	The Authority and PMC chose to include baseline specifications in the contract to give the DB clear direction on what was expected, while many more reference documents gave the contractor some ideas to explore further at its discretion.	--	As the owner and operator, TriMet involved operations and maintenance staff during the design and construction phases, and would continue that involvement regardless of the procurement method.	--	--	The RTD project team was lean but successfully transitioned from design to construction with the help of some knowledgeable staff. Outside consultant were only used for the design of the LRT, railroad structures, and geotechnical services.	DB allows more innovation and permits the DB team to focus on the issues that are peculiar to the project and solve them. The DB process produces definite schedule savings.

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11	What were the key lessons learned?	--	Developed good and amicable working relationships (partnering) with User Department and Contractor; Required fast reliable turn around design support during construction; Selected and employed the right people for the particular job at hand; Advance procurement of systems elements.	3rd party management and design control are critical	The organizational structure seemed to work efficiently	Establishing and maintaining a partnership attitude with the prime contractors served the project well.	--	The way or method used somewhere else may not be the best for your project.	Negotiated with two freight railroads (UPRR and BNSF) one year prior to letting out the first segment contract to address the design, the use of the right-of way, construction, freight railroad dispatching and maintenance prior to letting our first segment contract. Also important were managing and maintaining multiple schedules and strengthening the Quality Management Plan.	DB process requires a strong project team that is well versed in the needs of the client. The Authority must develop and keep current a set of Design Criteria and standards.

V.	Project Budget/Cost Questions	Atlanta MARTA North Line Extension	New York NYCT 63rd Street Connector	Pasadena LACMTA Gold Line	Pittsburgh PAAC Airport Busway	ortland TriMet nterstate Max Extension	Portland TriMet Airport Extension	Salt Lake City UTA North South Line	Denver RTD Southwest Line	Washington WMATA Largo Extension
1	What was the final estimated cost of the project?	$ 463,200,000	$ 645,000,000	$ 403,000,000	$ 321,800,000	$ 350,000,000	$ 125,000,000	$ 311,000,000	$ 177,700,000	$ 456,000,000
2	What was the federal share?	80%	55%	0%	80%	74%	0%	80%	78%	60%
3	What was the state and local share?	20%	45%	100%	20%	26%	100%	20%	22%	40%
4	What did the soft costs (estimated) amount to?	$ 107,200,000	$ 209,766,066	--	$ 143,247,000	$ 124,175,000	--	$ 70,000,000	$ 13,300,000	$ 47,590,000
	What did the soft costs (actual) amount to?	$ 123,000,000	$ 196,973,732	$ 111,000,000	$ 115,000,000	$ 103,194,000	$ 26,000,000	$ 48,000,000	$ 33,000,000	$ 41,690,000

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5	What was the cost control employed for the project?	--	Identifying "deleteable" items, separation of contracts to encourage competitive bidding	Risk allocation	--	TriMet purchased and customized "Prolog" to handle cost tracking, document control, and field office requirements. In addition to monthly reports, the project twice annually prepared a cost-to-complete report to estimate the final project costs.	--	--	--	Departmental Oversight and full time Project Controls manager reporting to the Program Director
a.	Who was responsible for cost control-agency staff or consultant?	Agency staff	Agency staff	DB contractor	Agency staff	Agency staff	The DB contractor was responsible for cost control under the oversight of the agency	Both	Agency staff	Agency staff
b.	How was the PMO utilized in cost estimation and cost control?	Monthly review meetings	--	--	Independent assessment and advice	Oversight	--	--	Oversight	Oversight
6	Were there any delays in federal funds appropriations? Did this affect costs?	No	No	--	No	Yes, additional costs were part of interim finance line item	--	Yes, it affected costs	Yes, the agency incurred additional interest expense, however, the interest was absorbed within the agency's overall budget and was not included in the project cost	Yes, several months but did not affect costs

