Airport Capital Improvements: A Business Planning and Decision-Making Approach

DETAILS

64 pages | 8.5 x 11 | PAPERBACK
ISBN 978-0-309-30808-3 | DOI 10.17226/22259

AUTHORS

Joakim Karlsson, Scott Allard, Rohit Viswanathan, Robert Furey, and Jonathan McCredie; Airport Cooperative Research Program; Transportation Research Board; National Academies of Sciences, Engineering, and Medicine

AIRPORT COOPERATIVE RESEARCH PROGRAM

ACRP REPORT 120

Airport Capital Improvements: A Business Planning and Decision-Making Approach

Joakim Karlsson
Scott Allard
Rohit Viswanathan
MCR FEDERAL, LLC
Washington, DC

Robert Furey
HOYLE, TANNER & ASSOCIATES, INC.
Manchester, NH

Jonathan McCredie
FENNICK MCCREDIE ARCHITECTURE, LTD.
Boston, MA

Subscriber Categories
Aviation • Construction • Economics

Research sponsored by the Federal Aviation Administration

TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
2014
www.TRB.org

AIRPORT COOPERATIVE RESEARCH PROGRAM

Airports are vital national resources. They serve a key role in transportation of people and goods and in regional, national, and international commerce. They are where the nation's aviation system connects with other modes of transportation and where federal responsibility for managing and regulating air traffic operations intersects with the role of state and local governments that own and operate most airports. Research is necessary to solve common operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the airport industry. The Airport Cooperative Research Program (ACRP) serves as one of the principal means by which the airport industry can develop innovative near-term solutions to meet demands placed on it.

The need for ACRP was identified in *TRB Special Report 272: Airport Research Needs: Cooperative Solutions* in 2003, based on a study sponsored by the Federal Aviation Administration (FAA). The ACRP carries out applied research on problems that are shared by airport operating agencies and are not being adequately addressed by existing federal research programs. It is modeled after the successful National Cooperative Highway Research Program and Transit Cooperative Research Program. The ACRP undertakes research and other technical activities in a variety of airport subject areas, including design, construction, maintenance, operations, safety, security, policy, planning, human resources, and administration. The ACRP provides a forum where airport operators can cooperatively address common operational problems.

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The ACRP benefits from the cooperation and participation of airport professionals, air carriers, shippers, state and local government officials, equipment and service suppliers, other airport users, and research organizations. Each of these participants has different interests and responsibilities, and each is an integral part of this cooperative research effort.

Research problem statements for the ACRP are solicited periodically but may be submitted to the TRB by anyone at any time. It is the responsibility of the AOC to formulate the research program by identifying the highest priority projects and defining funding levels and expected products.

Once selected, each ACRP project is assigned to an expert panel, appointed by the TRB. Panels include experienced practitioners and research specialists; heavy emphasis is placed on including airport professionals, the intended users of the research products. The panels prepare project statements (requests for proposals), select contractors, and provide technical guidance and counsel throughout the life of the project. The process for developing research problem statements and selecting research agencies has been used by TRB in managing cooperative research programs since 1962. As in other TRB activities, ACRP project panels serve voluntarily without compensation.

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ACRP REPORT 120

Project 01-19
ISSN 1935-9802
ISBN 978-0-309-30808-3
Library of Congress Control Number 2014951769

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AIRPORT COOPERATIVE RESEARCH PROGRAM

are available from:

Transportation Research Board
Business Office
500 Fifth Street, NW
Washington, DC 20001

and can be ordered through the Internet at

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Printed in the United States of America

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CRP STAFF FOR ACRP REPORT 120

Christopher W. Jenks, *Director, Cooperative Research Programs*
Michael R. Salamone, *ACRP Manager*
Lawrence D. Goldstein, *Senior Program Officer*
Anthony P. Avery, *Senior Program Assistant*
Eileen P. Delaney, *Director of Publications*
Natalie Barnes, *Senior Editor*

ACRP PROJECT 01-19 PANEL
Field of Administration

Carol L. Niewola, *New Hampshire DOT, Concord, NH* (Chair)
Kalyan Balasubramaniam, *Mitra Aviation Consulting, LLC, Washington, DC*
Geoffrey S. Baskir, *Runway Safety CSA Team, Fort Worth, TX*
Marc Gambrill, *Broward County Aviation Department, Domip, FL*
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Robert Samis, *FAA Liaison*
Christopher J. Oswald, *Airports Council International—North America Liaison*
Christine Gerencher, *TRB Liaison*

AUTHOR ACKNOWLEDGMENTS

The research reported herein was performed under ACRP Project 01-19 by MCR Federal, LLC and its subcontractors Hoyle, Tanner & Associates, Inc. and Fennick McCredie Architecture, Ltd. The principal investigator was Joakim Karlsson of MCR Federal, LLC. The other authors of this report are Scott Allard and Rohit Viswanathan, PMP, of MCR Federal, LLC; Robert Furey, PE, of Hoyle, Tanner & Associates, Inc.; and Jonathan McCredie, AIA, of Fennick McCredie Architecture, Ltd.

The research team would like to express its gratitude to the members of the ACRP Project 01-19 panel for their valuable input and support throughout this project and the many individuals, agencies, and organizations who contributed to the airport construction cost database.

FOREWORD

By Lawrence D. Goldstein
Staff Officer
Transportation Research Board

ACRP Report 120: Airport Capital Improvements: A Business Planning and Decision-Making Approach provides a guidebook to cost estimating for airport capital planning, supported by a spreadsheet-based cost-estimating model. The guidebook and the accompanying model are designed to help airport operators, aviation/transportation agencies, and other industry stakeholders understand cost-estimating practices, including risks and sources of uncertainty.

Annual airport capital investment needs have recently diminished somewhat but are still expected to average approximately $14 billion annually over the next several years (ACI North America: *Airport Capital Development Needs 2013–2017*). Working to meet this need, individual airports, state and local agencies, and the Federal Aviation Administration are all dependent on individual case-by-case engineering cost studies and the bid process when estimating, planning, and budgeting for airport capital improvement projects. The engineering, planning, and finance staffs at airports do not always have access to necessary and sufficient information to prepare accurate capital cost estimates. In particular, many smaller airports often do not have staff to perform these functions and must, as a result, rely on external consulting expertise.

An additional problem in preparing cost estimates is a lack of consistency, standardization, and accuracy across the airport industry. This often precludes comparisons of project cost estimates that, by necessity, must take into account variations in regional costs, state and local conditions, or varying levels of technical expertise. The result is a high risk of inaccurate cost estimates, which can cause project cancellations and inefficient distribution of capital funds at the state level. Further, unique conditions at any given airport make simple comparison with similar projects at other airports often difficult if not problematic. Experience indicates that increased availability of relevant data can facilitate the capital budgeting process and improve overall project cost estimating, project planning, and implementation, while resulting in a more efficient and effective approach to developing an airport capital improvement program.

ACRP Report 120 provides a model and database for estimating the cost of construction projects regularly proposed in an airport's capital improvement plan. The particular approach presented as an outcome of this effort applies parametric cost estimating, using historical cost data to determine cost-estimating relationships (CERs). The CERs are mathematical functions that link construction cost to independent variables that represent key cost drivers. The CERs were developed using multivariable regression analysis conducted on a database of historical cost data collected for this study.

The model supports construction projects representing both the horizontal domain (i.e., projects that are not buildings and are primarily related to the airfield) and the vertical domain (i.e., buildings). The resulting analytical approach incorporates a spreadsheet-based cost model, with application to a total of eight project types. The model allows the user to enter airport information, project definitions, and cost drivers to generate a cost estimate. Cost estimates are also adjusted for inflation and geographical variations in construction cost at the state level. The cost model was assessed using statistical metrics of quality of fit, and validated using a case-study approach. Limited availability of historical cost data in a usable form presents the greatest challenge to implementing parametric cost estimating for airport construction projects and puts constraints on the robustness of the model. Building on the research, this guidebook includes recommendations for data collection practices intended to help overcome these constraints to support a more comprehensive and robust model in the future.

CONTENTS

Note: Photographs, figures, and tables in this report may have been converted from color to grayscale for printing. The electronic version of the report (posted on the web at www.trb.org) retains the color versions.

SUMMARY

Airport Capital Improvements: A Business Planning and Decision-Making Approach

This guidebook presents a cost-estimating approach that can be used to quickly and efficiently develop cost estimates for airport construction projects during the capital planning phase. The goal is to provide a model that produces consistent, standardized, and accurate cost estimates, employing a user interface that requires minimal training and cost-estimating experience. The guidebook describes the basic principles of cost estimating and the specific methodology applied—parametric cost estimating. This methodology uses multivariable regression analysis to derive mathematical relationships between construction cost and independent variables that describe key cost drivers.

This project includes an accompanying cost-estimating tool developed in Microsoft® Excel™. This tool can be used by airports to implement the proposed approach. It supports the preparation of cost estimates for eight different types of airport construction projects. Use of the tool requires no formal training in cost estimating and requires no software other than Microsoft Excel.

Background

The objective of this project was to develop and test an analytical approach to prepare cost estimates for airport construction projects, both in the horizontal and vertical domains. The proposed cost-estimating model is primarily intended for the capital planning phase, when uncertainty is high. At the same time, capital planning requires accurate cost estimates in order to optimize the use of scarce airport funding resources. This highlights the need for a standardized, consistent, and easy-to-use cost model, especially for smaller airports without extensive engineering resources.

Approach

The proposed approach was to use a parametric cost-estimating technique in which costs are correlated with observed data from historical construction projects. In this approach, multivariable regression analysis was used to model cost through mathematical functions known as cost-estimating relationships (CERs). The CERs model cost as a function of key cost drivers represented by candidate independent variables (CIVs). The variables are considered candidates because they are selected using subject matter expert input and are then tested for statistical validity and reasonableness.

The output of the model is a cost estimate for a single project or a portfolio of projects, with both a point estimate and a low-high range that takes into account the uncertainties and risks associated with cost estimating. The costs are adjusted for inflation and incorporate regional variations in construction costs. The inputs to the model that are necessary to prepare a cost estimate are values for the cost drivers represented by the CIVs for the project type in question. The CIVs are the independent variables in the CERs, which represent the analytical component of the model. Additional data required to be entered by the user include the geographic location of the project and the proposed year of construction.

Cost-Estimating Tool

The historical cost data collected during the course of this study was filtered, analyzed, and implemented in a database. The cost database was used in the statistical analysis that resulted in the CERs that form the backbone of the cost model. A cost-estimating tool titled ACCE—the Airport Capital Cost Estimation tool—was implemented in Microsoft Excel. The tool incorporates CERs for eight different types of common airport construction projects. Six of these are in the horizontal domain and two in the vertical domain.

ACCE is provided as companion software to this guidebook. A quick reference guide is reproduced in Appendix B. The ACCE user interface is designed to guide the user through the necessary steps to develop a cost estimate. In the input step, the user enters contact information, airport information, and project-specific data. ACCE displays a running cost estimate, which is updated as the project's inputs are changed. When the inputs are finalized, the user can switch to the reporting module. The report generator allows for the preparation of a cost-estimating report which documents the input data and presents a low, high, and best cost estimate. Additional features allow for exporting and printing the results, as well as the ability to prepare what-if analyses by altering one or more project inputs.

ACCE can be used by airports of any size to prepare cost estimates for the construction project types supported by the tool. Note, however, that due to limitations encountered during the data collection phase, ACCE should be viewed as a proof-of-concept tool used primarily to develop initial cost estimates for planning purposes. Actual construction costs may differ substantially from the estimates provided by the model. The estimates produced by the software should not be used as the sole means to evaluate the cost of a proposed airport construction project.

Findings

The data collection resulted in the development of CERs for eight airport construction types. The CERs were validated both using statistical metrics describing quality of fit, as well as a case study validation analysis. The user interface provides a simple but effective mechanism for members of the airport community to interact with the cost model. While the model validation shows that the performance of the cost model varies, this is to be expected given the relative small size of the underlying database.

Although the project objective of producing a cost database and model based on parametric cost estimating has been met, the resulting model is limited in its scope and robustness. This guidebook includes recommendations for future work, focusing on addressing the limited availability of historical construction data in a usable electronic format. The recommendations provide guidance on future data collection efforts, including specific suggestions for the type of data to be collected.

CHAPTER 1

Introduction

Objective

As part of its capital planning and master planning activities, airports are required to prepare cost estimates for proposed construction projects. These are presented and distributed to a number of stakeholders, including governing boards, state and regional transportation agencies, and the regional offices of the Federal Aviation Administration (FAA). The cost estimates can be developed by the airports' own staff, with varying levels of expertise and experience, by external consultants, or by planners and engineers at other agencies. These estimates are typically developed prior to any significant feasibility, investigative or preliminary design work being performed. The resulting accuracy of the estimates is therefore mixed and as the projects move into the execution phase, the initial cost estimates are often far removed from the actual construction costs. In turn, inaccurate cost estimates can lead to outright project cancellations or inefficient distribution of limited airport capital funds.

The importance of managing construction cost estimating and the risks associated with inaccurate estimates are reflected in the financial markets' evaluations of airports. For example, one national credit rating specifically takes into account "risk and complexity of [an airport's] capital programs," including "level of construction risk in capital projects" (Krummenacker et al. 2011, p. 13). The main risk is identified as construction cost escalation caused by delay, with specific risk factors listed as follows:

- Scope changes between design and completion
- Outdated or inaccurate cost estimates
- Project complexity
- Material or labor cost escalations
- Poor bidding procedures
- Contractor management/oversight issues
- Environmental concerns
- Community concerns

Another source of uncertainty is the presence of geographical (i.e., regional) variations in construction costs. These can be substantial and are caused by a number of factors, including labor supply, raw material costs, access to transportation, energy costs, and regulatory standards, with an emphasis on environmental regulations. A cost-estimating model must be able to take regional variations into account, both during the development and calibration of the model and during the cost-estimating phase.

The existence of a standardized cost-estimating model should allow airports to mitigate some of these risks. At the same time, it must be recognized that a number of these risks cannot be addressed even by the most exhaustive cost-estimating model. For example, an otherwise

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accurate cost estimate could be rendered ineffective by unusually demanding environmental regulations, fluctuations in market conditions, or inadequate construction management.

Only 139 of the 3,355 airports identified in the National Plan of Integrated Airport Systems (NPIAS) are classified as hub airports (FAA 2012). In other words, over 95% of airport sponsors represent non-hub commercial and general aviation airports, which tend to have no engineering staff on board. Consequently, most airports do not have any in-house cost-estimating experience or expertise. Even hub airports often rely on engineering consultants to provide cost-estimating and bidding services. Lack of access to cost-estimating expertise is another reason why there is a perceived need for a software-based cost model.

Investment decisions for large acquisitions within the FAA Air Traffic Organization require a benefit-cost analysis (BCA), in which a standardized cost estimate is compared against monetized benefits. This is not the case for the majority of airport capital projects and, consequently, the approach for developing airport capital cost estimates can vary considerably. The lack of a standard methodology and the limited cost-estimating resources available to airports result in substantial challenges. One challenge arises from substantial variation between the cost estimates obtained in the capital planning phase and the actual costs reported in the bidding phase or after the close-out of the construction projects. Airports also suffer because the resulting variations tend to be biased toward underestimating the overall cost. The potential result is that anticipated projects must be scaled back, delayed, or cancelled.

Cost estimates for airport capital improvement plans (ACIPs) are often first prepared during the development of the airport master plan, airport layout plan, or in support of the capital planning process of the relevant state aviation agency or the FAA. Often, the design data available at the time the first cost estimate is developed is limited to a conceptual layout, the approximate size, the location on the airport, and little else. The time frame for construction of the facility being estimated can vary from a few months to 20 years or more. At this point in the process, a rough order of magnitude estimate is the best that can be expected, due to the limited data available.

Airport projects are often complex: "Airport projects have a whole series of special systems which are seen nowhere else, on an enormous scale" (Merkel and Cho 2003). It is clear that two separate but related problems must be addressed: (1) improving the accuracy of the cost estimate as calculated from current and relevant cost data and (2) improving the specificity of the project scope and unique conditions which must be entered into the model by the user. The problems are linked: The accuracy of the result is completely dependent upon the specificity of the scope. The dual challenges of providing sufficient accuracy and specific scoping vary in their characteristics, depending on the type of project. Some project types have greater potential for significant deviations, and therefore more potential for improvement.

Before discussing cost estimating in more detail, it is necessary to clarify what the terms "horizontal" and "vertical" mean in the construction industry and how they relate to airport projects. Horizontal construction refers to projects that involve work on a road, bridge, traffic signal, water or sewer main, or any other improvement to land that is not a building (Massachusetts Certified Public Purchasing Official Program 2001, p. 2). Applied to airports, roads and bridges are substituted with runways and taxiways, traffic signals are substituted with airfield lighting, and so on. Examples of horizontal airport construction include runways, taxiways, aircraft aprons, security fences, and airfield lighting. Conversely, vertical construction is defined as work on a building. Examples of vertical construction on airports include terminal buildings, hangars, and facilities for storing airport equipment, such as snow removal equipment (SRE) and aircraft rescue and fire fighting (ARFF) vehicles.

The objective of this research project was to develop an interactive construction cost-estimating model and associated database for airport capital projects, along with a guidebook documenting best practices for cost estimating and guidance on using the cost model and database. The model should cover common airport construction projects, both in the horizontal and vertical domains. It should make use of existing databases and take into account regional cost factors and inflation. Finally, it should be flexible in its use, for example, by allowing for database updates and the ability to generate reports in Excel, PDF, and other formats.

How to Use this Guidebook

This guidebook is designed to provide a practical approach for developing cost estimates for airport construction projects. The guidebook contains the following:

- Information and background material on cost estimating intended to expand the reader's knowledge base. The guidebook describes best practices for cost estimating, as well as specific material on the parametric cost-estimating approach. This material will also aid the reader who wants to understand the methodology used by the cost-estimating tool.
- A primer and quick reference guide to ACCE—the Airport Capital Cost Estimation tool. ACCE represents the implementation of the cost model and database developed as part of this project. The ACCE cost model is implemented as a self-contained Microsoft Excel application that accompanies this guidebook.
- Recommendations for future work, with a focus on overcoming limitations on data availability that constrain the effectiveness and robustness of the cost model as currently implemented.

The material in this guidebook is organized to provide a logical path leading up to the use of ACCE to support cost estimating for airport construction projects. This guidebook is organized as follows:

- Chapter 1 provides an overview of the guidebook, objectives, information for the reader, and background material.
- Chapter 2 covers the fundamentals of cost estimating, as applied to the airport domain. This chapter identifies best practices, as well as specific challenges to cost estimating in the horizontal and vertical domains, respectively.
- Chapter 3 provides detailed information on parametric cost estimating: the cost-estimating methodology that was adapted for this project. The chapter provides guidance on the selection of CIVs, the development of CERs, and testing and validating the resulting cost model.
- Chapter 4 describes the development of the historical cost database, including a description of the database structure, approaches to collecting data, as well as challenges and limitations.
- Chapter 5 is a guide to ACCE, the Microsoft Excel-based application developed to implement the cost model and database for this project. It describes how to define a project, what data needs to be entered by the user, how the tool should be used, and the meaning of the data contained in the output—the cost-estimating report. Particular attention is spent on how to interpret the results and identifying the limitations of the cost model.
- Chapter 6 summarizes lessons learned, drawing both on internal findings from the research project and results from the validation of the cost model. Recommendations for future work are also included in this chapter.

Reference material has been placed in appendices to the main guidebook. Appendix A contains detailed information on the CERs for each of the project types supported in the cost model. Appendix B contains the ACCE Quick Reference, which is a concise user guide to the cost model.

Note that a full understanding of the material in this guidebook is not necessary for the purpose of using ACCE. The information provided is intended to explain the selected cost-estimating methodology and how it is implemented in ACCE. It provides background material to help the user understand the inner workings of the model. This, in turn, should help the user better understand and explain the resulting cost estimates. For readers who are interested in quickly getting started with ACCE, the following sections are recommended:

- Chapter 5: ACCE—Airport Capital Cost Estimation Tool
- Appendix B: ACCE Quick Reference Guide

Who Can Use this Guidebook?

This guidebook can be used by all airports who are considering construction projects within their ACIP. While ACCE itself supports a specific subset of project types, the best practices presented in the guidebook apply more broadly.

When developing cost estimates, it will be useful to have participation and input from a broad range of functional areas at the airport. The areas of responsibilities that should be represented include the following:

- **Management:** Executive leadership, policy, overall compliance with airport mission.
- **Operations:** Operational and certification requirements, efficiency, safety.
- **Maintenance:** Maintainability and sustainment of infrastructure.
- **Emergency Response/Law Enforcement:** Operational and certification requirements, safety, security.
- **Planning:** Capital improvement planning, funding, land use compatibility.
- **Finance:** Finance, funding, airport use agreements.
- **Environmental:** Impacts on noise, wetlands, air quality, water quality, wildlife, other environmental areas of concern.

At larger airports, these functional areas may be represented by separate individuals or departments. Conversely, at a general aviation airport, the airport manager may be solely responsible for all of the listed functions.

The guidebook and accompanying cost model can also be used by decision makers and planners at regional, state, and federal agencies with oversight over airport funding. For example, state aviation planners can use the tool to validate cost estimates submitted by airports in their requests for state and federal funding.

The decision support tool requires certain hardware and software to be available. These include a computer running Microsoft Excel (version 2007 or later).

Related ACRP Projects

This study is one of several projects conducted within the Airport Cooperative Research Program (ACRP) intended to support airports in planning for and funding capital projects. While this particular study focuses on cost estimating, it is valuable for airports to be familiar with the broader literature on finance, BCA, and innovative methods related to capital planning. This emerging body of research includes the following ACRP projects:

- ***ACRP Report 21: A Guidebook for Selecting Airport Capital Project Delivery Methods.*** This ACRP report provides guidance on three different types of project delivery methods for airport projects: design-bid-build (DBB), design-build (DB), and construction manager at risk (CMR). The report provides a two-tiered decision support approach for selecting an appropriate method. The report describes the advantages, disadvantages, and cost efficiencies of each of the three methods. The two-tiered project delivery selection framework can be used by airport owners and operators to evaluate the pros and cons of each delivery method and select the most appropriate method for their project. Tier 1 consists of an analytical delivery decision approach designed to help the user understand the attributes of each project delivery method. The goal is to decide whether the delivery method is appropriate for the airport's specific circumstances. Tier 2 uses a weighted-matrix delivery decision approach that allows airports to prioritize their objectives and, based on the prioritized objectives, select the delivery method that is best suited for their project. This report is useful for evaluating the effects that each delivery method has on the construction cost estimation process.

- ***ACRP Report 49: Collaborative Airport Capital Planning Handbook.*** This handbook provides guidance to those in the airport community who have responsibility for, and a stake in, developing, financing, managing, and overseeing the ACIP and the individual projects included in it. This guidance is useful to help to prioritize the projects in the ACIP, which influences the selection of project types to be modeled. It also creates a framework for using the ACCE tool in a collaborative fashion that results in constructive communication between internal and external stakeholders.

  The findings of *ACRP Report 49* were used in this project to refine the list of candidate projects for inclusion in the cost model. Two key principles were applied: (1) to focus on projects with high potential for reducing the uncertainty in cost estimating and (2) to focus on projects with potential for a high return-on-investment for the airport sponsor.
- ***ACRP Synthesis of Airport Practice 1: Innovative Finance and Alternative Sources of Revenue for Airports.*** This synthesis study discusses alternative financing options and revenue sources for funding capital projects. The report discusses existing and potential funding sources, newly developed revenue sources, and a review of privatization options. A solid understanding of funding availability is important, since there is a strong relationship between funding sources and the feasibility of including a project in the ACIP. The report may also help airports implement projects for which cost estimates have been developed using the ACCE tool.
- ***ACRP Synthesis of Airport Practice 13: Effective Practices for Preparing Airport Improvement Program Benefit-Cost Analysis.*** This synthesis study describes successful assessment techniques that can be used by airports in performing BCAs to quantify benefits for projects needing more than $5 million in Airport Improvement Program (AIP) discretionary funding. The synthesis includes a literature review, a review of BCAs submitted to the FAA for AIP funding, and an evaluation and summary of successful practices. While the focus is on the assessment of benefits, a framework for categorizing costs is presented. This study also provides a conceptual framework for how to use cost estimates to formally prioritize investments under consideration.

CHAPTER 2

Best Practices for Estimating Construction Costs

This chapter provides general guidance on cost estimating for airport construction projects. It discusses basic terminology, best practices, and challenges.

Basic Principles of Cost Estimating

Cost estimating is a dynamic process, encompassing interdependencies and integration with system engineering, benefit analysis, requirements, risks, schedule, and implementation planning. Lifecycle cost estimates include the total costs to acquire, implement, operate, maintain, technology refresh, and dispose of the proposed acquisition. The elements of such cost estimates include costs for both capital expenditures and recurring expenses for operations and maintenance. However, when developing construction cost estimates for an ACIP, only the initial capital expense is usually considered. This is because one main purpose of the ACIP is to align construction needs with the availability of capital funding. Many, if not most, of the sources for airport capital funds, including the federal Passenger Facility Charge (PFC) program and AIP, only provide funds for the initial planning, design, permitting, and construction, and not for recurring maintenance costs.

When a proposed investment consists of the procurement of commercial off-the-shelf (COTS) products, a cost estimate is relatively easy to obtain. This is because the cost can simply be determined by using the purchase price or a quote provided by one or more potential vendors. However, for anything other than a straightforward COTS procurement, cost estimating becomes much more complex. In the airport domain, construction usually requires significant planning, design, and engineering activities. Frequently, airport construction projects require facility needs analysis, site surveys, geotechnical investigation, environmental analysis, and permitting. Construction is usually preceded by site preparation activities, which can be extensive. Each of these cost elements can be complex enough to require substantial engineering and analysis. These cost estimates of construction and acquisition costs developed for ACIP are typically provided by the airport's engineer (in-house or through a consultant appointment).

More in-depth information and best practices are also available in existing reference material, for example, the U.S. Government Accountability Office's *Cost Estimating and Assessment Guide* (GAO 2009). FAA's guidance on BCAs for airport projects also covers cost-estimating principles (FAA 1999).

Benefit-Cost Analysis

The BCA is the broadest type of cost-estimating document and is used to justify specific capital planning decisions. The BCA is used to evaluate the lifecycle economic value of proposed public investments. It works by comparing streams of economic benefits over time with streams of costs, and then expresses the difference in terms of a number of metrics. These metrics include the discounted net present value (NPV), benefit-cost (B/C) ratio, internal rate of return (IRR), and payback period. The BCA provides a straightforward and consistent way to compare, rank, and select among competing alternatives that may differ in timing and/or scale. The key issues addressed by a BCA for a proposed investment decision include the following:

- Whether the economic benefits of a proposed project justify its economic costs
- Which alternative should be selected
- What the priorities and schedules should be for the selected projects

A BCA is required for projects funded through AIP grants of at least $10 million, when paid for using discretionary funds or letters-of-intent. In practice, this means BCAs are not required for most AIP-funded projects. BCAs are also not required for projects paid through other funding mechanisms, such as bonds or PFC funding. Guidance for conducting BCAs for airport projects is provided by the FAA (1999) and in *ACRP Synthesis of Airport Practice 13: Effective Practices for Preparing Airport Improvement Program Benefit-Cost Analysis* (Landau & Weisbrod 2009).

Cost-Estimating Analyses

Cost-estimating analyses cover all other types of studies focused strictly on the development of cost estimates. There are four commonly used methodologies to develop cost estimates (American Association of State Highway and Transportation Officials 2009):

1. **Parametric estimates.** Parametric estimates are developed by applying CERs that relate an independent non-cost variable such as runway length to a dependent cost variable such as amount of site work required. CERs are developed by quantifying hypothetical relationships between independent and dependent variables based on engineering experience, developing a database of actual historic variables, and performing statistical analyses of the relationship between the independent and dependent variables.
2. **Estimating using historical bid prices.** This method uses data from recently awarded contracts as a basis for the unit prices on the project being estimated. Data from previously awarded projects is typically stored in a database for three to five years to provide historical data to the estimator. The more data that is available and the more effectively it is organized by project types, size, and locations, the better the estimate that can be produced. Unit prices are adjusted for specific project conditions in comparison to previous projects awarded. Adjustments are generally made based on the project location, size of the project, project risks, quantities, general market conditions, and other factors.
3. **Cost-based estimating.** Cost-based estimating is a method that relies on estimating the cost of each component to complete the work and then adding a reasonable amount for the contractor's overhead and profit. A cost-based estimating approach can take into account the unique characteristics of a project, geographical influences, market factors, and the volatility of material prices. Since contractors generally utilize a cost-based estimating approach to prepare bids, this method can provide more accurate and defendable costs to support the decision for contract award. Properly prepared cost-based estimates require significantly more in terms of effort, time, and skill to prepare than historical bid based estimating. For this reason, cost-based estimates are often prepared only for those items that comprise the largest dollar value of the project. In order to successfully implement cost-based estimating, the estimators must have expertise in construction methodologies including required equipment, manpower, material, and scheduling. Additionally, the nature of cost-based estimating requires that a significant degree of information regarding the project scope, size, materials, and systems has been developed. Therefore this method is usually implemented only after the design of the project has begun.

4. **Risk/contingency analysis.** In addition to developing the most likely, or so-called "point," estimate, this method also addresses project risks and uncertainties. Using statistical techniques such as Monte Carlo analysis, risk analysis accounts for uncertainty surrounding the point estimate. The total risk-adjusted cost estimate for the project is derived by statistically adding the risk-adjusted costs for each of the contingent subelements that make up the project.

Parametric cost estimating was the approach used to develop the cost model presented in this guidebook. This methodology is described in detail in Chapter 3.

Summary of Best Practices

The science of cost estimating is relatively mature and there is a large body of knowledge documenting approaches and best practices. A summary of the most relevant best practices is presented below, organized by key reference works.

American Association of State Highway and Transportation Officials, *A Practical Guide to Estimating*

The American Association of State Highway and Transportation Officials (AASHTO) Technical Committee on Cost Estimating documents practical guidance on preparing final estimates, including recommended procedures and guidance on reviewing bids prior to award (AASHTO 2009). The guide draws on the expertise of AASHTO members and the agencies they represent to document the best practices in use by state agencies. This guide provides practical guidance on preparing final estimates. Of particular interest to this project is the discussion on the differences between cost estimation utilizing historical bid pricing and cost-based estimating. The guide contains an analysis and discussion of the importance of proper bid tabulation methods, as well as critical factors that affect cost estimating.

Government Accountability Office, *GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs*, GAO-09-3SP

The U.S. Government Accountability Office (GAO) has released a guide designed to help federal, state, and local government agencies develop more reliable cost estimates for government projects of all sizes. While the focus of the report is on federal acquisition projects, it contains extensive guidance on how to produce well-documented, comprehensive, accurate, and credible estimates. The report constitutes an exhaustive primer on the art and science of cost estimating, identifying the processes, key stakeholders, and best practices. Also included in this report is a large number of case studies. One of the case studies is from the field of aviation, but it is related to an FAA air traffic management system, not airport construction. Additionally, the report incorporates a thorough discussion of the identification and application of data sources, but does not identify any specific data sources applicable to airport construction projects. Generally, the report does not identify specific cost-estimating models or software packages.

American Society of Professional Estimators, *Standard Estimating Practice*, 8th Edition

The American Society for Professional Estimators is one of two industry organizations identified by the U.S. Bureau of Labor Statistics as providing industry certification for professional cost estimating. This manual is a standard "how-to" guide for use by professional estimators in the construction industry. It is updated on a regular basis to take into account new data and revised guidance.

Airports Today: Existing Cost-Estimating Practices

As part of the research process that resulted in this guidebook, a broad literature review and stakeholder survey were conducted. One of the objectives of this effort was to identify existing practices in the airport community for estimating costs for construction projects in both the horizontal and vertical domains. Existing practices use proven methodologies that draw on procedures and guidance published by a number of entities, particularly professional organizations and state agencies. Cost estimating for vertical projects has an added layer of structure through the use of standard classification schemes, such as those provided by the Construction Specifications Institute (CSI 2011).

The two primary methods used today are estimation through historical bid prices and cost-based estimating. The parametric estimation methodology, which is common for large-scale programs in the FAA Air Traffic Organization, has generally not been applied to airport construction projects. Risk/contingency analyses are applied but often in a simplified manner. Examples include the application of contingency factors to line item quantities or the total cost estimate. Approximately half of survey respondents reported using cost-estimating contingency factors. However, there appear to be few, if any, standards for using such contingency factors. The survey results indicate that these range from 0% (no contingency factor) to 25%, or even 50% for certain project types (e.g., airport security projects). Since overall contingency factors can be applied on top of contingencies for line item quantities, the cumulative contingency can be substantial. The lack of established standards in this area results in potentially large variations.

Existing methods appear limited in their ability to accurately account for unique project conditions. These can significantly affect the estimate and can result in wide variations from initial cost assumptions to actual costs incurred on a particular project. Environmental planning and cost of mobilization are examples of areas that have specifically been identified as difficult to quantify.

The cost-estimating procedures are backed up by cost data drawn from a number of data sources. The two most common data sources are past bid tabulations and commercially available products. The practice of storing past bid tabulations is common. The literature survey and industry stakeholder survey did not reveal any particular weaknesses in the application of these data sources. Moreover, a number of agencies maintain their own cost data and eight survey recipients indicated a willingness to share this type of information for this research project. Nonetheless, for the purpose of developing a comprehensive cost model, three specific challenges present themselves in regards to the availability of cost data:

- Many of the most commonly used data sources are proprietary and cannot readily be distributed as part of a publicly accessible model.
- Data maintained by public agencies is distributed across a range of state and regional agencies.
- There is no standard format for data and in many cases the data is stored in formats that are notionally electronic but essentially represent digital versions of printed documents.

Use of computer models for cost estimating does not appear to be a common practice for airport construction. It is less clear whether this is due to the cost of commercially available models, the lack of suitable models, or the challenges in airport construction cost estimating not being easily solved through computer modeling techniques. It does, however, indicate potential for the development of an airport-specific model, provided the challenges identified are carefully considered and appropriate solutions identified.

A major finding of the survey was that at small airports, construction cost estimating is primarily accomplished through consultants. The most commonly estimated airport construction projects include terminals, runways, taxiways, and airfield lighting. While the majority of respondents store historical construction cost estimates, they are mostly stored in hard copy format. When electronic formats are used, a range of formats exist—there is no accepted file standard. Only a minority of survey respondents reported that they use online data to develop construction cost estimates.

Challenges

All airports within the NPIAS maintain an ACIP including both vertical and horizontal projects. At smaller, general aviation airports, the needs tend to be well known, but the amount of funds available for airport improvements is often very limited. The typical general aviation airport often has much less AIP entitlement funds available than that which would be required to fund the multiyear list of capital projects in its ACIP. One unintended consequence is a potential pressure to keep cost estimates low. As an example, in order to keep a project viable and within funding limits, a low estimate may be used for capital planning, with the assumption that project scope can subsequently be cut in order to match available funds. This can create disconnects in the process for planning the use of limited funding and can result in the outright cancellations of projects.

Since capital planning is usually conducted at a regional or state level, weaknesses in the cost-estimating process can end up shifting or distorting priorities across an entire airport system. Although more detailed cost estimating would mitigate this risk, time and budget limitations typically prevent high-fidelity cost estimates in this phase of the cost-estimating process. One risk is that airports default to working with cost estimates that are based on little to no technical research and choose to direct their time and money toward needs that are perceived as more imminent and pressing. A parametric cost-estimating model, once established, can be utilized at low cost, taking relatively little time and effort to use. A benefit of this approach is that it has the potential for reducing some of the existing flaws in the cost-estimating process for capital planning.

The stakeholder outreach effort conducted as part of this project confirmed a general lack of formal cost-estimating procedures. For example, only 17.4% of respondents reported accessing online cost data for generating construction cost estimates and only 26.5% reported storing historical construction cost estimations. This suggests that many airports use educated guesses to establish initial cost estimates, with varying levels of credibility. Moreover, once an initial cost estimate is prepared, it can be hard to adjust the resulting number if it has been shared with funding agencies or provided as public information.

The results of these challenges are not always predictable and can lead to either overestimation or underestimation. The former can be just as problematic as the latter. In the case of overestimation, potential bidders can be influenced by publicly available budget levels that are not supported by sound cost-estimating practices. This can ultimately influence project costs, regardless of the level of refinement after the completion of the initial cost estimate.

To understand how to improve this process through the use of the cost model prepared for this study, a discussion of issues related to current cost-estimating practices is provided below. The discussion is categorized by horizontal and vertical project types, but it should be noted that many projects integrate both domains. Moreover, in many cases the basic procedures and lessons learned are similar and apply to both types of construction project.

Cost Estimating for Horizontal Projects

Current practices for the cost estimating of horizontal airport construction projects are primarily taken from two of the categories identified previously: historical bid pricing and cost-based estimating. For a typical horizontal airport construction project, there are basic items that define the scope of work (SOW). The FAA provides a series of Advisory Circulars that define these items in their most basic form, utilizing an alphanumeric coding system. Some typical items and their codes are shown in Table 1. With these basic items established, an engineer can begin to identify planning-level components that will compose an estimate by extracting design data from preliminary planning or preliminary engineering design documents.

In some cases the only data available is an aerial-view planning document, which will provide proposed limits of improvements. In this case, there is a high probability of developing an inaccurate cost estimate. Conversely, in some cases, there is an abundant amount of data available such as aerial topographic survey, planning-level project layout data (taxiway alignment, aircraft apron size and geometry, width and length of runway extension, etc.), environmental data, and basic soils investigation data. In this case, a higher level of accuracy is likely.

The process of extracting design data from planning or engineering documents is referred to as "quantity takeoff" (QTO). The engineer is figuratively taking off key pieces of data from the design plans to create a list of pay items and a SOW. This process is typically conducted utilizing computer-aided design software and the three-dimensional models that are created during engineering design. The quantity data is then input into a spreadsheet, which begins the next step, assigning unit prices to the various item quantities.

At this point, a cost estimate can be developed using one of the two methods referenced earlier, historical bid pricing or cost-based estimating. The most common method in use for developing estimates for transportation projects is to use historical bid costs (AASHTO 2009, p. 31). As described previously, this is a process by which estimators collect cost data from previous, similar projects and apply unit prices based on averaging the results. Adjustments are made where necessary for factors such as the following:

- Topographic survey
- Soil investigations
- Wetland delineation
- Wildlife assessment
- Historic preservation
- Archaeological findings

It is incumbent on the designer to make allowances for various contingencies for each of these types of data collection until such a time that this data becomes available. This early cost-estimating process is sometimes problematic for owners as it often yields total project costs that appear to be unaffordable. However, if the engineer and owner can properly communicate the design and planning assumptions to funding agencies, there is a much better chance of the cost-estimating

Table 1. FAA codes for horizontal airport construction.

Code	Designation/General Item Description
P	Pavements
D	Drainage
F	Fencing
L	Lighting
T	Topsoil/Seeding
M	Miscellaneous

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Table 2. Typical engineering design milestones for horizontal construction.

Estimating Milestones	Level of Design Involved
Planning Level	Basic geometry and project scope. Typically, no engineering alignments have been assigned. Right-of-way and data collection are not included.
30% Design	Basic horizontal geometry. Right-of-way and property acquisition process is being started.
60% Design	Refined horizontal geometry and initial vertical geometry. Initial site grading being started. Initial drainage and other major utility designs are being started. Right-of-way and property acquisition process is ongoing.
90% Design	Final draft of horizontal and vertical geometry. Final grading is ongoing. Remaining utility designs are started. Electrical lighting, signage, and marking design are ongoing. Initial quantity takeoff estimate is started.
100% Design	Geometry and grading is completed. Utility design is completed. Grading cross sections are generated. Right-of-way and property acquisition process is complete. Electrical lighting, signage, and marking design complete. Final quantity takeoff estimate is complete. Typical design details are finalized.
Bid Documents	Incorporate final owner and agency comments. Engineer assigns pay items and cross references all items of work on plans with specifications and proposal documents.

process being successful at later stages. If this communication is not well executed, the project is often cancelled prematurely.