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7	Who paid for cost increases (federal, state, or local funds)? How was this determined?	Cost increases from amended FFGA were paid by federal funds, and local funds covered any further increases	Same share of original funds except for any re-do work which was paid for by agency	--	Because there was a FFGA, state and local would have had to pay for cost increases. When the project went severely over budget, Port Authority submitted a recovery plan to FTA that eliminated significant project elements.	Cost increases were paid for out of local funds via a formula established in the Master Agreement, except that scope increases or cost increases due to lack of diligence were to be paid for by the responsible party.	Ultimately local funds, but the agency had negotiated a fixed price DB contract	All cost increases were managed within the FFGA.	There were no cost increases. The budget was completed $3.0 million under budget.	Both federal and state funds. The project is now in the closeout phase. By Full Funding Agreement cost overruns above the budget will be the responsibility of the state
8	What were the key lessons learned?	--	- Establishment of adequate project reserves early on in the budget process - Having a budget/cost control team fully dedicated only to this project	--	--	Some flexibility about scope must be maintained in a project with significant budget pressures; early warning, good communication and solid documentation are key to avoiding increases and resolving them when they do occur.	--	Be firm with local government.	The importance of strict change control procedures along with limiting the cost for project enhancements	Ensure that there is a party responsible for funding shortfalls.

VI.	Project Schedule Questions	Atlanta MARTA North Line Extension	New York NYCT 63rd Street Connector	Pasadena LACMTA Gold Line	Pittsburgh PAAC Airport Busway	Portland TriMet Interstate Max Extension	Portland TriMet Airport Extension	Salt Lake City UTA North South Line	Denver RTD Southwest Line	Washington WMATA Largo Extension
1	What was the total estimated duration of the project? By individual start and completion of each phase? Estimate to actual?	8 years (Planning 3 years, design 3 years, procurement 2 years, construction 3 years)	June 1994 to August 2001 (86 months)	2000 to 2003 (30 months for construction)	Original estimated duration from start of final design until completion of construction was	4 years	Limited construction started March 1999, opening September 2001 (30 months)	Design Sept. 1995 to Nov. 1997; Opening in Dec. 1999	PE/EIS 09/94 – 03/96, Final Design 09/96 – 12/98, Construction 01/97 – 12/00	Approx. 9 years from NEPA/EIS though closeout.

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					3 ½ years. The Recovery Plan extended the schedule to 11 ½ years (end of 2004)					
2	What was the actual duration?	Completed within 2 months of estimates	June 1994 to September 2001 (87 months)	On time (30 months)	Actual opening of the busway was 6 ½ years after start of final design	FFGA in September 2000, opening in May 2004	March 1999 to September 2001 (30 months as planned)	About one year ahead of schedule	The project opened on 7/00 (5 months ahead of original schedule)	Approx 9 Years; Overall project duration met approx 8 months slippage from the original plan to award during Procurement Phase
3	What was the schedule control employed for the project?	Weekly meeting and monthly reports; baseline schedule used to measure progress was changed only with management approval	Utilized Primavera Project Planner, Work breakdown Structures (WBS) and Organizational Breakdown Structure (OBS)		Agency control with funding availability	Contract Control Board Approval	Primavera P3	Primavera P3	Primavera P3	Cost loaded CPM. Monthly updated and bi-weekly look ahead schedules
a.	Who was responsible for schedule control-agency staff or consultant?	Both, agency staff at program level and contractors at project level	Both	Contractor	Agency, but GEC/PM prepared the project schedule for FTA reporting	Agency	Contractor with agency oversight	Consultant	Agency project scheduler during first half, consultant during second half	Staff
b.	How was the PMO utilized in schedule control?	Review of monthly status reports and quarterly schedule review meetings	--	--	Independent assessment (quarterly reviews)	Oversight only	N/A	Review and oversight	Periodic reviews	Oversight
4	Did you require a centralized schedule electronic repository? How did you integrate the system to accept contractor schedule submittals?	Each contract had specifications to provide schedule in an importable electronic format with the major milestones identical to those in the master schedule on a monthly basis.	No	No, contractor performed stand alone schedule	Contractor submittals used by the CM for contract management only	No	Contractor provided a monthly P3 schedule to agency for discussion	No	--	No , Submittals were made electronically followed by a hard copy. The official transmission was a hard copy
5	What payment approach did you use? Lump sum,	Cost-loaded CPM schedule with progress payments	Lump sum based on cost loaded CPM schedules	Lump sum	Program Manager and designers: cost	Payment tied to completion of milestones	Lump sum with monthly progress	Schedule of values based on unit price, lump	Earned value on all contracts	Cost loaded CPM, Lump Sum