Beyond planning-level cost estimating, other stages of cost estimating typically occur at various milestones, based on overall project progress. Table 2 lists typical engineering design milestones and the levels of design associated with each one. Note that these milestones should be viewed as examples. The definitions of these milestones can vary from project to project or state to state.

The challenge for owners and funding agencies is that budgetary decisions for ACIPs are made at the planning-level stage. This is the stage when the least amount of data is available. This puts pressure on owners and engineers to make worst-case scenario assumptions, which are designed to provide a high level of contingency within the estimate. It is at this point in the process where a project requires justified costs with adequate proof, as well as an explanation of the assumptions, in order to support reasonable outcomes as the project continues through the design process.

Cost Estimating for Vertical Projects

Existing construction cost-estimating practices for vertical airport construction projects can be understood by considering the following aspects:

- Types of project costs
- Method of organizing and allocating hard costs
- Method of assigning hard costs in relation to the stage of the project's completion
- Sources of hard cost and soft cost data
- Special conditions relevant to airport projects

These aspects are described in further detail in the following paragraphs.

The total costs to the sponsor of a vertical construction project are typically separated into two types: hard costs and soft costs. Hard costs represent those expenses related to the actual construction of the building that are paid by the sponsor directly to a contractor or construction manager: material, labor, and fees (including overhead and profit). These hard costs typically represent 70% to 90% of the total cost of a vertical construction project. Soft costs include all other expenses necessary for the completion of the project that are not paid to the contractor or construction manager. These costs vary significantly depending on the unique characteristics for each project but generally include design fees for the architecture/engineering firm; costs of furniture and special equipment; fees incurred through local permitting agencies, utilities, and inspections; land acquisition costs; expenses incurred as part of a public procurement process; and administration costs incurred by the sponsor to oversee and administer the project in accordance with public requirements. Both types of costs must be considered when establishing a total budget for the project.

A key factor in accurate cost estimating is a standardized method of organizing and allocating costs. The construction industry has adopted a generally accepted format for cost estimating of vertical construction projects that is common across applications and used for both publicly and privately funded projects. CSI develops and maintains an organizational system that allocates all construction work into one of multiple categories (CSI 2011). Although some minor variations exist, the majority of architects utilize the CSI system of categorization when developing plans and specifications.

Under this standardized format, every major item of work is allocated to a particular category (termed "division of work"), which corresponds to a particular trade contractor. For example, all carpentry work on a project is categorized and defined under Division 6, electrical work under Division 16, etc. For larger projects, each division is further broken down into subcategories (termed "sections of work"). Using the example of carpentry (Division 6), rough carpentry is further categorized under Section 6100, finish carpentry as Section 6200, etc. By defining individual items of work using a standardized and detailed organizational format, a clear and standardized method of communication between the architect and the contractor is utilized in order to construct the project in accordance with the sponsor's expectations.

Originally developed to organize and standardize the definition of the work within the architect's construction documents, this same format has proven to be effective in organizing and standardizing the cost-estimating process. By utilizing the same categorization system, a more direct correlation between item of work and cost of work is achieved in a format easily understood by all parties. Other benefits of the system include the following:

- CSI categorization can be performed at any stage of the project design—from the earliest concept drawings through detailed design to construction—and as a post-construction audit.
- The system is easily expandable for more complex projects, or conversely can be collapsed to address smaller or simpler projects.
- Direct correlation of cost item to work item reduces misunderstandings and oversights of portions of the project by the estimator.
- Standardization allows for comparison to other past and current projects, and facilitates the creation and maintenance of a project cost information database.

However, there are limitations to the CSI allocation system that must be addressed. The CSI system does not provide a method to estimate soft costs. Also, the CSI system does not account for special circumstances that could affect the overall hard cost for the project, including escalation, phasing of the project, temporary work, special local conditions (i.e., a remote island location that would place a premium on transportation of materials and labor), and reasonable contingencies to account for the level of completion of the project documents.

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These additional cost factors are applied according to the experience and knowledge of the estimator.

Current industry practices include performing cost estimates of vertical construction projects at various stages of development during design. As for horizontal projects, estimates are typically performed during initial planning and at the 30% design, 60% design, and 100% design levels. The later estimates benefit from the greater level of detailed design and thus are usually more accurate. However, as described previously, project budgets are usually established during the very early stages of design and, sometimes, prior to any design work being completed. In these instances, arriving at a reasonable project budget is challenging.

It is typically advisable not to establish a project budget prior to any design or feasibility planning work being performed. However, this practice is not uncommon and is usually done with limited involvement from a design or construction estimating professional. Oftentimes the cost of a similar project constructed some years in the past and at a different location is used for budgeting. Because every project has varying conditions which affect cost and because of volatility in material and labor prices over time, this method is unreliable in establishing a reasonable project budget.

Where some initial design work or feasibility planning has been performed, a "square foot cost" method is often utilized to establish the project budget. At this stage, usually between the initial project planning and the 30% design stage, the project location, overall size of the building in square feet, and functions that the building will accommodate have been established. With this information, an overall cost per square foot is selected based on a database of projects that are in the same geographic region, accommodate the same functions, and incurred project conditions similar to those expected.

Cost databases are maintained by a number of organizations within the construction industry, the most well known and possibly most often utilized is *RSMeans Square Foot Costs Book*, which is updated annually (Reed Construction Cost, Inc. 2011). The accuracy of this method is dependent on the relevance of the precedent projects, the accuracy of the cost database, and the judgment of the estimator, especially in regards to the unique conditions of the project being estimated that differentiate it from the precedent projects.

For projects that have developed the design to the 60% level, most of the major risk factors to project cost, such as existing site conditions and local permitting hurdles, have been vetted through research and field investigations. There is also enough information contained in the documents to utilize the CSI method for allocating cost items, and material and labor unit costs can be established. As the documents are not complete, estimators apply a contingency factor to their estimate to account for the level of detail still under development. The proper contingency factor is established based upon the judgment of the estimator.

For estimates developed at the 90% or 100% levels, industry practice is to perform QTOs for each type of material used on the project, as defined in the construction documents. Unit costs for labor and material are then applied to each work item. The amount of detail provided at the 90% and 100% level, combined with the considerably short time frame between this estimate and the start of construction, usually result in a relatively low variance between the estimated cost and the actual construction bids received.

Hard cost databases are maintained by individual cost-estimating firms and through commercial providers of construction cost data. These databases are constantly updated and are used to create plausible estimates for each type of material and labor that may be used for a particular project. They are also adjusted according to geographic region. The databases do not provide guidance or methods as to cost adjustments necessary for unique project characteristics, including those characteristics that are unique to airport projects. Soft cost databases are not prevalent in the industry. Instead, estimates of soft costs are usually developed by the sponsor, with the assistance of an architect or engineer.

Certain airport projects have unique characteristics that over time have resulted in variations on standard cost-estimating methods. In some cases, these alternative methods have proven to be effective. Examples include the following:

- **Parking garages:** At the planning through 30% design level, the industry has developed a metric of unit cost per space as an effective method for preliminary estimating for these structures. Databases are informally maintained by consulting firms specializing in this form of structure. The relative simplicity of the building type allows this metric to be reasonably accurate even at the early stages of planning and design. Key factors include the type of structural system, architectural treatment, and lobby amenities.
- **Terminal buildings:** At the planning through 30% design level, the standard unit cost per square foot method is applied. However, the unit cost varies for individual areas of the terminal, since some areas represent significantly higher cost per square foot than others. For example, public lobby space is significantly more expensive than office and support space. Also, baggage handling and security space costs must take into account the high costs of specialized equipment.

Airport projects also pose a number of special project conditions for which a standard and reliable method of establishing cost impacts is currently not prevalent in the industry. These conditions include:

- **Permitting:** Local permit requirements and processes vary considerably. Additionally, construction at public-use airports oftentimes utilizes federal funding sources. In these cases, federal requirements, which are in addition to state and local requirements, must be followed in relation to environmental permitting. As construction cannot proceed until all permits are completed, an extended federal permitting process can result in extended project schedules. These procedures also require public hearings and notification that can result in additional time spent and soft costs incurred responding to public input.
- **Operational continuity:** Many airport projects are renovations or expansions or involve some impact to ongoing airport operations. As airports must remain fully operational during construction, additional costs are often incurred related to phasing, temporary construction, and protection of passengers and employees during construction.
- **Security:** All airport property is designated as being either "airside" or "landside." Airside refers to areas of the airport for which special security access is required. These areas generally correspond to the Security Identification Display Area (SIDA). All personnel working in these areas must be pre-screened by the airport, obtain special training, and receive a SIDA identification badge before being allowed access. This process is both costly and time consuming, and results in increased costs to the contractor. In addition to the screening and badging of the labor force, many airports require any material deliveries to be searched prior to accessing the airside work area. Some projects, especially terminal building renovations, involve construction on both sides of the SIDA access barrier as part of the same project. Here, costs are incurred to relocate and maintain temporary SIDA barrier locations in order to allow for the work to proceed without affecting the flow of passengers and ongoing airport operations. The high level of technology used in establishing these barriers makes relocation quite expensive.
- **Federal safety requirements:** In addition to the security measures outlined previously, an airside project triggers additional safety requirements in accordance with FAA and Transportation Security Administration (TSA) regulations.

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- **Soft costs:** Many airport projects are renovations or expansions or involve some impact to ongoing airport operations. As airports must remain fully operational during construction, significant additional soft costs will be incurred related to phasing, temporary construction, and protection of passengers and employees during construction.

Vertical projects pose a significant challenge to early stage cost estimates. These are estimates developed prior to a design being initiated as part of a capital program. The complexity of these projects can result in significant variations of unit costs within particular areas of the project. Such elements are typically not fully understood until later in the design process. Therefore, early stage estimates for complex vertical projects are better supported by historical total-project-cost data for projects of similar size, scope, complexity, and cost-driver characteristics.

CHAPTER 3

Parametric Cost Estimating

The parametric cost-estimating methodology consists of developing mathematical relationships between cost, the dependent variable, and a number of independent variables that are hypothesized to be the drivers for the cost. Strengths of the parametric cost-estimating technique include the following (GAO 2009, p. 108):

- Is reasonably quick
- Encourages discipline
- Provides a good audit trail
- Is objective, with little bias
- Has cost-driver visibility
- Incorporates real-world effects

Linear regression is the most widely used technique to develop parametric cost models. Historical values of dependent and independent variables are used to model a linear relationship between these variables. Once the model has been developed and tested, it can be used to make predictions, by letting the independent variables take on hypothetical values. In simple linear regression, the value of a single dependent variable is predicted from the value of a single independent variable. In this case, linear regression is equivalent to finding the best-fitting straight line through the historical data points. In multivariable regression analysis, multiple dependent variables are used. In this study, construction cost is regressed against several independent variables that represent the cost drivers for the project type in question.

The steps for implementing an airport construction cost-estimating model using parametric cost estimating include:

1. Identify CIVs for inclusion in the data collection process.
2. Develop CERs.
   a. Collect historical data and normalize to account for inflation and geographical variation.
   b. Hypothesize algebraic CERs for each project type, linking project cost to CIVs.
   c. Conduct statistical analysis of hypothetical CERs.
   d. Refine CERs and select most appropriate CER for each project type.
   e. Embed mathematical relationships into cost model.
3. Test and validate the cost model.

This process is described in more detail in the following sections.

Identifying Candidate Input Variables

The first step in the process used to derive the cost model is the selection of CIVs. These represent the key independent variables that are hypothesized to drive the costs of a particular construction project type. They are referred to as candidate variables because their inclusion in the model is based on a hypothesis of a relationship between cost and cost driver. During the model development, the selection of CIVs is altered in an iterative manner, until a cost model is derived that is robust and meets the target statistical metrics of quality of fit. CIVs selected for use in a parametric cost-estimating model should meet the following criteria:

- They should have a logical relation to the project type.
- They should have a causal relationship to the construction cost.
- The value of variable should be quantifiable both during the collection of historical data and when using the cost model to prepare cost estimates.
- The variables should, preferably, be continuous variables.

Continuous variables are variables that have numerical values that can take any value within an allowable range formed by a minimum and maximum variable. In the case of a continuous variable, a value of two is twice as large as a value of one and a value of four is twice as large as a value of two. Examples of continuous variables include runway length, aircraft weight, floor space, and so on.

In contrast, discrete variables include variables such as airplane design group, which can take on the values I through VI, or two-state variables such as “yes/no.” The fundamental problem with discrete variables is that one cannot tell with any mathematical certainty what the ratio is between terms such as “large,” “medium,” and “small.” For example, if “large” is not twice “medium” and “medium” is not twice “small,” the meaningfulness of the resulting mathematical model cannot be clearly stated.

The CIVs that were originally taken into consideration for inclusion in the data collection process are identified in the following list, along with brief explanations justifying their inclusion.

- **Aircraft approach category:** This value identifies the airport category (from A to E) based on the approach speed of the critical aircraft (design aircraft). The critical aircraft is usually taken to mean the most demanding aircraft that generates at least 500 annual operations.
- **Airplane design group:** This value identifies the airport category (from I to VI) based on the wingspan of the critical aircraft.
- **Airport size:** This value would be used to identify the overall complexity of the airport and could be represented by using a single continuous variable such as acreage, number of runways, maximum runway length, number of operations per year, or a discrete variable such as the Airport Reference Code.
- **Area:** This is a general sizing variable that would be used to support the cost estimates of new or renovated buildings or airport elements such as pavement surfaces and runway safety areas.
- **Federal Aviation Regulations (FAR) Part 139 category:** This category (from I to IV) determines the ARFF capabilities needed. The class is based on whether the airport has scheduled or non-scheduled service and whether it serves small or large air carrier aircraft. It applies only to commercial air carrier airports certified under FAR Part 139.
- **Discrete frequency:** This variable would be used to help estimate the cost to install weather reporting equipment.
- **Drainage type—above ground or below:** This two-state variable would be used to help estimate the cost to construct parking lots.
- **Obstruction type—equipment, tree, or ground:** This three-state variable would be used to characterize obstructions that would be removed as part of an airport improvement.
- **Height:** This variable would be used for estimating the cost to construct certain airport buildings.
- **Length:** This CIV, usually expressed in linear feet, would be used as a primary variable for estimating the cost of projects such as perimeter fencing.
- **Load rating:** This variable would be used to identify the maximum load that would regularly be placed on a runway by an aircraft. The rating is a combination of the maximum takeoff weight of the critical aircraft and the landing gear configuration.

- **Number of floors:** This variable would be used for certain airport buildings.
- **Number of intersections:** This variable would serve as a high-level proxy for the amount of signage associated with new runway, taxiway, or apron construction (see also "signs per intersection").
- **Number of navigational aids:** This variable would serve as a quantity variable which would be applied to the average cost per navigational aid (NAVAID) to reasonably estimate the total cost of all required new NAVAIDs.
- **Number of obstructions:** This variable would serve as a quantity variable which would be applied to the average cost to remove a typical obstruction to reasonably estimate the total cost to remove all required obstructions.
- **Number of spaces:** This variable would be used to estimate the construction cost of an airport parking lot and/or airport parking garage.
- **Number of systems:** This variable would be applied to new security systems, and also potentially to help estimate the cost of new NAVAIDs or certain guidance systems.
- **Number of vehicle gates:** This variable would be used to help estimate the cost to implement new security access systems and the cost to install perimeter fencing.
- **Runway approach type:** This three-state discrete variable would be used to determine the runway pavement markings required. The three states are visual, non-precision instrument, and precision instrument.

There is a direct relationship between the number of historical observations required to develop statistical meaningful CERs and the number of independent variables. Due to the extensive possible interactions between the CIVs, the number of required historical data points increases exponentially with the number of variables. For this reason, the number of CIVs must, in practice, be limited to those cost drivers that have the greatest influence on cost. There are a number of other variables not included as CIVs that have the potential to impact project cost. This is especially true for vertical construction projects, which by their nature involve a higher degree of complexity. The data collection and statistical analysis of the CERs were used to determine that the correct balance between data availability and number of variables has been reached.

The selection of CIVs (and project types) was an iterative process. The final list of CIVs is described in Chapter 4. A number of the originally proposed CIVs were not included in the model. The final selection was driven either by lack of data or other methodological reasons, such as the desire to limit the number of discrete variables.

Developing Cost-Estimating Relationships

This step involves identifying and recording interactions between the project cost and the cost drivers represented by the CIVs. An interaction between driver variables exists when the effect of one is conditioned on the value of one or more of the others. These interactions are modeled as CERs, which are mathematical expressions of the relationships between construction cost and the CIVs. These CERs are developed through statistical analysis, using multivariable regression. In some cases, the number of data points and/or a data set that exhibits odd variances may prohibit the development of statistically valid CERs. In these cases, a CER may not be able to be developed or adjustments may be required to the functional specification or choice of CIVs. For this reason, particular care must be used when selecting the CIVs to try to only include variables expected to be causal factors.

The fundamental statistical technique used in linear regression is called least squares regression. There are several computerized least squares regression programs or modules. This study used the Analysis Toolpack, an add-on to Microsoft Excel. Least squares regression was chosen because the mathematical formulas used to minimize the variance have explicit formulas and the resulting formulas are linear. This method of linear regression fits a straight line through each data set to minimize the sum of the squares of the differences between the data points and the fitted line.

The process for developing the CERs included the following steps:

1. Develop hypothetical CER using airport planning, engineering, and subject matter expert (SME) input.
2. Develop a database of historical CIV values.
3. Plot data against CIVs to visually identify trends.
4. Test dependent variables against independent variables individually using statistical software.
5. Select promising independent variables.
   a. Test combinations (i.e., interactions between CIVs).
   b. Analyze statistical metrics:
      i. Logic
      ii. Coefficient of variation
      iii. Adjusted coefficient of determination (adjusted R^2)
      iv. F-statistic
      v. T-statistic
      vi. Robustness
      vii. Outliers
6. Refine and finalize CERs.

The first step involves identifying and recording potential interactions between cost and the CIVs. An interaction exists when cost is affected by the value of one or more CIVs. Throughout the process, particular care was taken to identify causal factors, based on knowing and understanding the real-world effects of a potential cost driver.

To illustrate the first step in this process, consider a hypothetical CER to estimate the cost of constructing or rehabilitating a runway. Assume that the following hypothetical CER was developed in consultation with airport engineers and SMEs on horizontal airport construction:

$$\textit{Cost} = f(\textit{Area, MTOW, GearConfig, PvmtType, FreezingIndex})$$

where

Area is the surface area of the runway pavement to be constructed, measured in square feet (sq. ft.).
MTOW is the maximum certificated takeoff weight of the design aircraft, measured in pounds (lbs.).
GearConfig is the landing gear configuration, given by one of the following: single wheel, dual wheel, dual tandem wheel, or double dual tandem wheel.
PvmtType is the pavement type, given by one of the following: asphalt (i.e., hot mix), portland cement concrete (PCC), or hybrid.
FreezingIndex is the design freezing index value, measured in degree-days.

Testing and Validation

The simplest and most commonly used statistical measure of the statistical fit between the dependent and independent variables is called the coefficient of determination. This represents the portion of the total variation in the dependent variable that is explained by variation in the independent variables. The coefficient of determination is commonly called “R-squared” and is denoted by R^2. A value of one indicates perfect correlation between the dependent and independent variables, whereas a value of zero indicates no detected correlation. However, note that correlation does not necessarily imply a causal relationship.

Table 3 provides a summary of statistical metrics that can be used to test the quality of fit and statistical significance of the model, along with rules-of-thumb for satisfactory performance. More detailed explanations of the statistical measures identified in Table 3 follow:

- **Logic:** Logic is used to develop hypotheses that are tentatively advanced to account for particular facts. Hypotheses are testable ideas or testable questions on some phenomenon of interest. The hypothesis can then be tested by collecting and analyzing data using inferential statistics.
- **Coefficient of variation:** This is the ratio of the standard deviation of a data set to its mean. This is a relative measure of the amount of dispersion there is in the statistical sample represented by the data set.
- **Adjusted R^2:** R^2 is also referred to as the coefficient of determination. This measures how much of the variability in the data is accounted for by the model (in this case, the CER). This is an indication of how well the outcomes are predicted by the model and measures overall quality of fit. Adjusted R^2 corrects the coefficient of determination to account for the fact that it otherwise appears to improve as more independent variables are added to the model.
- **F-statistic:** The F-statistic is used to test the overall regression analysis for the existence of a statistically significant relationship between the dependent and the independent variables.
- **T-statistic:** This is the ratio of a CIV's coefficient to its standard error. The ratio can also be expressed as a confidence level that demonstrates the probability that the coefficient is a significant predictor of the independent variable.
- **Robustness:** A measure of whether the statistical model is unduly influenced by small variations in the underlying data.
- **Outliers:** An outlier is a data point that is abnormally distant from the remainder of the statistical sample represented by the data set. These are usually excluded from the data set, since they may be caused by errors in the data or misunderstandings in the data collection process. A specific example might be a grant that is described as funding a runway construction project, but which in fact only funded the design phase. The cost for a design-only project would be much lower than the cost of the associated construction.

CERs should be elected based on quality of fit, statistical significance, and robustness of selected cost drivers. These qualities are sometimes traded against one another. Depending on the hypothesis undergoing test, the data can span a wide range of values, which can affect the robustness of the model. Other times, the data set may be confined to a more limited set in order to exclude statistical outliers. This reduces the variability of data (measured by the resulting F-statistic), tightening its prediction interval (measured as a function of the t-statistics associated with each CIV). This also helps match the engineering logic behind the proposed CER.

Table 3. Statistical metrics for assessing linear regressions.

Measure	Criteria	Explanation
Logic	Make engineering sense	Valid estimator of cost because of causality
Coefficient of variation	CV < 20%	CER is a tight predictor of costs
Adjusted R^2	$R^2 > 0.90$	Good correlation between cost and cost drivers
F-statistic	F-Ratio > F* @ 90% CI	Regression equation is a better predictor of cost than the mean (average cost)
T-statistic	t > t* @ 90% CI	Correlation between cost and the independent variable is too great to have occurred by chance
Robustness	DF/N > 0.6	Data points are not excessively influential
Outliers	No statistical outliers	No obvious data homogeneity

Notes: CI = confidence interval; DF = degrees of freedom; N = number of observations, "*" is used to indicate critical value at a specified level of statistical significance (i.e., 90%)

Each CER must be evaluated both statistically and subjectively, based on its applicability to the project type in light of other cost drivers and their effects on cost. Ease of collecting data should also be taken into account. In some cases, no statistically valid relationship may be able to be developed, due to the lack of correlation between cost and the proposed CIVs.

An additional technique that can be used to evaluate the accuracy and usefulness of a CER is case study validation. This consists of reserving data points from the data collection effort or, alternatively, collecting additional data strictly for use in the case study validation. The independent variables associated with each reserved data point are then entered into the CER, to calculate predicted costs. The predictions are then compared to the actual costs from the collection of case studies. If the CER predicts the actual costs of the reserved data within a reasonable range, the confidence in the CER's predictive ability is increased. After the case study validation is completed, the data reserved for this purpose can be incorporated into the database and used to update the model.

CHAPTER 4

Developing an Airport Cost Database

As described in Chapter 3, parametric cost estimating relies on developing mathematical relationships between costs and cost drivers using historical cost data for previously completed projects. Consequently, a key step in implementing a cost model using the parametric cost-estimating technique is the establishment of a historical cost database. The following sections describe the analytical framework behind the development of the database used for this project. The discussion covers the selection of projects to be included, the database structure, data sources, the collection of data to populate the database, and the inclusion of adjustment factors for inflation and regional variations.

Candidate Project Types

The list of candidate airport construction projects was derived using a combination of sources and considerations, including the following:

- AIP and American Recovery and Reinvestment Act (ARRA) grant histories for general aviation and non-hub airports.
- Survey responses from the industry stakeholder outreach effort.
- Recommendations from *ACRP Report 49: Collaborative Airport Capital Planning Handbook.*
- Input from the airport construction SMEs.
- Technical feasibility of encoding each project type in cost model.
- Data availability.

AIP and ARRA grant histories served as the starting point. Five-year grant histories for fiscal year (FY) 2005–2009 were used as a starting point (FAA 2011). These were filtered to focus on general aviation and non-hub airports. A relatively low number of project types account for the majority of projects funded. In order to constrain the database scope to a feasible level, the 75th percentile was selected as an initial cut-off point (as measured by the amount of federal funding). Non-construction projects, such as planning studies and land acquisition, were eliminated from consideration.

The candidate list was then augmented by comparing the initial list against survey responses obtained as part of the industry stakeholder outreach effort. Specifically, the list of candidate projects was augmented using responses to the survey question "What are the most common types of construction projects that you estimate?" Key findings from *ACRP Report 49: Collaborative Airport Capital Planning Handbook* (Cullen et al. 2011) were used to further refine the list of candidate projects. Two key recommendations from this study were applied:

- Focus on projects with high potential for reducing the cost-estimating uncertainty
- Focus on projects with high potential for return-on-investment (ROI) for the airport sponsor

Table 4. Candidate project types.

Project Type	Share of AIP/ARRA Projects	Share of Survey Responses
Horizontal Construction Projects		
Airfield signage	N/A	2.80%
Construct or rehabilitate taxiway	12.07%	10.70%
Construct parking lot	N/A	N/A
Construct, expand, or rehabilitate apron	9.53%	8.50%
Construct, extend, or rehabilitate runway	16.32%	15.30%
Improve runway safety area	3.00%	1.70%
Install airport visual system	1.69%	N/A
Install NAVAIDs	1.57%	3.40%
Install perimeter fencing	4.04%	2.30%
Install weather reporting equipment	1.78%	N/A
Rehabilitate runway lighting	2.32%	10.20%
Remove obstructions	3.00%	2.30%
Runway pavement marking	N/A	2.30%
Security access systems	N/A	N/A
Vertical Construction Projects		
Construct ARFF facility	N/A	5.60%
Construct, expand, or rehabilitate terminal building	1.23%	10.70%
Construct parking garage	N/A	2.80%
Construct SRE building	1.15%	3.40%

Note: N/A = not available.

The list was reviewed and edited by the airport construction SME members on the team. For example, the AIP category "Construct Building" was expanded to include a list of specific vertical construction projects. A similar approach was employed to identify security-related projects, which otherwise are not adequately captured by the AIP and ARRA grant histories. The list was also reviewed for feasibility of implementation in the cost-estimating model. Table 4 represents the resulting initial list of candidate projects. The list identifies the project type, the percentage share of the AIP and ARRA grant histories, and the percentage share of survey responses.

During the course of the development of the cost model, this list was updated and refined in an iterative process. Projects were modified, added, or removed, driven primarily by data availability and feasibility of implementation. Parametric cost estimating relies on multivariable regression analysis, a statistical technique that, in general, yields more robust results with a large sample of data. Several project types were eliminated from inclusion in the model because of the lack of sufficient data. Table 5 lists the final selection of project types supported in the model, including the final number of data points (i.e., historical projects) collected.

Table 5. Final project types.

Project Type	No. of Observations
Horizontal Construction Projects	
Construct or rehabilitate taxiway	25
Construct or rehabilitate apron	29
Construct, extend, or rehabilitate runway	48
Install perimeter fencing	24
Install precision approach path indicator	10
Install weather reporting equipment	31
Vertical Construction Projects	
Construct ARFF facility	42
Construct SRE building	42

Selection of Candidate Independent Variables

The final selection was driven by hypothesized relationships between cost and cost drivers, availability of data, and methodological reasons such as the desire to limit the number of discrete variables. The CIVs that were included in the cost database are identified below, along with brief explanations justifying their inclusion:

- **Area:** This is a general sizing variable used to support cost estimates for pavement surfaces (i.e., pavement area) and buildings (i.e., floor area).
- **Landing gear configuration:** A discrete variable that describes the landing gear configuration of the design or critical aircraft. The landing gear configuration affects the distribution of an aircraft's weight and the resulting load on the pavement. Used to support cost estimates for pavement surfaces.
- **Length:** General sizing variable used to support cost estimates for fencing projects.
- **MTOW:** The maximum takeoff weight (MTOW) of the design or critical aircraft. Affects pavement load and is used to support cost estimates for pavement surfaces.
- **Number of systems:** This is a quantity variable that is applied against the average cost of a single installation of a visual or navigation aid. This is used in support of projects that may be installed in multiple locations on the airport, such as precision approach path indicator (PAPI) installations.

As described previously, the number of data points required increases with the number of CIVs included in the CERs. The final list of CERs was selected to achieve a balance between data availability and the number of hypothesized cost drivers.

Historical Construction Costs

Historical construction costs are included in the database in order to establish a statistical relationship between cost and the cost drivers represented by the CIVs identified for each project type. In order to create CERs that are universally applicable, they must be controlled for both inflation and regional variation. Since year-to-year changes in prices affect the purchasing power of the funds used, construction must be normalized in order to use historical observations spanning a multiyear period. Similarly, since the CERs incorporate historical data across a broad range of geographical locations, costs must be normalized to take into account regional variations in the cost of construction.

Adjusting for Inflation

Inflation data is used to control for variations in price levels across a broad range of project implementation dates. Since construction costs generally increase over time, all historical data are inflation adjusted. FY 2014 was selected as the reference year. This is an arbitrary choice but ensures that all cost data in the model have a common basis in terms of price level. Both input data used to determine the CERs and output data (i.e., cost estimates) are internally adjusted to FY 2014 price levels. This inflation adjustment is conducted at a national level; a separate geographic adjustment is included to take into account regional variations in cost (see the following subsection).

There are a number of commonly used indices available for adjusting inflation. Some of these are specifically intended for construction projects. Of these, a commonly used reference is the commercially developed RSMeans Construction Cost Index. However, in order to make the cost-estimating model freely distributable, cost indices that are not in the public domain were ruled out from consideration. Also, forecasts are generally not available for construction-specific cost indices. The cost-estimating model requires both historical and predictive inflation factors. For these reasons, the U.S. Bureau of Labor Statistics Consumer Price Index (CPI) and Gross Domestic

Product (GDP) deflators provided by the Office of Management and Budget (OMB 2012) were used. CPI was used to inflation adjust historical data; whereas the OMB's forecast of GDP deflators is used to inflation adjust cost estimates for planned projects.

Adjusting for Regional Variations

Construction costs can vary considerably by geographic location due to a number of factors, including transportation costs, utility costs, the cost of construction materials, the general price level of labor, and indirect costs due to regulatory processes such as permitting and environmental studies. A cost-estimating model must therefore be able to account for regional variations in price levels. This is particularly true if a national cost model is developed from historical data that spans a large number of geographic locations.

A challenge in compensating for regional variations is selecting the appropriate geographic unit. State-level adjustments allow for correcting a substantial amount of geographic variation. Correcting for variation at the state level is intuitive even to non-experts but can fail to account for more detailed variation, for example, at the county level or between urban and rural areas. While this argues for using a geographic unit with a finer level of distinction than state boundaries, in practice it is difficult to obtain construction-specific geographic adjustment factors without relying on commercial sources. For this reason, state-level factors published in the Department of Defense Facilities Pricing Guide (DoD 2011) were selected. These cover construction subject to Davis-Bacon wage requirements, which is generally relevant for airport construction projects that involve federal funding programs such as AIP grants or PFC funding. These adjustment factors specifically include airfield construction and provide separate rates for each state for construction and sustainment costs.

To normalize the cost data, a single state must be selected as an arbitrary reference point. All historical cost data are adjusted using adjustment factors that measure price levels relative to this state. When cost estimates are developed for future projects, initial calculations are conducted using the same reference state. In the final step, the cost estimates are converted to prices for the state in which the planned construction is to be conducted. While the choice of the reference state is arbitrary, for practical reasons, a state with price levels close to the national average is usually chosen. For this modeling effort, the State of Kansas was selected as the reference state. The adjustment factors for Kansas are 94% for construction and 91% for sustainment, relative to the national average (DoD 2011, p. 36).

Database Structure

Establishing a functional and efficient database structure is a critical step in ensuring the database serves its purpose. The database structure should be functional in that it should capture all the relevant data needed to conduct the analysis. It should be efficient in that it should avoid duplication and should be easy to interpret and analyze.

In the case of the cost model, a simple tabular form with one table for each project type was used. The database was implemented in Microsoft Excel for the sake of simplicity. While a number of dedicated database applications are available, these are preferred only when either a very large database is developed or when the database consists of many nested tables with relationships that link data between tables. In this particular application, the size of the database is relatively small (the final database consisted of a total of 255 observations). Moreover, the only links that exist between data tables are the links to the adjustment factors for inflation and regional variation, as well as a table of landing gear configurations.

Table 6. Database structure.

Historical Construction Data Tables	
Project Type	*Data Table*
Construct or rehabilitate taxiway	Taxiway
Construct or rehabilitate apron	Apron
Construct, extend, or rehabilitate runway	Runway
Install perimeter fencing	Fencing
Install precision approach path indicator	PAPI
Install weather reporting equipment	Weather
Remove on-airport obstructions (vegetation)	On-airport Veg Removal
Construct aircraft rescue and fire fighting facility	ARFF
Construct snow removal equipment building	SRE Bldg
Ancillary Data Tables	
Data	*Data Table*
Inflation adjustment factors	Inflation
Regional variation adjustment factors	Geographic_Adj
Landing gear configuration	Landing_Gear

The basic database structure is summarized in Table 6. The database consists of two main parts—historical construction data and ancillary data. The construction data portion of the database contains nine separate data tables, one for each project type. Note that while the project type "remove on-airport obstructions (vegetation)" is included in the database, no CER was developed for this project type and it is not represented in the final cost-estimating model. In addition, there are three tables for ancillary data.

The construction data tables share a similar structure, which consist of two basic parts. The first part is identical for each project type and consists of an identifier, location information, and basic project information such as a project description, year of construction, and total project cost. The structure of this portion of the construction data tables is shown in Table 7.

The second part of the construction data tables consists of the values for the CIVs for the project in question. Since each project type has different CIVs, the structure and number of fields vary from project to project. As an example, the structure for the runway construction project type is shown in Table 8.

Table 7. Structure of construction data tables—basic project data.

Field	Example
Record identifier	Data Point CETR #9
Airport FAA identifier	MVY
State	MA
Project description	Shift Runway 6-24 303' Northeast
Year	2010
Total project cost	$5,494,476

Table 8. Structure of construction data tables—CIV values.

Project Type: **Construct, extend, or rehabilitate runway**	
Field	*Example*
Pavement area	550,000 SF
MTOW of design aircraft	93,000 lbs.
Landing gear configuration	Dual wheel (DW)

Data Collection

The parametric cost-estimating methodology relies on multivariable regression analysis, a statistical technique that results in a mathematical relationship between a dependent variable and several independent variables. In this application, the dependent variable is construction cost and the independent variables are the cost drivers represented by the CIVs. The goal is to include as many explanatory factors as possible, so that all of the key variables that affect construction cost are included. However, the more independent variables that are included in the functional form of the regression model, the greater the sample of historical observations must be. In other words, there is a tradeoff between the explanatory power of the model and the amount of data that is available and can be collected.

In the original model specification, the proposed CERs typically included five to six CIVs for each project type. For example, the runway CER included the following CIVs: pavement area, MTOW, landing gear configuration, pavement type, and design freezing index value. However, due to limited availability of data, the proposed CIVs had to be revised so as to include fewer independent variables. The process for identifying data sources, collecting data, and the outcomes of the data collection effort are described in the following subsections.

Data Collection Methodology

The research plan for this project called for a data collection process that, whenever possible, relied on automated data retrieval processes. The focus of the data collection plan was to identify pre-existing, electronic data sources in spreadsheets and database formats. However, the stakeholder survey and the initial review of available data revealed several significant challenges in populating the database with construction costs and CIV values:

- Data is often stored in the PDF format, which is nominally an electronic format but cannot be used to automatically populate a database.
- In cases where construction project data is available in a usable electronic format, such as Microsoft Excel spreadsheets, the data usually does not include values for the required CIVs.
- Projects funded through federal grants often include several bundled construction projects, making it difficult or impossible to separate costs for specific projects.
- Federal grant histories only list the federal share and not the total construction cost.

These findings required a significant departure from the original plan of importing existing databases of cost and CIV values to form a comprehensive database. Instead, the data collection relied primarily on data entered manually, supplemented by some use of data in Microsoft Excel format. To facilitate manual data collection, spreadsheet templates were developed. Two separate data collection templates were developed, one for horizontal and one for vertical construction projects. The templates matched the structure of the cost-estimating database, by including a series of sub-templates, one for each project type. For each historical observation, fields for basic descriptive information were provided, such as a project description, location, and year of completion. Other data fields were used to store values for construction costs and the CIV values required for the proposed CER for the project type in question.

Data Sources

The following data sources were identified and used in the data collection phase:

- Project data history from individual airports, including:
  - Data submitted by members of the ACRP Project 01-19 panel.
  - Data submitted by the survey recipients.
  - In-house data provided by the airport construction SMEs who participated in the study.

- Ancillary databases:
  - FAA, Airport Engineering Division, Aircraft Characteristics Data.
  - FAA, National Flight Data Center, Facilities Table.
  - FAA, National Flight Data Center, Runways Table.
  - FAA, Terminal Area Forecasts.
- AIP/ARRA grant histories.
- Manual collection of project close-out information at state departments of transportation and aviation agencies.
- Web searches, media articles, and other sources.

The AIP/ARRA grant histories include project descriptions, locations, and construction cost information for nearly 20,000 projects. However, they generally do not include any information on the required CIV values. The grant histories were therefore of very limited value in developing CERs. They were, however, useful for estimating the total number of projects that could potentially be incorporated into the historical construction cost database.

In addition to these sources, a number of data sources were identified and reviewed, but were ultimately not used in the database development. These included AIP annual reports and airport bond statements. These sources provided useful background information, but did not include data in a usable electronic format. While they included some CIV values in narrative form, incorporating this data would have required extensive manual processing and follow-up.

CIV Reduction

The number of observations required for each project type in the database was primarily driven by the number of CIVs in the associated CER. Given the difficulties in obtaining data in suitable electronic format, the number of CIVs was reduced from the original model specification. The CERs that were carried forward to the model validation phase were reduced to no more than three CIVs, focusing on the primary causal cost drivers. In particular, most discrete CIVs were eliminated, due to the limitation of incorporating variables that do not take on continuous values.

In some cases, CERs feature CIVs that are functionally related and that can possibly be represented by a single variable. An example of the possibility of reducing the number of CIVs is landing gear configuration—a CIV identified as a potential cost driver for pavement projects. Landing gear configuration is included as a CIV because the pavement design depends on the pressure exerted by an aircraft through a tire's contact patch. The pressure is a factor of both the aircraft's weight (i.e., MTOW) and landing gear configuration. However, since the variation in aircraft landing gear design within any one type of configuration is relatively limited, it is possible to estimate factors for converting the MTOW for one specific landing gear configuration to another configuration. Such conversion factors have previously been published by the FAA, as shown in Table 9.

Table 9. FAA factors for converting between landing gear configurations.

To Convert From	To	Multiply By
Single wheel	Dual wheel	0.8
Single wheel	Dual tandem	0.5
Dual wheel	Dual tandem	0.6
Double dual tandem	Dual tandem	1.0
Dual tandem	Single wheel	2.0
Dual tandem	Dual wheel	1.7
Dual wheel	Single wheel	1.3
Double dual tandem	Dual wheel	1.7

Source: FAA (1995), p. 25.

These multipliers allow for the conversion from any combination of MTOW and a specific landing gear configuration to a single-wheel-equivalent MTOW. As an alternative to using this FAA guidance, it is also possible to derive conversion factors empirically by examining the relationship between the MTOW specified for different landing gear configurations for a broad range of aircraft models. As an example, Figure 1 shows the relationship between MTOW in the dual wheel (DW) landing gear configuration and MTOW in the dual tandem wheel (DTW) configuration for all aircraft models in the FAA Airport Engineering Division's aircraft characteristics data table. The data suggests a conversion factor of 1.84 (compared to a factor of 1.7 per the FAA guidance in Table 9).

Results of Data Collection

Due to the limited data availability described previously, the data collection was conducted in several rounds, establishing an iterative process. After the supplemental data collection and elimination of partial data points, the number of total data points for use in CER development encompassed a total of 255 observations. This was sufficient to support CER development for all of the project types identified in Table 6, with the exception of "Remove on-airport obstructions (vegetation)." With only four observations collected, this project type was removed from further consideration. The results of the data collection are summarized in Table 10.