VI.	Project Schedule Questions	Atlanta MARTA North Line Extension	New York NYCT 63rd Street Connector	Pasadena LACMTA Gold Line	Pittsburgh PAAC Airport Busway	Portland TriMet Interstate Max Extension	Portland TriMet Airport Extension	Salt Lake City UTA North South Line	Denver RTD Southwest Line	Washington WMATA Largo Extension
	earned value?		and jointly established baseline		plus not to exceed; Construction contracts had both lump sum and unit price items.		evaluations	sum by pay item		
6	How did you address security issues with respect to contractor proprietary schedule information?	Contractor allowed summarizing sensitive data prior to submitting the monthly updates or separate proprietary data from the schedule prior to submitting it.	All information kept by PM	--	No other parties had access to schedule submittals	--	--	--	--	There were no issues that we were aware of. The schedule was prepared using Primavera.
7	Were there any control strategies employed during final design and implementation? If so, please describe them?	Each monthly submittal was reviewed for work efficiency. Where work around schemes could compress the project duration, they were investigated by the project team and employed if possible. Project schedule contingency, added as an activity in the project, could only be utilized by upper management. Windows of time were inserted between contracts to absorb delays or to provide early access thereby improving schedule performance.	Minimize points of conflict by establishing intermediate milestones	--	Progressive design level submissions, design review meetings, cost control, schedule control and constructability reviews	--	Milestones at 30%, 60%, 90%, and 100% design for all major components	For design, maintained a task and drawing control log of hours and dollars spent per task and drawing, estimate to complete, percent earned.	Weekly status meeting to review contract, budget, schedule, and change orders	No control strategies during design/ implementation Requested that certain areas be performed out of sequence. Critical work on revised time-saving measure (1) Coordination of contractors resulted in an adjustment of milestones (2) Concurrent rather than series testing (3) Phased track energization. (4) Early coordination ,Operations, Construction, Contractors. (5) Weekend shutdowns, tie in of new systems.

VI.	Project Schedule Questions	*Atlanta MARTA North Line Extension*	*New York NYCT 63rd Street Connector*	*Pasadena LACMTA Gold Line*	*Pittsburgh PAAC Airport Busway*	*Portland TriMet Interstate Max Extension*	*Portland TriMet Airport Extension*	*Salt Lake City UTA North South Line*	*Denver RTD Southwest Line*	*Washington WMATA Largo Extension*
8	Did your agency have an existing document configuration/control program? Or did you have to develop one specifically for this project?	Existing document configuration and control programs	Existing, also enhanced during project	The PMC developed a configuration control program with a biweekly Configuration Management/Change Control (CM/CC) meeting	A Project Management Plan, incorporating these requirements, was developed specifically for this project	Customized the document control capabilities of Prolog	Primavera	UTA used a Parsons Brinckerhoff program initially and migrated to Primavera's Expedition product.	Existing program was refined for this project	Existing program was refined for this project
9	What were the roles and responsibilities of the contractor, owner, and consultant?	Contractor maintained the project resource loaded schedule on a monthly basis and submitted it to the CEI to track progress and interface issues.	Agency had overall project schedule responsibility and contractor was responsible for schedule performance and slippage mitigation measures according to the terms and conditions	--	Contractually defined	The contractor was responsible for producing a monthly schedule with changes noted; TriMet reviewed and commented on the schedule, directed and discussed any required changes to conform with the master schedule, and maintained the master schedule.	Contractor: Maintained project schedule and provided updates and reports Owner: Maintained Agency schedule used to coordinate project support efforts with all departments within the Agency and to inform the public. TriMet reviewed and commented on the schedule submittals from contractor.	The contractor submitted documents that were logged into document control. All sent and received documents were to be routed through DCC. The DCC technician was an agency employee. The consultant provided oversight and advice as needed to set up the Expedition transition.	Contractor: monthly updates with narratives; Owner: reviews and accepts schedule	Contractor took the lead in developing the schedule, owner reviewed /approved. Verified completed work each month and reviewed updated schedule

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10	What were the key lessons learned?	--	A well-defined work breakdown structure and a well-planned payment schedule were developed. A baseline Master Schedule formed the basis for all estimates of construction duration, force account projections, track outage planning, intermediate and inter-contract milestones and program contingencies. Schedule Readiness Reviews were held weekly with the construction management team and contractors to monitor planned vs. actual production, determine schedule slippage, and mitigation plan.	--	Early resolution of property issues are key to project schedule success	A partnership atmosphere fostered flexibility when needed with the contractors.	--	Keep it simple -- clear lines of communications and authority.	It was important to monitor key project milestones and to track the budget closely to insure that the project stayed on time and on budget.	Monitor the schedule regularly. Contractor will design facilities with due consideration of constructability & schedule if design build approach is allowed to work.