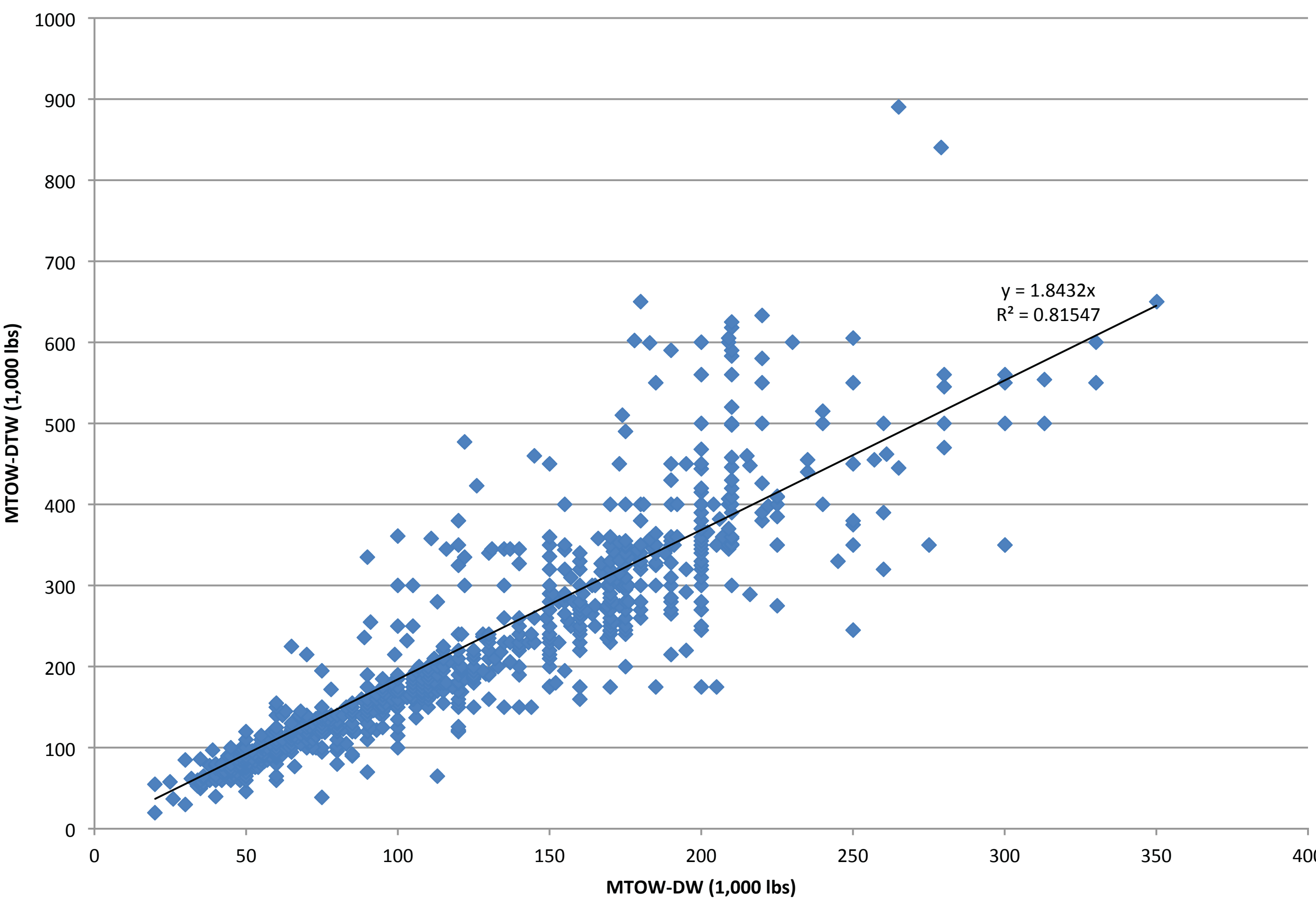


Figure 1. Relationship between MTOW in DW and DTW landing gear configurations.

Table 10. Results of data collection.

Project Type	Total Data Points Collected	Total Data Points Used	Yield
Horizontal Construction Projects			
Construct or rehabilitate taxiway	25	22	88.0%
Construct, expand, or rehabilitate apron	29	22	75.9%
Construct, extend, or rehabilitate runway	48	30	62.5%
Install perimeter fencing	24	18	75.0%
Install PAPI	10	5	50.0%
Install weather reporting equipment	31	28	90.3%
Remove on-airport obstructions (vegetation)	4		
Vertical Construction Projects			
Construct ARFF facility	42	25	59.5%
Construct SRE building	42	33	78.6%
All Projects			
Total	255	**183**	**72.9%**

The data set was analyzed for statistical outliers, which were removed prior to performing the multivariable regression analysis that establishes the CERs. Outliers were detected by identifying abnormal unit costs (i.e., cost per square foot of pavement), as well as other anomalies. For some observations, the project description did not provide sufficient clarity in regards to the scope and nature of the project. For example, in some cases, it was unclear from the description whether the cost was limited to a single project type or multiple project types covered by the same federal grant. Data points with problematic project descriptions were also removed as statistical outliers. Table 10 indicates how many of the collected data points were retained for CER development, as well as the overall yield (i.e., the share of data points that were actually used). The resulting CERs, along with plots of predicted versus actual cost for each data point used in the CER development, are documented in Appendix A.

CHAPTER 5

ACCE—Airport Capital Cost-Estimation Tool

Before Getting Started with ACCE

To ensure a smooth experience with ACCE, some preparations are necessary before running the application. These preparations include the collection of information that constitutes inputs to the cost-estimating approach. Since airport capital planning involves management, policy, planning, finance, and safety functions at the airport, the inputs should be vetted with relevant personnel and/or departments. Alternatively, ACCE can be run in a group setting to allow consensus discussion on the subjective inputs to the tool while it is being used.

Some of the inputs required by ACCE should be collected prior to starting. This includes the definition of the construction project(s) under consideration, consisting of a project description, planned construction year, and values for the cost drivers that are used in the CER for the project in question. It may also be useful to have a printed reference copy of the quick reference guide for ACCE, especially when using it for the first time. The guide is reproduced in Appendix B.

ACCE Work Flow

The user interface is designed to ensure all relevant information is displayed and associated input is requested in a guided, logical sequence. This keeps the interface simple and allows a user to navigate intuitively through the tool. The input screen of the ACCE tool is divided into four sections (see Figure 2):

1. **Contact information:** This section allows the preparer to enter identifying information, including name, organization, e-mail, and a phone number. This information is optional.
2. **Airport data:** In this section, the user specifies airport information including three-letter FAA airport identifier, the state, and an airport description. Airport location information is used to geographically adjust cost estimates and to identify the project location.
3. **Project input:** This includes project-specific information such as the construction type and all relevant CIV values.
4. **Cost estimate:** This provides a running display of a range of cost estimates, identified as a low, most likely, and high estimates. If the project inputs are modified, the cost estimate is updated. Once the user is satisfied with the inputs, a report can be generated from this section.

Airport Data

Airport data is necessary primarily to account for the regional variation in project cost. Having an airport identifier is also useful as a reference to help identify the cost estimate. This is particularly useful when cost estimates are generated for several different airports. The airport data section requires the three-letter FAA identifier to be entered, the two-letter state identifier,

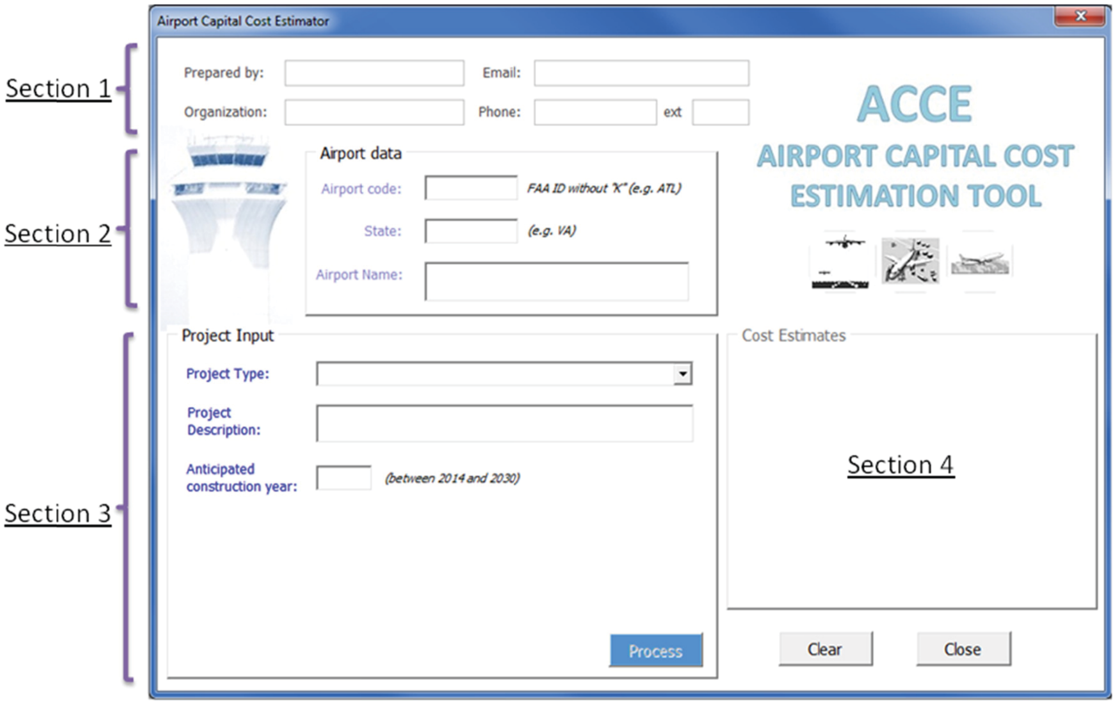


Figure 2. ACCE main user interface.

and the name of the airport. For NPIAS airports, the three-letter FAA code identifier is sufficient, as the remaining information is automatically retrieved and populated by ACCE.

Project Input

The cost model supports a total of six horizontal and two vertical construction projects. Each project type requires a specific set of input variables needed to apply the CER in order to derive a cost estimate. The drop-down menu in the project input window allows the user to specify the project type of interest. Once the project type has been selected, input fields are created for entering values for all the CIVs associated with that project type's CER. Table 11 lists the possible user selections for the project input window, including the project types and the associated independent variables for each.

Output: Cost-Estimating Report

Once the inputs have been finalized, a cost-estimating report can be generated. A sample cost-estimate report is shown in Figure 3. The tool generates cost estimates including low, most likely, and high estimates. The most likely estimate is determined by the CER and the CIV input values provided by the user. The low-high range is developed using the statistical metrics associated with the CER associated with the project type in question. CERs that feature a high quality of fit against the historical data have narrower low-high ranges than those that have a fit of lower quality.

The tool presents cost estimates both in base year (i.e., FY 2014) dollars and in nominal (i.e., then-year) dollars corresponding to anticipated construction year. The nominal dollar cost estimate is prepared using predicted GDP deflators to adjust for changes in prices. The cost-estimating report shows the percentage adjustment used to convert FY 2014 dollars to nominal dollars. For projects with a planned construction year of FY 2014, only the base year cost estimate is shown.

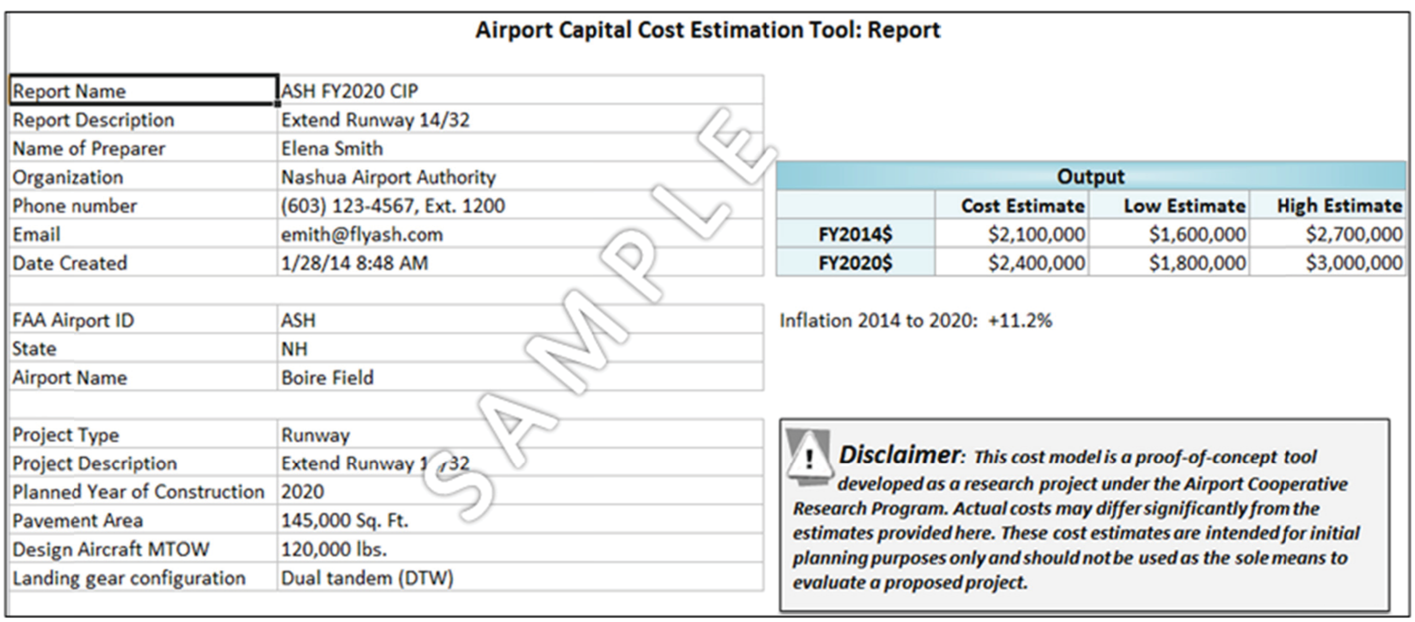
Table 11. Project input selections.

Project Type	Category	Input 1	Input 2	Input 3	Input 4
ARFF Facility	Vertical	Year	Combined floor area (sq. ft.)		
Apron	Horizontal	Year	Pavement area (sq. ft.)	Design aircraft MTOW (lbs.)	
Automated Weather Observing System	Horizontal	Year			
Perimeter Fencing	Horizontal	Year	Length (ft.)		
PAPI	Horizontal	Year	Number of systems/ runway ends		
Runway	Horizontal	Year	Pavement area (sq. ft.)	Design aircraft MTOW (lbs.)	Landing gear configuration
SRE Building	Vertical	Year	Combined floor area (sq. ft.)		
Taxiway	Horizontal	Year	Pavement area (sq. ft.)	Design aircraft MTOW (lbs.)	

Interpreting the Results

The cost-estimating report contains five distinct elements, which should all be taken into consideration when interpreting the results:

1. **Inputs:** This section summarizes the inputs that were used to generate the cost-estimating report. This includes the contact information for the preparer, the airport data, and the project-specific inputs, including the user-entered CIV values. The airport data is used to



Airport Capital Cost Estimation Tool: Report

Report Name	ASH FY2020 CIP
Report Description	Extend Runway 14/32
Name of Preparer	Elena Smith
Organization	Nashua Airport Authority
Phone number	(603) 123-4567, Ext. 1200
Email	emith@flyash.com
Date Created	1/28/14 8:48 AM
FAA Airport ID	ASH
State	NH
Airport Name	Boire Field
Project Type	Runway
Project Description	Extend Runway 1[illegible]32
Planned Year of Construction	2020
Pavement Area	145,000 Sq. Ft.
Design Aircraft MTOW	120,000 lbs.
Landing gear configuration	Dual tandem (DTW)

Output			
	Cost Estimate	Low Estimate	High Estimate
FY2014$	$2,100,000	$1,600,000	$2,700,000
FY2020$	$2,400,000	$1,800,000	$3,000,000

Inflation 2014 to 2020: +11.2%

***Disclaimer**: This cost model is a proof-of-concept tool developed as a research project under the Airport Cooperative Research Program. Actual costs may differ significantly from the estimates provided here. These cost estimates are intended for initial planning purposes only and should not be used as the sole means to evaluate a proposed project.*

SAMPLE

Figure 3. Sample cost-estimating report.

determine the adjustment for regional variation (based on the state the airport is located in). However, the airport location should also be considered when interpreting the resulting cost estimate. In particular, unique characteristics about the airport can affect the validity of the cost estimate. Examples include airports that are located remotely (e.g., island airports) or in environmentally sensitive surroundings (e.g., tidal marshes), which can substantially increase construction costs.

The values entered for the CIVs are critical in understanding the cost estimate, as the project cost is directly linked to these values through the CER. The project description provides context to the project. While this is an optional field that allows for free-form entry, a well-crafted project description can provide important context to allow for a critical and thorough evaluation of the resulting cost estimate.

The CERs were developed through a statistical analysis of a wide range of historical values for the CIVs. It was assumed that cost is a linear, well-behaved function within these ranges of values. While the model allows for user entry of CIV values that fall outside the range used to develop the CER for that project type, the resulting cost estimate will fall outside of the range used to validate the model. In these cases, a warning message is displayed (see Figure 4) and the resulting cost estimate should be viewed as uncertain.

2. **Most likely cost estimate:** The term "most likely cost estimate" (simply labeled "Cost Estimate" in the output table) is intended to emphasize that cost estimating is a stochastic science. In other words, every cost estimate is inherently uncertain and should be viewed as a range consisting of a random distribution of possible estimates. The most likely value in that distribution is generally accepted to be the best cost estimate. However, in interpreting the results, it is important to keep in mind that the most likely cost estimate is just one point in a range of possible values.
3. **Cost estimate range:** A range of cost estimates is formed by specifying the most likely cost estimate, as well as low and high estimates. These three values form a simplified representation of the underlying random distribution that makes up the output of the cost model. The low and high estimates are determined by adding and subtracting a percentage offset to the most likely cost estimate. The percentage value applied to create the range is computed using a rule-of-thumb that draws on the standard error resulting from the linear regression analysis used to develop the CER in question. Since the standard error measures the amount of scatter in the historical data about the best fit, the percentage range will vary by project type. Project types that have a CER where historical cost estimates closely match predicted cost estimates will tend to have a more narrow difference between the low and high estimates. Table 12 shows the resulting percentage values used to establish the low and high estimates.
4. **Inflation-adjusted cost estimate:** The base year for the cost model is FY 2014 and all cost estimates are displayed in FY 2014 dollars. However, for projects with a planned construction start beyond FY 2014, the cost estimate is also shown in inflation-adjusted dollars for the construction year in question. The base year results allow for comparing the costs of different

Project Type	Runway
Project Description	Extend Runway 14/32
Planned Year of Construction	2020
Pavement Area	**120,000 Sq. Ft. *****
Design Aircraft MTOW	120,000 lbs.
Landing gear configuration	Dual tandem (DTW)
***** Warning: This input value falls outside the range of data used to develop the cost model. The resulting cost estimate projects into an area that has not been validated and may be inaccurate.**	

Figure 4. Warning message for CIV values outside range used to develop CER.

Table 12. Values used to establish low and high cost estimates.

Project Type	Low/High Range
Construct or rehabilitate taxiway	±24.9%
Construct or rehabilitate apron	±23.2%
Construct, extend, or rehabilitate runway	±25.9%
Install perimeter fencing	±8.4%
Install PAPI	±18.1%
Install weather reporting equipment	±10.6%
Construct ARFF facility	±5.9%
Construct SRE building	±6.4%

projects regardless of scheduling. The nominal (i.e., then-year) results allow the airport to account for the general increase in price levels over time. Such increases can be significant: For example, price levels 10 years beyond the FY 2014 base year are projected to increase by nearly 20%.

5. **Disclaimer:** Each cost-estimating report generated by ACCE is accompanied by a disclaimer (Figure 5). The purpose of the disclaimer is to remind the user that the ACCE model was developed as a proof-of-concept tool, using a cost database limited in scope and through an applied research project within the ACRP. The cost estimates developed through ACCE are inherently uncertain, both because of the statistical method used, which is based on a sample of historical cost data with random variation, and because of limitations in both the data and the methodology. Prior to using cost estimates developed in ACCE for airport planning and development purposes, it is important that the user fully understands the limitations of the results.

To allow for a proper interpretation of the results and to understand the underlying limitations, a set of checklists follow—one each for the horizontal and vertical construction domain, respectively. The purpose of these checklists is to help identify factors that could cause the cost estimate to be either unusually high or low. They provide a mechanism for evaluating the uncertainty of the cost estimate through a self-assessment process to be conducted by the user after preparing a cost-estimating report using ACCE. If the responses to the checklists indicate the presence of several risk factors, the user should lean toward the high range of the cost estimate and/or seek an alternative estimate.

Checklist for Horizontal Projects

Existing Conditions

- Will the project be planned on a site that has evidence of previous environmental hazards such as contaminated soil, asbestos, lead paint, or the presence of threatened or endangered species, historic structures, or other unforeseen existing conditions? This may require special

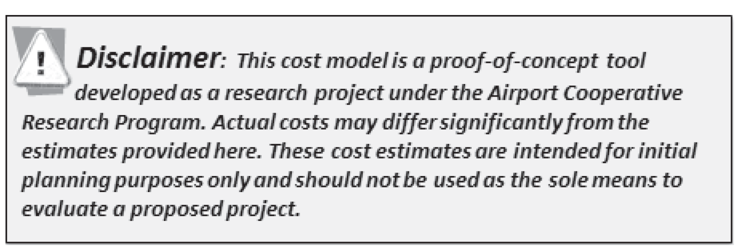


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Figure 5. Cost model disclaimer.

environmental studies, stakeholder negotiations, and mitigation initiatives, resulting in additional on- or off-site improvements or in-lieu fee transfer of funds. If so, an allowance for the related costs must be added to the estimate provided by ACCE.

- If this is a large pavement project, is the airport located far from the nearest asphalt or concrete supply plant? If so, the higher range of the estimate generated by ACCE is likely more reflective of the final cost.
- Is this project located on an island? If so, the higher range of the estimate generated by ACCE is likely more reflective of the final cost.
- Will the FAA require more than 60% protection from frost for the pavement design? Generally, 60% is the standard for cold-weather regions; however, in extremely cold climates, an increase in this value to 80% is sometimes required. If so, the higher range of the estimate generated by ACCE is likely more reflective of the final cost.
- Is the project located in a hot-weather region where grass is difficult to grow and maintain year round? This may require alternative site stabilization in areas between runways and taxiways, such as local stone products or hardscaping. The stone must be properly sized to prevent foreign object damage hazards, which increases cost. If so, the higher range of the estimate generated by ACCE is likely more reflective of the final cost.
- Is this project located in an urban community? Projects that have sensitive socio-economic factors can add time to construction due to public outreach requirements, restricted work hour requirements, and restricted work area requirements. If so, the higher range of the estimate generated by the ACCE is likely more reflective of the final cost.
- Will there be other construction projects ongoing near the project at the same time? This may result in more favorable bids and unit prices due to economies of scale. If so, the lower range of the estimate generated by ACCE may be more reflective of the final cost.

Project Scope

- Will the project be a combination of two or more separate project types? If so economies of scale may exist. If combining estimates generated by ACCE for projects occurring simultaneously, the lower range of the estimate is likely more reflective of the final costs.
- Will the project include non-standard materials such as warm-mix asphalt, underground stormwater treatment systems, or artificial turf? If so, the higher range of the estimate generated by ACCE is likely more reflective of the final cost.
- Will the project require newer, environmentally friendly technologies such as light-emitting diode lighting, solar-powered lighting, pervious pavement, or low volatile organic compound paint? If so, the higher range of the estimate generated by ACCE is likely more reflective of the final cost.
- Will the project provide improvements to technology infrastructure that is ancillary to the core project scope, such as airfield lighting touchscreen control panels, new access control hardware or software, new utility metering, stormwater collection, or outlet improvements? If so, the higher range of the estimate generated by ACCE is likely more reflective of the final cost.
- Will the project include many different trades of work? For example, if a project includes site work, paving, metal work, concrete work, electrical work, security work, and carpentry work, there is an increased chance that there will be multiple subcontractors reporting to one prime contractor. This has the potential to increase cost due to increased management oversight, as well as multiple levels of overhead and profit. If so, the higher range of the estimate generated by ACCE is likely more reflective of the final cost. Conversely, if a project scope is limited to a runway mill and overlay with minor supporting site work, the lower range of the estimate generated by ACCE is likely more reflective of the final cost.
- Will the FAA and the relevant state aviation/transportation agency support the use of polyvinyl chloride (PVC) conduit for all runway and taxiway electrical conductor circuits? In some regions, this is justified in order to protect wiring from damage by fire ants, reduce maintenance costs, or improve safety. The use of PVC conduit can add a significant amount of cost

to runway and taxiway projects. If so, an allowance for the related costs must be added to the estimate provided by ACCE.

Specific Project Conditions

- Will the project start in the fall within a cold-weather region? If a project starts late within a cold-weather region, there is potential the project mobilization cost will increase due to multiple start and stops. It is typical that an airfield pavement project will be temporarily shut down in November and restarted in May to avoid final paving, topsoil, and seeding activities in cold conditions. If so, the higher range of the estimate generated by ACCE is likely more reflective of the final cost.
- Is the project being constructed at a very busy airport? Cost of construction increases for an airport with high numbers of operations, especially when commercial operations dominate. High levels of activity can require construction phasing plans, which add time and cost to construction. If so, the higher range of the estimate generated by ACCE is likely more reflective of the final cost.
- Is there a risk associated with weather delays and damage due to severe weather events such as tropical storms, hurricanes, floods, or tornados? While difficult to predict, if a project is located in an area known to be subject to these weather hazards, the higher range of the estimate generated by ACCE is likely more reflective of the final cost.
- For pavement projects, will the project include a simple mill and overlay of existing pavement versus a full-depth reconstruction? If so, the lower range of the estimate generated by the ACCE is likely more reflective of the final cost.
- For pavement projects, will the project include replacement of an existing airfield lighting system such as taxiway or runway lights? If so, the higher range of the estimate generated by ACCE is likely more reflective of the final cost.
- For perimeter fence projects, will the fence serve as both a security fence and a wildlife deterrent fence? The FAA and U.S. Department of Agriculture have recently increased design requirements for wildlife deterrent fencing. Also, wildlife deterrent fencing is more likely to be located in wetlands or other environmentally sensitive areas. If so, the higher range of the estimate generated by ACCE is likely more reflective of the final cost.

Project Jurisdiction

- Will this project involve frequent coordination with the TSA or U.S. Immigration and Customs Enforcement? If so, the price of construction may result in significant increased costs due to added facility requirements and the application of non-standard facility layout requirements. Facility foundation plans and other supporting utility items can be affected by changes in wall locations, elevator shaft locations, and baggage handling support columns. If so, an allowance for the related costs must be added to the estimate provided by ACCE.
- Will the project have sources of funding from multiple agencies such as the FAA, Economic Development Administration, TSA, or state agencies? This may create additional delineations of work and/or present a construction phasing burden to the sponsor, contractor, and inspecting team. If so, the higher range of the estimate generated by ACCE is likely more reflective of the final cost.
- Are there deed restrictions or existing protective land overlays on the proposed project site? For example, is there a regional or district water protection overlay within an area where stormwater improvements are proposed? This may create added requirements and/or administrative and legal costs related to mitigation initiatives. If so, an allowance for the related costs must be added to the estimate provided by ACCE.
- Will any agency or municipality require special construction considerations such as energy-efficient vehicle fleets or idling restrictions for construction equipment? This will add cost to the project related to alternative fuel equipment or work site restriction. If so, the higher range of the estimate generated by ACCE is likely more reflective of the final cost.

Checklist for Vertical Projects

Existing Conditions

- Is the proposed site for the new building cleared of obstructions and level? If not, an allowance for this work must be added to the ACCE estimated value.
- Does an existing structure need to be demolished to make way for the new building? If so, an allowance for this work must be added to the ACCE estimated value.
- Do existing underground utility lines—including steam tunnels, NAVAIDs, power, water, sewer, fuel, communications, and security—require relocation to make way for the new building? If so, an allowance for this work must be added to the ACCE estimated value.
- Where existing structures and/or utilities are required to be removed, has a hazardous materials assessment survey (asbestos, PCB, lead paint, etc.) been performed? If not, it is recommended that this be performed prior to finalizing a cost estimate for the project, as hazardous materials remediation can represent a significant additional cost as well as a potential delay to the project schedule. Such impacts may be significant enough to reconsider the location of the new building.
- Have geotechnical borings and soils analysis been performed and analyzed? If not, it is recommended that this be performed prior to finalizing a cost estimate for the project, as unsuitable (organic) soils, contaminated soils, and rock/ledge would need to be removed and replaced with structural fill, resulting in a significant additional cost as well as a potential delay to the project schedule. Such impacts may be significant enough to reconsider the location of the new building.
- Has a comprehensive site survey been performed? If not, it is recommended that this be performed prior to finalizing a cost estimate for the project, as potential cost/schedule impacts related to underground utilities/structures and property boundaries can be revealed and estimated.
- Is the project site in an area where archaeological resources may be present? If so, it is recommended that the local and/or state historic commission be consulted regarding their potential requirements for study prior to proceeding with construction, as this could impact the project schedule.

Project Scope

- Is the proposed project a renovation? If so, has an existing conditions assessment been performed in relation to code deficiencies which may be required to be addressed as part of a renovation? If not, it is recommended that this be performed prior to finalizing a cost estimate for the project. Examples include structural, energy efficiency, and accessibility (ADA) upgrades which may be triggered by the local building code and increase the intended scope of the renovation. Such impacts may be significant enough to consider demolition and new construction rather than renovation.
- Is the proposed project an addition to an existing building? If so, has an existing conditions assessment been performed in relation to code deficiencies in the existing building which may be required to be addressed as part of an addition? If not, it is recommended that this be performed prior to finalizing a cost estimate for the project. A significant size addition may require code-related upgrades to the existing building even if such upgrades are not desired by the owner. Such impacts may be significant enough to consider construction of a separate new building rather than an addition.
- Does the existing and/or new building contain tenant spaces? If so, a number of considerations come into effect:
  - If the tenant will be displaced, temporary facilities to allow the tenant uninterrupted operations may be required.
  - If the tenant lease includes a clause which limits disruption from noise or vibration, certain construction activities may need to be limited to occur after hours.

  - If the tenant requires special infrastructure (i.e., power, grease trap, ventilation, etc.), facilities (i.e., hazmat storage), or fit-out of furnishings and equipment (i.e., cooking/kitchen equipment), it is recommended the costs associated with these items be negotiated between tenant and airport prior to finalizing a cost estimate for the project.
- Are the required utility connections (power, water, gas, sewer, and telecommunications) available directly at the proposed building location? If not, extension of the primary utility lines to the building location may be required as part of the project, and consultation with the utility companies to establish additional costs is recommended prior to finalizing a cost estimate for the project.
- Are there any separate but related "enabling" projects that must occur for this project to proceed? If so, the capital plan should clarify if these enabling project costs are to be included in the cost of this project, or are to be addressed separately. Examples include relocation of a security fence, construction of new space for current occupants of a building scheduled to be demolished, construction of a new access road, etc.
- Does the new facility require purchase of any special equipment, technology, or infrastructure which is beyond that typically provided as part of this type of facility? If so, the higher range of the estimate generated by ACCE is likely more reflective of these special equipment costs.
- Will the project include all new furniture, computers, communications equipment, appliances, and the like? If so, the higher range of the estimate generated by ACCE is likely more reflective of these added costs.
- Will the airport need to engage the services of a professional moving company to relocate their furniture, materials, and operational items from an existing facility into the new facility? Will any of these items need to be placed in off-site storage during construction? If so, the higher range of the estimate generated by ACCE is likely more reflective of these moving and storage costs.

Specific Project Conditions

- Is the airport located in a remote area where construction labor and materials are in limited supply, or where physical access to the airport is challenging (i.e., an island location). If so, the higher range of the estimate generated by ACCE is likely more reflective of these remoteness costs. In this instance the airport may consider setting the project schedule so that the majority of work occurs during periods of the year where access to the airport is least challenging and therefore least expensive.
- If the airport is located in a cold-weather climate, will major portions of the exterior construction be performed during winter months? If so, the higher range of the estimate generated by ACCE is likely more reflective of these winter-conditions costs. In this instance the airport may consider modifying the project schedule to avoid exterior construction work during cold-weather months.
- Will temporary facilities be needed for operational staff during construction? In cases of a major renovation, or where the demolition of an existing building is required to occur prior to the new building being ready for operations, some form of temporary facility is needed to maintain operations until the new building is complete. If so, an allowance for this work must be added to the ACCE estimated value.
- Will the project be phased in order to accommodate both construction and ongoing airport operations within the same general area? Limiting the physical areas where construction work may proceed to various time periods is very common with airport projects, but does involve cost premiums. If so, the higher range of the estimate generated by ACCE is likely more reflective of these winter-conditions costs.
- Does a critical completion date exist for the project? Furthermore, must the project be completed within an accelerated time frame? If so, the higher range of the estimate generated by ACCE is likely more reflective of this accelerated schedule.

- Does the project involve airside construction? If so, the higher range of the estimate generated by ACCE is likely more reflective of these security/operational costs, as airside projects require more extensive security and operational restrictions. In this instance the airport may consider relocating the SIDA barrier temporarily to allow for the project site to be designated as occurring landside throughout construction.

Project Jurisdiction

- Are any federal or state environmental permits required? It is recommended that this be determined prior to finalizing a cost estimate for the project, as both state and federal environmental permit processes can last a year or longer and incur significant consultant fees.
- Are any special local variances, hearings, or approvals required? Local approvals which can sometimes impact a project cost and/or schedule include the following:
  - Local design review board: Many communities have regulatory design standards (sometimes related to historic districts), which are often more appropriate to residential and/or small commercial developments than to functional and secure airport facilities.
  - Conservation commission: Stormwater drainage, rare species habitats, and wetlands habitat are common considerations.
  - Zoning board: Airport buildings are often larger than typical buildings in small communities, and thus require zoning exemptions and/or special permits.
- Will any special mitigation measures be required by local authorities in order to obtain approval for the project? It is recommended that this be determined prior to finalizing a cost estimate for the project, as certain mitigation measures can significantly impact both cost and schedule. Examples include creation of a replacement habitat elsewhere on airport property, noise/visual barriers between the project location and abutters, and purchase of adjacent properties.

There are of course numerous other considerations which could affect project cost and schedule and which are unique to each airport. The preceding checklists are intended to assist the airport in anticipating and planning for potential issues in advance, thus assisting in a more predictable process of design and construction which would more closely align with the estimates developed by ACCE.

CHAPTER 6

Lessons Learned

An accurate cost estimate is recognized by practically all stakeholders as being a significant contributor to successful airport capital improvement planning. Access to reliable cost estimates helps ensure optimal use of limited airport investment funds and reduces the risk of project cancellations or cutbacks. At the same time, there are a number of recognized risks that affect the quality of any cost estimate, no matter how sound the underlying methodology is. These include scope changes, volatility in material costs, uncertainty in mobilization costs, environmental issues, community concerns, the inherent complexity of airport systems, contractor management issues, and poor implementation of best practices.

The literature review and stakeholder survey conducted for this study describe the current practices for estimating costs for airport construction projects in both the horizontal and vertical domains. In general, existing practices utilize well-established and proven methodologies. The methodologies draw on procedures and guidance published by a number of entities that provide relevant resources, particularly professional organizations and state agencies. Cost estimating for vertical projects has an added layer of structure through the use of standard classification schemes.

The two primary methods used for estimating airport project costs are estimation through historical bid prices and cost-based estimating. All existing methods are limited in their ability to accurately account for unique project conditions. Such uncertainties can significantly affect the estimate and can result in wide variations between initial cost assumptions and the actual costs incurred on a particular project. To account for such risks, contingency analyses are often applied, but usually in a simplified manner. A typical method is the inclusion of a percentage multiplier to line item quantities and/or an overall contingency factor that is applied to the final cost estimate. There are few, if any, standards for applying such contingency factors. The stakeholder outreach effort conducted for this project indicates that the numerical values used can vary greatly. Since overall contingency factors can be applied on top of contingencies for line item quantities, the cumulative contingency can be substantial. The lack of established standards in this area results in potentially large variations.

Use of computer models for cost estimating is not currently a common practice for airport construction. It is less clear whether this is due to lack of availability of suitable models or whether the challenges in airport construction cost estimating are not easily solved through computer modeling techniques. It does, however, indicate the potential for the development of an airport-specific model, provided the challenges identified previously are carefully considered and the appropriate solutions are identified. Lessons learned through the course of this study, potential solutions to some of the challenges, and recommendations for future work are discussed in the following sections.

Challenges to Developing an Airport Cost-Estimating Model

The literature review and industry stakeholder survey conducted as part of this study addressed existing sources of cost data. The practice of storing past bid tabulations is common and a number of agencies maintain their own cost data. Nonetheless, for the purpose of developing a comprehensive cost model, several significant challenges related to data availability exist:

- Many of the most commonly used data sources are proprietary and cannot readily be distributed as part of a publicly accessible model intended for delivery through the ACRP.
- Data maintained by public agencies are distributed across a range of state and regional agencies and stored in inconsistent formats.
- There is no standard format for data and in many cases the data is stored in formats that are notionally electronic but essentially represent digital versions of printed documents (e.g., the PDF format). This precludes automated transfer of historical cost data into a comprehensive cost database.
- Even when cost data is available, data for the key cost drivers represented by the CIVs is often not. For example, for a pavement project, the amount of asphalt or concrete required is usually included, but quantified as volumes. Key cost drivers such as the pavement surface area, design aircraft MTOW, landing gear configuration, and design freezing index are usually not included.
- Historical grant information often contains several projects that have been bundled together in such a way that prevents costs and CIV data to be separately identified and assigned to specific project types.

The main challenge in developing an effective cost model for airport projects using parametric cost-estimating methodology is in fact the availability of a sufficiently large and rich set of historical data. Assembling a cost database that is sufficiently rich in both quantity and variation across geographic locations and project types would address a number of the challenges identified previously. The potential benefits of expanding the cost database are many and include the following:

- Each project type is represented by a unique CER, requiring its own data set. Expanding the data collection would enable cost modeling support for additional project types.
- CERs incorporate independent variables that represent cost drivers and that have a causal relationship with cost. Lack of data limits the number of cost drivers that can be included, reducing the explanatory power of the CER. Variables that are not included but that affect cost result in unexplained variation and less accurate models. Expanding the number of historical observations would allow the inclusion of additional CIVs in the CER, thereby improving the model's ability to predict cost.
- Linear regression is based on statistical samples, which inherently have some random variation. This random variation introduces errors in the resulting cost model. Increasing the number of observations reduces the errors due to random variation in the sampling process.
- Similarly, in the case of a small sample, it is more likely that the results are biased because of lack of variation. For example, if the database is small and contains a disproportionate number of observations from a particular geographic region or type of airport, the likelihood is greater that the model will be biased due to lack of variation in the data. The database should be sufficiently large to ensure variation across geographic locations, urban versus rural communities, and types of airports.
- The larger the database, the less likely it is that user-entered inputs will fall outside the range of the historical observations used to develop the CER in question. As described in Chapter 5, when the CIV input values fall outside the range of historical CIV values used in the cost modeling, the cost estimate is generally more uncertain.

Future Work

As described previously, future work on the development of a cost model for capital planning purposes should first and foremost focus on expanding the database. This section includes specific recommendations for future data collection practices. These are based on lessons learned during the implementation of the ACCE cost model, as well as recommendations by the research team's airport construction SMEs.