VII.	Change Order Management Questions	Atlanta MARTA North Line Extension	New York NYCT 63rd Street Connector	Pasadena LACMTA Gold Line	Pittsburgh PAAC Airport Busway	Portland TriMet Interstate Max Extension	Portland TriMet Airport Extension	Salt Lake City UTA North South Line	Denver RTD Southwest Line	Washington WMATA Largo Extension
1	Please describe the change order process employed by your agency?	RFPs were issued, priced and agreed to prior to performing work unless performed on a force account basis when the project schedule did not allow for time to complete the Change procedures.	Begins with a scope meeting, preparation of schedule and cost estimate by day 15, agency review by day 20, negotiations and NTP before day 90 or extended to day 120. (See Flow Diagram)	The primary technique used was a biweekly Configuration Management/Change Control (CM/CC) meeting in which the CEO, CFO, Engineering Manager, Construction Managers, and Program Manager met with the Contracts Manager to review and approval all changes within the CEO's authority.	--	All change orders begin as a potential change in Prolog. The resident engineer enters summary information with an order-of-magnitude estimate, and tracks additional information related to the potential change as it develops.	Order of magnitude estimates were prepared for most changes to support a decision. If decision to proceed was taken, then detailed scope would be developed and priced by the contractor. This change order package would be reviewed and fair cost estimate done by agency.	UTA had a change control board which reviewed design and construction changes >$25,000 on a weekly basis.	All changes are incorporated into the various contracts through "Contract Amendments". Request for Proposals are addressed through "Change Notices" and unilateral changes are addressed through "Change Orders".	--
2	How are owner-directed change orders addressed?	Same as Owner directed except the scope was reviewed for compliance with the contract to issue RFP for pricing.	Same way	Unilateral issued to contractor	--	Same way	--	CO < $25,000 requires signature from Project Manager; CO > $25,000 requires review through change order committee, signature from General Manager, Legal, Director and Project Manager. Independent estimate and contractor estimates used to negotiate change.	The RTD project manager sends a request for proposal through a Change Notice and prepares an independent cost estimate prior to negotiations with the contractor. Negotiations start upon receiving the contractor's pricing and ultimately incorporated into the contract through a Contract Amendment. In emergencies or in situations where agreements are not reached with	These begin with the preparation of scope and an independent estimate. A PCO review board at the Project Level and approval to proceed with issuance. Scope meeting with the Contractor once the direction is received, contractor estimate, negotiations and settlement. Modification issued through appropriate process.

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									the contractor's pricing, unilateral Change Orders are used which are ultimately incorporated into a Contract Amendment	
3	How are contractor-initiated change orders addressed?	Contractor initiated changes were evaluated and if found to be in the best interest of the Authority addressed as described in Section 5 of the Resident Engineer's Manual and the General Conditions.	--	Negotiated	--	Same way	--	Reviewed by construction manager or by project manager.	The contractor sends his change request to the RTD project manager. If the change request has merit, the RTD project manager will negotiate with the contractor and process the change through a Contract Amendment.	Changes are generally from two sources. For Contractor claims that were determined to have merit a full scope was agreed and Change Orders issued after the project has developed a cost estimate. Negotiations followed settlement with the appropriate modification. Change Orders over $200K are taken to the staffed through WMATA offices, Planning, Development and Administration Committee and to the Board for Approval.
4	Were proposal documents escrowed? If so, please describe the process?	No	No	Yes	No	Yes, escrowed with bank to be released at closeout	No	No	No	Yes, in WMATA main office with copies on-site

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5	Were there any unique procedures employed for change order management?	No	Scope discussions for extra work took place before receipt of proposals	No	No	Any changes involving schedule or greater than $50,000 required approval by the Contract Control Board	--	Negotiation of cost/quantity with contractor using independent estimate	No	No
6	How was scope change authorized and controlled through the planning, engineering and design phases?	Planning: Project definition documents; Design: Work Authorization letters provided to the designer by MARTA to add scope for the project and the estimated amount of design effort to accomplish the work. Many scope changes were handled in this fashion, including major revisions such separating the earthwork contract for schedule advantage and changing the surface parking to garage. There were several significant scope changes during construction.	Maximum number of days	The changes beyond the CEO's authorization were taken to the Board of Directors Construction Committee, which consisted of two Authority Board members. To accomplish the goal of completing the project without any claims, the Authority, PMC, and DB used informal Dispute Review Boards (DRB), Escrow Bid Documents (EBD), DRB Avoidance meetings (DRBA), and the use of risk based settlement agreements. Together these techniques allowed the settlement of all disputes prior to them reaching the claim status.	--	Fixed budget	--	On the consultant side, scope change was managed by a task and drawing control log. When direction impacted the estimate to complete, then a change order was initiated.	Scrutinizing change orders and requiring approval by the project Configuration Board	The change may be issued in phases

VII.	Change Order Management Questions	Atlanta MARTA North Line Extension	New York NYCT 63rd Street Connector	Pasadena LACMTA Gold Line	Pittsburgh PAAC Airport Busway	Portland TriMet Interstate Max Extension	Portland TriMet Airport Extension	Salt Lake City UTA North South Line	Denver RTD Southwest Line	Washington WMATA Largo Extension
7	How were claims resolved?	All claims were settled by negotiation and none were resolved through the Judicial System.	Claims went to the NYCT-CPM Chief Engineer for review and resolution. There were only 4 to 6 claims on the entire project	Only two Change Orders for a differing site condition (totaling $450,000) were submitted to the Authority	--	There were no claims	Through negotiations -- most claims were lump sum	Configuration Control Committee	All claims were attempted to be resolved at the lowest level possible. In case of a disagreement between the RTD and the contractor's project managers, the claim would be escalated to the construction manager, project director and ultimately to the RTD general manager.	Bilaterally through negotiations
8	Did your agency utilize an Alternative Dispute Resolution board, or similar?	No	No	Yes	No	No but contract allowed for one	No but contract allowed for one	Contract contained provision for it	No	Yes
9	Were changes and claims tracked by cause? Was this used to effect the construction process?	Yes, but it did not effect the construction process	No	Yes, change order group	Yes, tracking of change orders with associated cause was used internally for Board of Director use only	Database was in development	--	No	No	No

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10	What were the key lessons learned?	1) Insuring that all parties involved understood changes through meetings to discuss the exact scope 2)Try to identify changes early in the construction process to prevent interrupting the Contractor's momentum. 3) Determine a date or percent complete when no more discretionary changes will be accepted. 4) Issues need to be finalized in a timely manner to insure the Owner does not have to pay for unneeded schedule compression. Often, overtime on the design will be much less than that on the construction time. Force account work should be minimized as it requires the CEI and the contractor to dedicate resources to additional paper work.	· Timely processing of change orders and claims · Agreement on scope between the agency and contractor prior to receiving cost proposals for the extra work	The Authority and PMC adopted the claims management philosophy of settling all DB claims in a fair and expeditious manner through regular meetings.	Early issues resolution at the field supervisory level is key to dispute and/or claim avoidance	Opening a potential claim file in the tracking system as soon as an issue was identified allowed TriMet to know all issues and potential costs (even just order of magnitude) easily.	--	Changes in scope were only allowed if reviewed by the CCC.	Empowering the field front line and providing adequate financial authorization is important for providing fast resolution to issues that arise during construction.	Scope of changes must be defined early, estimated, negotiated and settled in an expeditious manner. The project must have estimating staff based on site along with regular support from the procurement staff for Claims negotiations. Design costs can be controlled by releasing the change order for design only if possible, with review points.

VIII.	Quality Assurance/Quality Control (QA/QC) Questions	Atlanta MARTA North Line Extension	New York NYCT 63rd Street Connector	Pasadena LACMTA Gold Line	Pittsburgh PAAC Airport Busway	Portland TriMet Interstate Max Extension	Portland TriMet Airport Extension	Salt Lake City UTA North South Line	Denver RTD Southwest Line	Washington WMATA Largo Extension
1	Does your agency have an existing QA/QC manual, or did you develop one for the project?	--	Project specific QA/QC manual was developed	Contractor developed a manual for project	A QA/QC Manual was developed for the project as part of the Program Management Plan	Manual developed for this project based on previous project	Used an existing agency manual	UTA and contractor both had manuals which were harmonized for design, UTA requires each contractor to develop CQCP manuals for both design and or construction.	A QA/QC plan was developed for the project	There is QA program and requirements for the Design-Builder are detailed in the contract specs. A project specific QA/QC program was developed
2	How was the quality audit process conducted?	--	Using Internal Audits (ad hoc) and Contractor Audits (quarterly); Contractor also responsible for audits with agency staff of subcontractors, subconsultants, and vendors	A Compliance Audit System comprised of a proprietary, computer-based database that allowed for random sampling of work in both design and construction. The database made it possible to track, trend, and develop monthly reports at a significantly less cost than a conventional field reporting method.	--	TriMet's quality assurance manager conducted formal audits of specific documentation and procedures during design, construction and start-up. The manager prepared a narrative following each audit, citing non-conforming work, missing documentation or other observations. Follow-up audits were performed to ensure that the corrections were made. The Project Management Oversight field representative frequently	DB contractor provided both QC and QA staff. TriMet provided field inspection staff as well as a QA staff member that participated in all QA audits	The quality audit has been conducted by a contract staff following UTA procedures and direction. The audits have been conducted for design at progress submittal milestone dates. Audits for construction have been nominally conducted monthly.	Design audits were conducted at various design levels. Additionally, construction audits were conducted regularly to ensure workmanship, testing and construction documentation.	No

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						accompanied the QA manager during the audits.				
3	What were the roles and responsibilities of the owner, agency, and contractor?	--	Contractor was responsible for the quality of the construction; they performed and documented their QA and QC. the agency/owner, was responsible for the oversight, ensuring that the contractor implemented their QA/QC; project performed its own QC to confirm and when needed to supplement Contractor's QC.	DB contractors were responsible for performing their own QC and the Authority performed quality compliance auditing of these contractors' QC programs. Strict contractual language was instituted to ensure that the DB's performed their QC programs in an unbiased manner in order to provide a quality product.	--	Contractor: QC/QA work; Owner: Review and approval of QA/QC work	Owner: Field Inspection and QA activities Contractor: QA/QC work Permitting Agencies: Field inspection for permit sign-off	Contractor is nominally required to perform quality control on either design or construction in accord with criteria described in the performance contract including preparation and compliance with an approved CQCP. Agency had a Quality Assurance Manager full time on the project. Contractor project manager performed the role of Quality Manager.	The contractor was responsible for the Quality Control. The owner/agency was responsible for inspections, surveillance and QA audits.	: WMATA focused on verifying that the approved plan was being followed. The Contractor (Design-Builder) focused on the implementation of the plan as approved
4	Describe the inspection and testing program.	--	Contractor was responsible for ITP with agency monitoring	Contractor subbed QA/QC and used an independent lab	The CM, as a subconsultant to the GEC/PM, provided construction inspection services.	Contractor was responsible for ITP with agency monitoring	Contractor was responsible for ITP with agency monitoring	Daily quality control is the responsibility of the contractor with oversight by UTA either directly or by a contracted construction manager. For the majority of material testing the contractor was required to employ a testing laboratory.	RTD provided inspectors who were responsible for ensuring that all work performed by the contractor was in compliance with the contract documents and conformed to the quality standards.	WMATA depended on audits by project staff to verify that testing was advancing as approved. Also the Design-Builder (DB) QC staff was the front line on testing. The

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	Did you use an independent testing organization?	--	Yes, some material testing	Yes	Yes, an independent testing agency was utilized on each construction contract.	Laboratories on-call	Yes, used by contractor	Yes, agency employed an independent testing contractor for random audits or for third party data in disputes.	Yes, agency provided an independent test lab to perform all of the testing requirements.	DB did use independent testing agencies for specific tests. A testing lab was approved specifically for concrete and soils testing
5	Highlight unique feature of the quality program.	--	Leadership attention, involvement and support; Teaming with Contractors and all other project participants; Enthusiasm and dedication of the project team.	Union inspection	--	The quality assurance manager was on site daily during construction and observed all key construction activities (setting girders, etc). He also inspected manufacturing facilities to verify that quality control procedures were followed and documented.	Longstanding contractor QA program	UTA can employ oversight contractor for the term of the contract and avoid permanent staff.	--	--
6	What were the key lessons learned?	--	The lessons identified by the NYCT (and documented in the FTA QA/QC Guidelines) involved three key elements of the quality program (1) preparatory phase construction inspection, (2) performance measuring and	Coordination of inspection over 14 miles	--	Regular audits of various aspects of the project were effective in keeping procedures and documentation accurate and timely.	Although there were no issues or concerns with the testing frequency or resolution of failed tests, confidence tests on some key elements would have been a good idea	Quality assurance is achieved by UTA ensuring comprehensive monitoring/oversight of the contractor's performance of quality control.	Addressing quality issues at an early stage helped avoid unnecessary complications.	More attention must be paid to the auditing of subcontractors and the implementation of their QA/QC programs by the Design-Builder

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			recognition system for contractor quality, and (3) just-in-time training.							

IX.	General	Atlanta MARTA North Line Extension	New York NYCT 63rd Street Connector	Pasadena LACMTA Gold Line	Pittsburgh PAAC Airport Busway	Portland TriMet Interstate Max Extension	Portland TriMet Airport Extension	Salt Lake City UTA North South Line	Denver RTD Southwest Line	Washington WMATA Largo Extension
1	What were the lessons learned in executing this project at all phases?	Interfacing was made easier by a single GEC being the successful contractor on the four biggest projects.	The importance of momentum was evident throughout the project execution. The implications of project delays were grave. There were potential ripple effects to all contract schedules and the attendant claims and economic loss. Owner response time to contractor requests for information (RFIs) needed to be carefully controlled. Formal communication channels had to be challenged in the interest of maintaining momentum. While traceability and control is necessary it must be subjugated in the interest of keeping the job moving. Real	Project traversed 5 communities making communication with 3rd parties essential.	--	Community involvement, education and information brought project acceptance and tolerance during construction. Making the contractors partners instead of adversaries, encouraging a safety culture, and facilitating participation by DBE firms contributed to the positive atmosphere.	Provide constructability input early in the design process, including construction means and methods to reduce project costs. Apply and maintain realistic contingencies throughout project development. Integration of transit systems with facilities, both during design and construction. Address the Type, Size, and Location (TS&L) process early in the design process and integrate the appropriate personnel from the reviewing agency,	Federal process takes too long. In the time it takes to develop a project the community and context changes and project costs change to reflect these external changes.	It was important to manage the budget and limiting scope creep. Cost savings were realized as a result of in-house design.	Rolling over some staff through the phases produces superior results

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			delay costs in excess of $25,000 per day were measured. It was imperative that design and owner reps were on site or immediately available to respond to field conditions that threatened to slow the job.				e.g.state DOT. For DB projects, align design packaging to support early construction activities and a fast-track schedule (e.g., complete design of early activities such as foundation and utility relocations first to allow construction to begin). Obtain agreements with permitting and Agencies Having Jurisdiction (AHJs) early in the design process and establish roles and responsibilities.			
2	Were any changes made to the estimation process because of the lessons learned on this project?	No	Creating of a change order scope meeting to ensure mutual understanding of the changed work and reduction in estimate iterations	No	No	No	No	No	No	No

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3	Was value engineering employed? When and what types…VECP?	Yes	Yes, peer review type during design and cost savings type during construction	No	VE was employed during final design and when submitted by the construction contractor. If VE proposals accepted, the savings were split evenly between the contractor and the agency.	Yes	Yes, but not in a formalized approach. When scope or products were identified as potential VE items, pricing, life cycle, and industry trends were evaluated.	Yes	Yes, at every phase contractors were encouraged to provide creative alternatives and share the savings with the agency.	It was available for use. Revised materials (eg. Roofing: concrete slab with built up roofing vs. membrane)
4	Were there organized or team oriented value engineering exercise?	--	Yes	No	Yes, during the final design phase	Yes, once early in project	Yes, VE was used in the early stages to scope key project items to meet the budget	Yes, both	Yes, by an independent consultant.	This process occurred early in the RFP when cost drivers were addressed over several weeks

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5	Were there any partnering concepts used on the project? Describe when used, at what point and what effects on the project.	Partnering Concepts were utilized on many of the components of the Project. On the components of the Project with formalized partnering, an off site initial partnering session lasting 1-2 days was held. Follow-up meetings to reinforce the partnering ideals and to discuss any barriers to Partnering were then held quarterly. On the components without formal partnering requirements, an informal partnering relationship developed which did a great deal to improve communication between all parties.	Yes, initial partnering sessions to establish hierarchy and reporting channels and follow-up sessions to focus on long-standing issues. The project's scope and definition was understood by the entire project management team prior to the commencement of construction. During the design stage, on board design and constructability reviews prepared the core construction management team for the challenges of construction. This also allowed open discussion of alternate design possibilities that might be proposed by perspective contractors. Contractor felt that partnering cannot be prescribed, it has to be decided by the leaders of each organization and then driven down to their managers in their placement and direction.	Partnering used throughout job and very beneficial. To ensure this vital coordination between the DB and the third parties occurred, the Authority used third party coordinators dedicated to a specific functional specialty, held weekly meetings with staff level representatives of the stakeholders, held quarterly partnering sessions with senior level management from all involved parties, and maintained constant communication.	Partnering was used during the construction phase of the project with varying degrees of success	Yes, partnering used at Final Design and early construction	The DB delivery system is built upon sharing and evaluating collective risks, therefore partnering is essential. We also had a formalized partnering session in advance of final design. It is a necessary step – but is no substitute for building and maintaining relationships.	Yes, both for design and construction and at the beginning.	A formal facilitated partnering session was conducted shortly after the Notice to Proceed. Numerous informal sessions were also conducted as needed. In addition, bi-weekly coordination/partnering meetings were held with both railroads.	Yes, quarterly meetings for the life of the project helped keep the team aware of the concerns of other groups and focused on the goal of completing the project within budget and on schedule.

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6	Were any design to budget procedures or provisions used? Describe techniques and effects. Were any other unique techniques used?		No, but did use VE, peer reviews, and cost-cutting initiatives	No	No	Yes	Yes by DB contractor	Not formal policy but basic philosophy of UTA and clearly understood by design consultant	No	DB would use this. Design was always checked based on approved criteria. Extensive use of design review meetings and discussions from early stage
7	Highlight the main issues or challenges faced in the development and implementation of your projects.	Contractor: tight construction zones, multiple NTP's and milestones, limited access and work with private property owners	Time to achieve political consensus, change in economic conditions, seizure of private property	At-grade crossing applications, 3rd party management, property acquisition, and station and artwork design	Real estate issues and unforeseen site conditions were the major challenges	Project had to reduce the purchase of light rail vehicles to meet the federally imposed contingency levels. The project was completed $25 Million under budget but the balance was not allowed to be used.	It was difficult for many of the agency technical staff to communicate the critical requirements, give up "control" of the design, and trust that the design criteria would be met acceptably.	Keeping 3rd parties satisfied and containing scope creep; Intense pressure to build the project ahead of budget and ahead of schedule.	Limited number of change orders authorized, negotiating with both railroads upfront, schedule coordination issues.	Ensuring that we are fully aware of the client's wishes. Keeping up with revisions because of operating revisions or changes

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8	What did you learn?	When the Owner, CEI and contractor have a common goal of building a quality and safe project on time than it is a rewarding project for all. Periodic partnering meetings, strategic real estate procurement, breaking project packages into incremental units	Engineering challenges are often the most manageable because they can be defined and resolved; outreach to community and businesses is important to minimize controversy and resistance. There were overriding environmental issues such as the political economic conditions that were generally tolerated. It is prudent to allow time in the overall project for the political consensus process that is an undefined but very real part of large infrastructure projects. Property takings have the potential to be difficult because of the emotional aspects of relocation. Community outreach helps to sooth the pain but the community has to accept and endure the project for the “greater good”. Keeping the community	The Authority mitigated risk through its own Third Party Coordinators and by holding partnering sessions with the appropriate agencies. Overall the outcome was a moderate success, while at the same time requiring very proactive management.	--	It was critical to have a solid, up-to-date agency policy on unsolicited proposals; Agency concerns about DB should be addressed early and in a straightforward fashion; Close management liaison amongst stakeholders was critical to success	The DB contractor and agency co-authored the Program Requirements and this was the guiding document describing the intent and scope of the projects. This process helped both sides get a shared vision of priorities and scope and forced us to step back from the drawings to explain not only what would be built, but what types of meetings were needed, what the agency expected during construction, key and support staff, project milestones, start-up support etc. All key info in a simple format, in one place, edited, priced and agreed to by both parties.	The importance of good early cost and schedule estimates because it often sets internal and external expectations. In Salt Lake, a public referendum was passed based on the early estimates.	The Southwest Corridor Project was successfully completed on time and under budget. Ridership exceeded original expectations.	Allowing the DB to work within the criteria without placing an excessive amount of mandates produces innovative and cost effective designs

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			operational was also a challenge. Close interface with the local businesses helps. We were able to coordinate work operations around Christmas production seasons which were in July. Through mutual disclosure and development of trust controversy was kept to a minimum. Contract interfaces and systems integration was challenging issues since there were sometimes competing goals. There is a desire to keep the interfaces down by combining work into larger contracts, but there is a practical limit to contract size where competition and bonding capacity are affected.							

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9	What would you do differently next time?	Timeliness of responses to changes in scope		Establish 3rd party communication earlier.		§ Push for an owner's contingency § Spend more time in advance "stress testing" our DB provisions against likely areas of difficulty/contention § Spend more time getting in-house staff on board with the DB concept	Try to better align staff-review and permit processes with the DB process			Have a computer (possibly internet) based submittal, review and document control