Initiating an effort to expand the data collection requires addressing a number of challenges. These include establishing a framework for collecting the data, establishing support from the airport community, obtaining necessary resources, and creating standards for collection of historical cost and project data. While identifying solutions to some of these challenges is beyond the scope of this study, the key issues that need to be addressed include the following:

- **Organization:** For an expanded data collection effort to be implemented, ideally a framework should be established that can engage a large number of airport participants across the United States. This is necessary to ensure that the resulting database has sufficient number of observations, which is currently the biggest limitation in implementing the parametric cost-estimating method. It would also provide sufficient regional variation, preventing biases due to smaller and more narrowly focused samples. While there are a number of potential options to establish an organization framework, it is not possible to predict the exact makeup. Key stakeholders would likely include trade and industry organizations, state aviation agencies and their umbrella groups, and the Airports organization of the FAA.
- **Resources:** The resources required for this effort would depend on the framework and implementation of an expanded data collection program. The effort would require development of standards, a mechanism to collect data, and management and development of the database. A potential option for an initial effort would be a voluntary pilot project. However, a full implementation of an expanded data collection effort may require identifying a source of project funding.
- **Data collection:** Prior to initiating an expanded data collection effort, standards must be established for the type of data to be collected, including definitions for each field in the database. This is required in order to ensure that the right type of data is collected and that data from different airports, projects, and regions shares consistent definitions. One of the lessons learned in this project is that it can be very difficult and resource intensive to retroactively fill gaps in the database. For this reason, it is important to invest sufficient resources upfront, to ensure that effective and comprehensive data standards are established. These standards should balance the need for a rich data set to support the cost model development with ease of data collection. If the data requirements are too onerous, the data collection will suffer from an insufficient number of submitted projects. It is important to keep in mind that the parametric cost-estimating technique requires that each record is complete. In other words, records that are missing value for one or more data fields cannot be included in the statistical analysis used to develop the CERs.

The following section includes additional detail on recommended practices for establishing the data collection framework. These recommendations are based on lessons learned during the conduct of this research project, best practices identified in the literature review and stakeholder outreach effort, and SME input.

Recommendations for Data Collection Practices

The most important step in ensuring a successful data collection effort is the establishment of data standards. These standards should include the following:

- Specifications for general data to be collected for all projects.
- Specifications for project-specific data (i.e., data that varies by project type).

These specifications should both identify the data fields to be collected for each project, as well as provide definitions that clearly identify the intent and meaning of each field. These definitions should be sufficiently detailed so as to ensure that data are collected consistently. As an example, consider the CIV "area" for vertical projects. The definition should specify that the combined floor area across all stories should be included. The definition should also determine whether the floor space should be measured to the exterior and interior walls and address the handling of unusable space. Finally, for each data field, the units of measurements should be specified (where applicable).

General Data

The requirements for collecting general data are likely to be very similar to the data collected during the course of this project. However, some added specificity and improvements are possible. Likely data fields include the following:

- **Record identifier:** Each record in the database should be assigned a unique identifier that can be used for indexing and cross-referencing purposes.
- **Airport identifier:** A unique airport identifier is required in order to establish the location of the project. This is necessary to adjust for regional variation and can also be used to test that the database is not biased toward a specific geographic area. It also allows for follow-up queries, for example, if the data collected for the airport contains inconsistencies or missing fields. The data requirements should specify whether the FAA or International Civil Aviation Organization identifier should be used. If the identifier is linked to an airport database, no additional geographic information needs to be collected. If this is not the case, or the airport is not in the database being used, it is recommended that one or more of the following geographic identifiers be collected: zip code, county, and/or state.
- **Project type:** The project type allows the data to be mapped to a specific CER. While this requires that the project types be static (i.e., they must be established in advance), the research conducted during this project suggests that a relatively small number of project types account for the majority of construction projects. In this study, the number of supported project types was limited to eight. However, this was primarily the result of limited data availability. In an expanded data collection effort, it is recommended that a broader range of project types be supported. The projects originally identified as candidates for inclusion can serve as the starting point for identifying the project types to be supported in a future effort:
  - Airfield signage
  - Construct ARFF facility
  - Construct or rehabilitate taxiway
  - Construct parking garage
  - Construct parking lot
  - Construct SRE building
  - Construct, expand, or rehabilitate apron
  - Construct, expand, or rehabilitate terminal building
  - Construct, extend, or rehabilitate runway
  - Improve runway safety area
  - Install airport visual aid
  - Install NAVAIDs
  - Install perimeter fencing
  - Install weather reporting equipment
  - Rehabilitate runway lighting
  - Remove obstructions
  - Runway pavement marking
  - Security access systems

- **Project description:** The project description is useful for identifying project type and, especially, for determining whether the project includes bundled construction types. It appears most practical to leave the project description as a free text field. However, guidelines should be established for the level of specificity desired in the description. For example, for pavement projects, it should be clear whether the project consists of constructing a new pavement area, expanding an existing pavement area, or rehabilitating old pavement. The type of pavement used (i.e., asphalt, PCC, or a hybrid) should be specified. The description should specify whether the project includes design only, construction only, or both. A table of relevant keywords may serve as a useful guide to craft clear and comprehensive project descriptions.
- **Year:** The year of construction is required for normalizing construction costs to take inflation into account. This is a relatively straightforward input, but the guidance should specify whether calendar or fiscal year should be used, and how to treat projects that span multiple years. Also, some thought should be given as to which is most relevant to the cost modeling—the year(s) of construction activity or the budget year(s) associated with the grant funds expended on the project.
- **Total project cost:** Project cost is the sole dependent variable in the parametric cost methodology presented here and is the most critical variable in the model. For this reason, particular care should be taken in both defining the meaning of total project cost and in ensuring that the data is collected according to the resulting definition.

  In the database created for this project, cost was unavailable for some data records and had to be estimated based on the federal share for AIP-funded projects. While the federal share is theoretically established by formula allocation, in practice, the share can vary from project to project due to items ineligible for federal funding. For this reason, estimating the total project cost based on the federal share is not ideal and is likely to introduce inaccuracies in the cost database.

  The guidance for collecting historical project cost data should clearly specify that total costs should be considered. This total includes the federal share, the state share, and the sponsor's share. Moreover, guidance should specify which stage in the project the historical cost should be based on. Options range from the cost provided during the bidding phase to that provided on the project close-out report. In general, the latest available cost data is preferred.

  Another important aspect of providing specifications for the collection of historical costs is the treatment of soft costs. Soft costs typically range from 10% to 30% of total project costs. These include design fees, permitting fees, utilities, costs associated with inspections and land acquisition, costs associated with the bidding and procurement process, and project administration and management costs. The guidance should clearly specify which costs should be included, so that the historical cost data follows a consistent pattern that allows for pooling historical observations across many projects and airports.

Project-Specific Data

The project-specific data is the set of historical values for the CIVs that are part of the hypothesized CER for the project type under consideration. Since one of the major goals of any expanded data collection effort is to improve the performance and robustness of the cost model, the number of CIVs should be expanded significantly from the final list selected for the development of ACCE. The goal should be to identify and include all major variables that are measurable and that have the potential to affect the cost of a project significantly. At the same time, since the number of data points required increases with the number of CIVs included, the guidelines should not call for the inclusion of CIVs that only have a minor impact on cost. If the number of CIVs is excessive, the labor effort required to collect historical project data could also increase to the point that the number of records collected is substantially reduced. It is important to keep in mind that in order for a past project to be included in the model, all fields must be complete, which means a value must be collected for each CIV included in the CER.

Table 13. Potential cost drivers for horizontal airport construction project.

Project Category	CIV 1	CIV 2	CIV 3	CIV 4	CIV 5
Airfield signage	No. of intersections	Airplane design group	Control tower		
Construct or rehabilitate taxiway	Area	MTOW	Landing gear configuration	Pavement type	Design freezing index value
Construct parking lot	No. of spaces	Drainage type			
Construct, expand, or rehabilitate apron	Area	MTOW	Landing gear configuration	Pavement type	Design freezing index value
Construct, extend, or rehabilitate runway	Area	MTOW	Landing gear configuration	Pavement type	Design freezing index value
Install airport visual aid	Type of system	No. of systems/ runway ends			
Install NAVAIDs	Type of NAVAID				
Install perimeter fencing	Length	No. of automatic gates	No. of manual gates	No. of pedestrian gates	
Install or rehabilitate runway lighting	Length	Runway approach type			
Install weather reporting equipment	Type of equipment				
Rehabilitate runway lighting	Length	Runway approach type			
Remove on-airport obstructions (vegetation)	Acres				
Runway pavement marking	Length	Runway approach type			
Security access systems	No. of pedestrian gates	No. of vehicle gates			

In identifying which CIVs to include, the CERs hypothesized at the beginning of this project will serve as a useful starting point. This is because the original CERs included many more CIVs than contained in the final database, since the number of CIVs was reduced substantially to deal with the lack of available data. An expanded data collection effort should allow for a number of the rejected CIVs to be included in the model as originally intended. Table 13 displays a list of proposed CIVs for potential horizontal projects and Table 14 displays a similar list for vertical projects. These lists employ up to six CIVs per project type (compared to three for the cost model implemented in ACCE).

Table 14. Potential cost drivers for vertical airport construction projects.

Project Category	CIV 1	CIV 2	CIV 3	CIV 4	CIV 5	CIV 6
Construct ARFF facility	Area	No. of stories	No. of bays	Construction type	Building skin type	Site conditions
Construct, expand, or rehabilitate terminal building	Area	No. of stories	No. of spaces	Structural system	Architectural treatment	Lobby area
Construct parking garage	Area	No. of stories	Construction type	Building skin type	Site conditions	
Construct SRE building	Area	Annual enplanements	No. of stories	Building skin type	Site conditions	

Conclusions

The goal of this project was to develop a model and database for estimating the cost of airport construction projects during the capital planning phase. The recommend approach—parametric cost estimating—uses historical cost data to establish mathematical relationships between construction cost and the hypothesized cost drivers for the project type in question.

The study resulted in the creation of a database that includes data on construction cost and cost drivers for eight different types of airport construction projects. The database was used to develop a statistical cost model using the parametric cost-estimating approach. Both the database and the model were implemented in Microsoft Excel. A user interface allows the user to enter airport and project-specific information and generate a cost estimate report that can then be saved, printed, or exported. The model also provides a simple what-if analysis capability that allows the user to modify the assumptions. The resulting cost estimates are adjusted for inflation and geographical variations in construction cost. The cost estimate is presented as a range of estimates, with best, low, and high values. This allows the user to take into account uncertainties and unique factors that affect cost.

The cost model was evaluated using statistical measures of quality of fit and subjective evaluations by the research team's SMEs. The model was also validated using a case study approach. The model passes the statistical tests of significance and quality of fit and, in general, generates cost estimates that match the experience of the SMEs. The research team concludes that the parametric cost-estimating methodology is a suitable approach for cost estimating for airport construction projects. This is especially true in the capital planning phase, where cost estimates need to balance accuracy with the effort required to develop the estimates. At the same time, the validation effort showed that the performance of the model is highly variable. Depending on the project type and specific circumstances, actual costs may vary significantly from those predicted by the model. This is true even when considering the range of low and high estimates provided by the model to take uncertainty into account. For this reason, the model should be treated as a proof-of-concept tool. Estimates prepared with the current model should only be used for initial planning purposes and should not be the sole means for evaluating the cost of a proposed project.

The lack of robustness and variations in performance in the model are primarily caused by the limited availability of historical cost data. Collecting data in a format that supports inclusion in a cost database was the greatest challenge identified by the research team. Data is often stored in a manner that prevents the data from being imported electronically. Also, in many cases the total project cost is available but not the values of the cost drivers that are required to perform the cost estimate. Finally, bundling of multiple projects frequently prevents historical project data from being used in the model.

Because the model suffers from a lack of robustness, the guidebook contains specific and in-depth recommendations on how to interpret the results and identify specific risks. Checklists are included for evaluating the results in order to assess the uncertainty of the cost estimate report. If the checklists identify risks that could drive the cost up or down, the airport should consider using the high or low range of the estimate. If the risk assessment reveals an unusually high level of uncertainty, an alternative cost estimate should be considered.

The guidebook includes a series of recommended best practices for any future data collection intended to update and expand the model. Increasing the number of observations and incorporating additional cost drivers are likely to substantially improve model performance. For this reason, the guidance on expanded data collection is the focus of the discussion on recommended future research.

Any expanded data collection would require a framework for collecting the data in a centralized manner. Standards need to be established to ensure data consistency and that the format supports transfer into a spreadsheet or database. Consideration should also be given to collecting site plans. These drawings provide important information on project dimensions, such as the size of pavement surface areas. Analyzing such information would require analysis by an architect or engineer to interpret the drawings, however.

A key finding of the data collection effort is that there is no single entity that can provide the data required to expand and improve the model. Consequently, the research team suggests that a cooperative approach to data collection be considered that involves state aviation agencies, transportation departments, industry organizations, and the FAA Airports organization, especially at the regional level. The research team believes that a broad-based, collaborative approach to the collection of airport project and cost data has the greatest potential for achieving the best outcome. The resulting improvements could provide substantial benefits to the airport community by enabling standardized and more accurate cost estimates to be available in the capital planning phase.

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APPENDIX A

Cost-Estimating Relationships

Table A.1 shows the coefficients that define the cost-estimating relationships (CERs) in the final cost model. The CERs used here take the general linear form:

$$C = \beta_0 + \beta_1 \mathrm{CIV}_1 + \beta_2 \mathrm{CIV}_2$$

where C is the total construction cost (normalized to FY 2014 Kansas dollars), β_0 is the intercept, β_1 is the coefficient multiplying the value of the first candidate independent variable (CIV_1), and β_2 is the coefficient multiplying the value of the second candidate independent variable (CIV_2). Note that in the final version of the cost model, for all but one CER, the intercept is zero. Also, only the pavement-related CERs have two independent variables (i.e., the runway, apron, and taxiway project types). "Adjusted" maximum takeoff weight (MTOW) indicates that the MTOW has been converted to a single-wheel-equivalent MTOW, as described in Chapter 4.

Table A.2 displays measures of statistical fit for each CER in the final cost model. The measures shown are adjusted R^2 and the P-values associated with the t-statistics for the coefficients for the independent variables. As described in Chapter 3, adjusted R^2 value is a measure of the overall correlation between construction cost and the cost drivers (i.e., CIVs) selected for inclusion in the CERs. Values close to one indicate a good statistical fit. Unlike adjusted R^2, P-values are computed separately for each coefficient (i.e., β_1 and β_2). They represent measures of the statistical significance of the corresponding independent variable as a predictor of cost. Low P-values (i.e., close to zero) indicate high levels of statistical significance.

The P-value for a statistical test associated with the F-statistic is also shown. This test indicates whether a significant linear relationship exists between cost and the CIVs (as opposed to a constant value). For this project, a statistical significance of 95% was adopted as the standard, which corresponds to a target P-value of 5% or less.

Note that the CERs for installing PAPIs and weather reporting equipment consist of a simple arithmetic mean of the historical cost of each installation in the database. For this reason, statistical measures of quality of fit are not available. Since the construction of PAPIs can involve installations at multiple runway ends, the CER consists of the mean cost per system multiplied by the number of systems to be installed.

The remaining sections of this appendix contain graphs that plot the predicted cost for each data point, as estimated using the CER derived for the project type in question, against the observed actual cost. Note that both predicted and actual cost values have been normalized to thousands of FY 2014 Kansas state dollars. For a CER that predicts costs perfectly, the plot of predicted versus actual costs would fall on a line through the origin with slope one. This line is

Table A.1. Final cost-estimating relationships.

Project Type	Intercept (FY 2014 KS $)	Coefficient 1		Coefficient 2	
Horizontal Projects					
Construct or rehabilitate taxiway		11.9	Pavement area (sq. ft.)	6.1	MTOW (lbs.)
Construct, expand, or rehabilitate apron		1.2	Pavement area (sq. ft.)	12.2	MTOW (lbs.)
Construct, extend, or rehabilitate runway		2.9	Pavement area (sq. ft.)	35.4	Adj. MTOW (lbs.)
Install perimeter fencing		32.2	Fencing (linear ft.)		
Install PAPI		83.1	No. of systems		
Install weather reporting equipment	171,700				
Vertical Projects					
Construct ARFF facility		374.5	Floor area (sq. ft.)		
Construct SRE building	111,500	116.5	Floor area (sq. ft.)		

Table A.2. Statistical tests.

Project Type	Adj. R2	P-value β_1	P-value β_2	P-value F-statistic
Horizontal Projects				
Construct or rehabilitate taxiway	82.5%	0.0%	0.4%	0.0%
Construct, expand, or rehabilitate apron	87.4%	1.6%	0.0%	0.0%
Construct, extend, or rehabilitate runway	83.7%	0.1%	0.1%	0.0%
Install perimeter fencing	83.5%	0.0%		0.0%
Install PAPI	N/A	N/A	N/A	N/A
Install weather reporting equipment	N/A	N/A	N/A	N/A
Vertical Projects				
Construct ARFF facility	88.2%	0.0%		0.0%
Construct SRE building	88.3%	0.0%		0.0%

shown as a reference: The amount of scatter about the reference line serves as a visual indicator of the predictive ability of each CER. One graph is shown for each project type in the final cost model (except for "install PAPI" and "install weather reporting equipment," which use simplified CERs, as described previously).

Horizontal Projects

Figures A.1 through A.4 plot the predicted cost for each data point against the observed actual cost for four of the horizontal project types in the final cost model.

Vertical Projects

Figures A.5 and A.6 plot the predicted cost for each data point against the observed actual cost for the vertical project types in the final cost model.

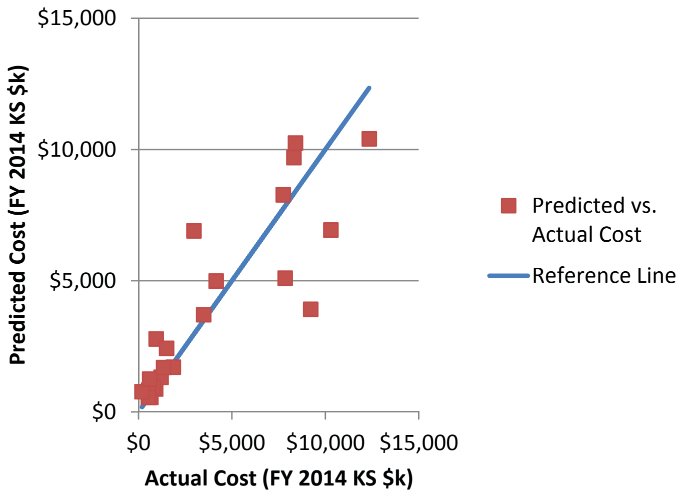


Figure A.1. Predicted vs. actual cost—construct or rehabilitate taxiway.

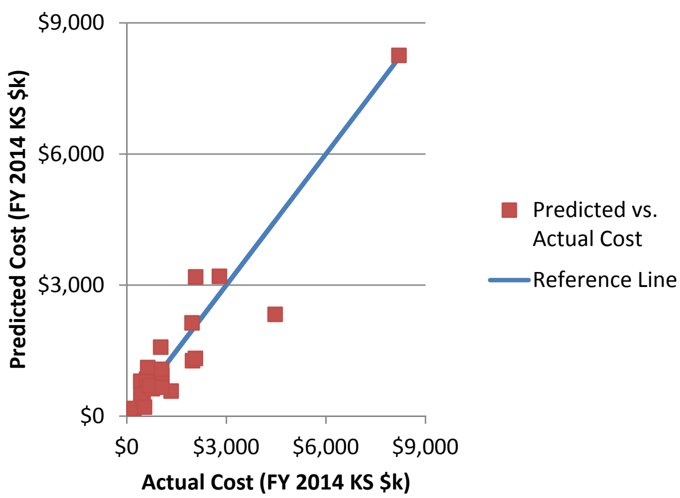


Figure A.2. Predicted vs. actual cost—construct, expand, or rehabilitate apron.

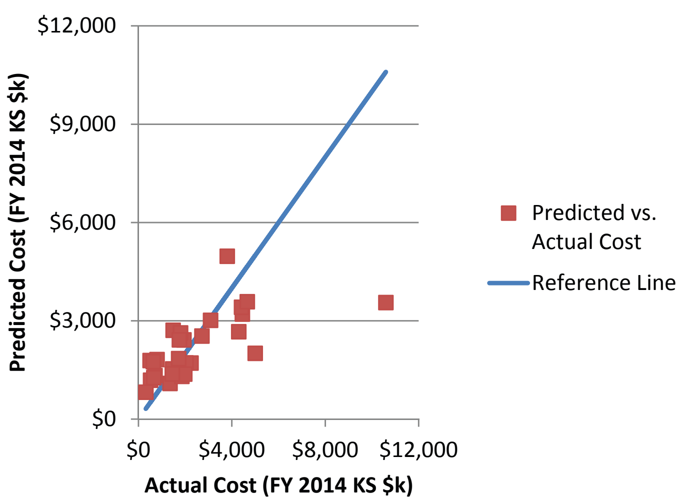


Figure A.3. Predicted vs. actual cost—construct, extend or rehabilitate runway.

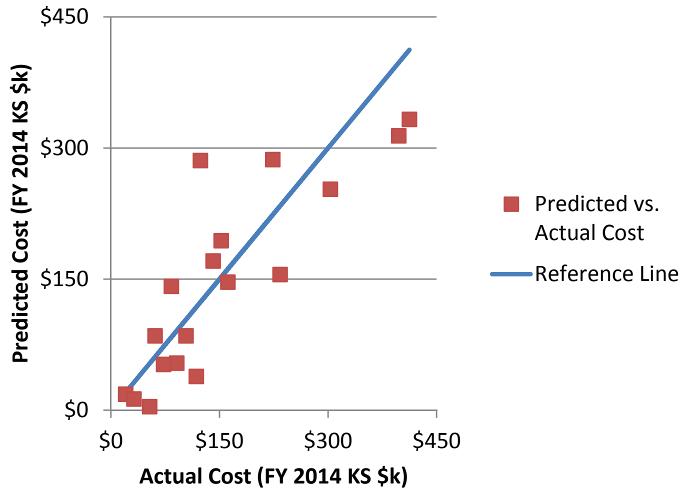


Figure A.4. Predicted vs. actual cost—install perimeter fencing.

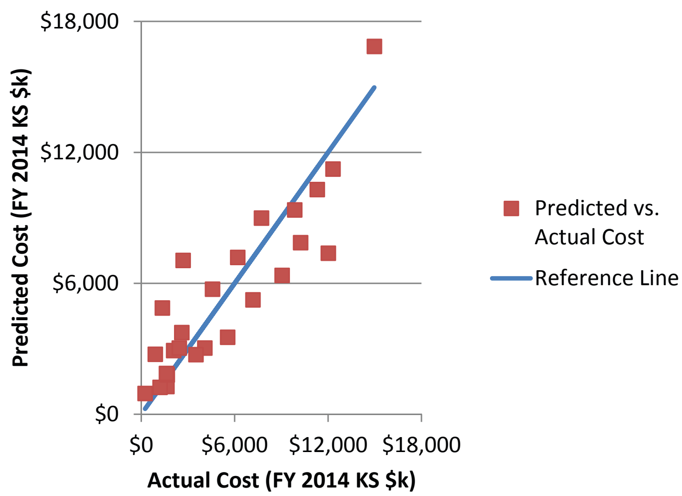


Figure A.5. Predicted vs. actual cost—construct ARFF facility.

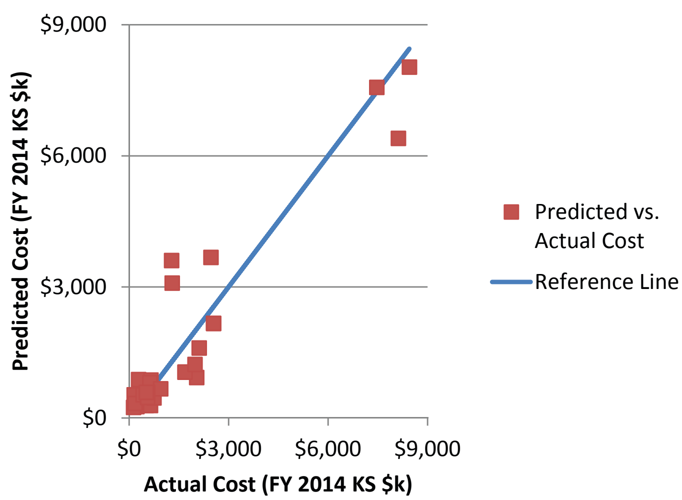


Figure A.6. Predicted vs. actual cost—construct SRE building.

APPENDIX B

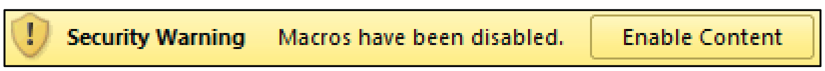
ACCE Quick Reference Guide

Running ACCE

✓ ACCE requires 32-bit Microsoft® Excel (version 2007 or later) and a display resolution of 1024x768 pixels or greater.

✓ To start ACCE, click on the button **ACCE** on the accompanying CD or right click on the file **ACCE.xlsm** and select “Open” (or double click on the file name to begin the program).

✓ ACCE requires an Excel function known as “macros” in order to function properly. If a pop-up message with an “Enable Macros” or “Enable Content” button appears, that content should be enabled:



If no warning appears, macros have already been enabled and ACCE is ready to be used.

Before Starting

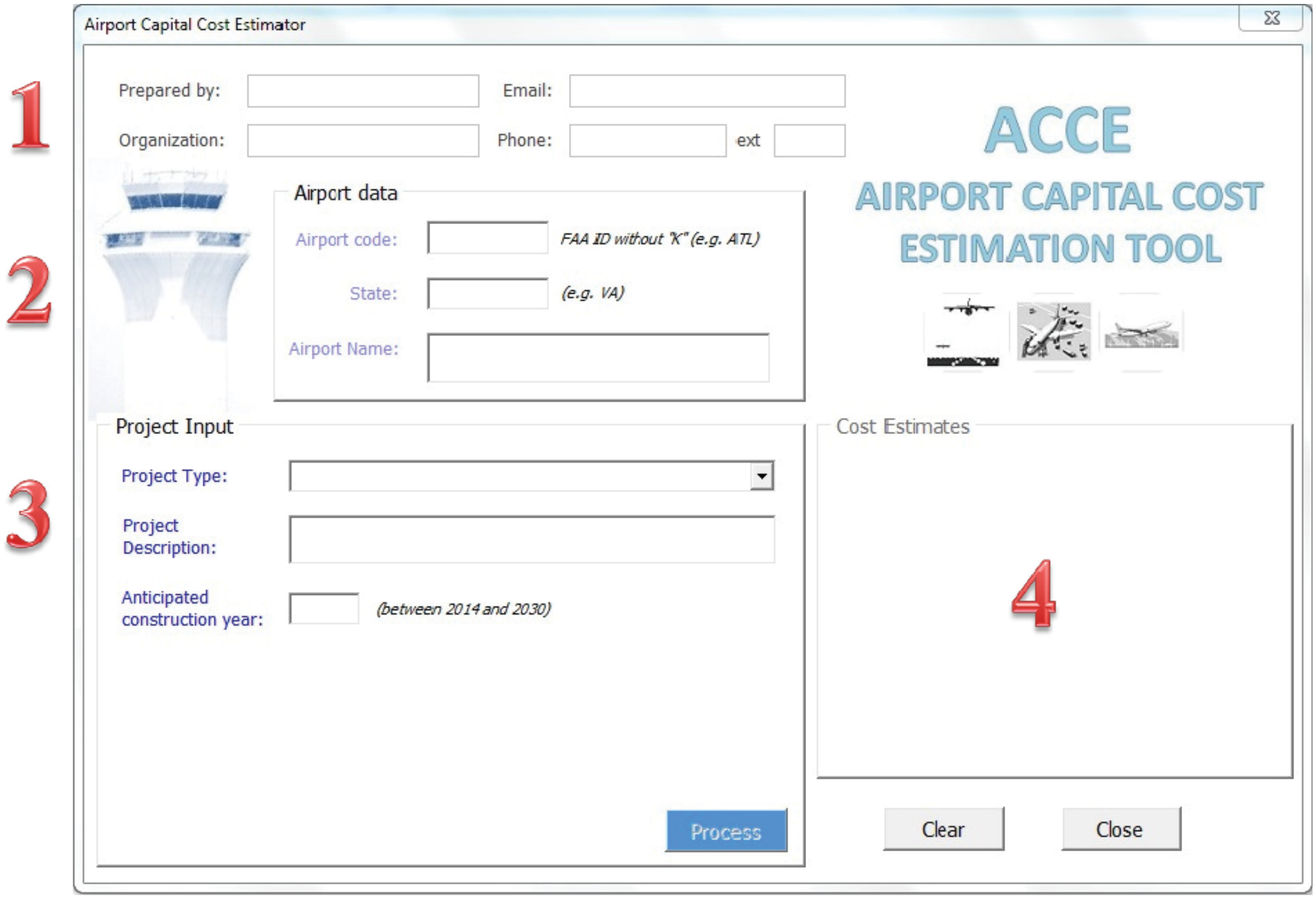
Before starting, have the following information ready:

- Description of proposed construction project.
- Planned year of construction.
- Values for key cost drivers:
  - Pavement projects: Pavement area (square ft.), design aircraft MTOW (lbs.), and, for runway construction projects, design aircraft landing gear configuration (SW/DW/DTW/DDTW)
  - Security fence projects: Length (ft.)
  - SRE building and ARFF facility projects: Combined floor area (square ft.)

Input Window

✓ The ACCE input window is displayed automatically when opening the tool. It consists of four sections:

1. Contact information: To be used for entering the name and contact information of the preparer of the cost estimate. This information is optional.
2. Airport data: Includes the three-letter FAA identifier, state abbreviation, and name. For NPIAS airports, only the identifier has to be entered: The remaining information is retrieved automatically. This information is required.

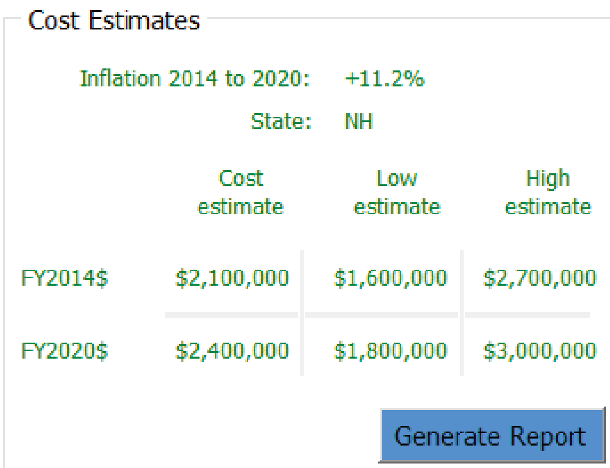


3. Project input: This includes a drop-down menu for selecting the project type, a text field for free-form entry of a project description, and a field for the construction year. Once the project type has been selected, additional input fields are shown for entering the input values for the key cost drivers. This information is required.

Example:

4. Cost estimate: Once the project input data has been entered, the "Process" button can be used. This causes a cost estimate to be instantaneously calculated and shown to the right of the project input section. This estimate can be updated by changing the project input values and pressing "Process" again. Selecting "Generate Report" will produce the final output—the cost estimate report.

   Example:



Other features:

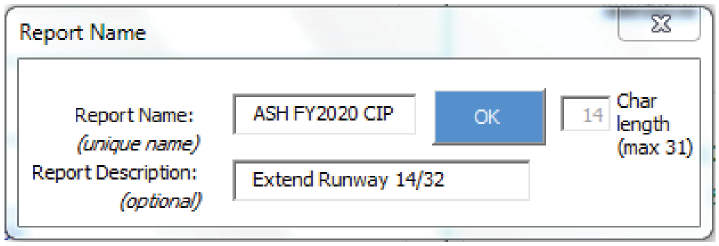
✓ The "Clear" button can be used to clear the input values, in order to generate a brand new cost estimate.
✓ The "Close" button closes the ACCE tool and returns the user to Microsoft Excel.

Project Types

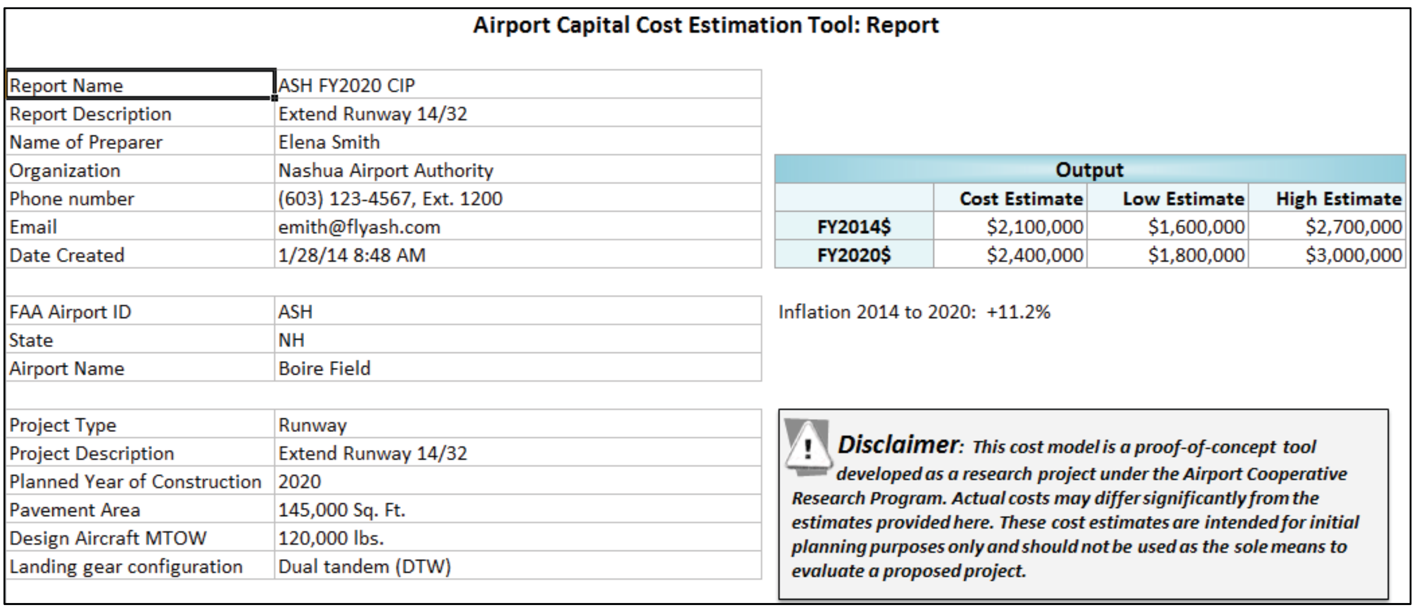
✓ The project type is selected using a drop-down menu in the project input section.
✓ The following project types are supported:
- Aircraft Rescue and Fire Fighting (ARFF) Facility
- Apron
- Automated Weather Observing System
- Perimeter Fencing
- Precision Approach Path Indicator (PAPI)
- Runway
- Snow Removal Equipment (SRE) Building
- Taxiway

Cost Estimate Report

✓ Provide a name and an optional description to identify the cost estimate. **Note: The report name can be a maximum of 31 characters and must conform to Excel naming conventions.**
✓ Press OK to generate the cost estimate report.
✓ The cost estimate report displays the contact and airport information, the date and time the report was generated, the project input data, and the cost estimate.



✓ The cost estimate includes a low estimate and high estimate that create a range of possible costs. The low and high estimates are based on the level of statistical uncertainty in the cost model for the project type in question.
✓ Cost estimates are provided both in fiscal year (FY) 2014 dollars and in inflation-adjusted dollars for the proposed year of construction. The inflation adjustment is based on predicted increases in general price levels (i.e., not increases in construction-specific costs).



Airport Capital Cost Estimation Tool: Report

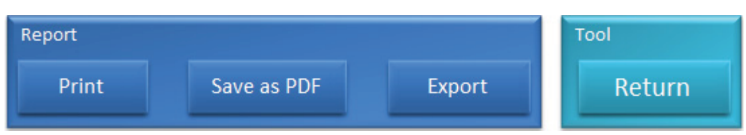
Report Name	ASH FY2020 CIP
Report Description	Extend Runway 14/32
Name of Preparer	Elena Smith
Organization	Nashua Airport Authority
Phone number	(603) 123-4567, Ext. 1200
Email	emith@flyash.com
Date Created	1/28/14 8:48 AM
FAA Airport ID	ASH
State	NH
Airport Name	Boire Field
Project Type	Runway
Project Description	Extend Runway 14/32
Planned Year of Construction	2020
Pavement Area	145,000 Sq. Ft.
Design Aircraft MTOW	120,000 lbs.
Landing gear configuration	Dual tandem (DTW)

Output			
	Cost Estimate	Low Estimate	High Estimate
FY2014$	$2,100,000	$1,600,000	$2,700,000
FY2020$	$2,400,000	$1,800,000	$3,000,000

Inflation 2014 to 2020: +11.2%

***Disclaimer**: This cost model is a proof-of-concept tool developed as a research project under the Airport Cooperative Research Program. Actual costs may differ significantly from the estimates provided here. These cost estimates are intended for initial planning purposes only and should not be used as the sole means to evaluate a proposed project.*

✓ A disclaimer is shown explaining that ACCE is a proof-of-concept tool and that actual costs may differ significantly from the cost estimates produced by the tool.
✓ A toolbar is available below the report:



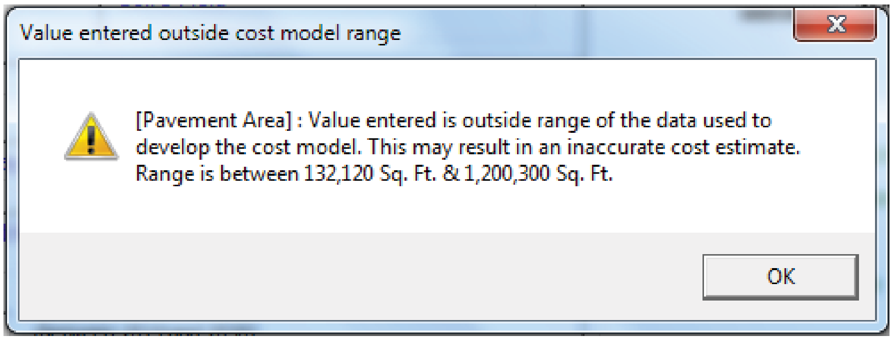
This toolbar supports the following functions:

- Print: Sends the report to a printer attached to the computer or on the network.
- Save as PDF: Saves the report as a PDF file.
- Export: Prompts the user to select a folder and then saves a copy of the report as a Microsoft Excel file with the specified name. Note that only the output is saved (i.e., the cost estimate report). The macros that make up the ACCE tool are not exported.
- Return: Returns to the input window—this allows the user to enter new inputs and generate a different cost estimate (i.e., to create a what-if analysis).

Notes

✓ If the planned year of construction is FY 2014, then inflation-adjusted results are not shown, since these would be identical to the cost estimate expressed in FY 2014 dollars.

✓ If an input value for a key cost driver falls outside the range of values used to develop the cost model for the project type in question, a warning message is displayed indicating that this may result in higher than usual levels of uncertainty:



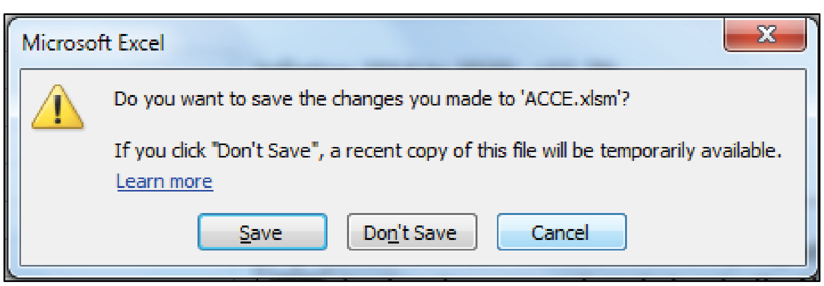
This warning does not, however, preclude use of the entered value—it is only a cautionary note explaining that the value may result in a greater than usual level of uncertainty.

If the user proceeds with the entered value, a similar warning is also displayed in the cost estimate report:

Project Type	Runway
Project Description	Extend Runway 14/32
Planned Year of Construction	2020
Pavement Area	**120,000 Sq. Ft. *** **
Design Aircraft MTOW	120,000 lbs.
Landing gear configuration	Dual tandem (DTW)

***** Warning: This input value falls outside the range of data used to develop the cost model. The resulting cost estimate projects into an area that has not been validated and may be inaccurate.**

✓ When exiting Microsoft Excel, the following message may appear:



Generally, "Don't Save" should be selected, to avoid overwriting the ACCE tool with entered data. To save results from a cost estimate, use the "Export" button in the cost estimate report.

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation