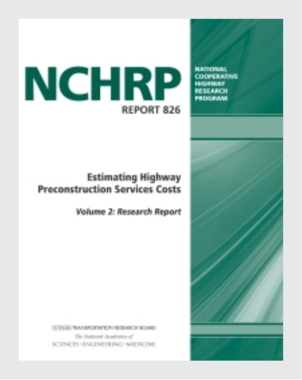

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP REPORT 826

Estimating Highway Preconstruction Services Costs

Volume 2: Research Report

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research is the most effective way to solve many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation results in increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

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The needs for highway research are many, and NCHRP can make significant contributions to solving highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement, rather than to substitute for or duplicate, other highway research programs.

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FOREWORD

By Andrew C. Lemer
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NCHRP Report 826: Estimating Highway Preconstruction Services Costs presents guidance for state departments of transportation (DOTs) and other agencies for estimating preconstruction services (PCS) costs for transportation project development. PCS refers to a varied assortment of project-specific engineering and other professional services required before construction begins on a bridge, highway, or other transportation project, whether provided by agency staff or consultants. The guidance—a guidebook and supporting research report—addresses principal sources and components of PCS costs, PCS estimating methodologies, trends (such as changes in design and construction technology, design standards, program requirements, and professional workforce) likely to affect PCS costs, and advice on agency policies and practices that can help control program risk through improved PCS cost estimation. The report will be helpful particularly to DOT staff and management responsible for the agency's project development and delivery activities.

State DOTs and other agencies responsible for development of major capital facilities rely throughout the project development process on cost estimates to verify that adequate funds are available for project completion, to negotiate for contracted services, and to ensure that the development process is responsibly conducted. Substantial effort is required for a variety of activities that must occur before construction begins, and the ability to define the scope and estimate accurately the costs of these preconstruction activities is essential to agency planning, programming, budgeting, and management functions. Tighter budgets, funding limitations, and growing emphasis on accountability in government spending increase the importance of accurate and reliable cost estimation.

Timely and accurate estimates of the costs for preconstruction services are an important basis for management decision making. In the research underlying this document, PCS refers to engineering and other professional services required before construction begins on a bridge, highway, or other transportation project. The activities for which services are required—whether provided by agency staff or consultants—are project specific and may include planning, PCS contract negotiation, preliminary engineering, environmental studies, subsurface investigations, rights-of-way surveys and acquisitions, design and bid document preparation, design modifications and associated PCS scope changes, and construction procurement. Similar professional services may be required during and following construction (such as construction engineering, inspection and quality assurance, and claims analysis) but were not explicitly considered in this research.

PCS cost-estimating practices vary greatly among DOTs and even within a single agency for different types of services and different stages of project development. The resources allocated to cost estimation and the policies, procedures, and information systems that support cost estimating vary as well. Uncertainties at the outset of the project development process, such as regarding the range of design alternatives to be considered; the extent of environmental, safety, and traffic mitigation activities likely to be required; and the need for phasing strategies to accommodate budgetary limitations, make PCS cost estimating particularly challenging.

The objective of NCHRP Project 15-51 "Preconstruction Services Cost Estimating Guidebook," was to develop a guidebook, for use by DOTs and other agencies, on estimating PCS costs for transportation project development. The guidebook addresses topics ranging from the principal sources or components of PCS costs (for example, direct labor, other direct costs, indirect costs, and profit, in terms of dollars and labor hours), as estimated at various stages of project development; estimating methodologies; and external trends likely to influence PCS costs (such as changes in design and construction technology, design standards, program requirements, and professional workforce). The guidebook is suitable for adoption by responsible groups within the American Association of State Highway and Transportation Officials.

The research was conducted by a team led by Iowa State University. The research team reviewed current PCS estimating practices in DOTs and other transportation agencies and private-sector firms that work with these agencies, collected and analyzed data on actual PCS cost experience, and extracted lessons about accuracy and reliability. Useful background information from the research team's work is presented in the research report that accompanies the guidebook.

CONTENTS

SUMMARY

Building long-lasting roads necessarily involves planning and designing those roads in a manner that results in a high-quality constructed product. To achieve this requires that the necessary resources be allocated to the preconstruction process to permit planners and designers the time and funding to be able to solve technical, environmental, and constructability problems before the construction contract is advertised. Research has proven that correcting errors, omissions, and ambiguities in preconstruction is far less expensive than during construction (Anderson et al. 2007). This issue becomes more critical if the preconstruction process is outsourced to a consultant whose fee limits the number of billable hours it can spend before releasing final construction documents. Therefore, ensuring that the preconstruction phases are allocated sufficient funding to adequately complete the necessary investigations, analyses, and so forth is a previously unrecognized determinant of not only the project's final quality but of the agency's ability to control cost and schedule growth during project delivery. Hence, making a reasonably accurate estimate of preconstruction services (PCS) costs becomes the first stage in delivering the best possible project for the available funding. NCHRP Project 15-51, "Preconstruction Services Cost Estimating Guidebook," was initiated to provide agencies guidelines for conducting PCS cost estimates.

The question of whether "better, faster, cheaper" truly applies to a public transportation agency's construction projects has rarely, if ever, been asked. A strong argument can be made that the traveling public deserves something better than "cheap" roads and bridges. One can also argue that since the agency must operate and maintain the completed project, it would want to build the best and most resilient facility that its appropriated budget allows to minimize life-cycle and road user costs during the facility's actual service life.

In 2010, the FHWA introduced the Every Day Counts program, the aim of which is to propagate proven methods to "get in, get out, and stay out" (Mendez 2010). To accomplish that aim, the FHWA administrator stated that "it's imperative we pursue better, faster, and smarter ways of doing business" (Mendez 2010). One must note that the FHWA substantially changed the "better, faster, cheaper" phrase by substituting "smarter" for "cheaper." As the nation's transportation infrastructure continues to deteriorate, the apparent policy shift from *cheap* to *smart* tacitly advocates the delivering of transportation projects that ultimately last longer with less maintenance than the ones previously built.

Public-sector transportation projects must be delivered on tight budgets, within statutory funding constraints, and with an increased emphasis on government accountability. Thus, the need to manage and control costs for state departments of transportation (DOTs) on capital development projects has become more critical. The result is a drive to develop more accurate cost estimates for construction projects. Past research largely focused on construction and to a lesser extent on design cost estimates. In this project, a guidebook detailing effective practices for estimating the cost of the entire preconstruction period, termed preconstruction

services, was developed to provide guidance for state DOTs to estimate the cost of planning, engineering, and other professional services required before a construction project is let. The research uses case study methodology and results in the development of a stochastic parametric estimating model.

The guidebook produced by this research presents a data-driven holistic framework that comprises both top-down and bottom-up approaches to estimate PCS costs that meet various stakeholders' needs during the preconstruction phases of the project. It demonstrates how to complete PCS cost estimates at the point in project development where the typical project is assigned a project identification number. The proposed top-down estimating approach addresses the need to make estimates at a point where very little design detail is known. This approach assumes that a database of past projects' PCS costs is available and that the data are reasonably accurate. The research that led to this document found that this assumption is not necessarily valid in most state highway agencies. As a result, the guidebook contains guidance on how to collect, clean, reduce, and assemble the necessary data to populate the PCS cost-estimating database.

The proposed bottom-up approach is provided to allow agencies to conduct the independent cost estimate required by statute for federal-aid projects where preconstruction planning and design services are outsourced to an engineering consultant. As such, it is based on establishing a PCS work breakdown structure that forms the framework for both collecting PCS cost data for top-down estimates and for providing an apples-to-apples comparison with consultant fee proposals. The two approaches converge and furnish the required back-check on the PCS cost estimate.

The guidebook was created using information obtained from case study research performed in nine states: California, Colorado, Iowa, Maryland, Montana, New York, Oklahoma, Rhode Island, and Utah. The guidebook represents the effective practices observed in those states validated by 5 years' worth of PCS cost data received from DOTs in California, Iowa, New York, and Utah. The major finding of the research and the guiding principle of the guidebook can be expressed in the following way:

> Investing in preconstruction activities by ensuring that they are fully funded based on a rational, project-specific PCS cost estimate leads to increased cost and schedule certainty during construction.

Therefore, it is essential that agency upper management provide the necessary resources to populate the PCS cost database and then commit the resources to maintain that database as a robust tool for mitigating project cost and schedule uncertainty. Doing so will enhance the quality of the bidding documents produced to build and maintain the nation's transportation infrastructure.

CHAPTER 1

Introduction

1.1 Background

The issue of accurate estimating of preconstruction services (PCS) costs is essentially tied to the efficient use of available public capital (Janacek 2006). Early estimates conducted during the planning phase often become legislative authorizations and turn into project budgets before the final scope of project work is adequately quantified (Anderson et al. 2007). Additionally, since preconstruction costs are by definition a small portion of the total project delivery cost, they are typically estimated as a standard percentage of estimated construction costs. Hence, if the capital project is underestimated, PCS costs will be similarly underestimated. A 2002 study involving 258 transportation projects collectively valued at $90 billion found that 86% experienced actual costs that were on average 28% higher than estimated (Flyvbjerg et al. 2002). That study concludes that "underestimation of costs at the time of decision to build is the rule rather than the exception for transportation infrastructure projects" (Flyvbjerg et al. 2002). If one applies the U.S. Army Corps of Engineers (U.S. ACE) supervision and administration rate of 5.6% (U.S. Army Corps of Engineers 1997) to Flyvbjerg's sample, the PCS cost would be roughly $5.0 billion, a significant amount of money in any context. Using Flyvbjerg's cost growth would mean that the agencies delivering these projects would be short $1.4 billion in the preconstruction phases of project development. The fact that project scope and quality are defined during the planning and design process leads one to infer that poor estimating accuracy is actually robbing the project of proper resources to complete a thorough preconstruction process and perhaps ultimately results in imperfect construction documents that actually become the basis for construction cost growth after contract award (Molenaar 2005).

A study by Carr and Beyor (2008) reported that consultant design fees have not kept pace with inflation for the past three decades. This creates a situation where "the high-quality professional services rightfully expected by the public will become increasingly difficult [to attain] if the erosion in fees continues unabated into the future" (Carr and Beyor 2008). In essence, this pricing pressure forces engineers to literally furnish the requisite level of design services with a steadily decreasing amount of resources. This could unintentionally induce a bias toward minimizing planning and design activities to maintain necessary project profitability, which in turn would manifest itself in the form of declining quality of construction documents.

This environment is further exacerbated by the recent demand by owners to compress project delivery periods via programs like the FHWA's Every Day Counts. A survey by the Construction Management Association of America found that the "demand for increasing speed of project delivery is the top reason for decline in construction document quality" (Construction Management Association of America 2003). The survey also reported that:

> In their responses to questions about the quality of construction documents, more than half of the owners surveyed responded that these documents often have significant amounts of missing information. Specifically, 45% of respondents indicated that construction documents, while sufficient, still had "significant information needed," while an additional 12% found that documents were typically inadequate because of major information gaps (Construction Management Association of America 2003).

A number of studies have looked at the relationship between design quality and subsequent construction contract modifications. Studies by Morgen (1986) and Kirby et al. (1998) found that design deficiencies are the major cause of construction contract modifications and that 56% of all modifications are aimed at correcting design deficiencies. Additionally, a study by Burati et al. (1992) found that deviations due to design errors discovered during construction account for 79% of all modification costs and average 9.5% of the total project cost. Thus, research has shown that improving planning and design quality has the potential to accrue benefits through reducing construction cost growth. A study completed for

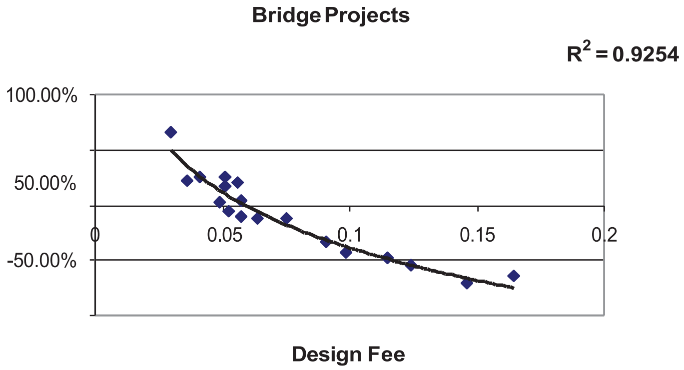


Figure 1.1. OTA bridge projects' cost growth from the initial estimate versus design fee (Gransberg et al. 2007).

the Oklahoma Turnpike Authority (OTA) confirmed this inference and demonstrated for one agency that, to a point, increases in actual construction costs compared to the early estimate were inversely proportional to the amount of money allocated for PCS (Gransberg et al. 2007). Figure 1.1 comes from that work and illustrates the relationship for OTA design–bid–build (DBB) bridge projects, specifically for the design fee expressed as a percentage of construction costs. The figure illustrates that, within the limitations of the research, providing adequate funding to properly complete PCS gives the agency more control over the final cost of the project. Said another way, an accurate PCS cost estimate increases cost certainty for DBB projects. This conclusion is confirmed by a recent study that found "DB [design–build] and CMGC [construction manager/general contractor] display lower cost growths than DBB and therefore provide greater cost certainty" (West and Gransberg 2012).

Given this discussion, developing a pragmatic system with which to estimate PCS costs will promote final design quality by reducing construction document errors and omissions (Carr and Beyor 2008; Construction Management Association of America 2003) and will accrue an immediate benefit by enhancing cost certainty for projects delivered using both traditional and alternative delivery methods (Gransberg et al. 2007; West and Gransberg 2012).

1.2 Problem Statement

The first expenses borne in all projects are the costs to perform planning, programming, and preliminary engineering. Construction uncertainty is at its absolute highest level, making the practice of setting a budget for PCS costs using a percentage of construction costs merely the act of multiplying an arbitrary number by an estimated figure that will change as project development progresses. Hence, in many cases, the budget for developing a given project is effectively more uncertain than the budget for the project itself. To exacerbate the problem, research has shown that 86% of the time, the initial construction estimate and subsequent estimates are too low (Flyvbjerg et al. 2002), which means that the budget for PCS costs will also be too low. The phrase "you get what you pay for" applies in this situation. The amount of effort that can be applied to quantifying the cost of the project's scope of work is limited by the available budget, and the inaccurate PCS cost estimate becomes a design quality issue, with in-house engineers and department of transportation (DOT) preliminary engineering consultants forced to make the time spent on refining the design fit the available budget. The final product is often a set of poorly prepared construction documents detailing a product that is functionally overdesigned because the designers did not have the budget to produce a fully optimized design (Carr and Beyor 2008; Construction Management Association of America 2003).

The state of the practice in PCS cost estimating ranges widely among DOTs. At times the variation is present within a single agency for different types of services and different stages of project development. Issues such as the range of design alternatives to be analyzed; the impact of environmental permitting, construction safety, and options for traffic control; and construction phasing to meet construction financing and budget constraints all make PCS cost estimating challenging at best and nearly arbitrary at worst. Therefore, the need for standardized guidance for estimating PCS costs is critical for DOTs to achieve the transparency, accountability, and fiscal responsibility that come with the tighter budgets experienced in the past several years. Hence, the objective of this research was to develop, test, validate, and package an accurate, consistent, and reliable method for estimating PCS costs.

1.3 Research Objectives and Tasks

The NCHRP Project 15-51 request for proposal (RFP) states:

> The objective of this research will be to develop a guidance document on cost estimating for preconstruction services. The guide will address cost estimating for all types of preconstruction services, whether performed by agency staff or consultants, addressing particularly issues specific to engineering and design services required for highway improvement projects (for example, surveying, preliminary engineering, environmental impact projection and mitigation planning, final design engineering). The guide will also address agency policies, procedures, and support systems that will enhance an agency's cost-estimating and management practices.

To accomplish the stated objective, two sub-objectives were established to guide the research plan:

1. Identify, analyze, and understand the current models for PCS cost estimating; and

2. Develop a guidebook for agency implementation of a standardized approach to estimating PCS costs for construction projects.

Accomplishing these objectives yields a PCS cost-estimating model that is specifically adapted for DOT projects and is not a repurposing of models in use in private industry. The specific model is flexible enough to be tailored for implementation within the statutory constraints of a given jurisdiction and is responsive to the concerns for equity and transparency of a state's design and construction industry partners.

The research has produced the following deliverables:

1. A guidebook for initiating and implementing a PCS cost-estimating system for highway projects at transportation agencies,
2. A research report that addresses the implications of adopting the guidelines and barriers to implementation, and
3. An effective practices and tools report that documents findings that could be implemented before the final guidebook was produced.

1.4 Research Framework

The research framework was derived from the NCHRP RFP, which was logically divided into three phases:

- Phase 1–benchmark PCS cost-estimating practice,
- Phase 2–develop and implement PCS cost-estimating method, and
- Phase 3–furnish technical support to the AASHTO Subcommittee on Design (SCOD) during guidebook review and balloting.

The outcome of the research is a guidebook and this research report based on a rigorous analysis of a state-of-the-practice review updates of past work on similar projects. The state of the practice then functions as a baseline from which the new contributions to this area are built.

Phase 1 has comprehensively identified and categorized the PCS cost-estimating models that are currently in use. A significant barrier identified during this phase was the poor quality of collected PCS cost data and the lack of confidence held in it. This finding resulted in the need to alter the research plan for this project. Instead of prescribing a single PCS cost-estimating model, the research would need to show how to collect, clean, and properly maintain databases along with providing models for different applications depending on agency needs.

Phase 2 investigated data-driven models and refined three stochastic techniques for PCS cost estimating along with a functional-level approach for resource management. The product of this research was used to create *NCHRP Report 826: Estimating Highway Preconstruction Services Costs, Volume 1: Guidebook*. The topical content was validated by the NCHRP panel and furnished to the NCHRP project oversight panel for review and approval.

Phase 3 was to furnish technical support to the AASHTO SCOD during review and balloting of the guide.

1.5 Task Descriptions

1.5.1 Phase 1: Benchmark the State of the Practice

As shown in Figure 1.2, during Phase 1 the research team evaluated current applications of PCS cost estimating in transportation and vertical construction industries. It also evaluated the state of the practice with respect to parametric cost-estimating theory and the way it is applied on a variety of project types. Due to the interdependent nature of the tasks in Phase I, the research aggressively overlapped in Tasks 1 and 2, and much of the work was performed concurrently in accordance with the work-effort assignments. The output of the literature review and the screening survey of AASHTO SCOD members was synthesized and documented in Task 2.

> Task 1. Define the state of the practice in PCS cost estimating for transportation projects through a comprehensive literature search and collection and analysis of relevant preliminary engineering and ICE consultant procurement documents, design contracts, relevant DOT policy/guidance documents, and a screening survey issued to AASHTO SCOD members at 2013 meeting. Select case study agencies and projects for Task 2.

The literature review and content analysis from NCHRP Project 10-85 in the area of PCS costs for CMGC projects was updated and expanded to include the full suite of project delivery methods. Barriers to implementation from the literature were identified, and information regarding PCS estimating cost models and contingency development was collected. A methodology for developing a rational contingency for consultant design contracts was developed. Previous work on DB design administration costs was extended to cover DBB and CMGC. As a result, the final guidebook now covers the full spectrum of DOT project delivery requirements.

The research team was able to move immediately to the development of a coding structure for data collection and characterization. The final coding structure permitted mapping of both cost-estimating system and project delivery characteristics. The team modified the CMGC preconstruction services contract pricing model developed in NCHRP Project 10-85 as a basis for mapping.

The second stage of Task 1 involved a screening survey concerning the use of PCS cost-estimating systems and variants for specialty items such as right-of-way (ROW). The team developed a short, comprehensive questionnaire.

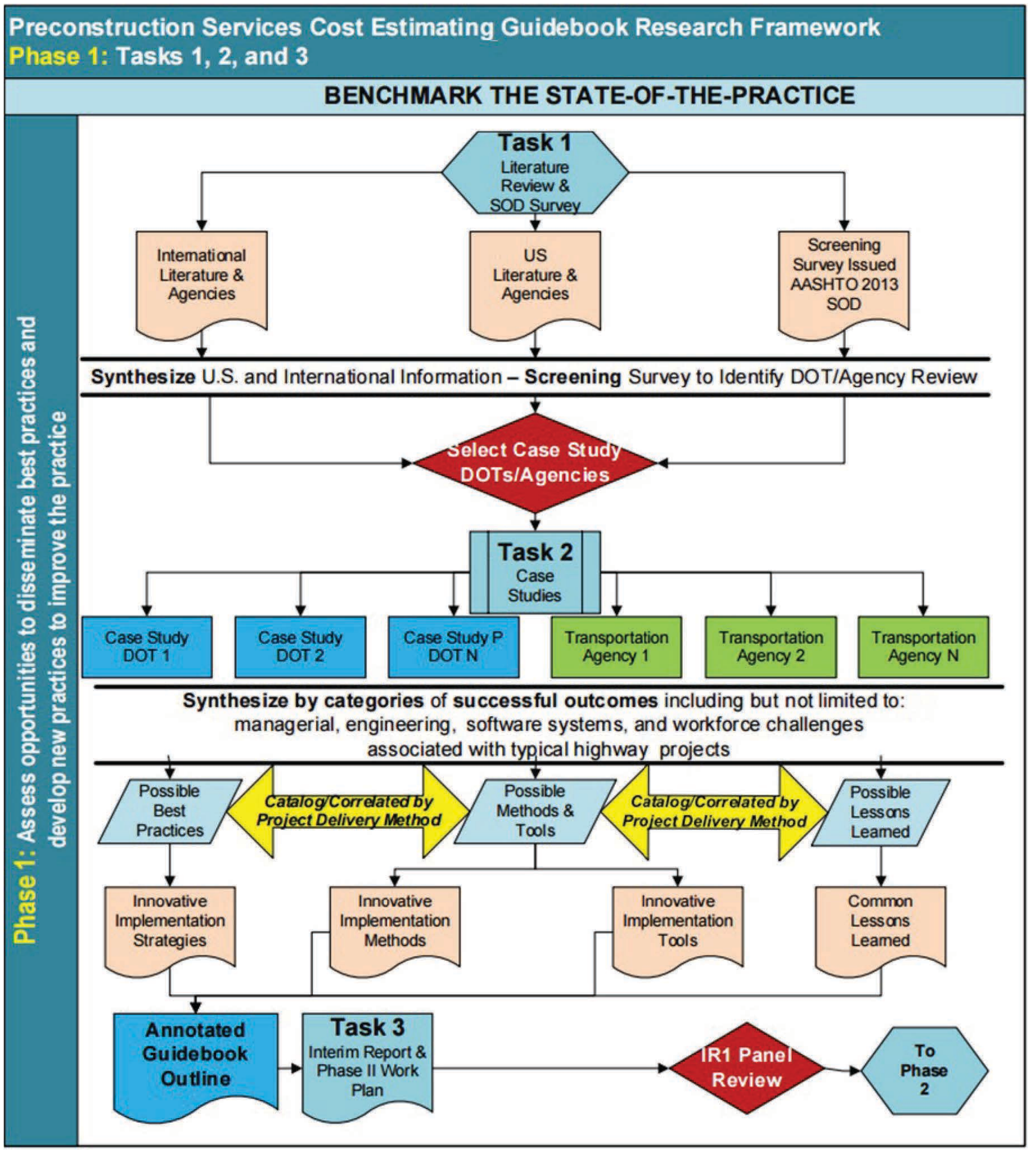


Figure 1.2. Phase 1 research plan.

The survey for this study was directed at the members of the AASHTO SCOD to the various PCS cost-estimating practices and identify both potential case study opportunities. The entire team contributed to the survey. Finally, a set of case study projects and case study agencies was assembled for use in Task 2.

> Task 2. Prepare case studies of PCS cost estimating at transportation agencies. After conducting the case studies, conduct pattern matching analysis between the case studies and determine effective PCS cost-estimating practices, methods, and tools to be included in the guidebook content.

The initial step in Task 2 involved consolidating and documenting the Task 1 information that would add value to the guidebook.

Ultimately, the documentation was used as a basis from which questionnaires for the case study structured interviews were built. The first step involved assembling the case studies identified in Task 2 and filtering to ensure that the case study population covered the full spectrum of the research interest. The goal was to have a set of possible case study projects that furnished these attributes:

- Range of project types–roads, bridges, tunnels, intelligent transportation systems (ITSs), vertical, and so forth;
- Range of project sizes–typical small project to mega-project;
- Range of project complexities–simple to highly complex;
- Range of project locations–regionally dispersed;
- Range of project delivery methods–DBB, DB, CMGC, and so forth; and
- Other factors that may be found in Tasks 1 and 2.

Once the potential case study population was developed, the final list and the rationale for selecting each case were submitted to the NCHRP panel. On receipt of the panel's agreement, the case study data collection began ahead of schedule. To achieve the objective of this task, nine individual case studies were conducted on projects using predominantly DBB project delivery. Other delivery methods were also investigated on a smaller scale. The case study protocol followed the guidance provided by Yin (2008). Case studies are empirical inquiries that investigate contemporary phenomena in their real-life context. The research team strongly believes that to adequately evaluate how the various agencies have successfully implemented PCS cost-estimating methods, case studies must be conducted. These are the primary efforts needed to accomplish this objective:

1. Develop a case study protocol for conducting the case study interviews,
2. Conduct the case study interviews, and
3. Document the raw information collected and integrate it with data from the literature review.

The key step in Task 2 is the first one: develop a case study protocol for the case study interviews and data-collection plan. In the proposed multi–case study analysis, the final protocol determined how the case studies were conducted, who the case study informants were, what information was collected, and how it was analyzed. The case study protocol followed rigorous qualitative research design and analysis methodologies based on Eisenhardt (1989, 1991), Yin (2008), Miles and Huberman (1994), and others. The protocol included a research synopsis of objectives, projects, field procedures that detail the logistical aspects of the investigation (such as permission to access projects for data collection), interview questions, and documentation to collect, as well as a format for documenting and analyzing the individual case studies (for internal research team distribution) (Eisenhardt 1989, 1991; Yin 2008). In addition, a plan was developed for cross-case comparisons to determine similarities and differences between cases (Eisenhardt 1989; Miles and Huberman 1994).

Use of a case study protocol permitted the research team to conduct case studies separately in different parts of the country while maintaining the reliability of the case study results. Internal validity was addressed by attending to multiple sources of evidence, and the use of multiple case studies improved the external validity of the project delivery and project control tools that were identified as promoting project success. The protocol included different categorizations of project characteristics, such as project procurement methods, payment provisions, and entity involvement in project development (managerial, engineering, and so forth). The protocol design also solicited data on barriers to implementation and methods and tools to overcome these barriers.

> Task 3. Prepare an interim report presenting the results of Tasks 1 and 2. The interim report will also include an updated work plan for the remaining tasks.

The objective of Task 3 was to produce a comprehensive summary of findings and conclusions from Tasks 1 and 2, as well as an updated work plan for Phase 2 of the research. The team began planning, formatting, and categorizing prior to preparing the report itself. The team also applied that structure to keep the oversight panel informed through the monthly and quarterly reports.

The next step was the development of a detailed interim report outline, based on the panel's feedback from the quarterly reports. The outline was used to guide the preparation of the report and assign responsibilities for drafting specific chapters or sections of the report. The report is comprehensive and describes in some detail methodology and results used to complete Tasks 1 and 2. It was submitted to the NCHRP panel on February 28, 2014.

1.5.2 Phase 2: Develop and Implement PCS Estimating Method

Phase 2 entailed the research team creating a fully implementable practice document that could be revised as required by local transportation agencies to align constraints and preferences as shown in Figure 1.3. It included the development of data-driven models for estimating PCS costs.

> Task 4. Prepare a guidebook for initiating and implementing a PCS cost-estimating system for highway projects at transportation agencies.

Since Task 3 resulted in an interim report, the major findings and highlights of the information were combined to produce a white paper containing a short synopsis of emerging findings. The process defined an effective practice, method, or tool as the intersection of two independent streams of information. In other words, the protocol for concluding that some practice is effective is that it was found in the literature, and its effectiveness was verified by either survey or case study evidence showing that it has actually been used successfully in the field.

The white paper was entitled "Effective Practices and Tools for Estimating Preconstruction Service Costs" and was submitted to the panel in October 2014. The paper also served as an in-progress review that could be disseminated with NCHRP permission to those agencies that need immediate guidance.

The primary objective of Task 4 was to develop the guidebook for implementation of the data-driven PCS cost-estimating models found in this research. The task began

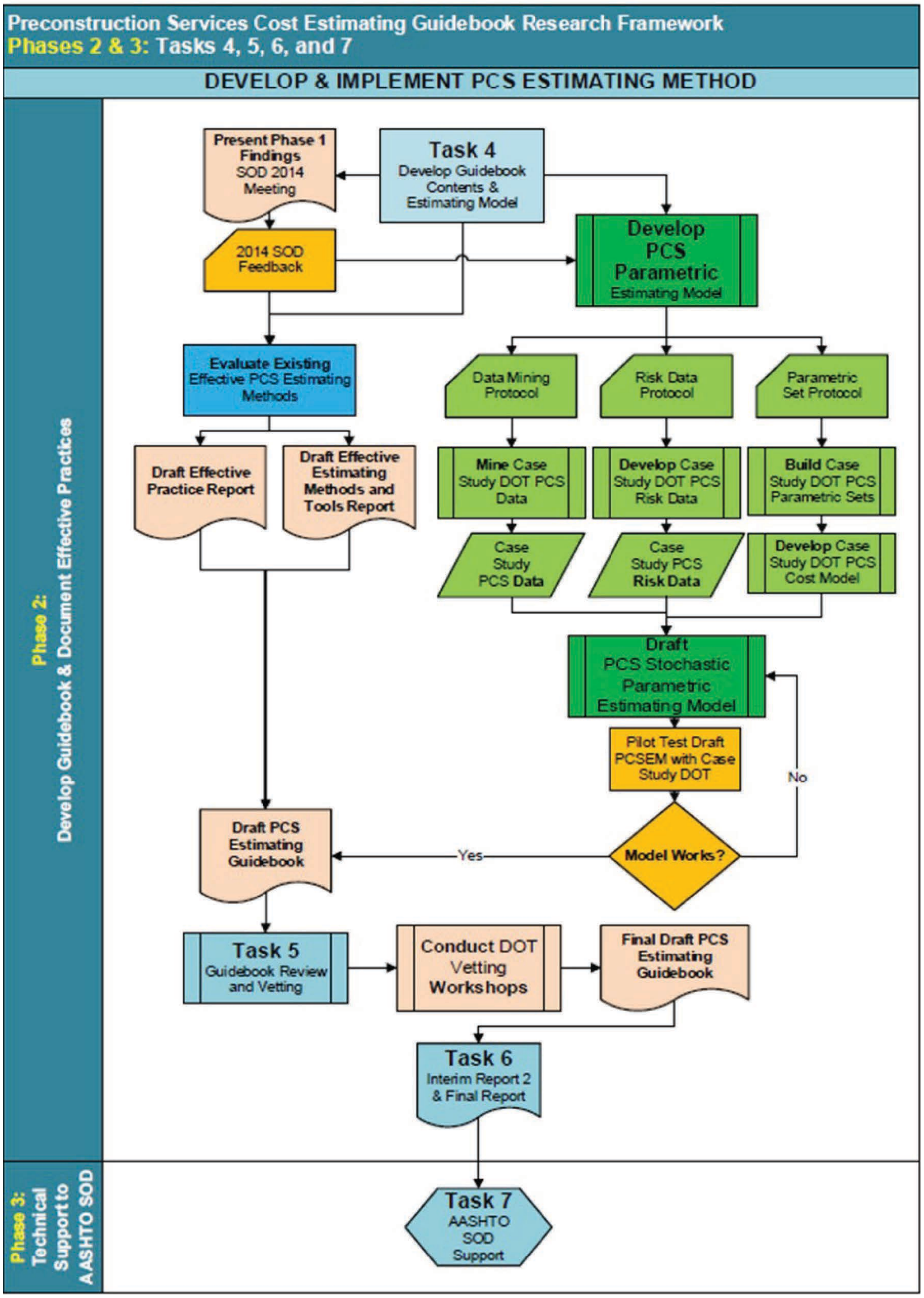


Figure 1.3. Phase 2 and 3 research plan.

ahead of schedule after the presentation of Phase 1 results to the AASHTO SCOD meeting in 2014. After assembling feedback from that event, the team continued with the development of a PCS model.

After collecting case study data, the research team began developing databases. As the team reduced, cleaned, and collated the data, it found it difficult to be able to guarantee that the data were complete and accurate. A number of inconsistencies were observed within collected data sets, and numerous blank cells indicated that some information was not complete. These issues of data quality and data availability created a number of challenges for the research team. The outputs of any model are only as good as its input, placing the quality of any estimating model produced into question.

After becoming familiar with the Utah and Iowa data sets, the team became concerned at how different the two sets were. Such variation between the agencies' classification of data indicated that it would be difficult to achieve a consistent result between the two DOT's models.

These observations were reported to the panel in the October 2014 quarterly report. The panel was notified that the research might ultimately lead to a process model that must be customized specifically to the way data are collected in a specific DOT rather than a fairly generalized approach that could be used by all DOTs.

As a consequence of these findings, the direction of the research was modified slightly. Instead of creating a single PCS cost-estimating model, three different data-driven models would be developed and complemented with a cost-estimating process. This allows DOTs to maintain their own data-collection and administration processes.

1.5.3 PCS Cost-Estimating Model

In many of the case study projects, the DOT personnel expressed doubt regarding the accuracy of the available data associated with preconstruction activities. Some of the DOTs have a sophisticated process for collecting the PCS data, but in all cases, the data depended on the diligence of individual employees to accurately reflect the distribution of the hours charged to a given project in a normal day. Additionally, despite these sophisticated data-collection mechanisms, DOTs lack the tools to process these data into meaningful information to support decision-making procedures during planning and design, including the development of reliable PCS cost estimates. In order to address this issue, this study presents a framework for the development of data-driven PCS cost-estimating models. This framework covers the entire development and application process, from an initial requirements analysis of new models to the monitoring, control, and continuous improvement of existing estimating models. The PCS cost-estimating guidebook resulting from this study describes this framework in detail and explains how it can be used with three different PCS cost modeling methodologies: artificial neural networks, multiple regression analysis, and decision trees.

Likewise, this study recognizes that the need for PCS cost estimates and the estimating capabilities of the available project data vary throughout the project development process. Thus, the guidebook defines and describes three types of estimates intended to fulfill needs at different levels: top-down, bottom-up, and functional-level estimates. Top-down estimates are conducted with very little information early during the project development process and are aimed to support strategic decision making. A bottom-up approach provides more precise estimates at the project level, but it requires more detailed project information, making it only available after investing some planning and design efforts. Finally, functional-level estimates (a type of bottom-up estimate) refer to the forecasting of costs or labor hours within each work area involved in the project (e.g., structural, environment, geotechnical). Thus a bottom-up estimate may be performed by the aggregation of all functional-level estimates.

1.5.4 PCS Cost-Estimating Guidebook Development

The guidebook explicitly describes the business case for making the change, discusses the barriers to making the change, provides a tool for structuring the PCS cost model to fit specific agency constraints, and provides tools for implementation. With this wide variety of audiences and goals, the guidebook can only provide guidance. It is not a how-to textbook for all agencies to apply directly. The guidebook is written to give readers the necessary guidance for their individual roles in the development and adoption of PCS cost-estimating models in their agencies.

An initial draft of the guidebook was submitted to the NCHRP panel on December 1, 2014. Reviews from the panel were related to the level of accuracy DOTs could expect from PCS cost-estimating models and the complexity added to the guidebook by including the description of some research instruments and computational details.

As a result of this, the format of the guidebook was drastically modified. Special efforts were invested in the second draft of the guidebook to explain the major factors affecting the accuracy of data-driven PCS cost-estimating models. Several suggestions have been made to optimize the effectiveness of these estimates. These suggestions include tips to improve data management practices, the implementation of a PCS cost monitoring system, and the formalization of continuous improvement practices to progressively enhance the estimating capabilities of the models. Additionally, computational details and other complex technical content have been removed from the guidebook and placed in appendices, as suggested by the project panel. The updated guidebook also included an additional chapter on functional-level estimating since this bottoms-up approach that can be applied on the ground by departmental managers was not previously addressed, and it was deemed important to provide holistic guidance to agencies.

Task 5. Conduct review and vetting in the field.

Task 5's objective was to test the applicability of the draft PCS cost-estimating guidebook. Vetting workshops of the guidebook were conducted with Iowa and Montana DOTs. A report of this process is detailed in Section 5.3. The feedback gained from the workshops was used to further tweak the guidebook before its final review by the panel.

Task 6. Prepare a revised guidebook (Interim Report 2) and a final report documenting the entire research effort.

Due to the substantial changes made to the guidebook since the NCHRP panel's initial review, the research team proposed that the guidebook be submitted separately from this final research report to give the panel time to provide feedback on the numerous modifications. The key deliverable of this task is the guidebook. It was therefore imperative that it be appropriately reviewed. A response to panel members' review comments was submitted at the same time as the report, but were contained in a separate document. The final research report (this document) presents a summary of the entire research effort.

Task 7. Furnish technical support to AASHTO Subcommittee on Design for review and balloting of the guidebook.

The research team anticipated that the details of Task 7 would be developed as a part of the Task 6 panel review, and that the AASHTO SCOD would make known its support requirements before this task began. At this writing, the team expects that the majority of the technical support would be in the form of answers to SCOD member requests for information. The team believes that this could be served by preparing two webinars that would provide a forum to quickly disseminate the fundamental description and explanation of the PCS cost-estimating system. The first webinar's subject would be a guided tour through the guide with a hypothetical example project designed to demonstrate the capability of the system. The second webinar would focus on implementation and would cover topics like training, resource requirements, documentation, data issues, and other similar topics. Finally, the team will make itself available during this period to provide on-site presentations within the limits of the remaining project travel fund.

1.6 Report Format

This final research report encapsulates all of the work completed as part of this research project. Material from the interim report is included and built on to ensure a comprehensive documentation of the entire project.

- Chapter 1, this introduction, provides a brief background for this research project and functions as a guide to the rest of the report.
- Chapter 2 is focused on establishing and documenting the current state of practice for preconstruction services (work from Tasks 1 and 2, the literature review, and initial screening survey).
- Chapter 3 is a synopsis of the results of the PCS cost-estimating case studies and describes the types of data that were collected from each agency.
- Chapter 4 is an explanation of the three data-driven PCS cost-estimating models and functional-level estimating method developed by the research team for implementation at transportation agencies. This chapter summarizes Task 4.
- Chapter 5 explains the vetting procedure required for Task 5 and its results.
- Chapter 6 concerns the outcomes of the project and provides recommendations for future research.

CHAPTER 2

State of the Practice

2.1 Introduction and Overview

In the past, there has been a substantial amount of research into estimating construction costs for highway projects, and there are also a handful of articles about estimating design cost and preliminary engineering for highway projects, but somehow preconstruction services costs have been left out. Due to the changing nature of state DOT work with increased funding uncertainties and shrinking budgets, it is more important than ever to ensure proper allocation of funds for highway projects. Uneducated estimates for preconstruction services or using a fixed percentage across multiple projects can lead to a misallocation of available capital funding in the PCS phase, which may force the need to redistribute funding late in an agency's fiscal year to cover overages and expend underruns before authorization expires (Hollar 2011).

2.2 Relevant Definitions

The definition of preconstruction services covers a broad spectrum of project services and includes all work completed on the project, from project conception up until contract award. This process includes effort that may not be assigned to a particular project and also effort for projects that never eventuate. After considering this, the research team consulted the panel and chose to define PCS activities as those defined in Section 2.2.1.

2.2.1 Standard Definitions

- **Preconstruction services.** All work completed on a project once it has been authorized for funding and costs related to the project can be charged accordingly, up until construction contract is awarded. The project timeline and a list of included activities is shown in Figure 2.1.
- **Overhead costs.** Costs applied to the DOT staff above the operational level of planners, designers, and so forth who directly worked on projects.
- **Corridor projects.** Also referred to as "parent projects." The term "corridor" is defined by the U.S. DOT as "a combination of discrete, adjacent surface transportation networks (e.g., freeway, arterial, rail networks) that link the same major origins and destinations. It is defined operationally rather than geographically or organizationally" (Smith et al. 1999). Corridor projects are usually multiphased projects that require various preliminary engineering studies such as environmental assessment [acquiring wetland permits, National Environmental Policy Act (NEPA) documents, etc.] and ROW during the early planning stages. These types of projects are represented by project identification number (PIN) and usually fall under a Type I category. Thus, a corridor project is defined as a group of single projects divided either into multiple sections or work types aimed at repairing, preserving, or improving a transportation network associated with a given roadway.
- **Single projects.** Also referred to as "child projects," these are projects that are created from corridor projects and whose preconstruction expenses are at some level jointly estimated and recorded within a corridor project. For funding purposes, single projects are identified by project numbers. For single projects, it should be noted that preliminary engineering works might be performed for a particular type of project conducted at the planning stage of multiphase projects (PIN projects), and care must be taken to account for all works and costs associated with the project.
- **Independent projects.** Independent projects are typical projects that are contracted by a DOT on an annual basis. In this type of project, the total preconstruction costs are individually estimated, assigned, and recorded. Thus, single projects that do not share any recorded preconstruction services expenses with corridor projects will be considered as independent projects. Independent projects are also identified by project numbers.

The projects investigated by the researches are termed "typical projects." These projects were defined in the kick-off

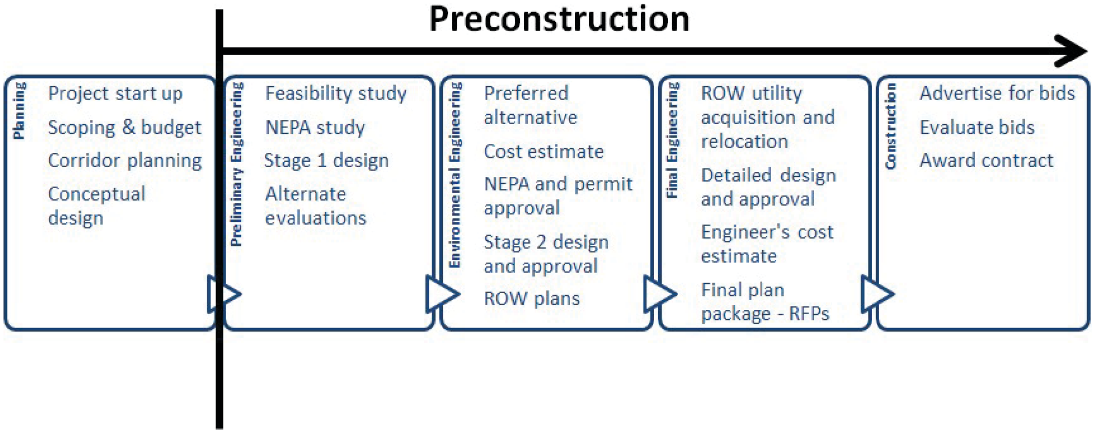


Figure 2.1. Preconstruction services activity timeline.

phone conference as DBB projects within the $2 million to $25 million cost range. The main focus of the case studies was on these projects, but there were also some projects collected that were delivered using DB and CMGC.

2.3 Project Development Timeline

Documents from various agencies on the project development timeline were collected to create a standardized project development process that could be adapted to fit all agencies' processes. Table 2.1 is from *NCHRP Report 574: Guidance for Cost Estimation and Management for Highway Projects during Planning, Programming, and Preconstruction* (Anderson et al. 2007). This report focused on the construction cost estimates through these phases but provided the researchers with definitions of each phase that were then manipulated to fit other literature found during the research. The first four activities—planning, programming and preliminary design, final design, and advertise and bid—are the areas of interest in this research.

Project delivery processes from the Arizona Department of Transportation (2013), Western Federal Lands Highway Division (2007), Ohio Department of Transportation (2014), New York State Department of Transportation (2004), and Iowa DOT were reviewed and synthesized to develop Figure 2.1. Most of these documents can be found in Appendix A of this report. Figure 2.1 shows the preconstruction timeline starting at the preliminary engineering stage; this is designed to coincide with the Statewide Transportation Improvement Plan (STIP) for most agencies (see Section 2.3.1). All activities that occur prior to this, including initial start-up, scoping and budget,

Table 2.1. Project development phases and activities (Anderson et al. 2007).

Development Phase	Typical Activities
Planning	Determine purpose and need, determine whether it is an improvement or requirement study, consider environmental factors, facilitate public involvement/participation, and consider interagency conditions
Programming and preliminary design	Conduct environmental analysis, conduct schematic development, hold public hearings, determine right-of-way impact, determine project economic feasibility, obtain funding authorization, develop right-of-way, obtain environmental clearance, determine design criteria and parameters, survey utility locations and drainage, make preliminary plans such as alternative selections, assign geometry, and create bridge layouts
Final design	Acquire right-of-way; develop plans, specifications, and estimates; and finalize pavement and bridge design, traffic control plans, utility drawings, hydraulics studies/drainage design, and cost estimates
Advertise and bid	Prepare contract documents, advertise for bid, hold a pre-bid conference, and receive and analyze bids
Construction	Determine the lowest responsive bidder, initiate contract, mobilize, conduct inspection and materials testing, administer contract, control traffic, and construct bridge, pavement, and drainage

corridor planning, and conceptual design, are considered sunk costs and are included in the project's overhead.

2.3.1 Statewide Transportation Improvement Plan

Federal regulations require that state DOTs develop a STIP. The STIP contains capital and noncapital transportation projects proposed for funding under Title 23 (highways) and Title 49 (transit) of the U.S. Code as well as all regionally significant transportation projects that require an action by the FHWA or the FTA.

In July 2012, the president signed the Moving Ahead for Progress in the 21st Century Act (MAP-21). The STIP is developed under current federal regulations (23 CFR). Currently, the development of a new STIP is required at least every 4 years and must contain a minimum 4-year listing of federal-aid projects. The STIP must be approved by the FHWA and the FTA.

Federal regulations require each STIP to be fiscally constrained. All federally funded transportation projects must be included in the STIP. In some states it is transportation commission policy to include state-funded projects and local projects with the department's oversight in the STIP. The STIP was identified as a good baseline for the start of preconstruction services once a project gains funding authorization.

2.4 Design Cost Estimating

The 2012 update of ASCE Manual of Practice 45 states that there are five methods for charging for design services:

1. Multiplier: salary cost times multiplier, plus direct nonsalary expense;
2. Hourly: hourly billing rate, plus reimbursable expenses and a "not to exceed" amount for specific services;
3. Per diem: fixed charge per day;
4. Cost plus fixed fee; and
5. Lump sum or fixed price (ASCE 2012).

The first four methods are variable cost methods as the price the client will pay varies depending on the actual amount of work performed (ASCE 2012). The fifth method, lump sum or fixed fee, is a single factor and is useful if there is a well-defined project scope. When an agency outsources design, there is commonly a defined but general scope of work. However, as the project is yet to be designed, that scope is conceptual, and both the owner and the consultant must estimate the design effort to achieve the necessary functional requirements. By adding a contingency, the need to request authorization for additional funds to complete the design process is avoided. Without a contingency, there exists a strong bias against requesting additional funding (Flyvbjerg 2002). If a contingency is not used during the design, those funds can then be released.

2.4.1 Contingencies

When estimating project design cost, the scope is articulated in functional terms, but the design details are unknown. Nevertheless, current practice tends toward negotiating a lump sum design fee, which unintentionally implies a level of certainty and may not be dependable (Gransberg et al. 2007). Some agencies will only use variable cost methods to allow for the uncertainty; however, it is important to have a known range for funding authorization. A design estimate is the expected value of design, and a contingency can be included in the estimate to account for the higher end of the possible cost range for the project (Mak and Picken 2000). In public works, the project's contingency is used to effectively account for the risks associated with both the design process and the construction project. However, in many cases, it is calculated as an arbitrary percentage. For example, the U.S. Army Corps of Engineers (U.S. ACE) requires a 5% contingency (U.S. Army Corps of Engineers 1997), and the Riverside County California DOT uses 10% to be added to project cost estimates before design commences (Riverside County 1999).

Figure 2.2 shows the project development process, how the risk is allocated, and how the contingency can be retired as the project progresses and risks are realized. Most of the research conducted about contingencies pertains to construction cost contingencies; however, an argument can be made that Figure 2.2 shows that the construction contingency is greater in the design stage where the unknowns are much greater, and as such, a design contingency is warranted for the very same reason.

2.4.2 Design Fee Estimating Approaches

This section highlights a number of methods used for estimating design costs within the transportation sector. One method found by the researchers is to estimate the design fee on a cost-per-plan-sheet basis. This method has been explored as a good PCS cost modeling technique; however, cost-per-plan-sheet methodology is becoming obsolete. This is due to the development of technology that permits plans to be produced electronically, making the correlation between number of plan sheets and design fee difficult to measure. New York State DOT (NYSDOT) developed a model using a commercial spreadsheet/database program to estimate the design hours for each project (Williams et al. 2013). The model allows the DOT to either search similar projects or generate an estimate of total design hours to be expected for a project. The model was developed using a 12-key project characteristic

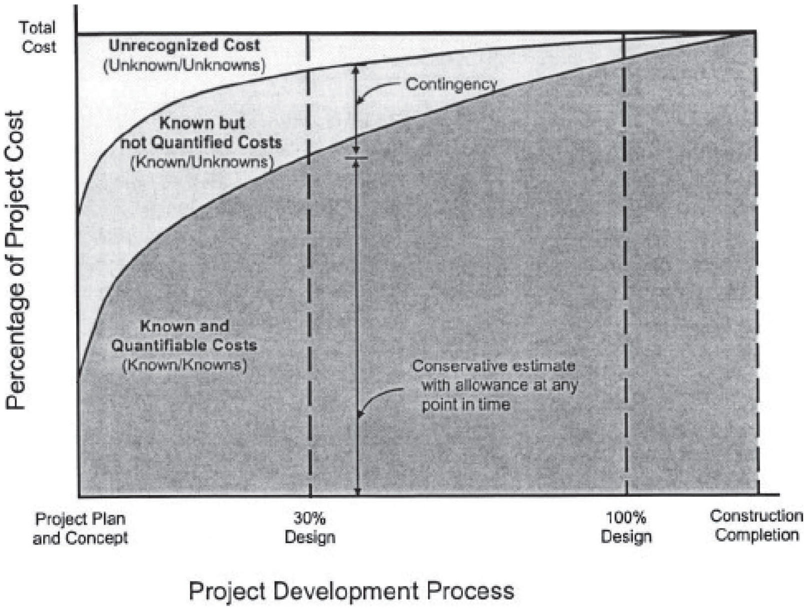


Figure 2.2. Conceptual components of a cost estimate (Molenaar 2005).

approach chosen by the NYSDOT engineers as defining factors of a project. These were:

1. Complexity,
2. Project type,
3. Number of sub-consultants,
4. Construction cost,
5. Number of lanes,
6. Number of plan sheets,
7. State Environmental Quality Review classification,
8. NEPA classification,
9. Predominant bridge type,
10. Number of bridges,
11. Highway classification, and
12. Length of project (Williams et al. 2013).

These characteristics became the input factors in the model. The number of plan sheets is used as the independent variable to calculate the total design hours. Hours are calculated from a simple regression model that is expected to become more accurate as more project data are made available (Williams et al. 2013). This methodology is similar to what the researchers used in Phase 2 of the project while developing the PCS model. Refer to Section 3.6.1 for more information.

It has been suggested that using labor hours as an estimating tool could cause a misrepresentation of the total work performed (Sturts and Griffis 2005). Due to the advancement in available technology and computer-aided design, the labor hours can be significantly reduced but the value of the design could be increased (Sturts and Griffis 2005). This was also suggested by Carr and Beyor (2008), who found that the design fees are not keeping up with the inflation of construction prices. Another study (Gransberg et al. 2007) found that if the design fee of a project is too low, it can lead to major cost growth in the construction process due to incomplete construction documents. The issue of underestimating the reasonable cost of the necessary design effort must be considered when using past project data to estimate direct hours, and adjustments should be made if necessary.

The American Council of Engineering Companies of Texas (ACEC) released a formula to estimate a fee for consultant design of a transportation project. The formula uses a number of technical factors related to the project to determine the percentage of design fee estimate. Table 2.2 shows all the factors that are considered. The estimator must determine the appropriate value for each factor for each individual project. Equation 2.1 is the ACEC formula (American Council of Engineering Companies of Texas 2005):

$$F = \frac{12(1+C)}{(P/A)0.1} \qquad \text{Eq. 2.1}$$

where:

F = engineering fee as a percent of construction cost,
C = sum of fee factors (See Table 2.2),
A = cost index factor = CCI current/CCI1993,
CCI = Engineering News Record construction cost index,
CCI1993 = 3,484.85 (Dallas, Texas–March 1993), and
P = construction cost in millions of dollars.

Table 2.2. ACEC table of technical factors (American Council of Engineering Companies of Texas 2005).

Technical Factors	Factor Values
1. Level of information required on plans/drawings	-0.20 to 0.10
2. Project requirement a. Scope of services b. Rehab vs. grass roots project c. Interface with other contracts/consultants d. Numerous disciplines required e. Alteration/modification of existing facility f. Complexity of project	-0.20 to 0.33
3. Existing data (e.g., preliminary engineering report, as-constructed drawings/specifications)	-0.35 to 0.20
Owner-Controlled Factors	**Factor Values**
1. Risk/liability (base standard of risk limited to fee)	-0.10 to 0.10
2. Time required for owner review/approvals (2 weeks standard)	0.0 to 0.20
3. Number of submittals/owner reviews	Add 0.05 for each submittal in addition to preliminary and final
4.Schedule for completing work – fast-track vs. reasonable schedule	0.0 to 0.20
5. Payment schedule – 30 days after receipt of invoice	0.01 for each late 30-day period
6. Owner requested sub-consultants	0.05 to 0.15 of the value of the subcontract
7. Owner participation in project/partnering	0.0 to 0.20
8. Construction inspection limiting participation of engineer	0.05 to 0.20
External Factors	**Factor Values**
1. Coordination with other entities	0.0 to 0.12
2. Environmental regulations	0.0 to 0.12
3. Not-in-my-backyard/citizen's involvement	0.0 to 0.20
4. Governmental constraints	0.0 to 0.20

This estimate considers a variety of technical factors to either increase or decrease the estimated fee depending on project conditions. Table 2.2 incorporates all 12 of the factors influencing project design cost specified in ASCE Manual of Practice 45 (ASCE 2012).

ASCE published design fee curves in the 2002 edition of Manual of Practice 45. These curves displayed a range of design fees versus construction costs. In the 2012 edition of the manual, it was noted that the fee curves were followed by owners as absolute fee estimates, which was not ASCE’s intention. As a result, the 2012 data did not contain the fee curves (ASCE 2012). Figure 2.3 shows the total fee percentage versus new construction cost. This graph used the cost data from the 2012 edition of the Manual of Practice 45, and the line representing the fee curve has been added by the researchers to mimic the curves in the 2002 edition. This curve can be used to determine the percentage of construction cost that would be the design fee.

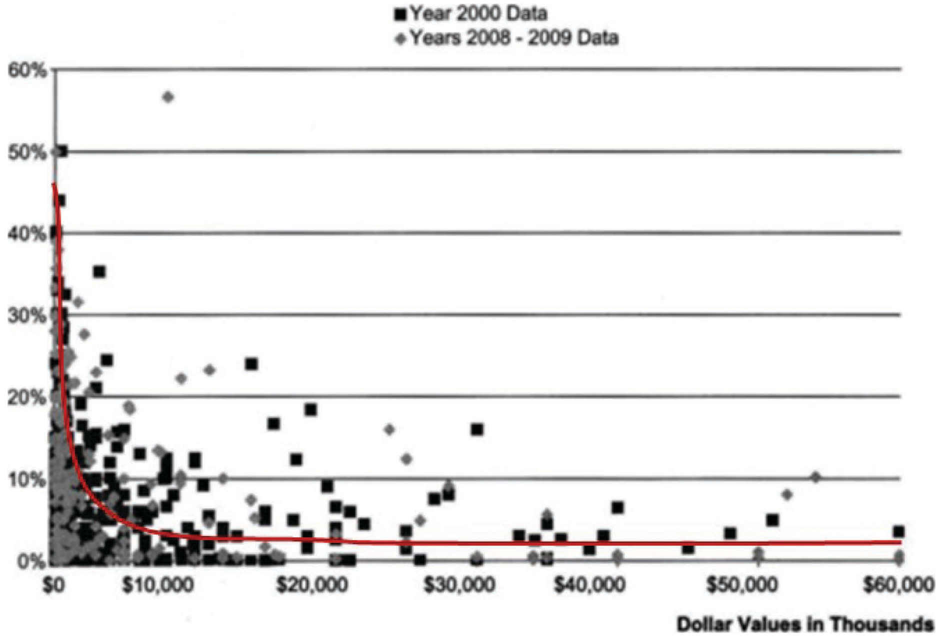


Figure 2.3. Total design fee percentage versus new construction cost (ASCE 2012).

The Institute of Professional Engineers New Zealand and the Association of Consulting Engineers New Zealand also developed a guideline for estimating consulting engineering services fees as a percentage of the estimated construction cost (Association of Consulting Engineers New Zealand and Institute of Professional Engineers New Zealand 2004). This is a common method for estimating design cost as the construction cost tends to be easier to quantify than the design cost (Sturts and Griffis 2005). The curves were developed using data from past projects and provide a best practice for estimating consultant fees; however, individual project interpretation is encouraged. It is noted in the guideline that the fee estimate includes project estimates, economic studies, alternative evaluations, and schedule of quantities. If the required services for a particular project are different, an adaptation of the fee is required.

The method divides projects up into nine different classes, with each type having subtypes to define the project. Figure 2.4 shows the fee guideline for the class GG; this class corresponds to the following types of projects in the highway sector:

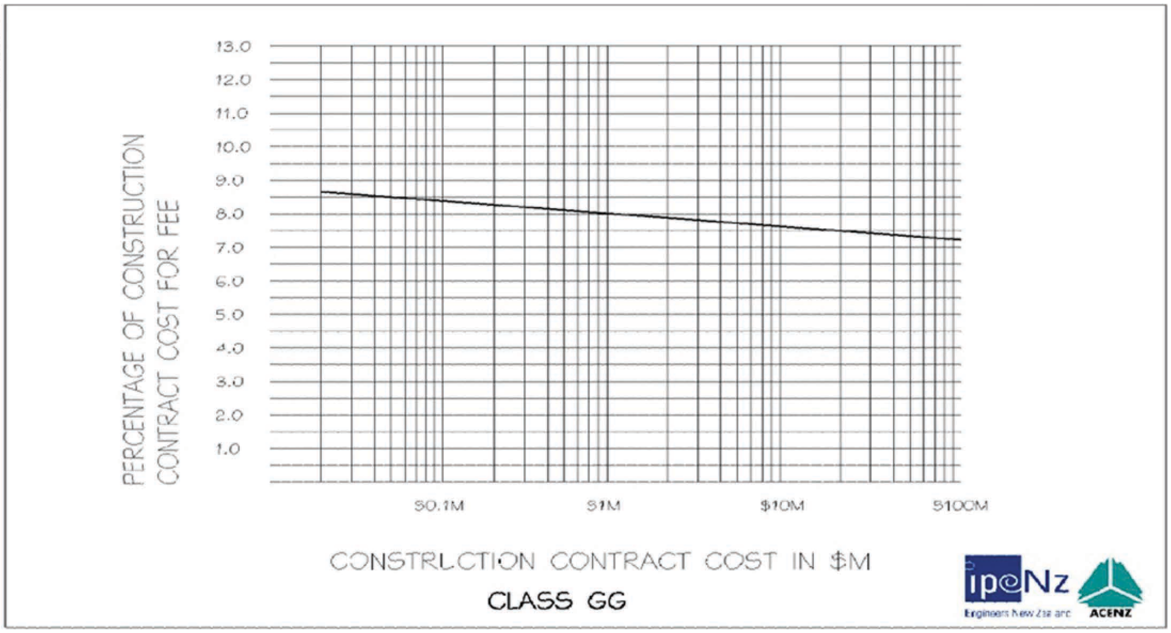
- State highway,
- State highway state correction,
- State highway rehabilitation,
- Bridges: urban, and
- Bridges: state highway.

The graph relates the project complexity and degree of urbanization to the design effort required. From Figure 2.4 it can be seen that there is a logarithmic relationship between the construction cost and design fee (Association of Consulting Engineers New Zealand and Institute of Professional Engineers New Zealand 2004).

2.5 Screening Survey

A screening survey was issued at the AASHTO SCOD conference in Bozeman, Montana, June 2 through June 6, 2013. A copy of this survey can be found in Appendix B. From the 35 states represented at the conference, the researchers received 18 responses. The survey was designed to give the researchers a basic idea of the preconstruction services makeup of an agency and to identify what methods were being used to estimate preconstruction services costs, what data an agency had available on PCS, and whether it would be willing to share it with the researchers. A summary of the results from the screening survey is shown in Tables 2.3 and 2.4.

It can be seen from Table 2.3 that all agencies except for Wyoming outsource PCS services, and most agencies outsource more than 31% of these services. The results of the survey also identified potential case study candidates who had available PCS cost data and were willing to share these data with the research team. It can be seen from Table 2.4 that there is a wide variety of methods in use to estimate PCS



Note: All costs are in New Zealand dollars.

Figure 2.4. State highway road, shape correction, pavement rehabilitation, bridge, and urban bridge fee guideline (Association of Consulting Engineers New Zealand and Institute of Professional Engineers New Zealand 2004).

costs, and there are some overlaps, which could indicate that the agency uses two estimating methods and compares the results. The planning and construction phases were the least familiar to the survey respondents. This is likely due to the fact that most state design engineers completing the survey do not work in these areas of the project development process.

After a discussion with the panel of the results of the screening survey, the team chose to not include the planning phase in the PCS definition because it is difficult to pinpoint the beginning of this process for a particular project. However, the construction procurement section is included in the definition for PCS. This information is likely to be more readily available within the agency but from different staff. As this survey was distributed at the AASHTO SCOD conference, design engineers were the respondents, and they do not usually perform the procurement section of the preconstruction process. In the interviews with the agencies, the research team was able to meet with a wide range of the DOT personnel involved in the agencies' PCS processes and get responses covering construction contract preparation and procurement.

Table 2.3. Summary results from screening survey.

Response from 17 of the 35 States Present				
Do you outsource PCS?	Yes		No	
	AK, ME, AL, CA, GA, KS, MD, MS, WA, WI, NE, SD, MN, NC, WV, AZ		WY	
What % PCS do you outsource?	0%–30%	31%–60%	61%–90%	>91%
	CA, GA, KS, WI, NC	AK, ME, AL, MD, MS, NE, MN, WV, AZ	WA, SD	
Do you collect in-house cost per project?	Yes	No	No response	
	AK, AL, CA, GA, KS, MS, WA, WI, NE, SD, NC, WV, AZ	ME, MD, MN	WY	

Table 2.4. Methods that states use to estimate the cost of the following activities.

Phases	Planning		Preliminary Engineering		Environmental Engineering		Final Engineering		Construction
Activities / Methods	Project Start-Up (before MOP or STIP)	Scope and Budget – Concept	Stage 1 Design – Evaluating Alternatives	Initial Cost Estimations	Environmental Field Studies – Preferred Alternatives	NEPA and Permit Approval	Detailed Design	Final Plan Package	Procurement
Trns.port software	–	–	–	–	–	–	AL	AL	AL
Standard % of estimated const. cost	AK, AL, CA, GA, MD, WA, NE, MN	AK, AL, CA, MD, MS, WA, NE, SD, MN	ME, AL, KS, MD, NE, SD, MN	ME, AL, MD, WA, NE, SD	AL, KS, MD, WA, NE, SD	AL, MD, WA, NE, SD	KS, MD, NE, SD, MN, AZ	KS, MD, NE, SD, AZ	KS, SD, AZ
Direct estimate of hours	–	GA, NC	CA, MS, WI, NC, AZ, WY	CA, MS, WA, WI, NC, AZ, WY	AK, CA, MS, WI, MN, NC, AZ, WY	AK, CA, MS, WI, NC, AZ, WY	AK, CA, MS, WA WI, MN, NC, AZ, WY	AK, CA, MS, WA WI, NC, AZ, WY	CA, WA, AZ, WY
Past project cost range	AL, WA, MN	AL, WA, MN	ME, AL, MS, WI, MN, WV, AZ	ME, AL, MS, WA, WI, WV, AZ	AL, MS, WA, WI, MN, WV, AZ	AL, MS, WA, WI, WV, AZ	ME, MS, WI, MN, WV	ME, WI, WV	ME
Don't know	ME, MS, NC, WV, AZ, WY	ME, WV, AZ, WY	AK	AK	ME	ME	–	–	AK, MD, MS, NE, NC, WV

Note: MOP = maintenance operations plan.

CHAPTER 3

Preconstruction Services Case Studies

3.1 Introduction

There has been a substantial amount of research into estimating construction costs for highway projects, and there are a handful of studies about estimating design cost and preliminary engineering, but there has been no research about estimating preconstruction services costs. The focus here is on the 16 projects and the nine agency case studies collected by the research team and the relevant analyses and observations of those case studies. Case studies formed the bulk of the original research conducted in Phase 1 of this research project and offered examples of PCS cost-estimating practices as well as agencies' breakdown of the PCS information available within each agency.

The chapter begins by discussing the case study data-collection protocol and methodology that allowed the team to secure information from each agency in a verifiable manner. This section includes a description of case study demographics and the rationale for choosing each case study agency and the accompanying projects. Following the methodology section are condensed synopses of the case study summaries. Detailed case study summaries are contained in the appendices. Because of the large amount of information contained in the summaries, tabular summaries of relevant details are presented at the end of the summaries section to assist the reader in comparing information from each study.

3.2 Case Study Protocol

While the benchmarking survey conducted in Task 1 provided some useful insights into the overall state of the practice, the case studies were the primary source of data on the PCS cost-estimating techniques in Phase 1 and eventually became the basis for the practices suggested by the guidebook in Phase 2. This information on an agency's PCS structure will also aid in the development of the parametric estimating model. Since the collection of information via agency interviews and project case studies is the predominant research instrument in the research project, a large amount of time was invested to determine to how best to conduct the case studies, reduce the subsequent data, and capture valuable information.

Researchers differ in their preference for research techniques and protocols best used in various environments; case study research has been shown to be a powerful research tool to evaluate and analyze emerging business practices such as PCS estimating techniques (Eisenhardt 1991). Case studies are particularly useful in answering questions about how things are done in detail, especially when examining a number of different cases (Yin 2008). The use of the case study method was essential in this research for capturing the unique nature and methods of the differing PCS cost-estimating procedures employed by each agency and understanding the rationale behind the agencies' chosen methods.

The major objection to the use of case studies has been the perceived lack of statistical rigor. Recognizing this criticism, the researchers sought to generate a defensible, repeatable method to guide the case study process. This method was formalized and recorded in the case study protocol for the project. Creation of the case study protocol was guided by an influential book on the technique written by Yin (2008).

The case study protocol served to establish the purpose of the case studies and the research questions to be answered by them. Clearly stating the specific information sought by the researchers at the start of this crucial task ensured that all researchers who were conducting case study interviews understood the ultimate goals of the research. The background information for the protocol included key sections of the project proposal and work plan, such as the three questions used to further explore the objectives of this research:

1. What project characteristics are important to developing an accurate PCS cost estimate?
2. What steps must be followed to implement a standardized PCS cost-estimating methodology?

3. How are PCS cost-estimating consultant contracts successfully procured?

The most important aspect of the protocol was the field data-collection procedures. These procedures standardized the method to conduct all of the case study data and facilitate consistent and comparable results among the case studies. The key research instrument is the structured interview based on a standard case study questionnaire (U.S. Government Accountability Office 1991). The questionnaire was sent to the participants a week in advance of the interview. Each agency's PCS estimating procedures are unique, and the interview process was designed to capture that uniqueness while generating a standard comparable output. To that end, the questionnaire maximized the use of yes/no questions and matrices of checklists to be complete for every case study. Additionally, open-ended questions were crafted to generate in-depth discussion to fill in the details that surveys and questionnaires cannot easily capture.

3.3 Case Study Process

The case study protocol included a pilot case study to evaluate the efficacy of the process before modifying the case study protocol and completing the remaining cases. The pilot study also served to allow the research team an opportunity to become familiar with the case study protocol for this project and provide comments on it or recommendations for changes. After the pilot study took place with the Montana DOT, a few minor adjustments were made to the agency structured interview questionnaire. There were additional explanation boxes added to gain a more in-depth understanding of each agency's PCS processes, and both loss of design effort and geographic factors were added to the matrix concerning the list of factors that influence the PCS estimate. Finally, there was the addition of a question about the impact the DOT thought a better PCS estimate would make on the planning process.

The case study protocol for this project mandated a specific sequential order for communications and interactions with project participants that was followed for each case study. First, all interviews with the participating agencies were conducted on site and in person at the agency's headquarters to ensure appropriate people were available to answer the questions provided. Other initial inquiries were made via email, but the personal contact was vital to the quality of the information collected in each case study. The personal contact with the key PCS cost-estimating personnel participants provided a champion for the research effort and a specific point of contact for queries during data reduction and interpretation. The participants were not compensated for their time by the research team, making it essential to secure at least one agency staff member who was enthusiastic about assisting with the research effort and was in a position to coordinate with the rest of the agency.

3.4 Case Study Selection

As this was a national research project, the research team wanted a fair representation of states considering factors like population, budget, land area, and in-house versus outsourced PCS makeup. There was an original shortlist of 16 states proposed to the panel in the kick-off meeting on April 17, 2013. After a discussion with the panel, nine DOTs were selected. Four were selected as agency case study states where all the cost data for multiple projects were captured for use in Task 4. These four agencies along with the other five were all project case study agencies where data were collected on the agencies' PCS cost-estimating procedures, and some project case study projects were collected. The nine participating agencies are listed in Table 3.1 along with population, land area, and the DOT's yearly construction budget.

Table 3.1. Case study agency information (U.S. Census Bureau 2014).

Agency	Area Population (million)	Land Area (square miles)	Budget ($ million)
California*	38.3	155,779	$13,000–$15,000
Colorado	5.27	103,642	$500– $700
Iowa*	3.09	55,857	$400
Maryland	5.93	9,707	$600–$800
Montana	1.02	145,546	$385
New York*	19.7	47,126	$1,000
Oklahoma	3.85	68,595	$632–$790
Rhode Island	1.05	1,034	$300
Utah*	2.90	82,170	$1,100

*Indicates agency case study state where data for all projects from the previous 5 years was collected.

Figure 3.1. Geographical distribution of the case study states.

Representatives from these nine agencies were interviewed in a structured interview process to determine the agencies overall PCS cost-estimating procedures. The interview template is shown in Appendix C. Each agency was also asked to provide two to five projects for case studies for the research. The researchers ended with 16 projects from six of the nine agencies. Figure 3.1 shows the geographical distribution of the states. A synopsis of these interviews and case studies is provided in Section 3.5.

3.5 Case Study Agency Synopsis

For full case study reports refer to Appendix D.

3.5.1 Agency Case Studies

Agency: *California Department of Transportation–Caltrans*

Data Collection Details

- Collected

Caltrans collects project cost data for PCS through engineers' timesheets. Caltrans uses data collected from past projects to estimate the PCS cost for future projects. It also has a system called PIPE scan, which is used as a starting point for PCS estimates. Current methods used to estimate PCS costs for a project include a direct estimate of hours as well as an average percent support-to-cap ratio.

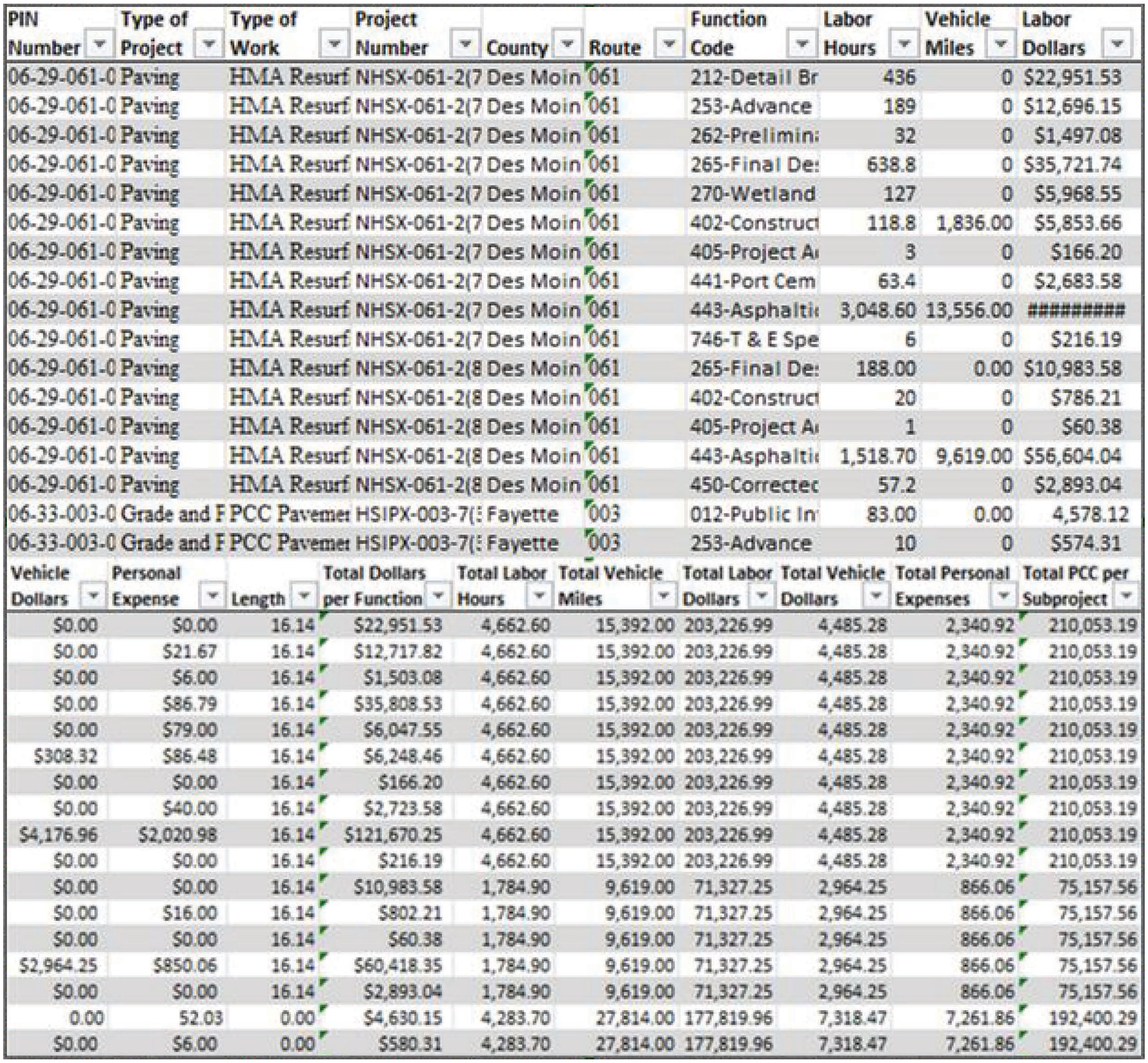
Caltrans performs 90% of PCS in-house and contracts out 10% of PCS. Each district has its own on-call contracts with preselected qualified architect and engineering consultants. Caltrans can outsource all PCS activities except advertisement for bids, evaluation of bids, and award of contract. It is rare for Caltrans to outsource PCS concerning cost estimates, ROW plans, and ROW utility acquisition and relocation.

At Caltrans, if there is a loss of funding for a project when it is in the PCS phase, the project will be terminated. Once funding for the project is resumed, a new project number is assigned; therefore, it does not consider loss of design effort. These costs will be included in the overhead rate. To improve PCS estimates, Caltrans believes it needs a better model for historical data analysis and needs to do bottom-up estimates. At this stage, the project manager does not control the people working on projects in the PCS phase. Caltrans believes that having more accurate PCS cost estimates would have some impact, mainly on the budget process.

Agency: *Iowa Department of Transportation–Iowa DOT*

Data Collection Details

- Collected
- Approximately 1,303 projects
- 11 project types
- Figure 3.2 shows an example of the data collected for Iowa DOT projects.



PIN Number	Type of Project	Type of Work	Project Number	County	Route	Function Code	Labor Hours	Vehicle Miles	Labor Dollars
06-29-061-0	Paving	HMA Resurf	NHSX-061-2(7	Des Moin	061	212-Detail Br	436	0	$22,951.53
06-29-061-0	Paving	HMA Resurf	NHSX-061-2(7	Des Moin	061	253-Advance	189	0	$12,696.15
06-29-061-0	Paving	HMA Resurf	NHSX-061-2(7	Des Moin	061	262-Prelimin:	32	0	$1,497.08
06-29-061-0	Paving	HMA Resurf	NHSX-061-2(7	Des Moin	061	265-Final De:	638.8	0	$35,721.74
06-29-061-0	Paving	HMA Resurf	NHSX-061-2(7	Des Moin	061	270-Wetland	127	0	$5,968.55
06-29-061-0	Paving	HMA Resurf	NHSX-061-2(7	Des Moin	061	402-Construct	118.8	1,836.00	$5,853.66
06-29-061-0	Paving	HMA Resurf	NHSX-061-2(7	Des Moin	061	405-Project A	3	0	$166.20
06-29-061-0	Paving	HMA Resurf	NHSX-061-2(7	Des Moin	061	441-Port Cem	63.4	0	$2,683.58
06-29-061-0	Paving	HMA Resurf	NHSX-061-2(7	Des Moin	061	443-Asphalti	3,048.60	13,556.00	#########
06-29-061-0	Paving	HMA Resurf	NHSX-061-2(7	Des Moin	061	746-T & E Spe	6	0	$216.19
06-29-061-0	Paving	HMA Resurf	NHSX-061-2(8	Des Moin	061	265-Final De:	188.00	0.00	$10,983.58
06-29-061-0	Paving	HMA Resurf	NHSX-061-2(8	Des Moin	061	402-Construct	20	0	$786.21
06-29-061-0	Paving	HMA Resurf	NHSX-061-2(8	Des Moin	061	405-Project A	1	0	$60.38
06-29-061-0	Paving	HMA Resurf	NHSX-061-2(8	Des Moin	061	443-Asphalti	1,518.70	9,619.00	$56,604.04
06-29-061-0	Paving	HMA Resurf	NHSX-061-2(8	Des Moin	061	450-Correctec	57.2	0	$2,893.04
06-33-003-0	Grade and F	PCC Paveme	HSIPX-003-7(:	Fayette	003	012-Public In	83.00	0.00	4,578.12
06-33-003-0	Grade and F	PCC Paveme	HSIPX-003-7(:	Fayette	003	253-Advance	10	0	$574.31

Vehicle Dollars	Personal Expense	Length	Total Dollars per Function	Total Labor Hours	Total Vehicle Miles	Total Labor Dollars	Total Vehicle Dollars	Total Personal Expenses	Total PCC per Subproject
$0.00	$0.00	16.14	$22,951.53	4,662.60	15,392.00	203,226.99	4,485.28	2,340.92	210,053.19
$0.00	$21.67	16.14	$12,717.82	4,662.60	15,392.00	203,226.99	4,485.28	2,340.92	210,053.19
$0.00	$6.00	16.14	$1,503.08	4,662.60	15,392.00	203,226.99	4,485.28	2,340.92	210,053.19
$0.00	$86.79	16.14	$35,808.53	4,662.60	15,392.00	203,226.99	4,485.28	2,340.92	210,053.19
$0.00	$79.00	16.14	$6,047.55	4,662.60	15,392.00	203,226.99	4,485.28	2,340.92	210,053.19
$308.32	$86.48	16.14	$6,248.46	4,662.60	15,392.00	203,226.99	4,485.28	2,340.92	210,053.19
$0.00	$0.00	16.14	$166.20	4,662.60	15,392.00	203,226.99	4,485.28	2,340.92	210,053.19
$0.00	$40.00	16.14	$2,723.58	4,662.60	15,392.00	203,226.99	4,485.28	2,340.92	210,053.19
$4,176.96	$2,020.98	16.14	$121,670.25	4,662.60	15,392.00	203,226.99	4,485.28	2,340.92	210,053.19
$0.00	$0.00	16.14	$216.19	4,662.60	15,392.00	203,226.99	4,485.28	2,340.92	210,053.19
$0.00	$0.00	16.14	$10,983.58	1,784.90	9,619.00	71,327.25	2,964.25	866.06	75,157.56
$0.00	$16.00	16.14	$802.21	1,784.90	9,619.00	71,327.25	2,964.25	866.06	75,157.56
$0.00	$0.00	16.14	$60.38	1,784.90	9,619.00	71,327.25	2,964.25	866.06	75,157.56
$2,964.25	$850.06	16.14	$60,418.35	1,784.90	9,619.00	71,327.25	2,964.25	866.06	75,157.56
$0.00	$0.00	16.14	$2,893.04	1,784.90	9,619.00	71,327.25	2,964.25	866.06	75,157.56
0.00	52.03	0.00	$4,630.15	4,283.70	27,814.00	177,819.96	7,318.47	7,261.86	192,400.29
$0.00	$6.00	0.00	$580.31	4,283.70	27,814.00	177,819.96	7,318.47	7,261.86	192,400.29

Figure 3.2. Snapshot of Iowa DOT project data.

Iowa DOT collects project cost data for PCS through engineers' timesheets. These data are collected and stored mainly for accounting purposes. Iowa DOT does not use data collected from past projects to estimate the PCS cost for future projects. It does not estimate PCS cost for a project.

Iowa DOT can use both in-house and on-call consultants; it also uses other consultants, but only for larger, less-common projects.

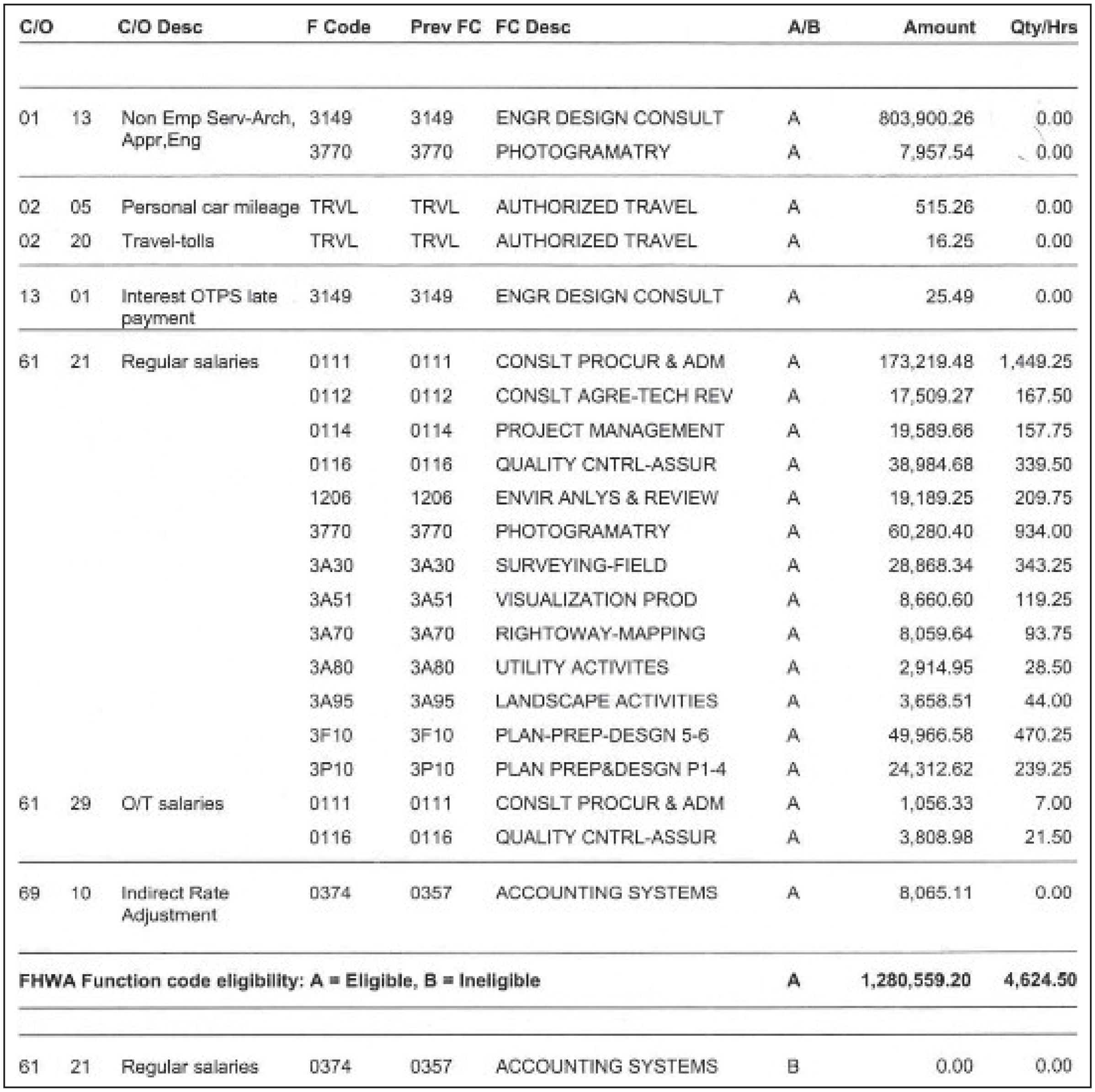
Currently, Iowa DOT is not estimating PCS cost for projects, but it is looking to adopt this in the future. To improve these estimates, Iowa DOT believes it needs to learn how to use the data it already has. Iowa DOT has been capturing PCS hours for a few years, and it needs a way to organize these data to make them useful in PCS estimating. Iowa DOT thinks that having a more accurate estimate of PCS costs would have a large impact on the planning process for the agency and would allow it to better budget staff time. It also would be valuable to know the number of hours per task and to be able to compare these to consultant design hours.

Agency: *New York State Department of Transportation–NYSDOT*

Data Collection Details

- Collected

Figure 3.3 and Table 3.2 show examples of the data available for NYSDOT projects. NYSDOT collects project cost data for PCS through engineers' timesheets. These data are used by



C/O	C/O Desc	F Code	Prev FC	FC Desc	A/B	Amount	Qty/Hrs
01 13	Non Emp Serv-Arch, Appr,Eng	3149	3149	ENGR DESIGN CONSULT	A	803,900.26	0.00
		3770	3770	PHOTOGRAMATRY	A	7,957.54	0.00
02 05	Personal car mileage	TRVL	TRVL	AUTHORIZED TRAVEL	A	515.26	0.00
02 20	Travel-tolls	TRVL	TRVL	AUTHORIZED TRAVEL	A	16.25	0.00
13 01	Interest OTPS late payment	3149	3149	ENGR DESIGN CONSULT	A	25.49	0.00
61 21	Regular salaries	0111	0111	CONSLT PROCUR & ADM	A	173,219.48	1,449.25
		0112	0112	CONSLT AGRE-TECH REV	A	17,509.27	167.50
		0114	0114	PROJECT MANAGEMENT	A	19,589.66	157.75
		0116	0116	QUALITY CNTRL-ASSUR	A	38,984.68	339.50
		1206	1206	ENVIR ANLYS & REVIEW	A	19,189.25	209.75
		3770	3770	PHOTOGRAMATRY	A	60,280.40	934.00
		3A30	3A30	SURVEYING-FIELD	A	28,868.34	343.25
		3A51	3A51	VISUALIZATION PROD	A	8,660.60	119.25
		3A70	3A70	RIGHTOWAY-MAPPING	A	8,059.64	93.75
		3A80	3A80	UTILITY ACTIVITES	A	2,914.95	28.50
		3A95	3A95	LANDSCAPE ACTIVITIES	A	3,658.51	44.00
		3F10	3F10	PLAN-PREP-DESGN 5-6	A	49,966.58	470.25
		3P10	3P10	PLAN PREP&DESGN P1-4	A	24,312.62	239.25
61 29	O/T salaries	0111	0111	CONSLT PROCUR & ADM	A	1,056.33	7.00
		0116	0116	QUALITY CNTRL-ASSUR	A	3,808.98	21.50
69 10	Indirect Rate Adjustment	0374	0357	ACCOUNTING SYSTEMS	A	8,065.11	0.00
FHWA Function code eligibility: A = Eligible, B = Ineligible					**A**	**1,280,559.20**	**4,624.50**
61 21	Regular salaries	0374	0357	ACCOUNTING SYSTEMS	B	0.00	0.00

Figure 3.3. Snapshot of NYSDOT project data.

Table 3.2. NYSDOT project data.

Project name	Western Ave – NYS	I787 NYS
Procurement method	DBB	DBB
Project type	Reconstruction	Bridge rehabilitation
PCS performance	Consultant	In-house
Total project cost	$9,700,000.00	$28,000,000.00
Total PCS cost	$1,280,000.00	$1,333,346.08
PCS percentage	13%	5%
Complexity	2	4
Sub-consultants	2	0
Lanes	6	6
Plan sheets	198	648
NEPA classification	Cad X	Cad X
Bridges	0	6
Highway classification	Interstate	Interstate
Length of project (miles)	12.1	4.3

project managers to predict an estimate for future projects with similar qualities. NYSDOT uses an in-house system called DPR that contains a selection of tools to estimate PCS hours. NYSDOT is looking at moving to the use of Primavera P6 in the future.

By dollar value, NYSDOT performs 50% of PCS in-house and 50% is outsourced, and by number of projects, 90% is in-house and 10% is outsourced. NYSDOT does not perform environmental sampling and testing or surveying services; it uses on-call contracts for these services even if all PCS services are performed in-house. NYSDOT can outsource all PCS activities except advertisement for bids, evaluation of bids, and award of contract.

NYSDOT does not consider number of plan sheets as an influential characteristic in the PCS estimating due to recent advances in technology and the general move to electronic plans. NYSDOT believes that a major setback to estimating PCS costs is how to estimate inflation as it is difficult if project development occurs over multiple years. NYSDOT believes that to improve its PCS cost estimating, it needs to move to task-based estimating, but it is skeptical about whether the time and effort would result in any real value for the agency.

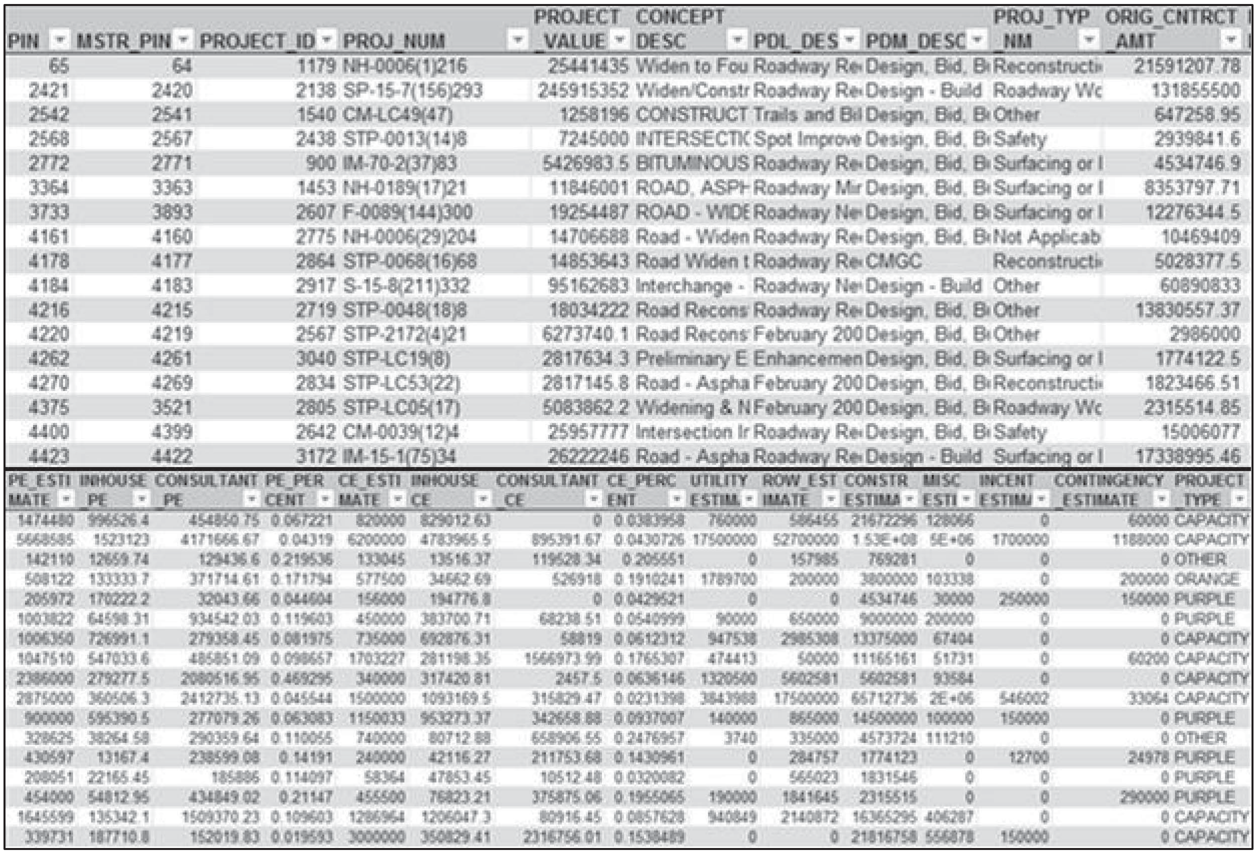
Agency: *Utah Department of Transportation–UDOT*

Data Collection Details

- Collected
- Approximately 564 projects
- 21 project types
- Five procurement methods ≈ 516 design–bid–build
- Figure 3.4 and Table 3.3 show examples of the data collected for UDOT projects.

UDOT collects project cost data for PCS through engineers' timesheets. These data are stored in ePM (electronic project management) and are used by project managers to predict an estimate for future projects with similar qualities. UDOT also performs a direct estimate of hours for PCS work, which is compared with the past project cost range as a check.

By dollar value, UDOT performs 25% of PCS in-house and 75% is outsourced. UDOT can outsource all PCS activities except advertisement for bids, evaluation of bids, and award of contract. UDOT tries to decide early on whether the project will be outsourced or performed in-house so that it can set the budget early.



PIN	MSTR_PIN	PROJECT_ID	PROJ_NUM	PROJECT _VALUE	CONCEPT DESC	PDL_DES	PDM_DESC	PROJ_TYP _NM	ORIG_CNTRCT _AMT
65	64	1179	NH-0006(1)216	25441435	Widen to Fou	Roadway Re	Design, Bid, B	Reconstructi	21591207.78
2421	2420	2138	SP-15-7(156)293	245915352	Widen/Constr	Roadway Re	Design - Build	Roadway Wc	131855500
2542	2541	1540	CM-LC49(47)	1258196	CONSTRUCT	Trails and Bil	Design, Bid, B	Other	647258.95
2568	2567	2438	STP-0013(14)8	7245000	INTERSECTI(	Spot Improve	Design, Bid, B	Safety	2939841.6
2772	2771	900	IM-70-2(37)83	5426983.5	BITUMINOUS	Roadway Re	Design, Bid, B	Surfacing or I	4534746.9
3364	3363	1453	NH-0189(17)21	11846001	ROAD, ASPH	Roadway Mir	Design, Bid, B	Surfacing or I	8353797.71
3733	3893	2607	F-0089(144)300	19254487	ROAD - WIDE	Roadway Ne	Design, Bid, B	Surfacing or I	12276344.5
4161	4160	2775	NH-0006(29)204	14706688	Road - Widen	Roadway Re	Design, Bid, B	Not Applicab	10469409
4178	4177	2864	STP-0068(16)68	14853643	Road Widen t	Roadway Re	CMGC	Reconstructi	5028377.5
4184	4183	2917	S-15-8(211)332	95162683	Interchange -	Roadway Ne	Design - Build	Other	60890833
4216	4215	2719	STP-0048(18)8	18034222	Road Recons	Roadway Re	Design, Bid, B	Other	13830557.37
4220	4219	2567	STP-2172(4)21	6273740.1	Road Recons	February 200	Design, Bid, B	Other	2986000
4262	4261	3040	STP-LC19(8)	2817634.3	Preliminary E	Enhancemen	Design, Bid, B	Surfacing or I	1774122.5
4270	4269	2834	STP-LC53(22)	2817145.8	Road - Aspha	February 200	Design, Bid, B	Reconstructi	1823466.51
4375	3521	2805	STP-LC05(17)	5083862.2	Widening & N	February 200	Design, Bid, B	Roadway Wc	2315514.85
4400	4399	2642	CM-0039(12)4	25957777	Intersection Ir	Roadway Re	Design, Bid, B	Safety	15006077
4423	4422	3172	IM-15-1(75)34	26222246	Road - Aspha	Roadway Re	Design - Build	Surfacing or I	17338995.46

PE_ESTI MATE	INHOUSE PE	CONSULTANT PE	PE_PER CENT	CE_ESTI MATE	INHOUSE CE	CONSULTANT CE	CE_PERC ENT	UTILITY ESTIM	ROW_EST IMATE	CONSTR ESTIMA	MISC ESTI	INCENT ESTIM	CONTINGENCY _ESTIMATE	PROJECT _TYPE
1474480	996526.4	454850.75	0.067221	820000	829012.63	0	0.0383958	760000	586455	21672296	128066	0	60000	CAPACITY
5668585	1523123	4171666.67	0.04319	6200000	4783965.5	895391.67	0.0430726	17500000	52700000	1.53E+08	5E+06	1700000	1188000	CAPACITY
142110	12659.74	129436.6	0.219536	133045	13516.37	119528.34	0.205551	0	157986	769281	0	0	0	OTHER
508122	133333.7	371714.61	0.171794	577500	34662.69	526918	0.1910241	1789700	200000	3800000	103338	0	200000	ORANGE
205972	170222.2	32043.66	0.044604	156000	194776.8	0	0.0429521	0	0	4534746	30000	250000	150000	PURPLE
1003822	64598.31	934542.03	0.119603	450000	383700.71	68238.51	0.0540999	90000	650000	9000000	200000	0	0	PURPLE
1006350	726991.1	279358.45	0.081975	735000	692876.31	58819	0.0612312	947538	2985308	13375000	67404	0	0	CAPACITY
1047510	547033.6	485851.09	0.098657	1703227	281198.35	1566973.99	0.1765307	474413	50000	11165161	51731	0	60200	CAPACITY
2386000	279277.5	2080516.95	0.469295	340000	317420.81	2457.5	0.0636146	1320500	5602581	5602581	93584	0	0	CAPACITY
2875000	360506.3	2412735.13	0.045544	1500000	1093169.5	315829.47	0.0231398	3843988	17500000	65712736	2E+06	546002	33064	CAPACITY
900000	595390.5	277079.26	0.063083	1150033	953273.37	342658.88	0.0937007	140000	865000	14500000	100000	150000	0	PURPLE
328625	38264.58	290359.64	0.110055	740000	80712.88	658906.55	0.2476957	3740	335000	4573724	111210	0	0	OTHER
430697	13167.4	238599.08	0.14191	240000	42116.27	211753.68	0.1430961	0	284757	1774123	0	12700	24978	PURPLE
208051	22165.45	185886	0.114097	58364	47853.45	10512.48	0.0320082	0	565023	1831546	0	0	0	PURPLE
454000	54812.96	434849.02	0.21147	455500	76823.21	375875.06	0.1955065	190000	1841645	2315515	0	0	290000	PURPLE
1645599	135342.1	1509370.23	0.109603	1286964	1206047.3	80916.45	0.0857628	940849	2140872	16365295	406287	0	0	CAPACITY
339731	187710.8	152019.83	0.019593	3000000	350829.41	2316756.01	0.1538489	0	0	21816758	556878	150000	0	CAPACITY

Figure 3.4. Sample of UDOT agency project data.

Table 3.3. UDOT project data.

Project name	Region 3 - UT	Region 2 - UT	Region 4 - UT
Procurement method	DBB	DB	DBB
Project type	Reconstruction	Continuous flow intersections	Rehabilitation
PCS performance	ROW – Consultants All other PCS in-house	Consultant	In-house
Total project cost	$4,200,000.00	$48,981,854.37	$2,260,000.00
Total PCS cost	$277,253.92	$3,704,380.09	$17,634.00
PCS percentage	7%	8%	1%
Complexity	2	5	1
Sub-consultants	1	4	0
Lanes	6	6	2
Plan sheets	98	115	0
NEPA classification	Cad X	SES	Cad X
Bridges	0		0
Highway classification	Rural principal arterial	Major arterial	Major arterial
Length of project (miles)	2.5	2	8.48

UDOT does not believe it sets out to make mistakes; therefore, it does not consider loss of design effort necessary in estimating PCS costs. To improve PCS estimating, UDOT believes it needs to retain, hire, or train new experienced staff. UDOT believes that having more accurate PCS cost estimates could have some impact on the planning process and allow them to refine allocation of resources and negotiate with consultants better.

3.5.2 Project Case Studies

Agency: Colorado Department of Transportation–CDOT

CDOT does not collect past project cost data for PCS. For federally funded projects, CDOT has to submit an independent project cost estimate, and in this case, 10% is used for PCS costs. CDOT will collect all project data for projects in the bridge enterprise program and also for large projects. Table 3.4 shows an example of CDOT project data.

By number of projects, CDOT performs 45% of PCS in-house and 55% is outsourced. CDOT can outsource all PCS activities except advertisement for bids, evaluation of bids, and award of contract. CDOT does not have a policy on the amount of work outsourced; however, it needs to have reasonable justification before outsourcing a project.

CDOT considers the construction cost of a project to be a major influence on the PCS estimate for in-house projects but only a minor influence if PCS will be contracted out. CDOT is looking to adopt a tool that can help it estimate PCS costs, especially as there is a loss of experience when it employs young engineers. To improve its PCS estimating, the agency believes it requires good tools as well as data that align with the systems already in place at the agency. An improved PCS estimate is likely to benefit budget portfolio management as people usually involved with these estimates are often not engineers but are planners.

Agency: Maryland State Highway Administration–MSHA

MSHA does record in-house PCS hours on a per-project basis. It records these hours using time-tracking software. MSHA uses data collected from past projects along with

Table 3.4. CDOT project data.

Project name	Eagle interchange
Procurement method	CMGC
Project type	Major structure
PCS performance	Consultant
Total project cost	$15,100,000.00
Total PCS cost	$1,510,000.00
PCS percentage	10%
Complexity	4
Sub-consultants	8
Lanes	4
Plan sheets	515
NEPA classification	Cad X
Bridges	2
Highway classification	Major collector
Length of project (miles)	0.35

Table 3.5. MSHA project data.

Project name	Taneytown streetscape	MD 924
Procurement method	DBB	DB
Project type	Reconstruction	Safety
PCS performance		
Total project cost	$22,000,000.00	$10,000,000.00
Total PCS cost	$2,200,000.00	$800,000.00
PCS percentage	10%	8%
Complexity	4	4
Sub-consultants	8	2
Lanes	2	4
Plan sheets	354	
NEPA classification		Cad X
Bridges	0	0
Highway classification	Urban other principal arterial	Urban arterial
Length of project (miles)	2	0.5

standard percentages to estimate the PCS cost for future projects. The old system used 15% of the construction cost as preliminary engineering; MSHA now uses a curve system on preliminary engineering. Table 3.5 shows an example of MSHA project data.

MSHA has a standing contract for a general engineering consultant (GEC). MSHA can perform the entire preconstruction process in-house and can also outsource all PCS except ROW utility acquisition and relocation, advertisement for bids, evaluation of bids, and award of contract.

MSHA is currently estimating PCS costs for all projects. To improve these estimates, the agency believes it needs to develop a historical database of previous estimates. MSHA believes that having more accurate PCS cost estimates would have a large impact on the planning process since it believes that it would provide more efficiency to managing funds.

Agency: Montana Department of Transportation–MDT

MDT does record in-house PCS hours on a per-project basis. It records these hours using the engineers' timesheets and has a time allocation system per job. MDT does not use data collected from past projects to estimate the PCS cost for future projects. Table 3.6 shows an example of MDT project data.

MDT has a system that records past hours and durations of activities of 3 to 5 years to reconcile with activities to average activity hours. This system has no feedback loop, and therefore it is not used to look at past projects or to re-access the activity hours in OPX2 (project management tool).

MDT can perform the entire preconstruction process in-house except for feasibility studies, and it can outsource all PCS except advertisement for bids, evaluation of bids, and award of contract, which is considered in the construction department. Approximately 20% of the PCS program for MDT is outsourced.

Currently MDT is estimating PCS costs for all projects using a standard percentage of construction costs. To improve PCS estimates, MDT believes it needs to get to function-based estimating, and it also needs to determine how to allocate the funds in split-corridor projects. MDT also believes that it needs to improve how it captures the hours on timesheets.

Agency: Oklahoma Department of Transportation–ODOT

ODOT does not record in-house PCS hours on a per-project basis. Approximately 50% of engineers' time spent on PCS is billed to departmental overhead. Table 3.7 shows an example of ODOT project data.

ODOT can perform the entire preconstruction process in-house except right-of-way acquisition. It can also outsource all PCS except preferred alternative, NEPA and permit approval, final plan package [RFP and request for quotation (RFQ)], advertisement for bids, evaluation of bids, and award of contract.

Currently, ODOT believes estimating PCS cost would add value to the agency, but it has yet to implement a process to do so. To improve PCS cost estimates, the agency believes it needs to make direct changes to its projects and agency culture. ODOT believes that it would be difficult to convince all people within the agency to adopt a PCS estimating system.

Agency: Rhode Island Department of Transportation–RIDOT

RIDOT does record in-house PCS hours on a per-project basis. It records these hours using the engineers' timesheets.

Table 3.6. MDT project data.

Project name	Alberton – MT	Yellowstone – MT	Richey – MT	Libby – MT	Manchester – MT
Procurement method	DBB	DBB	DBB	DBB	DBB
Project type	Rehabilitation	Bridge replacement	Reconstruction	Rehabilitation	Rehabilitation
PCS performance	In-house	61% in-house, 39% consultant	81% in-house, 19% consultant	69% in-house, 31% consultant	In-house
Total project cost	$15,160,216.69	$11,117,526.18	$11,671,335.94	$5,154,041.00	$13,654,704.61
Total PCS cost	$ 326,984.74	$ 1,350,022.32	$ 747,932.55	$ 523,441.08	$ 221,626.30
PCS percentage	2%	12%	6%	10%	2%
Complexity	1	4	3	4	2
Sub-consultants	0	3	1	3	0
Lanes	4	2	2	2	4
Plan sheets	41	113	351	284	258
NEPA classification	Cad X	EA/FONSI	Cad X	Cad X	Cad X
Bridges	6	1	1	0	3
Highway classification	Principal arterial	Urban arterial/rural minor arterial	Major collector rural	Major collector rural	Principal arterial (freeway)
Length of project (miles)	9.8	0.7	10.7	5.1	5.4

RIDOT does not use data collected from past projects to estimate the PCS cost for future projects. Design costs are estimated by using 15% of total construction cost. However, this is not uniform; smaller projects tend to be of a higher percentage, and larger projects tend to be of a lower percentage. This process is only an educated guess.

RIDOT does contract out PCS. It has several on-call consultants because almost all its design work is outsourced. It uses two consultants for highway work, two for bridges, and four for traffic engineering. No single firm is the dominant GEC. RIDOT can advertise for bids, evaluate bids, award contracts, and perform some ROW utilities acquisition and relocation; all other PCS processes are outsourced.

RIDOT did not provide data for project case studies.

RIDOT does not see value in estimating PCS costs. Since it is a small organization, it has yet to develop a database to keep track of and evaluate PCS costs. Its priority lies in estimating construction costs. To improve these estimates, the agency believes it needs a database to pull scattered records and documentation of PCS into one place. There is a 2-year

Table 3.7. ODOT project data.

Project name	Garvin – OK	Beckham – OK	Payne – OK
Procurement method	DBB	DBB	DBB
Project type	Resurfacing	Resurfacing/ Bridge rehab	Pavement overlay
PCS performance	In-house	Outsourced	Outsourced
Complexity	4	4	3
Sub-consultants	0	2	2
Lanes	4	4	4
Plan sheets	131	60	50
NEPA classification	Cad X	Cad X	Cad X
Bridges	6	5	0
Highway classification	Interstate	Interstate	I-35
Length of project (miles)	6.5	7.93	5.4

election cycle, so government and legislative representatives change regularly; therefore, projects continue to lose and gain importance depending on the political influence. RIDOT believes that having more accurate PCS cost estimates would have no impact on the planning process. It believes that PCS costs have very little impact on the overall program, and projects will be executed no matter what the magnitude of PCS costs are.

3.6 Case Study Analysis

The purpose of Phase 1 of the research project was to benchmark the state of the practice and identify, analyze, and understand current models for PCS cost estimating. In Section 3.2, three questions were given to further explore the objectives of this research:

1. What project characteristics are important to developing an accurate PCS cost estimate?
2. What steps must be followed to implement a standardized PCS cost-estimating methodology?
3. How are PCS cost-estimating consultant contracts successfully procured?

The case study analysis looks to answer these questions and furnish information on emerging trends within the DOTs.

3.6.1 What Project Characteristics Are Important to Developing an Accurate PCS Cost Estimate?

A report from Williams et al. (2013) identified 12 project characteristics that are inherent in each project for NYSDOT and can be used to estimate design effort. These characteristics were evaluated by a team of NYSDOT and FHWA personnel so are applicable to the target audience of this research. These characteristics were used as a base for identifying the project characteristics important in developing an accurate PCS cost estimate.

Each agency was asked to fill in a matrix identifying which project characteristics had the most influence on the PCS cost estimate. The average rankings for these characteristics were analyzed using a *t*-test to determine the equality of the means of the responses and to categorize the factors into the three levels of influence. The results for the most influential factors from an agency's perspective and then from a project perspective are shown in Table 3.8 and Table 3.9 respectively.

Question V.1 of the interview was as follows:

> How influential do you think the following characteristics are in estimating the overall PCS cost for a typical design–bid–build project?
>
> 1–No influence
>
> 2–Some influence
>
> 3–Major influence

Table 3.8. Influence factors ranked based on mean response values from nine DOTs.

Influence Factor	Mean Response
Tier 1 [2.56–3.00]	
1. Complexity	3.0
2. Project type	2.89
3. NEPA classification	2.67
Tier 2 [2.00–2.56]	
5. Length of project	2.56
6. Number of bridges	2.44
7. Number of plan sheets	2.33
8. Number of lanes	2.0
9. Geographical	2.0
Tier 3 [1.44–1.56]	
10. Highway classification	1.56
11. Number of sub-consultants	1.44
12. Loss of design effort	1.44

The list of characteristics or influence factors provided was as follows:

1. Complexity,
2. Project type,

Table 3.9. Project influence factors ranked based on mean response values from 16 projects.

Influence Factor	Mean Response
Tier 1 [2.42–2.75]	
1. Complexity	2.75
2. Project type	2.56
3. Construction cost	2.42
Tier 2 [1.92–2.07]	
4. Number of bridges	2.07
5. Length of project	2.06
6. Highway classification	1.94
7. Number of sub-consultants	1.93
8. Number of plan sheets	1.92
Tier 3 [1.62–1.81]	
9. NEPA classification	1.81
10. Number of lanes	1.63

3. Number of sub-consultants,
4. Construction cost,
5. Number of lanes,
6. Number of plan sheets,
7. NEPA classification,
8. Number of bridges,
9. Highway classification,
10. Length of project,
11. Geographical, and
12. Loss of design effort.

The question was answered by the DOT representative during the interview, and later the same question was answered in the context of a specific project. The researchers collected nine sets of responses from the DOTs. The mean value of the response to each influence factor is given in Table 3.8. In these tables, the factors are ranked based on the mean response value. It is worth noting that no additional factor was suggested to be added to the list that was presented to the interviewees.

The responses summarized in Table 3.8 represent the importance of influence factors from the point of view of the state departments of transportation. The researchers have categorized the factors into three tiers. Tier 1 consists of the factors that DOTs felt had the most influence on PCS costs. Tier 3 consists of factors that scored an average of well below 2.0 and, hence, were considered to have little to no influence on PCS costs. A statistical analysis was conducted to see the effect of variability of responses to each factor and to see if there were significant differences between factors. As an example, if a factor has a mean response of 2.89, is this really different from another factor with a mean response of 2.67?

In order to investigate this question, the researchers conducted a two-tailed *t*-test for comparison of mean responses. The null hypothesis was that the means for any of the two selected factors were equal. The alternative hypothesis was that the means were not equal. In general, for the factors in each tier of Table 3.8, one could not reject the hypothesis that the means were equal. This means that the factors within each tier will have more or less the same importance. There are some concerns with using this test for this application. First, the number of data points is only 9. Second, the assumption of normality is not realistic; however, the test provides an insight into the effect of variance on the possible values of each factor. So the main purpose for conducting these tests here was to have a systematic and consistent method to group these factors into the three tiers so that the most influential factors can be concentrated on.

Table 3.9 gives the project influence factors ranked based on their mean score from 16 projects. The main difference between these factors and the factors listed in Table 3.8 is the respondent was weighing the influence of each factor against a specific project rather than the whole agency. This table does not include two of the factors listed in Table 3.8 ("geographical" and "loss of design effort").

As can be seen, the most influential factors remain the same in both cases, with the exception of "NEPA classification," which has been relegated to Tier 3 in Table 3.9. This may merit further consideration. "Number of lanes" scored higher at the agency level, while "highway classification" and "number of sub-consultants" scored significantly higher at the project level. Overall, while these two tables agree on many of the most influential factors, in Tier 3 factors there are some differences.

The same statistical approach explained earlier for grouping factors (two-tailed *t*-test for comparison of means) was applied to the factors in Table 3.9. The three tiers presented are the outcome of that analysis. In other words, the equality of factor means within each tier could not be rejected statistically. This analysis was based on a sample that varied between 14 and 16 projects because not all respondents scored every influence factor.

As a comparison between the outcome of Table 3.8 and 3.9, a correlation coefficient was calculated between the ranks of factors in each table. The rank correlation between these factors was calculated as 0.60. A correlation coefficient of 0.64 was also calculated between the scores of factors in the two tables. In both cases, these values show that there is moderate correlation between the results of the two tables.

There seems to be little doubt that the most significant factors at the agency and the project level are the following:

- Project complexity,
- Project type, and
- Construction cost.

This was valuable information for developing the parametric estimating model as these three factors could be used as the most influential input variables to estimate the PCS costs for a project. Project complexity is a subjective variable, making it difficult to incorporate this as in input variable; in Phase 2 the researchers looked to develop a complexity index as a way of standardizing this variable.

One of the controversial characteristics that came from this analysis was the number of plan sheets. While some DOTs still do a lot of their work on paper, DOTs such as NYSDOT are moving more toward technological-based plans, making the measure redundant. This is also highlighted in a report by Tippett and LaHoud (1999), and Sturts and Griffis stated that "technology is revolutionizing the way engineers work and there is a need to revise the pricing strategies for engineering design services" (2005).

Loss of design effort was a characteristic added by the researchers after the pilot study. This was defined as "design work completed but not used in the final project due to changes in scope during the design process." During the PCS phase, this is likely to occur often, especially if the project scope is not well defined. It occurs when there is a change in the scope that renders hours already billed to the project redundant; the work is still a PCS cost to the project and, therefore, should be accounted for in the estimate. When they were questioned about this influencing factor, it was clear that this concept was either not fully understood or not considered by state DOTs. It was suggested by several interviewees that incorporating lost design effort into the PCS estimate was inappropriate because it indicates that the agency plans to waste valuable design time. The intent of this factor is to account for typical scope changes/refinements and human error that require reworking of the design. In the final analysis, the issue is moot since none of the case study agencies had a means of tracking lost design effort.

3.6.2 What Steps Must Be Followed to Implement a Standardized PCS Cost-Estimating Methodology?

One major trend that needs to be addressed in order to implement a standardized PCS cost-estimating methodology is to standardize the terminology used by state DOTs. Within the nine states visited for this project, there was a confusing mix of terminologies used for different phases of the projects. It was useful to have the PCS project development process to give a standardized template for each agency to adapt to their own project development process.

Figure 3.5 shows UDOT's project development process and the estimating process for UDOT. This figure shows three decision sections that act as roadblocks for the project. The estimate must be prepared and reviewed at these points before the project status can move forward. A similar process was seen in the literature for some agencies such as CDOT; however, when the researchers visited the agency, they were informed that the published process was not in use.

Having a project development process with milestones to ensure that engineers perform PCS estimates and then secondary milestones to recheck these estimates is an effective way of continually improving estimates.

3.6.3 Types of PCS estimates

Three basic types of estimates were found during the case study interviews:

- Direct estimate of hours,
- Standard percentage of construction cost, and
- Past project cost range.

Table 3.10 shows which method(s) each agency uses.

The level of sophistication used within each department varies, but it can be seen that Utah is the only state currently using two methods and comparing the results. Two states were found to not estimate PCS costs at all, which is a trend found in the screening survey. Two types of estimates have emerged from the case studies:

- Top-down (macro) estimates produced by an experienced estimator, useful for managers who have limited knowledge of the process to complete the project (Larson and Gray 2011); and

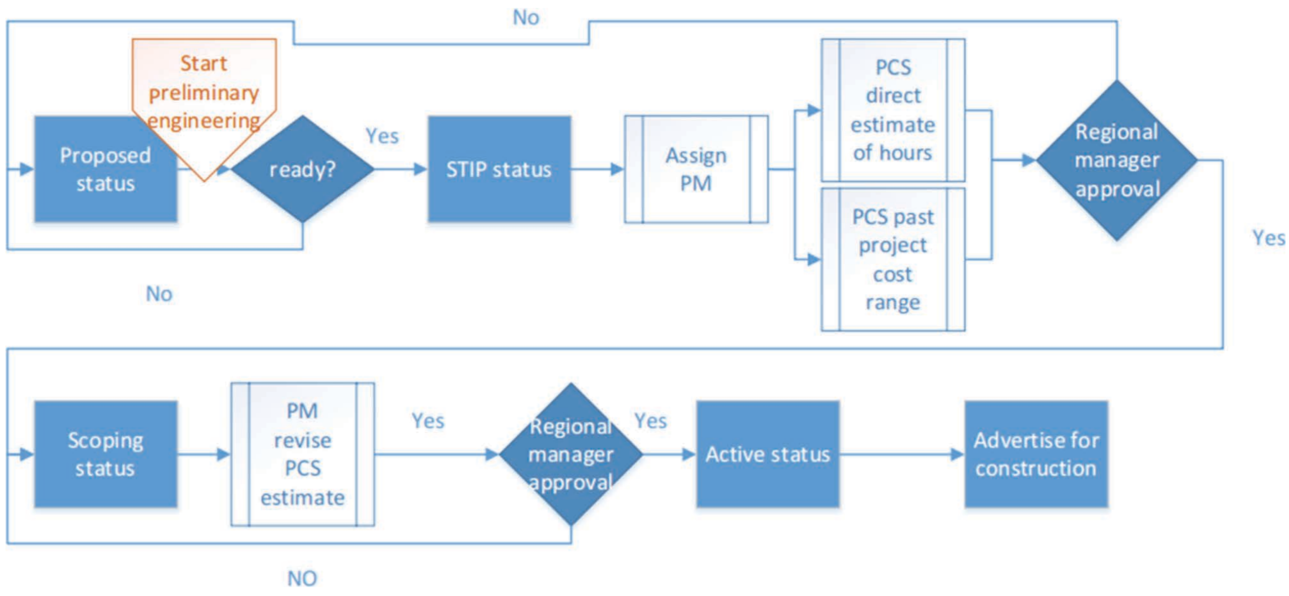


Figure 3.5. UDOT's project development process.

Table 3.10. Agencies' PCS estimating methods.

Method	Agency
Direct estimate of hours	• California • Utah
Standard percentage of construction costs	• Colorado • Montana • Rhode Island
Past project cost range	• Maryland • New York • Utah
Do not estimate PCS costs	• Iowa • Oklahoma

- Bottom-up (micro) estimates, which usually correlate to a work breakdown structure (WBS); each activity is estimated by the person who is involved with monitoring the project (Larson and Gray 2011).

Table 3.11 has been adapted from Larson and Gray (2011), and it shows the project characteristics associated with choosing to do top-down or bottom-up estimates. A top-down estimate is defined as the use of a parametric estimating factor like percentage of estimated construction costs to determine the PCS budget. A bottom-up estimate calculates the number of labor hours estimated for each PCS task, calculates the average labor-hour rate, and rolls the cost up from these detailed estimates of effort.

When the researchers met with Caltrans, two types of projects were used for corridor-level projects (termed "parent projects" by Caltrans; see Section 2.2.1) when the costs for planning and scoping are incurred. The parent projects spawn a series of child projects or single projects (Section 2.2.1). This project structure was also found in the Iowa DOT case study data. The following question was put to the panel in the December quarterly report:

> **Corridor projects versus single projects.** In many cases, the team found that much of the PCS work was being done on a corridor basis rather than an individual project basis because the DOT did not know the level of available funding. Once the funding was identified, the work was then split into phases/separate projects, and final PCS costs were then expended only for those phases/projects where construction funding was going to become available. Thus, attempting to separate the cost to complete planning, environmental, survey, right-of-way, etc. is impossible. We need guidance on how the panel thinks we should deal with this issue. The simple solution, which is our recommendation, is to only conduct further work on projects that stand alone and for which we have identifiable PCS cost data. This limits the results of the research, specifically, the Task 4 model to be applicable to only those types of projects.

The bigger question relates to who performs the estimate and the data used within the agency's project development process. The initial estimate of PCS costs for the parent project is typically done at the programmatic level. Therefore, Table 3.11 shows that a top-down estimate is more appropriate as it looks at the bigger picture. This estimate is useful for allocating program funds, making it valuable to regional or program managers. When the project moves into the child-project phase, the scope is likely to be better defined and require a more detailed estimate. In this situation, a bottom-up estimate is likely to be more appropriate (Table 3.11). The greater detail used in this estimate will more closely portray the level of effort required to complete each major task and will provide a more accurate PCS cost estimate around which to establish the budget for the PCS teams and the project managers.

Once a child project is generated from the larger parent project, Caltrans allocates a percentage of the costs incurred during the parent project stage to the child project. A variation of this was seen in an NYSDOT project. The project was initially procured as a large project; however, due to funding constraints, the project was changed to a much smaller project. In this case, the PCS for the project had already been awarded to a consultant, and this project ended up with a much higher PCS cost percentage than other projects within the agency. This also links with feedback the researchers received from NYSDOT that a way to improve its PCS estimate would

Table 3.11. Conditions for preferring top-down or bottom-up estimates (Larson and Gray 2011).

Condition	Top-Down	Bottom-Up
Strategic decision making	X	
Cost and time important		X
High uncertainty	X	
Internal small project	X	
Fixed price contract		X
Details needed		X
Unstable scope	X	

be moving into top-down estimates to make more informed decisions at the programmatic level.

3.6.4 How Are PCS Cost-Estimating Consultant Contracts Successfully Procured?

This section is derived from the literature review and shows all the states that have developed models to determine the cost of outsourcing design. A report by Ismail and Sutliff (2011) for Caltrans showed that out of the three states that have invested and developed these models, none could confirm that these processes were being implemented. Table 3.12 has been adapted from this report and shows the model and its use. This was also apparent in the case studies as all nine states responded that they do not compare the cost of performing work in-house to the cost of outsourcing as part of the outsourcing decision process. A report for the Louisiana Department of Transportation and Development found that outsourcing design cost was about 20% more expensive than performing the work in-house (Ismail and Sutliff 2011); however, this was not the same for all agencies. When asked why the agency chose to outsource PCS costs, all DOTs responded that staff availability and special expertise were the two main reasons. Other reasons that were mentioned were expedited project delivery, to strengthen the local economy, transfer design liability, and ability to release DOT personnel to perform PCS contract administration duties. It was common practice among DOTs to outsource larger, more complex projects.

It can be argued that this research will benefit DOTs more for outsourcing projects as DOTs can use the estimate as base for negotiations with the designer. However Iowa DOT indicated that it would adopt a model to aid with in-house resource allocation and help better identify shortfalls in resources. A possible option is to use the model to determine when it is necessary to employ consultants on work to avoid overloading DOT staff. This is becoming an increasing issue within DOTs as there is a move in many states to downsize the government staff. For example, UDOT’s staff decreased from 3,500 employees in 2000 to 1,530 employees in 2013.

3.7 Preconstruction Learning Curve

One of the obvious trends shown by the screening survey and the agency interviews is the abundance of data that exists within a typical agency and the lack of reliable tools to organize and convert the data into actionable information. In all cases, agency engineers were required to bill their time to specific projects, making the information available within the agency’s financial accounting system. On some occasions, staff did not think that the hours billed were completely accurate. Oklahoma DOT responded that approximately 50% of its time was billed to departmental overhead instead of to a specific job. This noise in the data is to be expected when working in this environment; the important thing to recognize when using these data is that the noise is there, so try to understand how it will affect the outcome of the estimate. In agencies with a high level of noise, a top-down approach would work better than a bottom-up estimate because of the lack of precise historic labor-hour information. For this research, there was no choice and noisy data had to be used. Therefore, the concept of developing two or more ways to estimate the same project is extremely important to the accuracy of the PCS cost estimate. The proposed method is documented in a simple and adaptable manner in the guidebook, and the parametric estimating model has been developed so that it can be adopted by an agency and adjusted to fit its needs.

With the proposed system in place, DOTs will no longer be as reliant on professional judgment for PCS cost estimating. This becomes more critical as DOTs are downsized. The PCS cost-estimating system is a knowledge management tool that institutionalizes the process, making it more consistent as DOTs lose experienced mid-career staff to the private sector. Feedback during the interviews shows that any system needs to be simple and user-friendly. This also demonstrates

Table 3.12. Outsourcing cost comparison models (Ismail and Sutliff 2011).

Agency	Model	Use
Arizona	Third-party transaction cost–benefit analysis	Unaware
Louisiana	Outsourcing decision assistance model (2002) available on CD-ROM by request	No
Oregon	Decision tree – cost-based outsourcing decisions (2007)	Could not confirm

the need for PCS training within DOTs on the importance of estimating PCSs as well as on effective practices to help improve PCS estimates.

3.8 Case Study Summary

3.8.1 Possible Effective Practices

A number of PCS cost-estimating methods have been identified throughout the case study analysis. A list of possible effective practices has been compiled. These were reviewed in Phase 2 of the research.

- **Back-check of hours.** This method was used by UDOT to check the estimate using a direct estimate of hours against a past project cost range. This is a useful tool to validate the estimate, especially for younger estimators with less experience.
- **Life-cycle project manager.** This practice assigns a project manager for the entire duration of the project's development and delivery period. This allows the project manager to control the costs and review the estimate as issues arise or the scope changes.
- **Estimate check milestones.** This process has been implemented by UDOT and is demonstrated in Figure 3.5. The practice ensures that estimates are reviewed and updated at various stages of the project development process.

3.8.2 Data Quality

Once the research team began developing databases from the data collected, reduced, cleaned, and collated, it found it difficult to be able to guarantee that the data were complete and accurate. A number of inconsistencies have been observed within collected data sets, and numerous blank cells indicated that some information was not complete. These issues of data quality and data availability created a number of challenges for the research team. The outputs of any model are only as good as its input, placing the quality of any estimating model produced into question.

After becoming familiar with the Utah and Iowa data sets, the team became concerned at how different the two sets were. Such variation between the agencies' classification of data indicated that it would be difficult to achieve a consistent result between the two DOT's models.

These observations were reported to the panel in the October 2014 quarterly report. The panel was notified that the research might ultimately lead to a process model that must be customized specifically to the way data are collected by a specific DOT rather than a fairly generalized approach that can be used by all DOTs.

The research team also noted at this point that implementing the research might be more difficult than expected as it would require a significant investment by each agency to configure the data it currently maintains.

CHAPTER 4

Preconstruction Services Estimating Process and Models

4.1 Introduction

This section presents the methodology followed to develop the data-driven PCS estimating models as described earlier (see Section 1.5, Task 4).

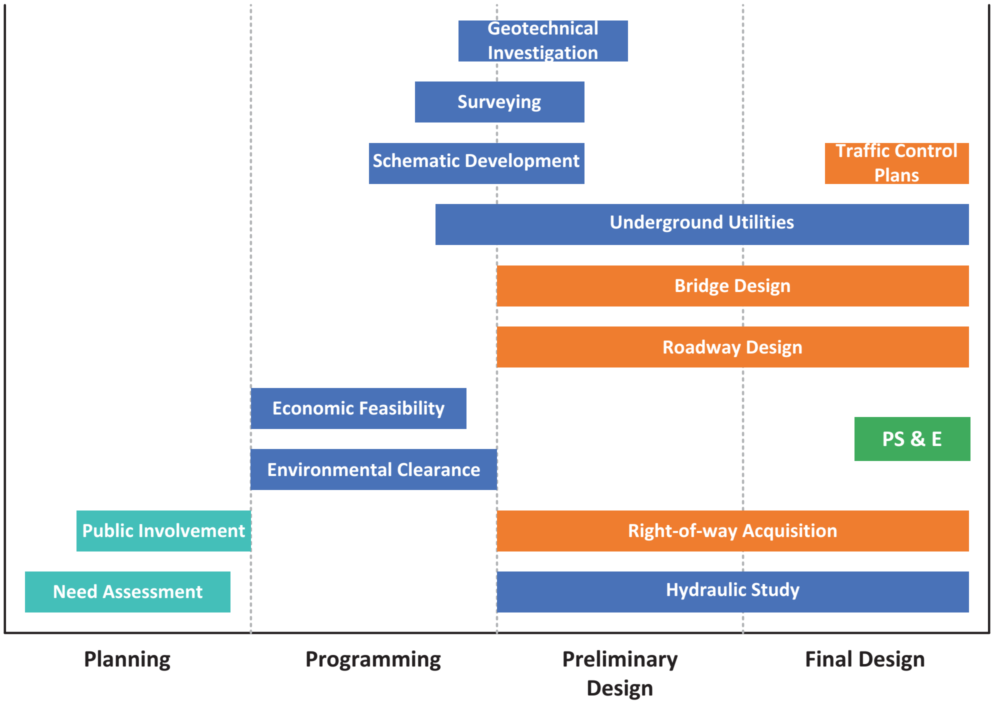
Preconstruction service activities typically take a long period of time (sometimes more than a decade) from planning to programming to preliminary design to final design. As the project evolves into downstream PCS activities, more information about the project becomes available, and consequently, more accurate PCS cost estimating is possible with better-defined project information. The accuracy of any estimating is directly related to the amount of information available about the project. As a result, a PCS cost-estimating process should be aligned with the typical project development process to reflect the maturity level of project definition.

A distinctive feature of the PCS cost-estimating process compared to construction cost estimating is that as a project continues to be defined, the project is broken down into different engineering functions, and each functional department takes charge of completing the functional analysis and engineering requirements for the project, as shown in Figure 4.1.

4.2 PCS Cost-Estimating Process

The PCS cost-estimating process during the project development stages is depicted in Figure 4.2. Very limited information about the project at the earliest stages of project development, such as planning and programming, makes it difficult to estimate PCS costs. However, there is the need to establish the probable and approximate PCS cost of the project for budgeting and funding authorization purposes. This estimated PCS cost can also be used as a baseline cost for monitoring and tracking the performance of PCS costs during the remaining PCS activities. Due to the low maturity of project definition at the early project development stage, only a parametric estimating approach, which is a common early and conceptual estimating method, is applicable. In parametric estimating, project characteristic information, such as project type, project location, project length, and project complexity, is used as major predictive parameters to estimate the anticipated cost of PCS activities. Thus, this PCS estimating is called *top-down estimating.*

When the project moves into the preliminary design and final design stages, the overall project scope gets defined more accurately, and it becomes clear which functional engineering departments should be involved. For example, a right-of-way department may play a significant role for a new roadway construction project as new parcels need to be purchased from property owners for the project, but the same department may have no role in a typical bridge rehabilitation project. When a project is determined to require a specific functional department's engineering service, the functional department needs to estimate the anticipated PCS work-effort hours or costs required to get the service fulfilled. This estimating needs to be as accurate as possible for internal resource management purposes and for determining the consulting costs if the department decides to outsource the service, which is becoming a more popular option as many transportation agencies are operating with fewer staff members. With better-defined scope of work and the experience of similar projects previously, functional departments typically know what specific work tasks need to be completed for a given project. Some transportation agencies, such as Georgia DOT, Florida DOT, and Ohio DOT, have a well-defined WBS for different engineering functions. As a result, PCS cost estimating at the functional department level can be performed as WBS-based estimating, and this estimating is called functional-level estimating in this guidebook. The summation of all of the functional-level PCS cost estimates for a given project is the total PCS cost of the project, and this aggregation process can be called a *bottom-up estimating.* The bottom-up estimating result needs to be cross-validated with the top-down estimating result as part of PCS cost monitoring and control.



Note: PS&E = plans, specifications, and estimates.

Figure 4.1. Examples of PCS activities throughout project development process.

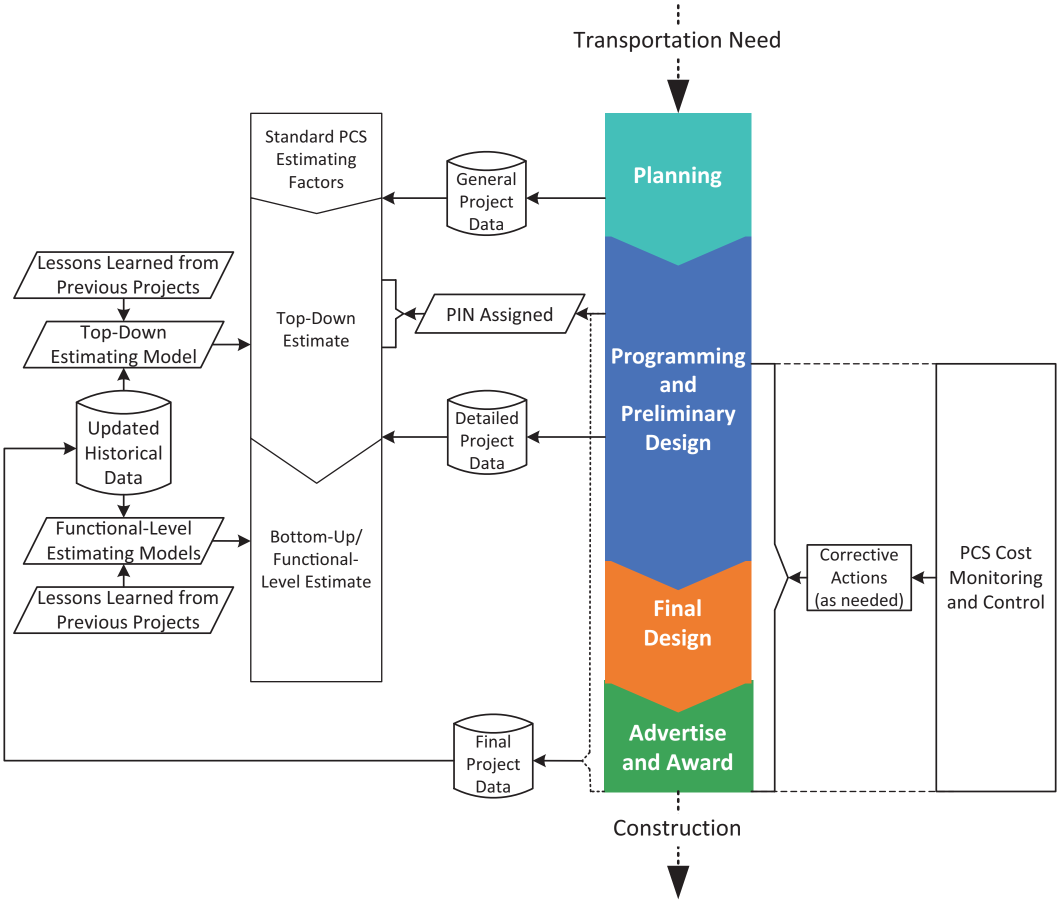


Figure 4.2. PCS cost-estimating process.

The cost differences need to be documented and explained. For example, scope changes during the project development process would significantly affect the total PCS costs from the bottom-up estimating approach, resulting in a significant deviation from the top-down PCS cost estimate. Proper documentation and implementation of a feedback loop in the PCS cost-estimating process will also assist in developing a more accurate top-down PCS cost estimate for future projects by allowing the calibration of the top-down estimating method.

4.3 Overview of PCS Cost-Estimating Model Development

Creating a framework for developing a data-driven PCS cost-estimating model requires the integration of a number of steps (as shown in Figure 4.3). This cyclic process allows transportation agencies to make continuous improvements in their models, and this process has been applied to develop the data-driven PCS cost-estimating models provided in the guidebook.

- **Step I: Requirements Analysis.** This step determines potential model usage and users as well as anticipated data requirements. This is a very important part of the process since it determines what approach [top-down or bottom-up (functional level)] should be used, the type of historical data required to build models, and potential data sources.

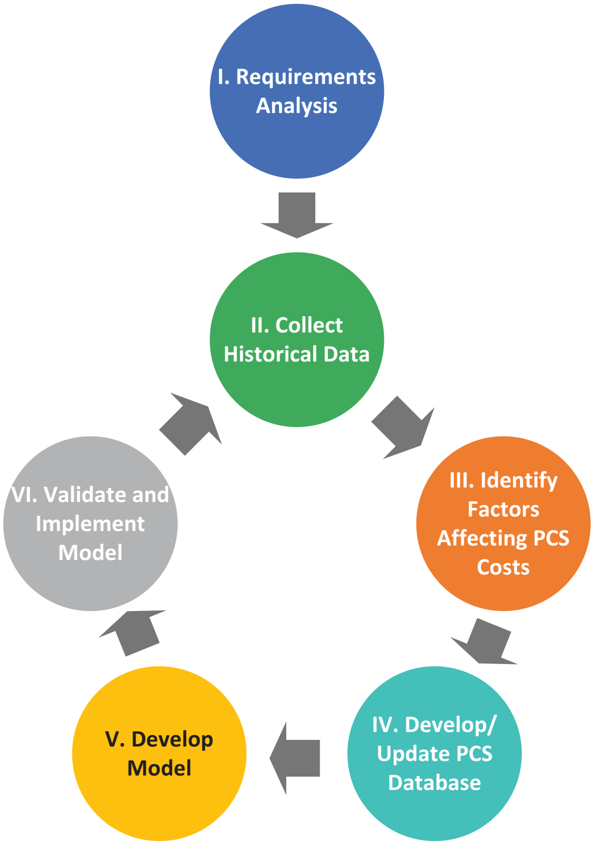


Figure 4.3. PCS cost-estimating model overview.

- **Step II: Collect Historical Data.** In this step, various databases are identified, studied, and compiled into one master database. The master database should be developed in accordance with the PCS cost-estimating needs determined during the requirements analysis stage. At this point, model developers should also determine if current historical databases and preconstruction data-collection procedures meet the minimum expectations of quality, quantity, and reliability required by the PCS cost-estimating approach to be performed. This guidebook describes some strategies to either improve existing databases or create new and more appropriate data sets.

  Both top-down and functional-level PCS cost-estimating methods depend on historical data collected from previous projects. However, the level of detail of the databases and their configuration depend on the PCS cost-estimating approach and the final users of the estimating models. Thus, it is suggested that transportation agencies customize their databases in accordance with the needs of different users. For example, a division director may require access to historical data with general project characteristics (e.g., project location, type of work, expected overall complexity) in order to make strategic decisions using an early top-down estimating model. On the other hand, the geotechnical engineering department may need other types of information, such as regional geology, subsurface soil conditions, and the required efforts and costs for a series of laboratory tests in order to perform a cost estimate of preconstruction geotechnical activities.
- **Step III: Identify Factors Affecting PCS Costs.** Once a master database is established, the next step is to identify significant factors to estimate PCS costs. The selection of these variables may be done with experience and engineering judgment, but a structured statistical process (discussed in Chapter 3 of the guidebook) would also greatly help in narrowing down influential variables as a statistical process typically helps better define the relationships across input variables and between input variables and PCS costs.
- **Step IV: Develop/Update PCS Database.** This step involves the development of a suitable PCS database of significant factors identified in the previous step and historical PCS data for a subsequent development and implementation of data-driven PCS cost-estimating models. Along with the quality and reliability of input factors used to produce PCS cost estimates, the amount of available historical data may be a decisive factor in meeting the desired level of accuracy. Chapter 3 of the guidebook presents a detailed descrip-

tion of the procedure associated with the development and optimization of a PCS database. Some of the strategies in this chapter are intended to minimize data management efforts while still producing reliable PCS cost estimates.

- **Step V: Develop Model.** In this step, top-down and/or bottom-up/functional-level estimating models are developed using the available historical data and preselected input variables. This involves the combination of qualitative and quantitative procedures. The qualitative part comes from the experience and judgment of model developers and users to make an adequate use of the historical data and to appropriately read, understand, and use the outcomes of the models. The quantitative part is the use of the mathematical and statistical tools used to process the available historical data into reliable PCS cost estimates. The guidebook describes four major quantitative tools: multiple regression, decision tree, and artificial neural network used in top-down estimating (Chapter 4 of the guidebook), and the three-point estimation approach for functional-level estimating (Chapter 5 of the guidebook).
- **Step VI: Validate and Implement Model.** This last step consists of two parts: the validation of the models to ensure a satisfactory performance, and the implementation of the validated models. The models that are developed are tested for their performances, and only the models that meet the expectations of the agency can be implemented. Once the performance of a PCS cost-estimating model is determined to be satisfactory, it is ready for its implementation in actual upcoming projects. An efficient implementation of PCS cost-estimating models involves an appropriate interpretation of the model outputs and their incorporation into decision-making procedures, a reliable system to track the performance of PCS cost estimates and expenses throughout the project development process, and a mechanism to capture and assess lessons learned from previous projects to enhance the performance of PCS cost-estimating practices. Chapter 6 of the guidebook presents specific implementation practices and generic systems to track the performance of PCS costs and capture lessons learned. The implementation and monitoring methodologies in Chapter 6 of the guidebook are equally applicable to top-down and bottom-up/functional-level estimating approaches.

4.4 Requirements Analysis

This step determines potential model usage and users as well as anticipated data requirements. This is an important part of the process as it defines what approach [top-down or bottom-up (functional level)] should be used, the type of historical data required to build models, and potential data sources.

4.5 Collect Historical Data

Within the construction industry, it is commonly accepted that collecting and archiving data on past project estimates and actual costs is a successful way to improve future estimates. This same principle applies for PCS cost estimating. Using specific project information and corresponding actual PCS costs and/or work hours from previous in-house projects and consultant contracts creates a knowledge base that is valuable in creating more accurate future estimates.

Today, highway agencies collect PCS data along with associated project costs and store them in various data management systems as part of their inventory or accounting systems. In a typical agency, these data management systems or data inventories can range from in-house spreadsheets to commercially available programs developed through manual data collection during the preconstruction phase. Other pieces of information that may be relevant to the estimation of PCS costs might be obtained from less-formal data sources such as paper-based and electronic documents not arranged in a database fashion. All possible data sources must be considered at this early stage of implementing data-driven PCS cost-estimating techniques before proceeding with the identification of project characteristics (herein after referred to as "factors" or "input variables") affecting PCS costs.

4.6 Identify Factors Affecting PCS Costs

The identification of factors that affect PCS costs is an important task when developing PCS cost-estimation models. Factors are distinctive characteristics of a project—for instance its length or level of complexity. The successful identification of factors that have a direct influence on the total PCS cost allows for the development of an efficient PCS database. Table 4.1 presents a variety of representative factors that were identified for highway projects based on existing literature, conversations with state DOT personnel, and review of project management documents generated at preconstruction stages. The values of the factors can be numerical, Boolean, or nominal. Numerical values are numbers such as length and number of bridges involved. Boolean variables can only have two values—generally yes or no. Nominal variables are categorical, where values are grouped quantitatively or qualitatively. For example, terrain type can be categorized as level, rolling, and mountainous.

It should be noted that some factors that are presented in Table 4.1 are alternatives to each other. For example, the number of lanes and lane width describe the same feature of the roadway (its width). As such, only one of the two factors may be necessary.

The factors listed in Table 4.1 and their values are only a small example. Transportation agencies have developed their

Table 4.1. Potential factors affecting PCS costs.

Category of Factors	Factors	Description	Variable Type
Project information	Project type	Replacement, interchange, new construction, reconstruction, rehabilitation, widening, and reconstruction	Nominal
	Pavement type	Asphalt/cement	Nominal
	Highway classification	Freeway, principal arterial, collector, etc.	Nominal
	Overall project complexity	Low, medium, high	Nominal
	Project location	Urban/rural	Boolean
	ROW acquisition required	Yes/no	Boolean
	Construction costs	Cost in dollars	Numerical
Geometry, topography, and geology	Length	Length in miles	Numerical
	Number of lanes	2, 4, 6, etc.	Numerical
	Roadway width	Width in feet	Numerical
	Divided roadway	Yes/no	Boolean
	Terrain type	Level, rolling, mountainous	Nominal
	Special geotechnical consideration required	Yes/no	Boolean
	Typical section	Open section, curb and gutter, combination	Nominal
Surveys	Topographic survey	Level of details required	Nominal
	Pavement elevation survey	Yes/no	Boolean
	Hydraulic survey	Yes/no	Boolean
	Utility surveys	Yes/no	Boolean
	Traffic survey	Yes/no	Boolean
	Stream crossing	Yes/no	Boolean
	Traffic noise impact analysis	Yes/no	Boolean
Design complexity	Horizontal alignment change	Yes/no	Boolean
	Vertical alignment change	Yes/no	Boolean
	Roadway crossing/intersection	Yes/no	Boolean
	Railroad crossing	Yes/no	Boolean
	Stream crossing	Yes/no	Boolean
	Sidewalk	Addition, improvement, or none	Nominal
	Type of sidewalk/shoulder	None, sod, aggregate, bituminous, concrete	Nominal
	Standard design exception	Yes/no	Boolean
	Number of plan sheets	Expected number of plan sheets	Numerical
	Level of service	A, B, C, D, E	Nominal
	Context-sensitive design	Yes/no	Boolean
Structural design	Predominant type of bridges/culverts	Reinforced concrete, steel, etc.	Nominal
	Number of bridges/culverts	Number of bridges/culverts	Numerical
	Bridge sufficiency rating	0–100	Numerical
	Bridge width	Width in feet	Numerical
Environmental factors	NEPA classification	Categorical exclusion (CatEx), environmental assessment (EA), environmental impact analysis (EIA)	Nominal
	Biological resources report/assessment	As required	Nominal
Traffic control	Work zone safety and mobility level	Basic/intermediate/major	Nominal
	AADT	Average annual daily traffic	Numerical
	Staging of construction	Yes/no	Nominal
	Crash severity	Crash severity rating	Numerical
	Access control	None, partial, full	Nominal

Table 4.1. (Continued).

Category of Factors	Factors	Description	Variable Type
Permits required	U.S. ACE, state water resource board, FAA	Various permits required	Boolean
Public involvement	Number of parcels affected	Indicates the amount of negotiation efforts with landowners for ROW acquisition	Numerical
	Preliminary land use	Residential, commercial, farming	Nominal
	Special land use	National parks, Indian reservations, etc.	Nominal
	Cultural resource management effort	None, low, medium, high	Nominal
Miscellaneous factors	Hazardous waste	Presence of hazardous waste material at the site resulting in special design requirements – yes/no	Boolean
	Guardrail	Addition/removal/improvement/none	Nominal

own values for various factors. For example, project type classification for the Iowa DOT may vary from that of the Montana DOT. Each DOT can use its own classification system and its associated values. Some factors presented in the table can indicate the level of work involvement for multiple activities. For instance, project length can be an indicator for level of surveying required, expected number of plan sheets, efforts for right-of-way acquisition, and so forth. Currently, not all of these factors are collected in a structured format. As such, a limited number of available factors were used to illustrate the process of developing a PCS cost-estimation model in this report.

Case studies conducted on nine DOTs led to the identification of a set of factors that could maximize the performance of PCS cost-estimating models. Even though the PCS cost-estimating modeling tools described in the guidebook have the ability to adapt to different preconstruction databases, transportation agencies should consider, to the maximum extent practical, the collection of these eight pieces of information for each project in order to use them as inputs in their PCS cost-estimating models. These eight items are:

1. Project type,
2. Complexity,
3. NEPA classification,
4. Early construction cost estimate,
5. Length of project,
6. Number of bridges involved in the project,
7. Number of lanes, and
8. Project location.

Project type is an important factor that, if appropriately used, may help to substantially improve the performance of PCS cost-estimating models. The following section discusses how different project classification systems may be incorporated into data-driven PCS cost-estimating procedures.

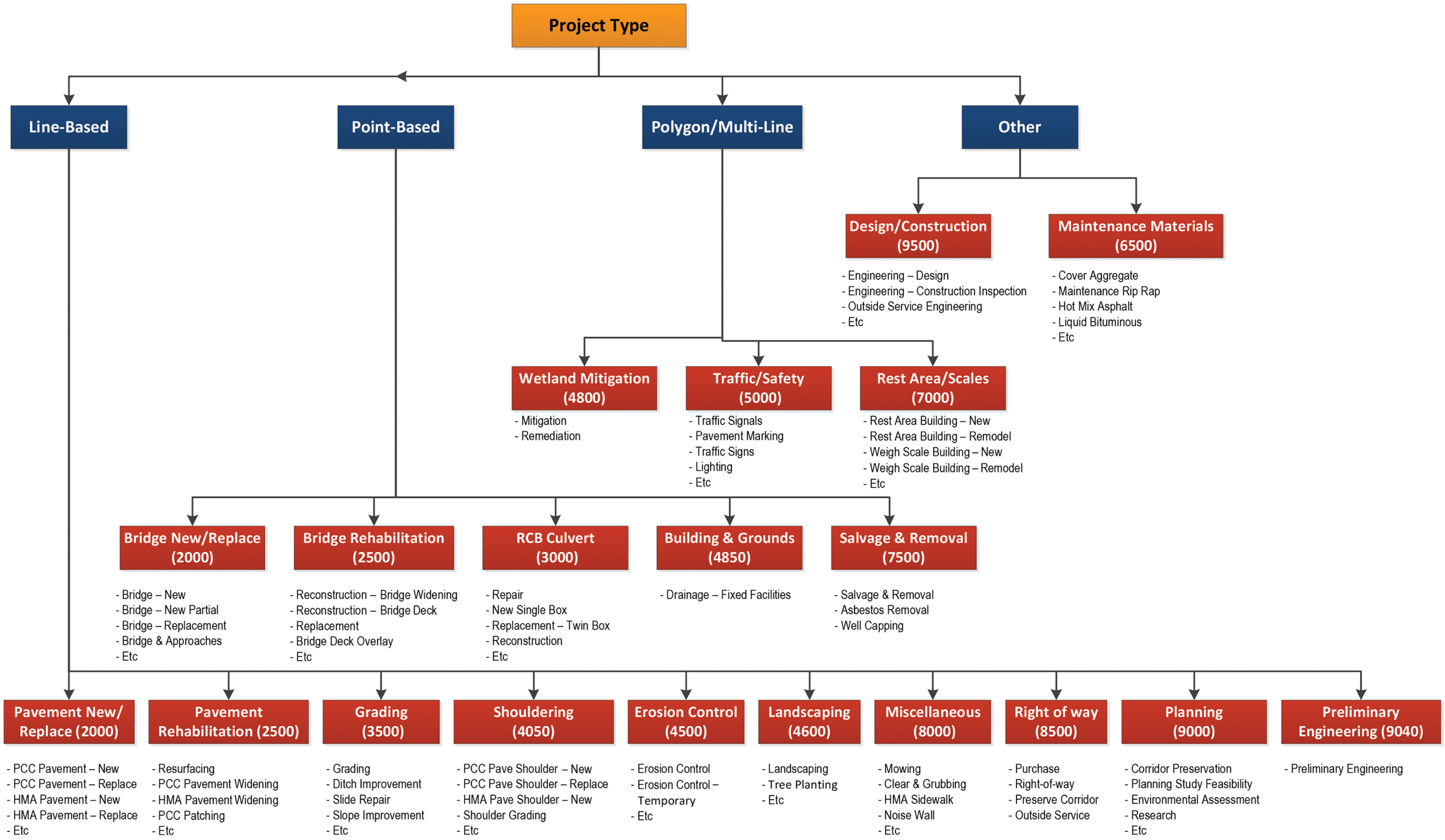
4.6.1 Project Classification

Various agencies use different classification systems to suit their strategic goals. These classifications help in defining the scope of the estimating model to be used in accordance with the agency's needs. Since different types of projects have unique design requirements, effective project classification schemes are expected to enhance the accuracy of PCS cost estimates. However, estimating models can only be improved if these classification systems are consistently included in the data inventory, as shown in the following hypothetical example:

> **Assume:** An agency classifies projects into three different groups: reconstruction, rehabilitation, and resurfacing. The agency may divide the available historical data into these three types of projects and create three independent models, one for each project type. **Or** model developers may include the project type as an input variable in the model. **Or** to optimize the estimate further, they might try both and determine which approach yields the most reliable output.

Common classification schemes used in top-down estimates at the project level are based on complexity and type of work. These variables could also be considered when estimating PCS costs at the functional level; however, it may not be sufficient in some functional areas. For example, the estimation of the costs of environmental studies may be approached in a different manner for projects near wetland areas than for those not located near wetlands. Likewise, the geotechnical department could prefer the use of different estimating models depending on the geological conditions surrounding the project.

Figure 4.4 shows an example of the project classification system used by Iowa DOT. For the purpose of data collection, the geometry-based classification categorizes projects into four classes: point-based, line-based, polygon-based or multi-line projects, and other projects.



Note: PCC = Portland cement concrete, HMA = hot-mix asphalt, RCB = reinforced concrete bridge.

Figure 4.4. Geometry-based project classification (Iowa DOT 2012).

4.6.2 Data Cleaning and Transforming

Data quality is one of the main issues confronted when developing a data-driven model. It is possible that some of the data attributes may have a significant number of missing values. Such variables may need to be removed before developing a model. For example, the number of land parcels to be purchased for ROW may have a significant effect on total PCS costs. If most projects do not have the relevant data to fill a certain variable field, use of such variables is likely to confuse the model, resulting in lower accuracy of its prediction. Also, while some data-driven models will accept the missing values, other methods will simply not work when data values are missing. Thus, such data should either be recorded manually or should not be used.

Similarly, some data attributes may have unexpected values if precautions are not taken in the data-collection system to validate the data before entering. For instance, if the length of a project is presented as "505,50" by error instead of a proper numerical format (505.50), such data will give errors when developing a model. The use of checklists, numerical data field validation, and so forth in the data-collection system will avoid collection of incomplete/incorrect data, but when a database is developed manually from other databases, it may have such errors. These data should either be transformed to a proper format or should be removed. If required, a regular data quality evaluation may be performed with the data stored in the database.

Another aspect of data transformation is to generate an additional set of input data attributes based on existing input data attributes. For example, project complexity can be developed based on the work type, land use, project length, environmental permits, and design complexities. A categorical or numerical complexity of the project can have a significant correlation with the PCS costs compared to the individual factors.

4.6.3 Optimization of Data Management Efforts

The optimization of data management efforts is done to select and manage the most effective input variables while minimizing data-collection, cleaning, and processing efforts. It is an iterative process that starts with those factors that represent the lowest data management effort for the agency and determines whether those factors are good enough to develop satisfactory models. If the performance of the models is not satisfactory, other factors that may increase the management efforts continue to be added until satisfactory models are developed.

There are two types of efforts that must be considered during the implementation of a data-driven PCS cost-estimating system. The first is the initial effort required to collect, clean, and evaluate the suitability of the data for PCS cost estimating. The second type of effort is related to the maintenance/update of the already created PCS database and cost-estimating models. The following example provides a better understanding of the difference between these two types of efforts.

> **Assume:** During the initial development of data-driven PCS cost-estimating models, the model developer considers that the distance between the agency's headquarters and the job site may be an input valuable to estimate PCS costs. However, this piece of project information has not been collected to date. It means that the model developer will have to invest a substantial amount of effort to check previous projects' documents, measure this distance, and provisionally add this information to the PCS database in order to evaluate its value for PCS cost estimating. Two things may happen at this point: (1) this piece of information may show a poor performance as an input variable and thus be discarded from the PCS database, or (2) it may positively contribute to the estimation of PCS costs. If the latter occurs, the agency would have to incorporate this piece of information into its regular data-collection procedure. This corresponds to the maintenance efforts mentioned in the previous paragraph (second type of effort).

In comparison with the initial efforts required to collect and evaluate the piece of data mentioned in this example, maintenance efforts would be substantially lower. The future collection of this information to update the PCS database would not significantly increase data management efforts once it is included in the data-collection protocol. For example, there are a number of information technology tools that can instantly provide the distance between two different locations. Thus, this distance could just be uploaded into the system along with other general project information. The optimization of data maintenance efforts, in the long run, will have a greater impact on the agency's day-to-day data management activities. The decision of whether to invest in the initial efforts required to evaluate the suitability of a potential input variable, given the risk of wasting time and other resources if the variable is discarded, must be made based on the potential influence of the variable on PCS cost estimating as determined by the experience and professional judgment of agency personnel.

Having identified all potential factors affecting PCS costs, the agency should proceed to rate each of them in accordance with the expected effort that would be required to continue tracking and recording them. They could be rated as *high*, *medium*, and *low.* As shown in Figure 4.5, the agency will start by creating a preliminary PCS database considering only low-effort variables and will move up in the scale of effort until reaching a satisfactory level of performance of the PCS cost-estimating models.

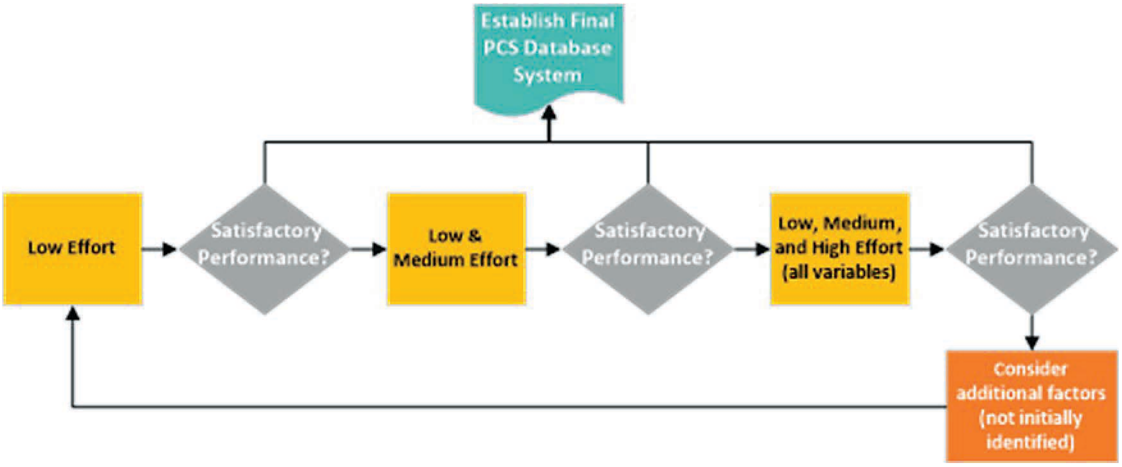


Figure 4.5. Optimization of data maintenance efforts.

4.7 Develop/Update PCS Database

Once the potential set of input variables has been defined for PCS cost-estimating modeling, the agency can proceed with the development of the PCS database. As discussed earlier in this chapter, there are different PCS cost-estimating approaches (top-down and bottom-up/functional level) that may be used by different types of users. This situation might require the development of multiple databases to be used at different levels and within individual functional areas. For instance, an agency may find it practical to use two separate PCS databases for the development of top-down estimates for paving and bridge projects. Likewise, each functional area within this agency (e.g., geotechnical, environmental, structural) may keep its own PCS database of work-effort hours for functional-level estimating. The data management techniques described here can be applied to develop each of these databases. The scale of the process and the data sources considered for each database vary in accordance with the scope of models previously defined during the requirements analysis. For management purposes, these databases should be considered as a single PCS database system rather than as separate entities. Several pieces of data may be contained in more than one database. Thus, data management efforts should concentrate on creating a single master database or a relational database that is connected to smaller databases, which can be accessed by users without much difficulty.

After identifying the factors that may be influencing PCS costs, historical data associated with these factors must be gathered to create a preliminary PCS database. Most transportation agencies maintain a large number of databases to record and store data generated throughout a project's life cycle. A lot of additional information is stored in paper-based and electronic documents not arranged in a database-friendly fashion. As a result, the development of a preliminary database may need the use of multiple data sources (see Figure 4.6) that can be combined using unique PINs. For example, the right-of-way acquisition division may have the total land area and total number of parcels acquired for the right-of-way, and terrain information may be collected in a structured format by the survey division. Many of those databases are likely to contain data tied to a unique PIN. A consolidated PCS database can be easily developed using the PIN.

Although data-driven estimating approaches depend on the amount of data, more data inputs do not always mean better estimates. PCS costs are time sensitive. Over a long period of time, typical PCS cost structures of an agency can vary for multiple reasons, such as inflation, changes in planning and design practices, and employee turnover. Therefore, the amount of data used for PCS cost-estimating purposes must not be so small that it prevents estimating models from efficiently correlating the input variables with the observed total PCS costs nor so large that it fails to reflect current design rates and practices.

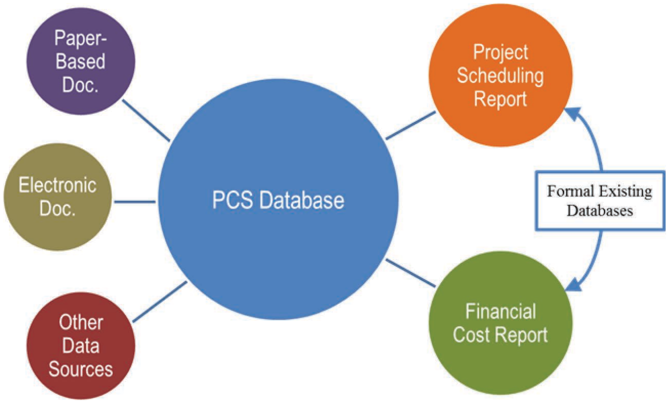


Figure 4.6. Consolidation of existing data sources.

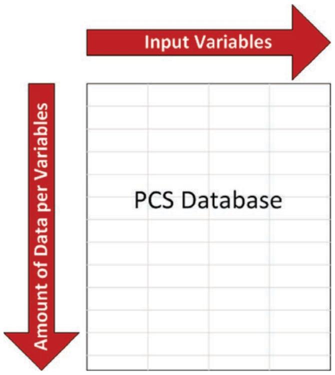


Figure 4.7. Dimensions of a PCS database.

The size of a PCS database is defined by the number of potential input variables and the amount of historical data for each of those variables (illustrated in Figure 4.7). The magnitude of these two dimensions must be carefully determined to avoid unnecessary data management efforts and to maximize the performance of the PCS cost-estimating models. The optimum amount of data per input variable is constrained by time. Data from projects executed during the previous 5 to 7 years are usually enough for the development of efficient cost estimates.

4.7.1 Evaluation of Factors Affecting PCS Cost

Data attributes in the preliminary database are potential factors that may influence PCS costs. While some of them have a significant effect on PCS costs, others may not. Thus, those factors should be analyzed to understand the effect of each factor on PCS costs. The evaluation of these factors is conducted at two different stages—first, through an analysis of the behavior of these factors in previous projects, which is the procedure described in this section, and then using some specific model performance indicators resulting from the use of different estimating tools. (This is the reason the arrows in Figure 4.7 move in two directions.) The latter stage is discussed later in this report.

Figure 4.8 shows an example of how the influence of each factor on cost can be determined through a simple analysis of the available data. The figure shows the total costs spent on various PCS activities in 53 projects awarded by Iowa DOT. It is observed that some factors, such as wetland permits, are a very small component of the total PCS cost compared to factors such as the existence of bridges within the project. This indicates that data on the presence of bridges provide more useful information to the estimating model than wetland permits; therefore, bridge data should be prioritized for collection.

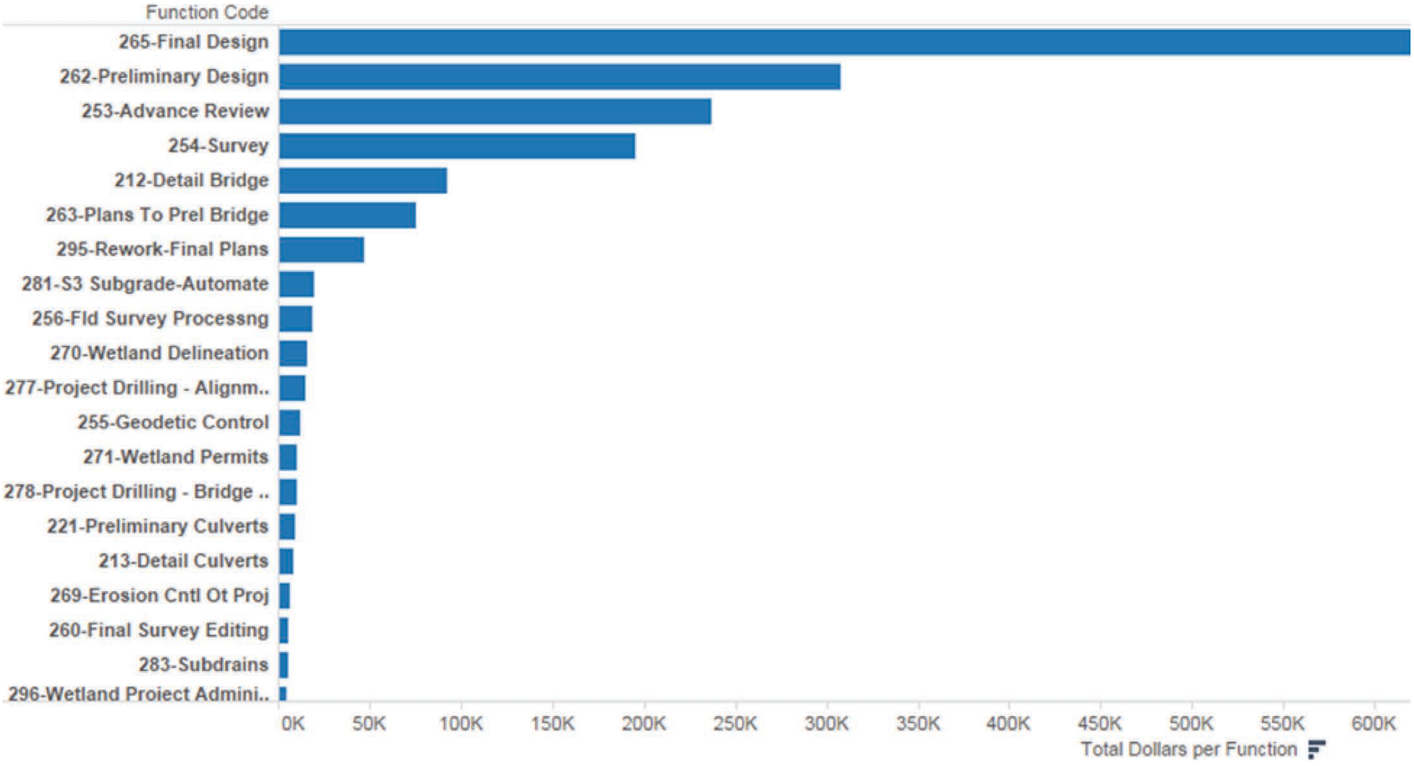


Figure 4.8. Components of preconstruction costs.

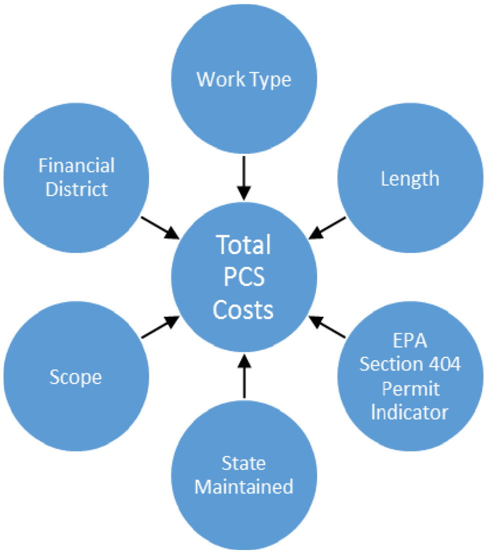


Figure 4.9. Factors affecting PCS costs – paving projects (Montana DOT sample data).

Along with the experience of model developers, there are formal methods that may help to evaluate the influence of factors before proceeding to the development of estimating models. Descriptive statistics and visualization techniques, such as scatter plots and box plots, can provide a better understanding of the data and their relationship to PCS costs. When a clear pattern is observed, those factors should be included for in further model development.

As another example, an analysis was conducted with a Montana DOT sample data set that included more than two-dozen factors to identify major cost influencers. The analysis identified six factors as significantly important factors affecting PCS costs (see Figure 4.9). It should be noted that the analysis was performed based on a data sample with only three types of project scope—chip seal, mill and fill, and reconstruction—and it should not be generalized.

4.8 Top-Down Model Development

After developing a database and identifying relevant and important data attributes, a number of modeling techniques can be applied to find the best-performing model. Three modeling techniques—multiple regression, decision tree, and artificial neural network—are presented briefly. The data sets used for each model are different and are used for illustration purposes only.

Various data-mining systems that are available to develop these models include *R*-statistics, RapidMiner, Weka, STATA, SAS, IBM SPSS, and Microsoft Data Mining Client for Excel. As all these systems were developed with a wide audience in mind, they may be regarded as complicated to use by transportation agencies. It is suggested to test the software programs and pick the most suitable one for the agency.

Microsoft Data Mining Client for Excel is a relatively easy-to-use system once setup is completed. Also, it is an Excel-based tool, as the name suggests. Because of its ease of use, this system has been used to demonstrate various data-mining models presented in the PCS cost-estimating guidebook. In this study, three data-mining techniques are presented: multiple regression, decision tree, and artificial neural networks. These are only three of many different data-mining techniques available.

4.8.1 Multiple Regression

Multiple regression is a statistical technique that determines a relationship between a dependent variable (also known as a response, output, or outcome variable) and multiple independent variables, which are usually referred to as predictor, explanatory, input, or regressor variables (Allison 1999).

Multiple regression is the simplest top-down PCS cost-estimation model out of the three presented in this research. The concept of multiple regression is fairly similar to that of linear regression. Instead of using a single data attribute as the input variable in linear regression, multiple regression uses multiple data attributes as input variables simultaneously. In the case of PCS cost estimation, the output variable is estimated PCS cost, and the input variables are project characteristics such as project type and project length. The model can be represented in a simple equation:

$$\text{Estimated PCS cost} = C_0 + V_1 \times C_1 + V_2 \times C_2 + \cdots + V_n \times C_n \qquad \text{Eq. 4.1}$$

where:

V_i = ith input variable,
C_0 = intercept (PCS cost when all variables are equal to zero),
C_i = coefficient associated with the ith input variable, and
n = number of input variables.

A positive coefficient shows that PCS cost increases with the increase in the value of the corresponding input variable. A negative coefficient indicates the inverse relationship of PCS costs with the value of the factor of the corresponding input variable. The process of developing a multiple regression model is illustrated in Figure 4.10.

Selection of suitable independent variables was explained in an earlier section. In this step, the variable selection is done using statistical technique by checking the *P*-values of all independent variables. If the *P*-value is lower, another iteration can be performed by removing the variable and checking if the adjusted *R*-squared value increased or not.

It may be noted that, unlike the other two modeling techniques that are presented in the following sections, multiple

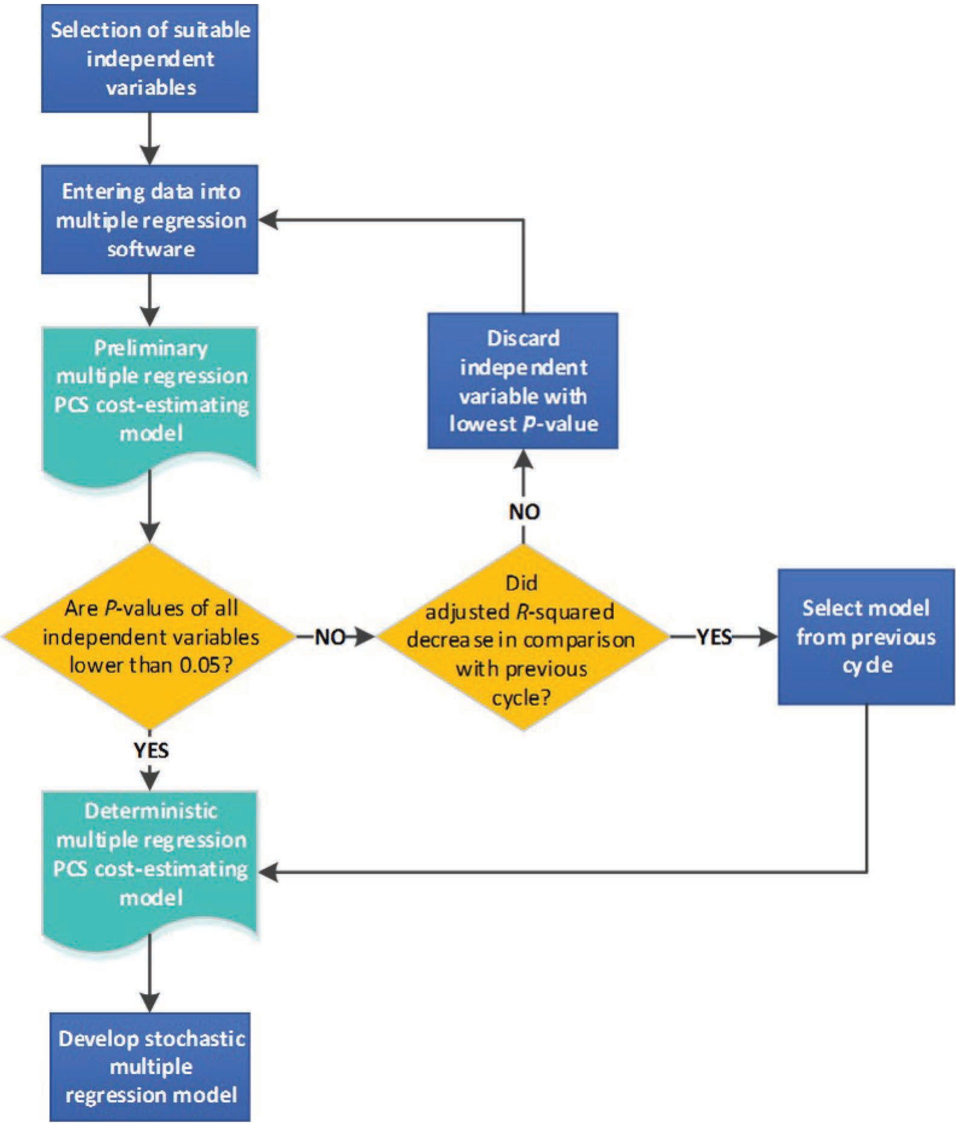


Figure 4.10. Multiple regression PCS cost-estimating model development.

regression cannot use nominal variables as input variables. Nominal variables are categorical variables that are not ordered. Type of project is an example of such a variable. This is a huge limitation of the multiple regression model. But nonetheless, it is the simplest modeling technique. Table 4.2 shows types of variables suitable for regression model development according to Allison (1999). Although all three types of variables can be used to build a multiple regression model, it should be noted that it is always preferred to use interval variables (as defined in Table 4.2). The multiple regression model cannot include categorical variables (also called nominal variables). These are descriptive variables that cannot be arranged in a logical order in accordance with their impact on the dependent variable, such as the name of a county or the number of the DOT district in which a project was built. Lastly, to use multiple regression modeling, there must be at least as many projects as the sum of the number of input variables and the dependent variable (Allison 1999).

As can be seen in Table 4.2, all independent variables in a multiple regression model should either be numeric or be transformable into a quantitative logic scale. Once a model is developed, its performance can be measured using various model performance indicators. Most statistical software packages yield complex outputs that are not easily understandable by the average engineer with little or no advanced education in statistics. However, to simplify the interpretation of the outputs in the multiple regression method, model developers can focus their attention on the three elements defined and explained in Table 4.3. It should be noted that the *R*-squared and adjusted *R*-squared values correspond to the entire model, while the standard error and *P*-value are model performance indicators at the variable level.

Table 4.2. Types of variables suitable for multiple regression.

Type of Variable	Description	Examples
Interval variable	Variable measured in such a way that the difference between two values is meaningful. An increase from 200 to 220 design hours is equivalent to an increase from 340 to 360 design hours.	• Length of project • Number of bridges
Ordinal variable	A variable that may be arranged in a logical order assigning numeric values in accordance with their position in the arrangement. Unlike interval variables, two equal increments of these values cannot be clearly compared.	1 = very simple scope 2 = simple scope 3 = neutral 4 = complex scope 5 = very complex scope
Indicator variable (also called “dummy variable”)	Nominal variable with only two possible categories identified with binomial values (0 and 1) for computation purposes.	0 = concrete pavement 1 = asphalt pavement

The model can be optimized by using a cyclic process intended to discard, one by one, those independent variables that do not show a statistically significant impact on final PCS costs (*P*-value > 0.05). Variables are discarded one by one to allow the model developer to understand the effect of a variable’s removal on the new model’s *P*-values. For the purposes of the guidebook, a cycle refers to an iteration of removing an independent variable and regenerating the model using the remaining variables. The term “cycle” will be applied to not only multiple regression models, but also to decision tree and artificial neural network models discussed in the guidebook.

Model developers should also look at the *R*-squared and adjusted *R*-squared values during each cycle. By removing variables with *P*-values greater than 0.05, the model is expected to be improved as measured by increasing the adjusted *R*-squared value and reducing the difference between this value and the *R*-squared value. However, when using a data set with a high degree of uncertainty, such as the one used to build an early PCS cost-estimating model, it is possible for the best model to include independent variables having *P*-values greater than 0.05. As a result, the developer will notice that the adjusted *R*-squared value between two cycles is reduced. In this situation, model developers should select the model from the previous cycle, which is the one that provided the largest possible adjusted *R*-squared value. It should also be noted that the *R*-squared value is not expected to increase between cycles.

Table 4.3. Model performance indicators – multiple regression.

Model Performance Indicator	Description	Values	Use
R-squared (R^2) and adjusted *R*-squared	These represent the percentage of the variability in the independent variable that can be explained by the multiple regression model.	0.00 (0%) – 1.00 (100%); 1.00 would mean that the model perfectly fits the observations. Adjusted R^2 is always lower than R^2.	The closer the adjusted R^2 and R^2, the better the model. An increase in the adjusted R^2 represents an improvement of the model.
Standard error	This indicator refers to the standard error for each variable. It measures the variability in the value of each coefficient. It is similar to the standard deviation of the mean values for the coefficients.	The magnitude of this value depends on the level of uncertainty associated with its respective variable. The larger the standard error, the higher the uncertainty.	In addition to being used to indicate the variability of a given coefficient, it is used to set confidence intervals and create stochastic models.
P-value	The *P*-value measures the level of significance of a given independent variable for the estimation of the dependent variable.	0.00 (0%) – 1.00 (100%); 1.00 would mean that the given independent variable has no impact on the dependent variable at all, and 0.00 would represent the opposite.	*P*-value < 0.01 (5%) = highly significant variable *P*-value < 0.05 (5%) = significant variable *P*-value > 0.05 (5%) = discard variable

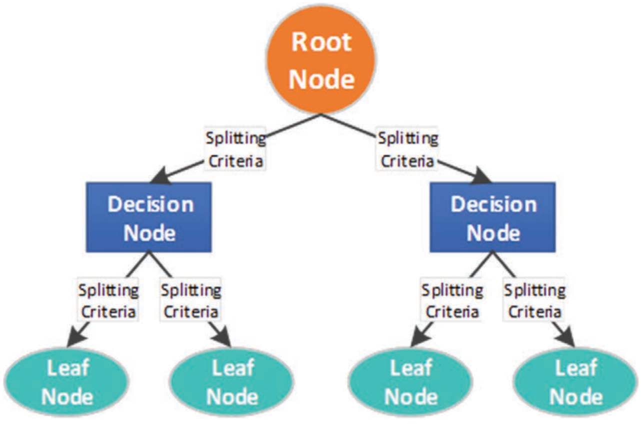


Figure 4.11. Decision tree model visualization.

An example of multiple regression is provided within the guidebook in Section 4.2.1.

4.8.2 Decision Tree

A decision tree identifies projects with similar characteristics and identifies more important cost influencers and presents them in a visual way. A decision tree model consists of nodes and branches, just like a tree (Figure 4.11). At the root or top node, the most important attribute is used to develop the first set of branches. The importance of each variable is evaluated by statistical software using expected information gain (i.e., better understanding of the data fluctuation) or similar measures after using that variable. The expected information gain is defined as the reduction in impurity or entropy of the data after using that variable. For example, if PCS costs of reconstruction projects (which would usually be very high) and resurfacing projects (which would be lower) are expected to be very different, then this project type variable will enable the branching of the root node into two isolated branches. The branching continues until there are a certain preset number of data points in each branch. If there are less than a desired number of data points or projects in any branch, the branching stops. This is known as pruning. Pruning is necessary to reduce the model's over fitting (i.e., development of branches based on very few data points, which might result in unrealistic results, which is especially problematic in data sets with outliers). The values at the end node represent the average output value of all projects that fall under that particular branch of the decision tree.

When the PCS cost for a new project is to be determined, the prediction is made by following the corresponding branches based on the values of input variables (i.e., factors affecting the PCS costs). The benefit of a decision tree is that it can provide a visual illustration of the internal computations used by the model. Further, the chart developed can then be used to compute PCS costs without any software. It can also use categorical variables in addition to the nominal types of variables mentioned previously in the Multiple Regression section.

The performance of a decision tree model can be measured using mean absolute percentage error and mean absolute error, as presented in Table 4.4.

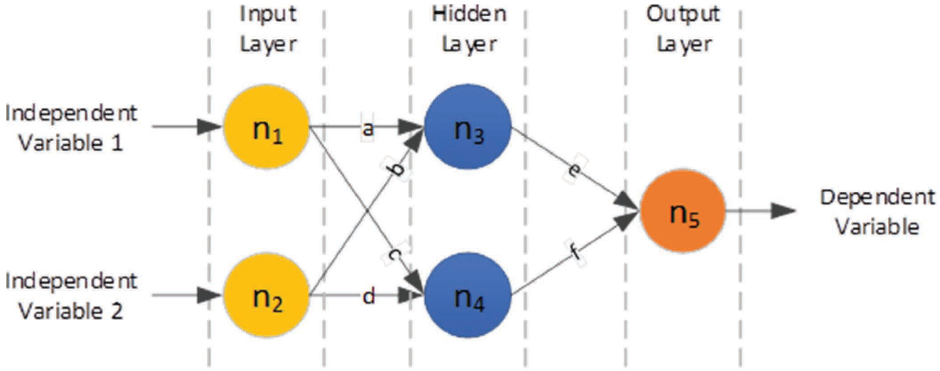
The mean absolute percentage error can be presented mathematically as:

$$\text{Mean absolute percentage error} = \frac{\sum \frac{|\text{Actual PCS Cost}_i - \text{Estimated PCS Cost}_i|}{\text{Actual PCS Cost}_i}}{n} \qquad \text{Eq. 4.2}$$

Where n = number of projects in the validation data set.

Table 4.4. Model performance indicators – decision tree.

Model Performance Indicator	Description	Values	Use
Mean absolute percentage error	Mean absolute percentage error measures the deviation of predictions from actual values.	Any positive value. A value of 0.00% would mean that the model perfectly fits the observations. It is usually calculated for both the training and validation data sets.	The mean percentage absolute error for the validation data set is used to identify the combination of independent variables that best fit the observations.
Mean absolute error	It measures the absolute sum of the total difference between the predicted and actual values.	Its value depends on the magnitude of the output variables (i.e., larger output variables will tend to have larger mean absolute error in terms of magnitude).	It is more challenging to determine the accuracy of a single model using this measure. However, when two models based on the same data set are compared, this measure can be compared to identify the better model.



Where: a–f = Weights to modify independent variables; and
n_1 = First node.

Figure 4.12. Basic artificial neural network diagram.

In addition to the measures in Table 4.4, the minimum and maximum errors can also be used to check the accuracy of the model.

When developing a decision tree, the factors affecting PCS costs can be selected based on attribute evaluation techniques such as subset evaluation and principal component analysis. Such functionality may or may not be available, depending on the software being used. Additionally, some software may automatically perform such evaluations when a decision tree is being generated. These techniques either provide ranks of each of the factors that affect PCS costs based on the factor's influence on the output variable or ranks of various combination of factors that affect PCS costs based on each factor's influence on the output variable. An example of a decision tree is provided in the guidebook in Section 4.2.2.

4.8.3 Artificial Neural Networks

An artificial neural network is a learning system that has the ability to generalize and learn from data by modeling the neural connections in human brains. Typically an artificial neural network consists of an input layer, a hidden layer or layers, and an output layer. Input values are assigned to each of the independent variables in the input layer; then these values are processed through the hidden layer(s) (working as a black box); finally, a single value is obtained though the output layer. The output value in this case is the estimated PCS costs of the project whose project features were used in the input layer of the model. This method is capable of modeling nonlinear relationships among variables with high accuracy; however, this accuracy depends on the quality, amount, and reliability of the data used to build the model. Berry and Linoff (1997) define an artificial neural network as a powerful, general-purpose tool readily applied to estimation, classification, and clustering, which are sometimes best approached as "black boxes" with mysterious internal workings. Figure 4.12 is a diagram of a basic artificial neural network with two independent variables and one hidden layer. This model is powerful, but the internal calculations are not visible to the users of the model.

Adding numbers to the independent variables and weights to the artificial neural network in Figure 4.12 might add more sense to the operation of a neural network. Figure 4.13 shows some sample values for these elements and how these values are modified as they move in the direction of the arrows until reaching the output layer. The procedure shown in this figure corresponds to the simplest way to calculate a dependent value in a neural network, but it is enough to explain the fundamentals of this method. Actual procedures followed by statistical software applications are usually more complex. To move a value from one node to the next, this value is multiplied by the weight of the corresponding arrow. The value taken by each node is equal to the sum of all values transmitted from the previous layer.

A general process of developing an artificial neural network is illustrated in Figure 4.14. This is similar to decision tree development. In this case, the relative variable indicator (RVI) that indicates the importance of each input variable is used to select the influencers. The variables with the lowest RVIs are discarded one by one on a per-cycle basis to improve the accuracy of the model. It is also possible that the combi-

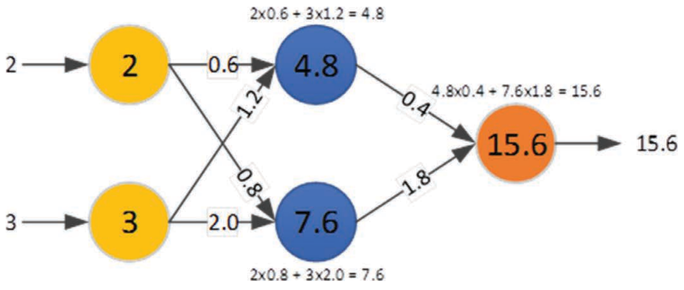


Figure 4.13. Artificial neural network calculation.

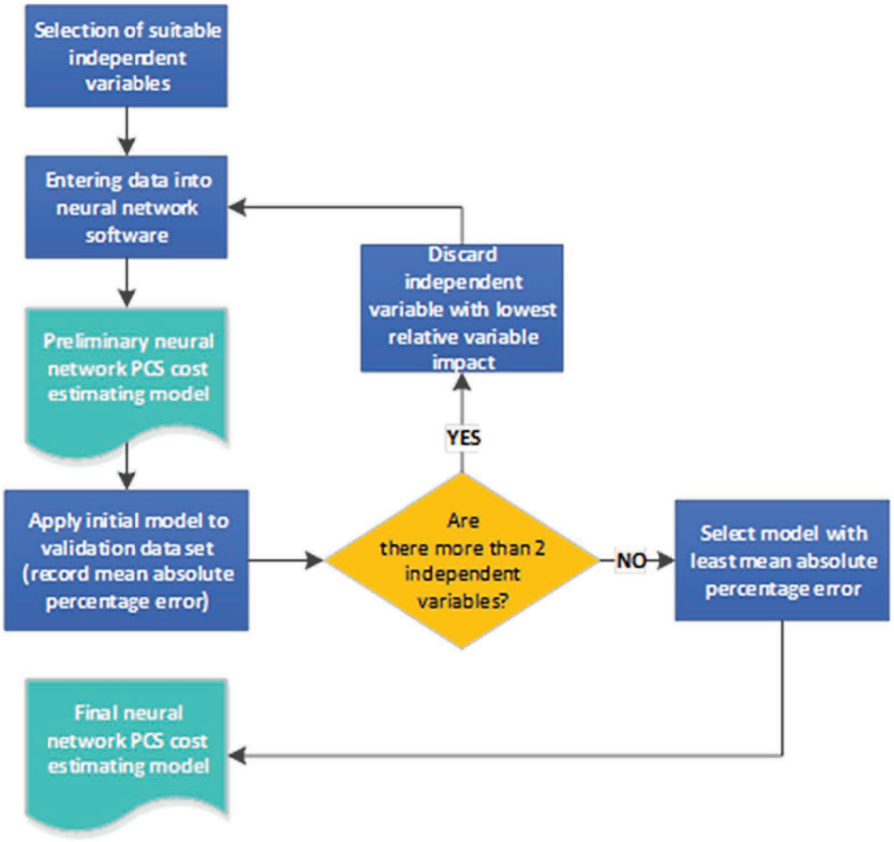


Figure 4.14. Artificial neural network PCS cost-estimation model development.

nation of the variables with less and high importance may provide better accuracy than the combination of the high-importance variables only. As such, various combinations of variables should be tried. As noted in the Decision Tree section, attribute selection methodologies that provide the ranks of combinations rather than single attributes can also be used.

The RVI is another model performance indicator that can be used in addition to other indicators mentioned in the decision tree discussion (see Table 4.5).

An example of an artificial neural network is provided within the guidebook in Section 4.2.3.

4.9 Validation of Models and Selection

The accuracy of PCS cost-estimation models can be measured using several goodness-of-fit tests. To obtain a better idea about the accuracy of a model, random sampling should be done for testing/validation. There are two general methods of generating training data sets and testing data sets—holdout and *k*-fold cross validation. In the holdout procedure, a fraction of data (usually 67%) is used as training data to develop a model. Then the remaining data are used to test the accuracy of the model. Predicted and actual values from the

Table 4.5. Additional model performance indicators – artificial neural network.

Model Performance Indicator	Description	Values	Use
RVI	This indicator measures the impact of each independent variable in the calculation of values for the dependent variable.	The sum of RVI values of all independent variables is equal to 100%.	Used to identify the independent variables that represent the lowest contribution to the model, which are discarded one by one on a per-cycle basis.

remaining 33% of data points are used to test the accuracy of the model.

In *k*-fold cross validation, usually 10-fold, the data set is partitioned into *k*-folds (say 10 parts). One part of the *k*-folds is used for testing, while the remaining data is used for training. This process is repeated until each part of the data is used for validation of the model developed using the remaining parts of the data. Thus, *k* number of models are developed and tested. The errors calculated from each model are then averaged out to calculate the overall accuracy of the model.

Given that any of the three PCS cost-estimating techniques described previously in this chapter may show the best performance under different databases and estimating conditions, transportation agencies are encourage to use all three approaches. The final PCS cost-estimating model would preferably be the one with the lowest average error.

The identification of the most accurate model among the three causal methods does not mean that its accuracy is high enough to fulfill the expectations of the agency. Thus, it is suggested that agencies establish standard parameters to accept a given model to proceed with its application, or reject the model and review again the original data set looking for possible errors or opportunities for improvement of data quality.

4.10 Bottom-Up (Functional-Level) Model Development

The preconstruction phase includes the delivery of many intermediate products and services, such as environmental investigations, geotechnical studies, public involvement, and permitting. The level of effort required to complete many of these tasks is often influenced by project location, resources affected, and regulations activated by the project rather than by a specific project characteristic such as lane miles or bridge length (American Association of State Highway and Transportation Officials 2008). As a result, the best way to quantify these services is to develop a scope of work for the effort required to complete each.

Functional-level cost estimation is a form of bottom-up estimating. The scope of work can be divided into smaller work tasks, which can be estimated individually. These smaller estimates are then combined to form a total estimate for a specific service. A bottom-up estimate is typically estimated by a person who is involved in monitoring the project, such as a senior designer who will manage the team to complete the work (Larson and Gray 2011).

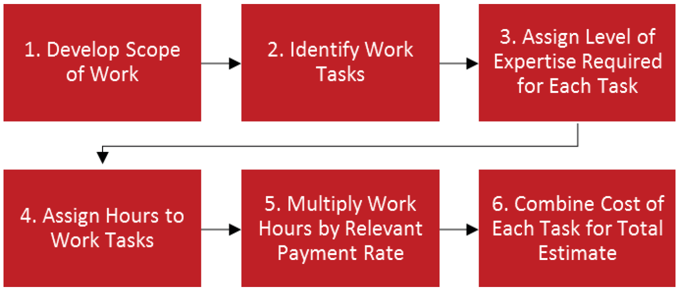


Figure 4.15. Functional-level estimating process.

Figure 4.15 illustrates the key steps that are taken to form a functional-level estimate. Once the scope of work has been defined, the tasks required to fulfill the scope must be identified. To simplify this process, some DOTs have a standard task inventory, also known as a WBS, which contains a comprehensive list of common activities that are typically required during preconstruction. This inventory of work tasks can then be assigned a level of effort to complete and, hence, a rate of pay for that effort. After the hours of each specific work task have been multiplied by the relevant payment rate, the cost of each task can be combined to calculate the total PCS cost estimate.

4.10.1 Use of Functional Level PCS Cost Estimating

Once there is a scope of work, an office will then need to assess who will complete the work. Should an in-house team be used or external consultants (see Figure 4.16)? While it appears most agencies would prefer to perform work in-house, this is not always possible.

The amount of PCS work that is outsourced varies from state to state. Some DOTs have sufficient staff capacity and expertise to complete the majority of work internally, while other agencies employ consultants more frequently.

A functional-level estimate can be used to quantify the number of work hours that will be required by a PCS team to complete a given work package. This can play a significant role

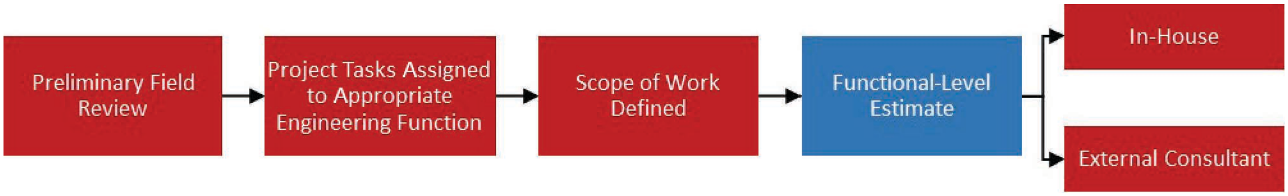


Figure 4.16. Functional estimate sequence.

in management's decision on whether to perform the work with in-house resources. If the estimated work effort does not require specialized services and can be accommodated into the department's schedule, then a decision to do the work in-house can be made. The estimate can aid the distribution and monitoring of forward workload to available team members.

The use of consultants to assist state DOTs with PCS is predicted to increase (Wiegers 2000). This surge in contracting external services has led to the implementation of various state policies and consultant services manuals. Within these documents, DOT engineers are often required to perform detailed in-house cost estimates or independent cost estimates for the work to be contracted out (Touran and Lopez 2006).

The Brooks Act, introduced in 1972, requires that all applicable architectural and engineering service contracts be awarded in accordance to an open negotiation process on the basis of demonstrated competence and qualifications. Federal regulation stipulates a "detailed cost estimate, except for contracts awarded under small purchase procedures, with an appropriate breakdown of specific types of labor required, work hours, and an estimate of the consultant's fixed fee for use during negotiations" [Office of the Federal Register, n.d. (23 CFR)]. A functional-level estimate fulfills these requirements.

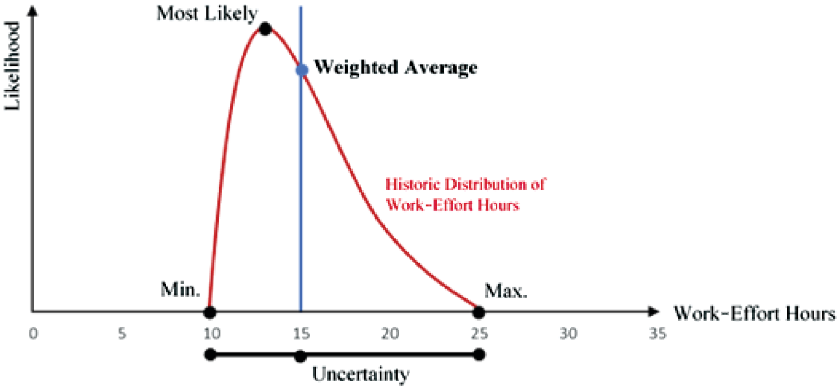
4.10.2 Assigning Hours to Work Tasks

Assigning a range of possible hours for any given task recognizes uncertainty and allows a three-point estimate to be formed. The weighted average hours calculated provide the best possible indication of how many hours will be required for a task, given the historic distribution of work hours from previous projects.

To combine the minimum, most likely, and maximum values from the range estimate into a single number, a weighted average number of hours can be calculated using Equation 4.3.

$$\text{Weighted average hours} = \frac{\text{Min.} + (4 \times \text{Most Likely}) + \text{Max.}}{6} \tag{Eq. 4.3}$$

This equation is based on a historical distribution of work-effort hours for the project type being estimated. It weights the average hour estimate four times more heavily than either the maximum or minimum hour estimates. The output of this equation is the expected value of the number of hours required for the specific task. An example is shown in Figure 4.17 for estimating the work-effort hours required for utility coordination and documentation for a project.



$$\textit{Weighted average hours} = \frac{10 + 4(13) + 25}{6} = 14.5$$

		Range			Weighted Avg. Hours
		Min	Most Likely	Max	
WBS	Utility Coordination and Documentation	10	13	25	14.5 ≈ 15

Figure 4.17. Calculating the weighted average hours required for utility coordination and documentation given an estimate range.

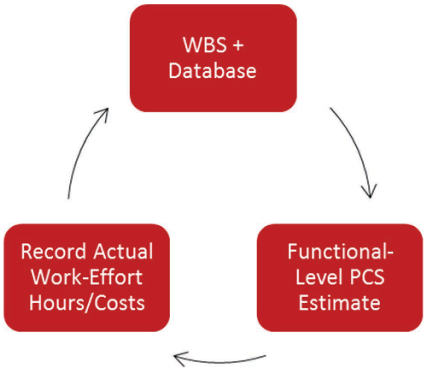


Figure 4.18. Feedback loop for continuous improvement of PCS functional-level estimating.

The most probable number of work-effort hours required for the task of utility coordination and documentation is 15 (after rounding up from 14.5). This total number of hours can now be assigned pro rata to the levels of expertise needed to complete the task.

Creating better functional-level estimates is an ongoing process that can continuously be improved upon. The flowchart in Figure 4.18 illustrates how a WBS and database feed into the development of a functional-level PCS estimate. Recording the actual PCS work-effort hours/costs that correspond to each past estimate strengthens the quality of the database that then goes on to form more accurate future estimates. All three elements in this diagram affect the success of each other.

For engineering offices with no formal estimating process, this feedback loop will take some time and effort to develop. Defining work tasks within a WBS is the best place to start. Once tasks are clearly identified, estimates of their work effort can be created. Review of each estimate compared to actual PCS work-effort hours will then provide the first pieces of data to the database. Over time, the quality of the database will improve as more projects' actual work-effort hours are recorded.

4.11 Implementation of PCS Estimating Models

4.11.1 Output Interpretation and Limitations

The selected model is ready for application if it shows a satisfactory performance in accordance with the expectations of the agency. It is important to recognize the scope limitations of each model when applying it to real projects. For example, if a given DOT develops a model using historical preconstruction data from its previous corridor projects, the final selected model is only applicable to corridor projects awarded by this agency. Likewise, if an agency develops a model using data from previous paving projects completed in a given county, the model would be only applicable to paving projects to be executed in this county by this agency.

4.11.2 Continuous Improvement

Since causal methods rely on historical data to estimate future values, PCS cost-estimating models can be constantly improved over time as more projects are executed and more data are collected, regardless of the model selected (multiple regression, decision trees, or artificial neural networks).

The model development procedure may be repeated on a regular basis every 2 or 5 years (or a period of time that the agency considers convenient), or before this time if observed PCS cost performance measures do not meet the standard parameters established by the agency.

4.11.3 Use of Output as a Decision-Making Tool

By definition, decision-making procedures involve the selection of the most suitable option from a set of alternatives based on the preferences and selection criteria of the decision makers. As a decision-making tool, PCS cost estimates can be used to select the design methods and technologies that best suit the needs and resource availability of an agency. For example, a given agency may decide whether to use in-house or external designers based on the expected PCS costs associated with each of these alternatives. Likewise, decisions can be made at the functional level related to the design of specific project activities. For instance, the geotechnical engineer may use PCS cost estimates to determine the cost implications of using 3-D technologies to model earthwork activities instead of traditional 2-D excavation and backfill plans. To make a comparison between these two design techniques, the model developed to estimate the cost of this work package must include a variable (probably a dummy variable) that indicates the design approach to be used.

Regardless of the nature of the decision to be made, decision makers should take into consideration the limitations of the PCS cost-estimating models. This means that if the agency intends to compare the cost of two different design approaches, it must develop two different models following the procedures described in this research.

Key performance indicators (KPIs) can be used to measure the effectiveness of PCS cost-estimating models. There are two types of KPIs used for two different purposes: measuring the performance of the model and tracking the performance of

Table 4.6. PCS cost estimate – key performance indicators.

At the Model Level	
The following KPIs are used to measure the overall performance of the PCS cost-estimating model. In order to draw any conclusions or take any corrective actions to improve preconstruction practices or the performance of the model, the agency should analyze the following three KPIs obtained from the application of the model in a series of projects. Corrective actions or model redevelopment may be needed only if one or more of these KPIs shows an average behavior that does not meet the agency's expectations.	
Construction cost growth (CCG) (%)	This KPI is intended to justify the use of PCS cost-estimating models. It represents the variation, as a percentage, of the early construction cost estimate in comparison with the actual construction cost of the project. $\text{CCG} = \frac{\text{Actual construction cost} - \text{Early construction cost estimate}}{\text{Early construction cost estimate}} \times 100\%$
Final cost performance index (FCPI)	This KPI measures the accuracy of the model by comparing the PCS cost estimate with actual PCS cost. $\text{FCPI} = \frac{\text{PCS cost estimate}}{\text{Actual final PCS cost}}; \text{FCPI} < 1 = \text{cost overrun}; \text{FCPI} > 1 = \text{under budget}$
Final cost of lost design effort (FCLDE) ($)	The FCLDE corresponds to the total cost, in dollars, of activities associated with the development of discarded alternative designs. It also includes the cost of those portions of the original design that at the end were not used to construct the project. Lower FCLDE values represent a better utilization of agencies' resources to perform final designs.
At the Project Level	
The following KPIs are used to track the performance of the PCS cost estimate throughout the preconstruction period. These KPIs allow the project manager to detect anomalies in the performance of preconstruction activities and take corrective actions in a timely manner.	
Cost performance index (CPI)	Unlike the FCPI, which is calculated at the end of the preconstruction period, this KPI compares the PCS cost estimate with actual PCS costs at any single moment during the preconstruction period. This indicator can only be determined in bottom-up estimates by comparing the estimated cost of completed work packages with the actual cost incurred by the agency to perform this work. $\text{CPI} = \frac{\text{Estimated cost of completed work packages}}{\text{Actual cost of completed work packages}}; \text{CPI} < 1 = \text{Cost overrun}; \text{CPI} > 1 = \text{Under budget}$
Cost of lost design effort (CLDE) ($)	Unlike the FCPI, which is calculated at the end of the preconstruction period, this KPI refers to the cost, in dollars, of activities associated with the development of discarded alternative designs at any single moment during the preconstruction period. A large value in this KPI may represent a poor definition of the project scope.
Design placement (DP) ($)	This KPI corresponds to the total PCS expenses incurred by the agency at any single point during the preconstruction period. This indicator is more suitable for top-down estimates since the lack of detail in these models does not allow the calculation of CPIs. The interpretation of this KPI is based on a comparison of its value with the total PCS cost estimate and the project manager's professional judgment.
Estimate at completion (EAC) ($)	EAC is an adjusted estimate of the total PCS cost calculated from the known cost of completed work packages plus the expected cost of uncompleted work packages. This KPI can only be calculated for bottom-up estimates. $\text{EAC} = \text{Actual cost of completed work packages} + \text{Estimated cost of uncompleted work packages}$

a PCS cost estimate throughout the project preconstruction period. Table 4.6 describes the different KPIs proposed in the guidebook. Likewise, within the guidebook, Appendix B: Project Monitoring–Preconstruction Services Progress, Part III, presents a template that may be used by DOTs to track and record values for these KPIs in a given project.

The Project Management Institute (PMI) recommends a methodology for capturing lessons learned (King 2008). King's methodology consists of a series of questions that the project team should answer and record at the end of each project. These questions are related to three key areas: people, process, and product. Table 4.7 shows some examples of these questions by category. Answers to these questions may be directed to improve preconstruction practices or PCS cost-estimating models. Within the guidebook, Appendix B: Project Monitoring – Preconstruction Services Progress, Part IV, presents a template to assist project teams with the recording of their answers.

4.11.4 Implementing Database Maintenance and Model Development Within an Agency

An agency may choose to maintain databases and develop data-mining models in any fashion that aligns most optimally

Table 4.7. Capturing lessons-learned methodology (King 2008).

People	Description	Questions in this category should relate to team effectiveness and stakeholder interactions. Sample questions include those in the next cell.
	Questions	• What did we learn about staffing—skills, knowledge, experience—that will help us on future projects? • What are the lessons learned about the issues that caused conflict among the team, and by the manner in which we resolved the problems and took corrective action?
Process	Description	Questions in this category should relate to the inputs, tasks, and outputs of the project processes. Sample questions include those in the next cell.
	Questions	• Were there any tools, techniques, or programs used on this project that should be used or avoided for future projects? • How effective was, or is, our data inventory? For whom, what, and when were these data collected?
Product	Description	Questions in this category should relate to the project deliverables and success factors. Sample questions include those in the next cell.
	Questions	• What is being done well or needs to be improved to define, evaluate, and ensure quality for the design? • What is being done well or needs to be improved to manage agency expectations?

with its resources and organizational structure. There are numerous approaches that can be taken. One possible system is to collect data and maintain databases from a central location. A centralized office may also be responsible for creating models with relevant data for decentralized offices (counties or districts). This means a dedicated team with thorough knowledge of the models and data processes is responsible for all models, and a typical engineer need only input the key characteristics of a project into the model to obtain a cost estimate. Such an arrangement relieves the burden of training all PCS staff in data-mining techniques and ensures continuity of data capture and analysis across the agency.

CHAPTER 5

Development of Guidebook

5.1 Introduction

This chapter provides an outline of *Estimating Highway Preconstruction Services Costs, Volume 1: Guidebook* (hereafter referred to as the guidebook). The purpose of the guidebook is to provide support to highway industry practitioners regarding the implementation of the PCS cost-estimating system and newly developed model.

The NCHRP Project 15-51 literature review, case studies, and interviews revealed a number of issues, practices, and techniques beneficial to the implementation of PCS cost estimating for transportation projects. The research team held an intensive 2-day workshop to develop a structure and format for effectively organizing and communicating the information gathered to a wide audience of transportation agencies, designers, contractors, researchers, educators, and others within the transportation industry.

The guidebook is delivered as part of Task 6; in conjunction with the submission of this final research report, it completes Phase 2 of the project.

The guidebook describes effective practices and high-impact decision points for estimating the costs of preconstruction. The guidebook also explains tools and techniques for the practical implementation of typical projects.

The first section of the guidebook is written for the upper management of agencies. It contains the business case and key management messages. The next sections of the guidebook explain the key principles of the PCS cost-estimating process during project development and the various approaches that can be applied at different stages of the process. The benefits of utilizing historical project cost data and the correct preparation of the data for modeling are presented. This is followed by a descriptive introduction to each of the three data-driven estimating models. In addition to the sophisticated data-driven models, a functional-level estimating technique is also provided to assess department resource allocation and costings for negotiation with external consultants. The implementation and continuous improvement of all these models are discussed in Chapter 6. Project-specific considerations are discussed in Chapter 7, along with contract administration guidance. Finally, an appendix containing agency-specific PCS cost-estimating tools and effective practices found in the Task 2 case studies is included to furnish examples for DOT implementation.

5.2 Guidebook Outline

The guidebook is intended to facilitate effective implementation of PCS cost-estimating systems to help improve the state of the practice in delivering transportation projects. The guidebook focuses on practical methods, systems, and protocols intended for immediate application by transportation professionals.

The research team acknowledges that each agency uses different terminology and project development processes. As a result, the content of the guidebook remains as general as possible and gives readers direction on how to create databases and models based on their unique agency requirements. There is no set estimating model to be used. Agencies are at liberty to use any or all of the data-driven models, depending on which suit their data best.

One of the key underlying assumptions developed from the research is that the ability to effectively implement the PCS cost model requires a dynamic, integrated team sharing a common vision of project success. An important component of this shared vision is an understanding of the interrelated nature of high-impact decisions made by the project team at critical points in the project development process.

The guidebook clearly describes the step-by-step process to develop a top-down PCS cost-estimating model with three different data-driven approaches:

- Multiple regression modeling,
- Decision tree analysis, and
- Artificial neural network modeling.

The guidebook also provides a complete guide on developing a functional-level PCS cost-estimating model or a bottom-up model.

The content of the chapters is summarized here:

- Chapter 2: PCS Cost-Estimating Process. This chapter describes the overall PCS cost-estimating process that is aligned with a typical project development process. The need of three different approaches for estimating PCS costs is explained. The appropriate timing of application and the effectiveness of use are discussed.
- Chapter 3: PCS Database Development and Management. This chapter discusses a database development and management process required for a successful implementation of data-driven PCS cost estimating. Some specific topics discussed in this chapter include data collection and cleaning strategies, identification and evaluation of potential input variables, and development/optimization of PCS databases.
- Chapter 4: Top-Down PCS Cost Estimating. This chapter explains the development process of top-down PCS cost-estimating models. Three data-driven methods—multiple regression, decision trees, and artificial neural networks—are discussed in detail.
- Chapter 5: Functional-Level PCS Cost Estimating. This chapter discusses the development process of functional-level PCS cost-estimating models. It discusses the use of a work breakdown structure in developing a functional-level PCS cost-estimating model, discusses the feedback loop for continuous improvement, and also addresses issues in database creation, maintenance, and management.
- Chapter 6: Implementing PCS Cost-Estimating Models. This chapter discusses important aspects related to the implementation of PCS cost-estimating models in practice, such as the interpretation of PCS cost estimates, incorporation of this estimate into decision-making procedures, tracking of PCS costs throughout the project development process, capturing lessons learned from the use of the framework described in the guidebook and specific models developed by using it, and continuous improvement procedures to optimize the performance of these models.
- Chapter 7: Project-Specific PCS Estimating Issues and Contract Administration Guidance. Finally, this chapter discusses project-specific and contract administration issues associated with the development and use of PCS cost-estimating models. This chapter covers project monitoring strategies, actions required under potential scope changes, how to use the PCS cost estimate to identify and quantify scope creep, and some aspects related to the use of in-house versus external designers/consultants.

Definitions specific to preconstruction services are included in Appendix A, and effective practices, methods, and tools information from the case studies are included in Appendix C.

5.3 Guidebook Vetting

5.3.1 Background

The guidebook is oriented toward decision making and a process view of preconstruction project management. It is meant to support decision making by the project team and does not provide a prescriptive recipe for how to use the PCS cost model's output.

Task 5's objective was to test the draft PCS cost-estimating guidebook to ensure that the materials are applicable for practice. The research team conducted a vetting workshop of the guidebook with two DOTs that are interested in investigating the use of the PCS cost models. For this study, the research group approached Iowa DOT and Montana DOT. These agencies were selected because they had both featured in case studies for this project, the research team was familiar with their practices, and real PCS data from each could be used for exercises.

Iowa DOT currently does not estimate the PCS cost for a project; however, the agency is looking at ways to introduce a process to do this. The lack of a formalized system or familiarity with PCS cost estimating made the agency a great candidate to pilot test the guidebook as it tested the guidebook's ability to communicate concepts at an introductory level.

MDT estimates PCS costs for all projects using a standard percentage of construction costs. It also records PCS hours; however, it does not use this collected historical data to estimate future projects' PCS costs. This agency provided a good environment to assess whether the business case of the guidebook models was compelling enough to warrant implementation of more rigorous data-driven models.

The PCS cost data collected from the two agencies during the case studies also allowed the team to customize workshop exercises and examples for each agency.

The vetting workshop took place over 2 days and involved upper management, design, construction, and contracting personnel from the selected DOTs. Each DOT was also at liberty to invite representatives from local consulting firms; however, despite invitations, none participated in the workshops.

The first day of each workshop consisted of a mixed program of presentations of guidebook material and interactive exercises to apply the concepts of the guide in practice. Table 5.1 illustrates the day's agenda.

DOT staff typically involved in preconstruction project tasks from different offices and departments participated. Participants were divided into groups for the day and worked together to complete each of the exercises. To provide a genuine experience, laptop computers were provided with loaded software that allowed the groups to physically develop linear regression, decision tree, and artificial neural network models. Historical PCS cost data collected from the DOTs was curated into a small database to use in the examples.

Table 5.1. Workshop agenda of Day 1.

DAY 1
Welcome and introduction
Introduction to PCS cost estimating
Break
Traditional PCS estimate exercise
Discuss guidebook estimating models
Lunch
Demonstration of software for model development
Estimate exercise using guidebook models
Discuss functional-level estimating
Functional-level estimating exercise
Feedback/discussion

A preliminary filed review form from a real highway reconstruction project was also used in an exercise on functional-level estimating. Participants were asked to assign activity hours to all the PCS activities required for the project given the information provided within the form. These hours were then aggregated and assigned an average labor rate to produce an early estimate.

The second day of the workshop involved a focus group with DOT preconstruction personnel and higher management. This meeting provided a platform to assess the previous day's results and separate the feedback that applies only to the given DOT and that which had broader application. Although this step was not required in the RFP, the research team believed it was vital to developing an implementable guidebook. This step has been extremely valuable on past guidebook efforts by research team members.

5.3.2 Measuring Results

The purpose of the workshops was to evaluate how effectively the guidebook communicated PCS cost-estimating practices and whether the research could be implemented by highway agencies using the resources provided within it. The workshops also aimed to collect feedback detailing recommendations for changes to the draft guidebook content.

To fulfill these goals, a number of research methods were employed. These included:

- Surveys,
- Observation, and
- Focus groups.

Using three methods to evaluate the performance of the guidebook allowed the research team to "detect recurrent patterns or consistent relationships" (Abowitz and Toole 2010) within the feedback received.

Observations were made during Day 1 of the workshop. Of particular interest to the research team was participants' engagement with the material provided. Specifically, the observers were looking to see if groups were able to relate the new estimating concepts to their prior estimating experience and find value in the information provided. Observations were also made during the exercises to see how well the guidebook aided groups in completing tasks. If the group had to ask additional questions, this was noted as it implied that the guide was not comprehensive enough in that particular area.

A survey was conducted at the end of Day 1 to measure participants' views on the guidebook and the concepts presented within it. The survey was developed following principles of Taylor-Powell and Renner (2009) and aimed to quantify perceived changes in motivation, knowledge, and estimating skills as a result of guidebook. At the end of Day 1, participants completed the survey, and an open discussion was held about the merits and problems of the guidebook.

"Focus groups are carefully planned discussions stimulated within a predefined group environment to obtain perceptions about a defined area of interest in a permissive, nonjudgmental environment" (Yu et al. 2006). Day 2 involved a structured discussion about the strengths and weaknesses of the guidebook and the realities of implementing its concepts within an agency. It was important for the research team to steer discussion to issues relating to the guidebook's applicability to all highway agencies and limit focus on just its application to the DOT participating in the vetting.

The final stage of the vetting process was to combine the feedback provided and address any issues within the guidebook to improve its quality. This was an iterative process. Feedback for the Iowa DOT vetting was used to revise the guidebook before it was provided to the Montana DOT for the second vetting. A summary of the feedback received from the two workshops is detailed in the following sections.

5.3.2.1 Iowa DOT Vetting

The first draft of the revamped guidebook was sent to Iowa DOT two weeks prior to the workshop to allow participants an opportunity to read it and bring any questions they had to the vetting. The research team conducted the workshop, which had 13 DOT participants

Observations made throughout the day were that the participants were very engaged and receptive to the concepts presented. The final survey confirmed this with very positive feedback. Of the survey respondents, 75% reported that they were "quite a bit" or "a great deal" more aware of the overall PCS cost-estimating process as a result of the guidebook. All participants reported a greater understanding of top-down data-driven models and how to develop a database. The focus group held the day after the workshop was very positive; there was a general consensus that the guidebook contained practical approaches that would significantly improve the preconstruction phase of a project.

The major findings of this vetting were:

- The guidebook is repetitive in some sections; this redundancy should be removed.
- While the guidebook contains many great figures, there is still a lot of text, using call-out boxes to draw out the important information would make it more readable.
- The business case in Chapter 1 should be aimed at higher management as they are the people who will make a decision on whether these practices are implemented.
- Appendix D needs to be written less technically.
- The guidebook needs to better explain that implementing these estimating techniques cannot be achieved by one person and that sufficient up-front resources will need to be committed by the DOT to maintain databases and develop models.

As a result of this feedback, the guidebook was reorganized, with Chapter 3 dedicated to database development and management to better illustrate the up-front investment required by DOTs to implement data-driven estimating processes. Redundant text was removed, and call-out boxes were introduced. Chapter 1 was revised, and Appendix D was modified.

5.3.2.2 Montana DOT Vetting

An updated draft of the guidebook was then provided to MDT two weeks ahead of its vetting. This workshop was led by Dr. Gransberg, Dr. Jeong, and one graduate student. There were 21 participants from a variety of districts and departments for Day 1.

Again participants were very engaged and there was lively discussion throughout the day. Groups worked diligently on the exercises provided and successfully applied guidebook concepts to their solutions. Survey responses at the end of the day recorded 80% of participants being “a great deal” or “quite a bit” more aware of the overall PCS cost-estimating process. All participants whose duties involved PCS estimating indicated that they would consider implementing concepts presented in the guidebook, especially using top-down estimating models. The focus group held the following day was very encouraging. The group believed the research was timely but would require a change in agency culture to work effectively. Staff will need to place more accountability on the PCS estimating phase.

The major comments and findings from this vetting are as follows.

Strengths of Guidebook

- Good organization–very methodical.
- It steps through process beginning to end very well.
- Easy to read.
- Thorough coverage of all the functions (survey, enviro, roadway, etc.).

Improvements

- Paragraph is very vague and could use a little more explanation.
- Could clarify that PCS can be whatever an agency wants–just preliminary engineering or can split out ROW.

Comments

- This research fits well with MAP-21 requirements.
- There is an increasing need for cost accountability from FHWA; these tools will help justify resource allocation.

Training

- Participants felt that a workshop (or consulting session) would help implement the tools of the guidebook. There were many comments that the workshop really helped the guidebook make more sense.
- A consulting session would be good to help an agency establish a database and analyze what factors are the most important inputs (what data to collect).

CHAPTER 6

Conclusions and Recommendations for Future Research

6.1 Introduction

This chapter focuses on the results of the research and the recommendations for future research that were recognized during the project. There were three separate research instruments used to reach conclusions: the literature review, the national survey, and the case studies from structured interviews with agency personnel.

6.2 Conclusions

Throughout the course of this research project, the research team was able to reach several conclusions. These are discussed in the following, in no particular order.

There is a need for improved PCS cost estimating. The literature has shown that underfunding preconstruction activities results in shifting problems that have not been identified or addressed to the construction phase, where the cost to correct them is much higher.

- The implications of bad/no PCS cost estimating are currently poorly understood: A number of the case study interviewees expressed the opinion that having a more accurate estimate of PCS costs would not add any value to the process. These opinions were based on the disparity between the cost of PCS and construction; roughly 3% to 6% for PCS and the remaining 94% to 97% for construction. Additionally, most indicated that there was little if any accountability for keeping actual costs within the amount budgeted for the preconstruction phase. This may account for the low level of confidence that respondents attributed to the quality of the existing data (e.g., there is no perceived reason to accurately post actual hours charged to a particular project because there is no monitoring of PCS costs). These observations reinforce the importance of crafting a PCS cost-estimating guidebook and educating practitioners on the importance of PCS cost estimating during the project development phase.
- Terminology and data coding systems: No standardized terminology was found across DOTs for the various components of the project development process. Hence, generalized estimating models and processes needed to be developed in the guidebook to allow DOTs to tailor them to their specific needs. This lack of standardization has also been seen in the management of preconstruction activities and data-collection methods within DOTs. Useful historical information to analyze and estimate PCS costs is being recorded in multiple databases using different terminologies and coding systems, reducing the agencies' ability to communicate and share information among functional areas. This issue adversely affects the accuracy with which an estimator can assign various expenses found in the financial record to specific tasks in the PCS process.
- Data quality: In many of the case study projects, the DOT personnel expressed doubt regarding the accuracy of the available data. Some of the DOTs have a sophisticated process for collecting the PCS data, but in all cases, the data depends on the diligence of the individual employees to accurately reflect the distribution of the hours charged to a given project in a normal day. These data quality issues have proven to be a critical factor affecting the development of effective PCS cost estimates. Thus, the PCS cost-estimating guidebook also provides some suggestions for DOTs to improve their data-collection techniques, making PCS information more accessible and easier to understand by all involved in the project development process. There is no elegant statistical methodology to remedy this issue. However, the result of this finding led the team to decide to use three different methodologies for modeling PCS costs (artificial neural networks, multiple regression analysis, and decision trees), which will yield three individual outcomes for any given data set. This permits the analyst to "bound the outcome" as there will be a low value, a high value, and a value in between, producing what is called a credible range in the risk-based estimating literature (Anderson et al. 2007).

Thus, the result is a worst, best, and most likely case for the project's PCS cost.

- PCS cost estimating is required when negotiating external consultant contracts. Federal law stipulates a "detailed cost estimate . . . with an appropriate breakdown of specific types of labor required, work hours, and an estimate of the consultant's fixed fee . . . [is required] for use during negotiations" (U.S. Government Printing Office 2015). As a result, a PCS budget determined from a percentage of construction costs is not sufficient to use for negotiating PCS contracts with external consultants. Top-down estimating approaches cannot be used in this application. Functional-level estimating is necessary for consultant negotiations.

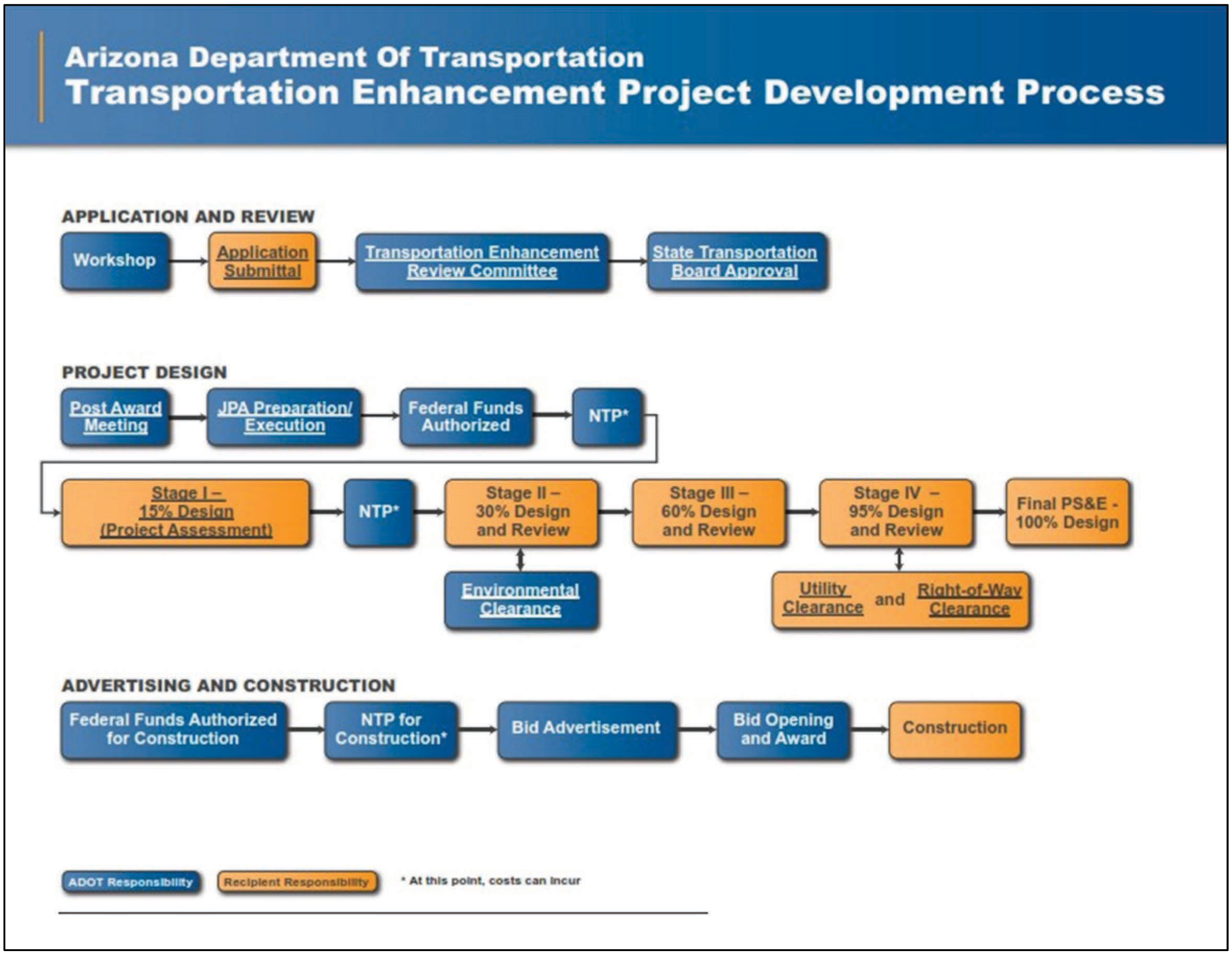
6.3 Recommendations for Future Research

Throughout the course of the research, the research team noted some areas that could be explored to further improve PCS cost-estimating practices:

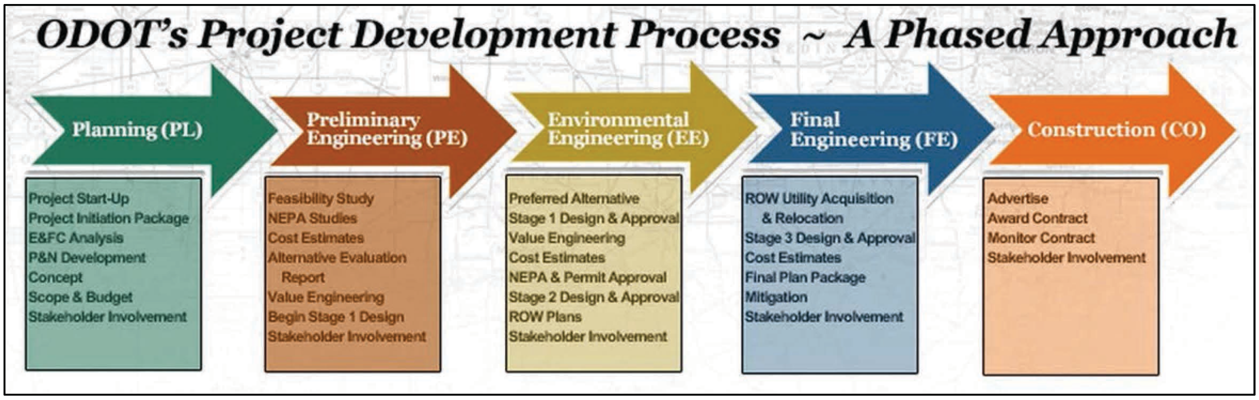
- The research identified the lack of similar terminology between agencies. Investigating the implementation of a standardized process to collect and use PCS cost data would enable information to be shared easily between DOTs. Lessons learned could then be universally applied to improve all agencies' practices. Another branch of this concept would be to develop a standard coding system for project factors.

APPENDIX A

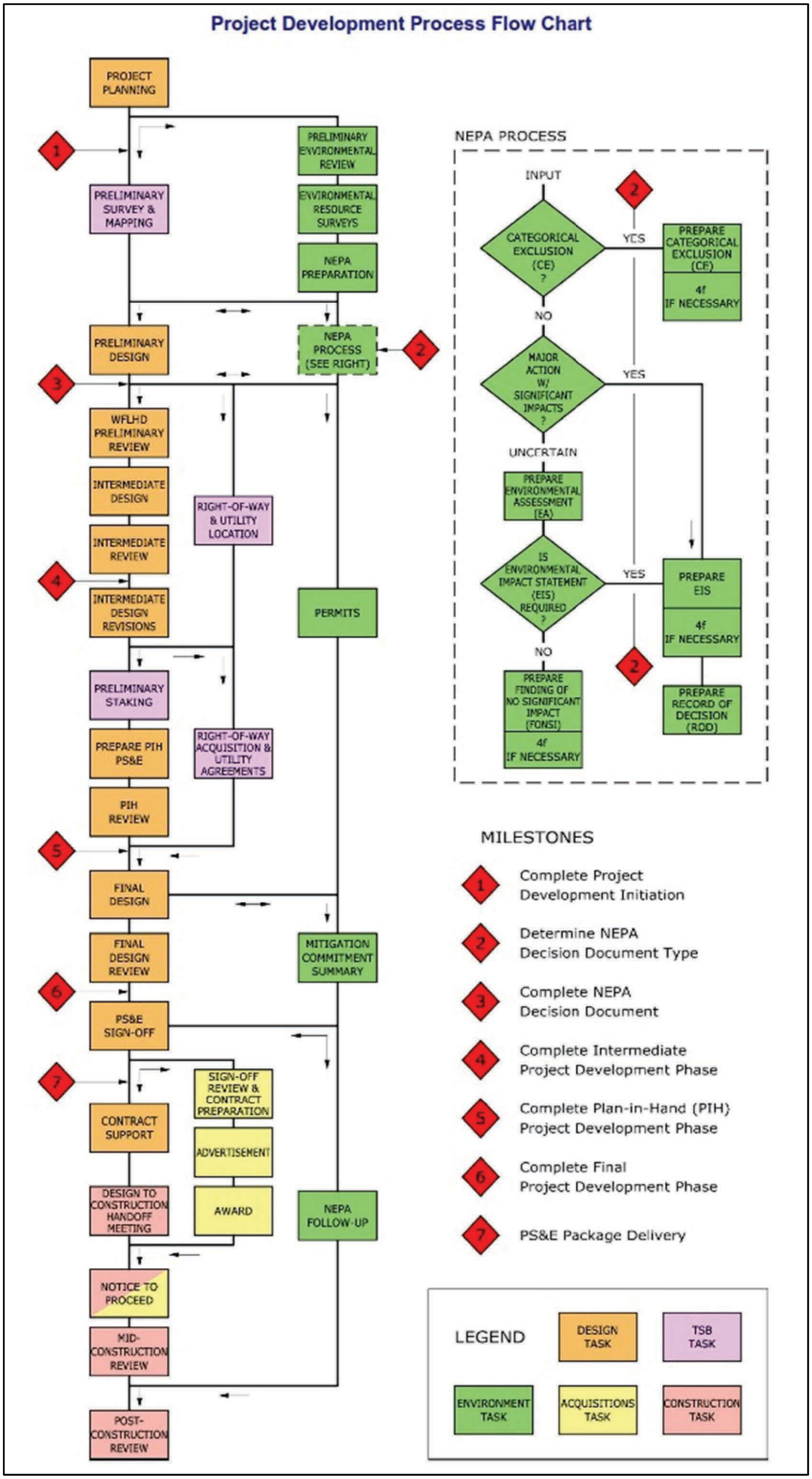
Project Development Processes



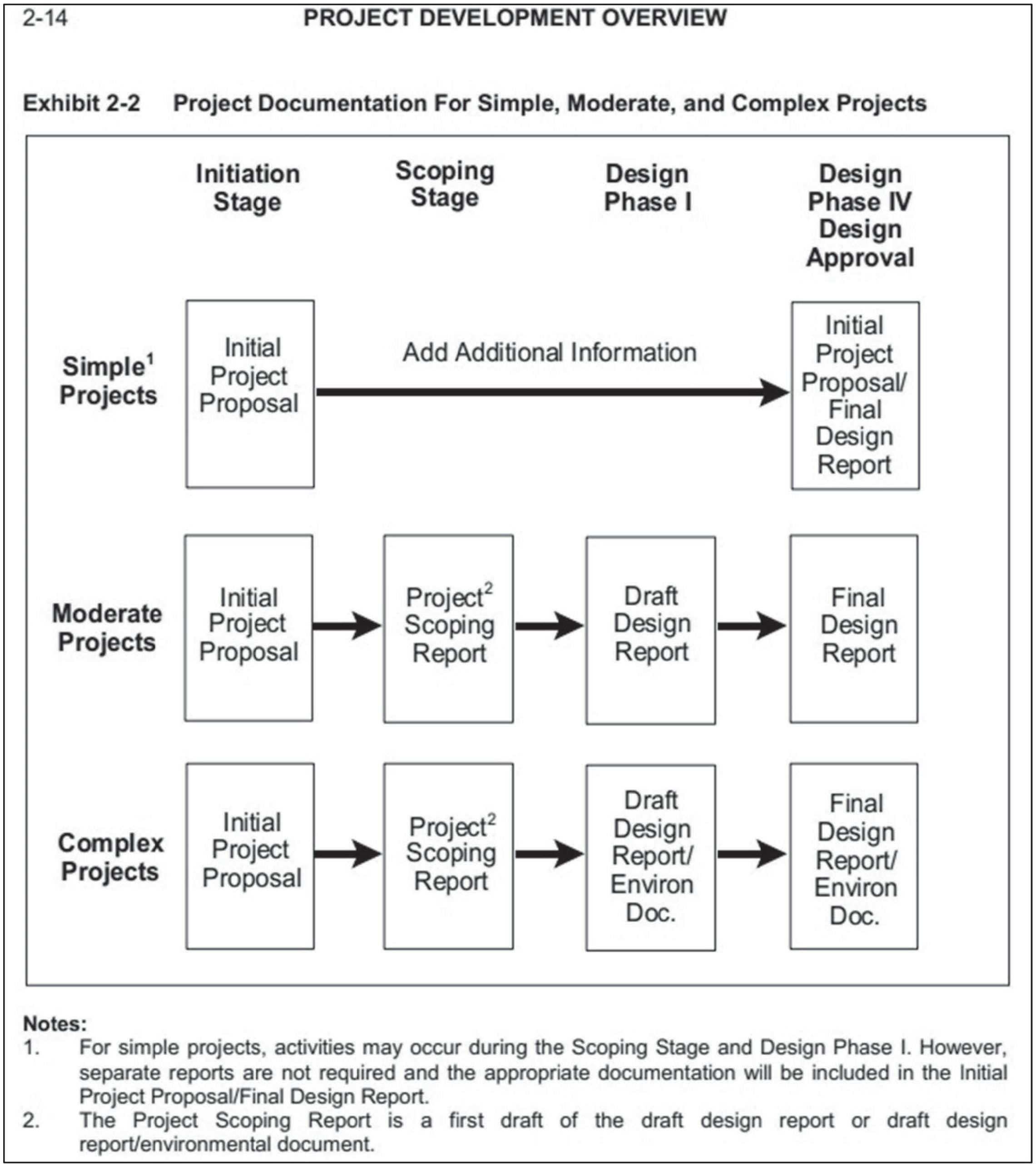
Arizona DOT project development process (Arizona Department of Transportation 2014).



Ohio DOT project development process (Ohio Department of Transportation 2014).



Western Federal Lands Highway Division project development process (Western Federal Lands Highway Division 2007).



2-14 **PROJECT DEVELOPMENT OVERVIEW**

Exhibit 2-2 Project Documentation For Simple, Moderate, and Complex Projects

	Initiation Stage	Scoping Stage	Design Phase I	Design Phase IV Design Approval
Simple[1] Projects	Initial Project Proposal	Add Additional Information →	→	Initial Project Proposal/ Final Design Report
Moderate Projects	Initial Project Proposal →	Project[2] Scoping Report →	Draft Design Report →	Final Design Report
Complex Projects	Initial Project Proposal →	Project[2] Scoping Report →	Draft Design Report/ Environ Doc. →	Final Design Report/ Environ Doc.

Notes:

1. For simple projects, activities may occur during the Scoping Stage and Design Phase I. However, separate reports are not required and the appropriate documentation will be included in the Initial Project Proposal/Final Design Report.
2. The Project Scoping Report is a first draft of the draft design report or draft design report/environmental document.

New York State DOT project development process (New York State Department of Transportation 2004).

APPENDIX B

Screening Survey

Please answer the following questions regarding preconstruction services of your department to the best of your ability.

Point of contact for future reference

- ☐ Name:
- ☐ State:
- ☐ Position:
- ☐ Email:

Do you outsource preconstruction services? Yes No

If yes, what % of preconstruction services are done in-house? 0%–30% 31%–60% 61%–90% >91%

Do you collect in-house labor costs on a project-by-project basis? Yes No

If yes, what do you use the data for?

Would you be willing to allow the NCHRP Project 15-51 research team to collect a case study of the preconstruction services cost-estimating system used by your department? Yes No Maybe

Is there anything you would like to add about your department's preconstruction services cost-estimating procedures?

Please circle the appropriate yes/no answer that describes the points in the project life cycle where you collect in-house labor costs.

Phases	Planning				Preliminary Engineering				Environmental Engineering				Final Engineering				Construction	
Activities	Project start-up (before MPO or STIP)		Scope and budget – concept		Stage 1 design – Evaluating alternatives		Initial cost estimations		Environmental field studies – preferred alternatives		NEPA and permit approval		Detailed design		Final plan package		Procurement	
	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
MPO – Metropolitan planning organization, STIP – Statewide Transportation Improvement Plan, NEPA – National Environmental Policy Act																		

Please check the methods that you use to estimate the cost of the following activities shown at the top of the table.

Phases	Planning		Preliminary Engineering		Environmental Engineering		Final Engineering		Construction
Activities Methods	Project start-up (before MPO or STIP)	Scope and budget – concept	Stage 1 design – Evaluating alternatives	Initial cost estimations	Environmental field studies – preferred alternatives	NEPA and permit approval	Detailed design	Final plan package	Procurement
Trns.port software	☐	☐	☐	☐	☐	☐	☐	☐	☐
Standard % of estimated construction cost	☐	☐	☐	☐	☐	☐	☐	☐	☐
Direct estimate of hours	☐	☐	☐	☐	☐	☐	☐	☐	☐
Past project cost range	☐	☐	☐	☐	☐	☐	☐	☐	☐
Don’t know	☐	☐	☐	☐	☐	☐	☐	☐	☐
Other – please specify									

APPENDIX C

Agency and Project Interview Template

STRUCTURED INTERVIEW:

I. Agency and Interviewee General Information:

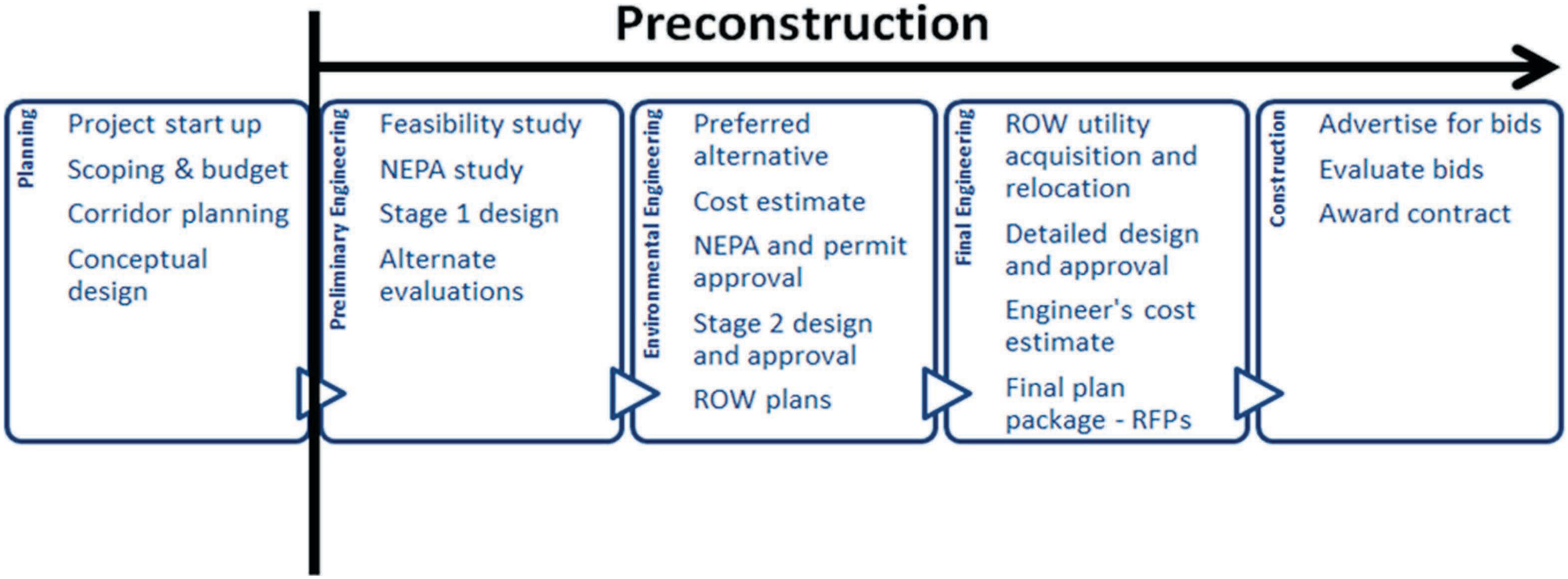
1. Interviewee name:
2. Interviewee job position in the agency:
3. Interviewee telephone number:
4. City and state in which the respondent agency is headquartered:
    A. Name of agency:
5. What type of organization do you work for?

☐ State DOT ☐ Other public transportation agency

☐ Other: {explain}

6. Annual construction budget:
7. Approximate average annual number of awarded construction projects:
8. Approximate average annual number of federally funded projects:
9. Approximate average annual number of non-federally funded projects:
10. Project monetary size range: $ to $
11. Average monetary size of a new construction project $

II. Preconstruction Services Project Development Process



III. Agency In-House Data Collecting:

1. Do you record in-house PCS hours on a per-project basis?

☐ Yes ☐ No

If yes, continue. If no, go to next section.

2. How do you record these hours?

☐ Engineers' timesheets
☐ Time-tracking software
☐ Time allocation system per job
☐ Other {explain}

3. How accurate do you think the hours are?

1 – Not Accurate 2 3 4 5 – Very Accurate

4. Do you allocate in-house overhead costs to an individual project?

☐ Yes ☐ No

If yes, how do you allocate these costs?

5. Do you use the data to determine PCS cost estimate for future projects?

☐ Yes ☐ No

If yes, continue. If no, go to next section.

6. What method do you use to estimate PCS costs for a project?

☐ Trns.port software
☐ Standard percentage of estimated preconstruction cost
☐ Direct estimate of hours
☐ Past project cost range
☐ Don't know
☐ Other {please specify}

IV. Agency Outsourcing Preconstruction Services Makeup:

1. Does your agency contract out PCS work?

☐ Yes ☐ No

If yes, continue. If no, go to next section.

2. Do you have a standing contract for a general engineering consultant (GEC)?

☐ Yes ☐ No

3. What services do you contract out?

	In-house	GEC	Other Consultant
Feasibility study			
NEPA study			
Stage 1 design			
Alternate evaluations			
Preferred alternative			
Cost estimate			
NEPA and permit approval			
Stage 2 design and approval			
ROW plans			
ROW utility acquisition and relocation			
Detailed design and approval			
Engineer's cost estimate			
Final plan package (RFP and RFQ)			
Advertise for bids			
Evaluate bids			
Award contract			
Approximate percentage			

4. If your agency contracts out PCS, why do you do it?

☐ Regulations	☐ Staff availability	☐ Special expertise
☐ Policy	☐ Transfer risk of design liability	☐ Other: {explain}

5. Do you have limitations or guidelines on how much you can or shall outsource?

☐ Yes ☐ No

If yes, please explain:

6. Do you compare the cost of in-house resources to the cost of consulting out as part of the outsourcing decision process?

☐ Yes ☐ No

If yes, please explain:

V. Preconstruction Cost Components:

1. How influential do you think the following characteristics are in estimating the overall PCS cost for a typical design–bid–build project? (*Interviewer check the appropriate box*)
    - 1 – No influence
    - 2 – Some influence
    - 3 – Major influence

	1	2	3
Complexity	☐	☐	☐
Project type	☐	☐	☐
Number of sub-consultants	☐	☐	☐
Construction cost	☐	☐	☐
Number of lanes	☐	☐	☐
Number of plan sheets	☐	☐	☐
NEPA classification	☐	☐	☐
Number of bridges	☐	☐	☐
Highway classification	☐	☐	☐
Length of project	☐	☐	☐
Geographical	☐	☐	☐
Loss of design effort	☐	☐	☐
Other	☐	☐	☐

VI. How to Improve PCS Cost Estimates:

1. What is your agency's current stance on estimating PCS cost?

☐ Already estimating PCS cost
☐ Looking to adopt it in the future
☐ Believe it would be valuable
☐ Do not see value for my agency
☐ Other: {explain}

2. What do you think your agency needs to do to improve its PCS cost estimates?

3. If there was a system available that would capture PCS cost information, would your agency consider adopting it?

☐ Yes ☐ No ☐ Maybe

Please explain:

4. If you were able to more accurately estimate PCS cost, what would be the impact on the planning process?

1 – No Impact 2 – Some Impact 3 – Large Impact

Please explain:

5. Is there anything you would like to add that you think would be valuable to the researchers in this study?

PROJECT CASE STUDY INTERVIEW:

VII. Project General Information:

1. Project name:
2. Project type: DBB DB CMGC Other
3. Project description:
4. Total monetary size of project:
5. Total cost of PCS for project:
6. Breakdown of the PCS cost for the project (if available):

	In-house	GEC	Other Consultant
Feasibility study	$	$	$
NEPA study	$	$	$
Stage 1 design	$	$	$
Alternate evaluations	$	$	$
Preferred alternative	$	$	$
Cost estimate	$	$	$
NEPA and permit approval	$	$	$
Stage 2 design and approval	$	$	$
ROW plans	$	$	$
ROW utility acquisition and relocation	$	$	$
Detailed design and approval	$	$	$
Engineer’s cost estimate	$	$	$
Final plan package (RFP and RFQ)	$	$	$
Advertise for bids	$	$	$
Evaluate bids	$	$	$
Award contract	$	$	$
Total percentage			

7. Complexity of project:

1 – Basic Project	2	3 – Typical Project	4	5 – Very Complex

8. Number of sub-consultants:

9. Number of lanes:

10. Number of plan sheets:

11. NEPA classification:

12. Number of bridges:

13. Highway classification:

14. Length of project:

15. How much influence did the following factors have on the PCS cost for this project?

	No Influence	Minor Influence	Major Influence
Complexity	☐	☐	☐
Project type	☐	☐	☐
Number of sub-consultants	☐	☐	☐
Construction cost	☐	☐	☐
Number of lanes	☐	☐	☐
Number of plan sheets	☐	☐	☐
NEPA classification	☐	☐	☐
Number of bridges	☐	☐	☐
Highway classification	☐	☐	☐
Length of project	☐	☐	☐
Other	☐	☐	☐

APPENDIX D

Case Study Write-Ups

Agency: Caltrans

Location: Sacramento, California

General information: Caltrans' yearly construction budget is approximately $13 billion to $15 billion, and it awards approximately 364 construction projects per year. Approximately 60% of all annual projects are federally funded, with the remaining 40% non-federally funded. Project monetary size ranges from $50,000 to $3.5 billion. The average monetary size of new construction projects ranges from $2 million to $5 million.

In-house data collection: Caltrans does record in-house PCS hours on a per-project basis. It records these hours using the engineers' timesheets. The data recorded on these timesheets are rated 3 out of 5 for accuracy. Caltrans does allocate in-house overhead cost to a specific project. These costs are allocated as an annual rate percentage, with a functional rate of 35% to 40% and an administrative rate of 20% to 30%. Caltrans uses data collected from past projects to estimate the PCS costs for future projects. However, the PIPE scan system is used as a starting point. Current methods used to estimate PCS costs for projects include a direct estimate of hours and an average percentage support-to-cap ratio.

Outsourcing data collection: Caltrans contracts out 10% of PCS work. It has a standing contract for a GEC. Each district has its own separate on-call staff. Caltrans can perform the entire preconstruction process in-house, and it also can outsource all PCS except advertisement for bids, evaluation of bids, and award of contract. It is rare for Caltrans to outsource PCS concerning cost estimates, ROW plans, and ROW utility acquisition and relocation.

Caltrans performs 90% of PCS in-house, and 10% is outsourced. The main reasons it outsources PCS are policies, staff availability, and special expertise. Caltrans does not compare the cost of performing PCS in-house to consulting out as part of the outsourcing decision process.

The major influences on PCS cost for Caltrans are:

- Complexity,
- Project type,
- Construction costs,
- Number of plan sheets,
- NEPA classification, and
- Length of project.

The minor influences on PCS cost for this agency are:

- Number of lanes,
- Number of bridges, and
- Geographical.

The characteristics that have no influence on the PCS cost for this agency are:

- Number of sub-consultants,
- Highway classification, and
- Loss of design effort.*
  *If funding is not allocated.

PCS estimate improvements: Caltrans is already estimating PCS cost for all projects. To improve these estimates, the agency believes it needs a better model for historical data analysis, needs to do bottom-up estimates, and needs good scoping documents. Caltrans already has a system that captures PCS cost information. It is difficult to buy a new program off the shelf, and Caltrans believes that a new program needs to fit current systems and data. It believes that having more accurate PCS cost estimates would have some impact, mainly on the budget process.

Researchers' observations: The largest issue is that it will be difficult to convince people to use the system.

Agency: CDOT

Location: Denver, Colorado

General information: CDOT's yearly construction budget is approximately $500 to $700 million, and it awards approximately 180 construction projects per year. From 85% to 90% of all annual projects are federally funded. Project monetary size ranges from $150,000 to $100 million. The average monetary size of new construction projects ranges from $1.5 to $1.6 million.

In-house data collection: CDOT does not record in-house PCS hours on a per-project basis. Whether the cost is recorded depends on the type of project. For federally funded projects, it needs to submit an independent project cost estimate; in this case 10% is assumed. For bridge enterprises and larger projects, it will collect all costs. It records these hours using the engineers' timesheets. The data recorded on these timesheets are expected to be 60% accurate. CDOT does allocate in-house overhead costs to a specific project. Its current organizational indirect rate of 20% is evaluated every year and distributed across the multiple phases of a project. CDOT does not use data collected from past projects to estimate the PCS cost for future projects. It uses standard percentages of estimated construction costs to estimate PCS hours.

Outsourcing data collection: CDOT does contract out PCS. It has a standing contract for GECs. CDOT can perform the entire preconstruction process in-house or it can outsource all PCS except advertisement for bids, evaluation of bids, and award of contract.

By number of projects, CDOT performs 45% of PCS in-house, and 55% is outsourced. The main reasons it outsources PCS are staff availability and special expertise. It does not have any regulations on how much it can or should outsource. It has to have justification to outsource projects. CDOT does not compare the cost of performing PCS in-house to consulting out as part of the outsourcing decision process. The decision to outsource or not is mainly based on the availability of staff and in-house capabilities.

The major influences on PCS cost for CDOT are:

- Complexity,
- Construction costs,*
- NEPA classification,
- Political elements (e.g., high-visibility project), and
- Schedule drivers.

The minor influences on PCS cost for this agency are:

- Project type,
- Number of sub-consultants,
- Construction costs,*
- Number of plan sheets,
- Number of bridges,
- Highway classification,
- Length of project, and
- Geographical.

The characteristics that have no influence on PCS cost for this agency are:

- Number of lanes, and
- Loss of design effort.

  * CDOT considers construction cost a major influence for in-house projects, but considers it as having only some influence for consultant projects.

PCS estimate improvements: CDOT is looking to adopt a system of estimating PCS costs for larger projects. To improve its PCS cost estimates, the agency believes it needs good tools as well as good data. It currently relies on guesstimates. This is an artistic process and involves loss of experience with younger engineers. The agency needs a data-collection effort to figure out the number of hours. If there was a system available that would capture PCS cost information, it would consider adopting such a program, depending on how the model aligned with other systems CDOT uses. CDOT believes that having more accurate PCS cost estimates could have a moderate impact on the planning process. It would really help with budget portfolio management. People involved in PCS cost estimating are not usually engineers. This position is usually left up to planning or environmental people. Planning personnel rely on past information to develop a ratio between PCS cost and estimated construction cost for each project.

Researchers' observations: When you hire a consultant, you need to negotiate the number of hours.

Agency: Iowa DOT

Location: Ames, Iowa

General information: Iowa DOT's yearly construction budget is approximately $400 million, and it awards approximately 500 to 600 construction projects per year.

In-house data collection: Iowa DOT does record in-house PCS hours on a per-project basis. It records these hours using the engineers' timesheets. The data recorded on these timesheets are rated 4 out of 5 for accuracy. Iowa DOT does not allocate in-house overhead cost to a specific project. Iowa DOT does not use data collected from past projects to estimate the PCS costs for future projects. It does not estimate PCS cost for a project.

Outsourcing data collection: Iowa DOT does contract out PCS. Iowa DOT can use both in-house and on-call consultants; it also uses other consultants, but only for larger, less-common projects; it does not have overall GEC contracts. Iowa DOT can perform the entire preconstruction process in-house, and it also can outsource all PCS except advertisement for bids, evaluation of bids, and award of contract.

The main reasons it outsources PCS are staff availability, special expertise, and timeline for design. It does not have any regulations about how much it can or should outsource; however, it cannot exceed the annual budget for outside services. Iowa DOT does not compare the cost of performing PCS in-house to consulting out as part of the outsourcing decision process.

The major influences on PCS cost for Iowa DOT are:

- Complexity,
- Project type,
- Construction costs,
- Number of plan sheets,
- NEPA classification, and
- Length of project.

The minor influences on PCS cost for this agency are:

- Number of lanes,
- Number of sub-consultants,
- Number of bridges, and
- Geographical (soils on west side of state).

The characteristic that has no influence on PCS cost for this agency is:

- Highway classification.

PCS estimate improvements: Iowa DOT is not currently estimating PCS cost for projects, but it is looking to adopt this in the future. To improve these estimates, the agency believes it needs to learn how to use the data it already has. Iowa DOT has been capturing PCS hours for a few years, and it needs a way to organize these data so that they are useful in PCS estimating. If there was a system available to help capture agencies' PCS costs, Iowa DOT would consider adopting it.

Iowa DOT thinks that having a more accurate estimate of PCS would have a large impact on the planning process and would allow the agency to budget staff time. It would be good to know the number of hours per task and to be able to compare these to consultant design hours.

Researchers' observations: Iowa DOT wants to capture costs that are meaningful in both planning and design and categorize them by function or office. The agency would like a model that is split up by function or by office.

Agency: MSHA

Location: Annapolis, Maryland

General information: MSHA's yearly construction budget is approximately $600 to 800 million, and it awards approximately 300 to 350 construction projects per year. Project monetary size ranges from $1 million to $150 million. Average monetary size of a new construction project is approximately $25 million.

In-house data collection: MSHA does record in-house PCS hours on a per-project basis. It records these hours using time-tracking software. The data recorded are rated 4.5 out of 5 for accuracy. MSHA does allocate in-house overhead costs to a specific project. MSHA uses data collected from past projects along with standard percentages to estimate the PCS costs for future projects. The old system used 15% of the construction cost as preliminary engineering; it now uses a cost-based system on preliminary engineering.

Outsourcing data collection: MSHA does contract out PCS. It has a standing contract for a GEC. MSHA can perform the entire preconstruction process in-house, and it can also outsource all PCS except ROW utility acquisition and relocation, advertisement for bids, evaluation of bids, and award of contract.

The main reasons it outsources PCS are staff availability and special expertise. It does not have regulations on how much it can or should outsource. MSHA does not compare the cost of performing PCS in-house to consulting out as part of the outsourcing decision process.

The major influences on PCS cost for MSHA are:

- Complexity,
- Project type, and
- Construction costs.

The minor influences on PCS cost for this agency are:

- Number of sub-consultants,
- Number of lanes,
- Number of plan sheets,
- NEPA classification,
- Number of bridges,
- Length of project,
- Geographical,
- Loss of design effort,
- Innovation,
- New technology, and
- Project delivery method.

The characteristic that has no influence on PCS cost for this agency is:

- Highway classification.

PCS estimate improvements: MSHA is already estimating PCS costs for all projects. To improve these estimates, the agency believes it needs to develop a historical database of previous estimates. MSHA believes that having more accurate PCS cost estimates would have a large impact on the planning process as it believes that it would provide more efficiency in managing funds.

Researchers' observations: Historical projection is incorporated into project factors.

Agency: MDT

Location: Helena, Montana

General information: MDT's yearly construction budget is approximately $385 million, and it awards approximately 80 to 100 construction projects per year.

In-house data collection: MDT does record in-house PCS hours on a per-project basis. It records these hours using the engineers' timesheets and has a time allocation system per job. The data recorded on these timesheets are rated 4 out of 5 for accuracy. MDT does allocate in-house overhead cost to a specific project; it allocates this using an indirect rate that it applies to all projects. This rate is approximately 9% to 11% but has been as high as 18%. MDT does not use data collected from past projects to estimate PCS cost for future projects. It has a system that records past hours and durations of activities of 3 to 5 years to reconcile with activities to average activity hours. This system has no feedback loop, and it is therefore not used to look at past projects or to re-access the activity hours in OPX2 (a project management tool).

Outsourcing data collection: MDT does contract out PCS. MDT can perform the entire preconstruction process in-house except feasibility studies, and it also can outsource all PCS except advertisement for bids, evaluation of bids, and award of contract; this is considered in the construction department.

The main reasons MDT outsources PCS are staff availability, special expertise, and to transfer risk of design liability. The agency does not have any regulations about how much it can or should outsource; however, there is an unwritten rule that approximately 20% of the program should be outsourced. MDT does not compare the cost of performing PCS in-house to consulting out as part of the outsourcing decision process.

The major influences on PCS cost for MDT are:

- Complexity,
- Project type,
- Number of lanes,
- Number of plan sheets,
- NEPA classification,
- Number of bridges,
- Length of project,
- Geographical,
- Loss of design effort, and
- ROW and utilities.

The characteristics that have no influence on PCS cost for this agency are:

- Number of sub-consultants,
- Construction costs, and
- Highway classification.

PCS estimate improvements: MDT is already estimating PCS cost for all projects. To improve these estimates, the agency believes it needs to get to function-based estimating and also needs to determine how to allocate funds in split-corridor projects. MDT also believes that it needs to improve how it captures the hours on timesheets.

Agency: NYSDOT

Location: Albany, New York

General information: NYSDOT's yearly construction budget is approximately $1 billion, and it awards approximately 300 to 350 construction projects per year.

In-house data collection: NYSDOT does record in-house PCS hours on a per-project basis. It records these hours using the engineers' timesheets. The data recorded on these timesheets are rated 4.5 out of 5 for accuracy. NYSDOT does allocate in-house overhead cost to a specific project. NYSDOT uses data collected from past projects to estimate PCS costs for future projects. It uses an in-house system called DPR, which contains a selection of tools to estimate PCS hours. NYSDOT is looking to move to a Primavera P6 software resource allocation model to help estimate PCS hours.

Outsourcing data collection: NYSDOT does contract out PCS. When design for a project is performed in-house, it uses on-call contracts for the environmental sampling and testing and survey services, but it does not have overall GEC contracts. NYSDOT can perform the entire preconstruction process in-house except for these services, and it can also outsource all PCS except advertisement for bids, evaluation of bids, and award of contract.

NYSDOT performs 50% of PCS in-house, and 50% is outsourced by dollar value and 90% to 10% by project number. The main reasons it outsources PCS are staff availability and special expertise. It does not have any regulations about how much it can or should outsource; however, it has quarterly meetings with consultants to ensure that there is enough work in the industry. Design staff for NYSDOT are unionized. Most consultant work for NYSDOT happens in the southern region in and around New York City and Long Island. NYSDOT does not compare the cost of performing PCS in-house to consulting out as part of the outsourcing decision process.

The major influences on PCS cost for NYSDOT are:

- Complexity,
- Project type,
- Construction costs,
- Number of lanes,
- NEPA classification,
- Number of bridges,
- Length of project,
- Geographical, and
- Inflation.

The minor influence on PCS cost for this agency is:

- Highway classification.

The characteristics that have no influence on PCS cost for this agency are:

- Number of sub-consultants, and
- Number of plan sheets.*
  * Electronic plan sheets mean that more can be produced, but the level of work put into the design is no longer directly reflected as before when CAD and other modeling software were not used.

NYSDOT also noted that loss of design effort is considered rare; the agency had problems when it shifted to a preservation mode 3 years previous. A lot of reconstruction was shifted later in the program (~10 years), and preservation was adopted.

PCS estimate improvements: NYSDOT is currently estimating PCS costs for all projects. To improve these estimates, the agency believes it needs to get to task estimating; however, it is skeptical about whether the time, effort, and cost of this would add any real value to the agency. NYSDOT believes that having more accurate PCS cost estimates could have some impact on the planning process. The agency believes that it may be able to have more projects, but the current number is already within ~10%, and having a more accurate estimate will not make the process cheaper so is not likely to affect the agency.

Agency: ODOT

Location: Oklahoma City, Oklahoma

General information: ODOT's yearly construction budget is approximately $632 to $790 million, and it awards approximately 364 construction projects per year. Approximately 60% of all annual projects are federally funded, with the remaining 40% non-federally funded. Project monetary size ranges from $50,000 to $25 million. The average monetary size of a new construction project is $1.7 million.

In-house data collection: ODOT does not record in-house PCS hours on a per-project basis. Approximately 50% of the time, PCS hours are billed to overhead.

Outsourcing data collection: ODOT does contract out PCS. ODOT can perform the entire preconstruction process in-house except for ROW, and it can also outsource all PCS except preferred alternative, NEPA and permit approval, final plan package (RFP and RFQ), advertisement for bids, evaluation of bids, and award of contract.

The main reasons the agency outsources PCS are staff availability and special expertise. It does not have any regulations on how much it can or should outsource. ODOT does not compare the cost of performing PCS in-house to consulting out as part of the outsourcing decision process.

The major influences on PCS cost for ODOT are:

- Complexity,
- Project type,
- Construction costs,
- Number of bridges, and
- Length of project.

The minor influences on PCS cost for this agency are:

- Number of sub-consultants,
- Number of plan sheets,
- NEPA classification, and
- Highway classification.

The characteristic that has no influence on PCS cost for this agency is:

- Number of lanes

PCS estimate improvements: ODOT believes estimating PCS cost would be valuable, but it has yet to do so. To improve PCS cost estimates, the agency believes it needs to make direct changes to its projects. If a system that would capture PCS cost information was available, ODOT might choose to adopt it. ODOT believes that having more accurate PCS cost estimates would have minimal impact on the planning process within its programs.

Researchers' observations: Will be hard to convince people to use the system.

Agency: RIDOT

Location: Providence, Rhode Island

General information: RIDOT's yearly construction budget is approximately $300 million.

In-house data collection: RIDOT does record in-house PCS hours on a per-project basis. It records these hours using the engineers' timesheets. The data recorded on these timesheets are rated 4 out of 5 for accuracy. RIDOT does not allocate in-house overhead cost to a specific project. RIDOT does not use data collected from past projects to estimate the PCS costs for future projects. Design costs are estimated by using 15% of total construction cost. However, this is not uniform; smaller projects tend to be a higher percentage, and larger projects tend to be a lower percentage. This process is just an educated guess.

Outsourcing data collection: RIDOT does contract out PCS. It has several on-call consultants as almost all its design work is outsourced. It uses two consultants for highway work, two for bridges, and four for traffic engineering. No single firm is the dominant GEC. The agency has only two persons in the area of historical and heritage issues and four in environmental groups. This workforce level is not adequate for performing the required studies in an appropriate timeframe. RIDOT can advertise for bids, evaluate bids, award contracts, and perform some ROW utilities acquisition and relocation. All PCS processes are outsourced except those just stipulated.

The main reasons the agency outsources PCS are staff availability, having better control over consulting engineers, and that it is easier to terminate/not extend consultant contracts. The agency relies heavily on federal funds (roughly two-thirds of the transportation budget), which are subject to approval. The agency does not have any regulations on how much it can or should outsource. Engineering staff for RIDOT are unionized. RIDOT does not compare the cost of performing PCS in-house to consulting out as part of the outsourcing decision process.

The major influences on PCS cost for RIDOT are:

- Complexity,
- Project type, and
- Number of plan sheets.

The minor influences on PCS cost for this agency are:

- Construction cost,
- Number of lanes,
- NEPA classification,
- Number of bridges,
- Highway classification,
- Length of project,
- Geographical,* and
- Loss of design effort.

The characteristic that has no influence on PCS cost for this agency is:

- Number of sub-consultants.
  *One clarification regarding the characterization of "geographical"—coastal projects need extra permits compared to non-coastal projects and are hence more difficult.

During the last 26 years at RIDOT, there has been just one new road project and one relocation of a major road (I-95). New roads are a rarity.

PCS estimate improvements: RIDOT does not see value in estimating PCS costs. Since it is a small organization, it has yet to develop a database to keep track of and evaluate design costs. Its priority lies in estimating construction costs. To improve these estimates, the agency believes it needs a database to pull scattered records and documentation of PCS into one place. If there was a system, RIDOT would probably not consider adopting it because the drivers of these costs tend to be out of the control of the agency. There is a 2-year election cycle, so government and legislative representatives change regularly; therefore, projects continue to lose and gain importance depending on political influence. Also, the projects will get built regardless of preconstruction; it is the construction cost that causes the most difficulties. RIDOT believes that having more accurate PCS cost estimates would have no impact on the planning process. The agency believes that PCS costs have very little impact on the overall program and that projects will be executed no matter the PCS costs.

Agency: UDOT

Location: Salt Lake City, Utah

General information: UDOT's yearly construction budget is approximately $1,100 million.

In-house data collection: UDOT does record in-house PCS hours on a per-project basis; it charges hours to a PIN. It records these hours using project management software called ePM. The data recorded on their timesheets are rated 4 out of 5 for accuracy; sometimes staff will bill to overhead instead of a project. UDOT does not allocate in-house overhead cost to a specific project; however, it does charge all staff costs to a management line item. UDOT uses data collected from past projects to estimate PCS costs for future projects. It uses a past project cost range as well as a direct estimate of hours to determine PCS hours. These estimates are project dependent.

Outsourcing data collection: UDOT does contract out PCS. The agency uses on-call contracts for most outsourced work, but it can only use up to $40,000/consultant/project. If more work needs to be outsourced, it will advertise for contracts. UDOT can perform the entire preconstruction process in-house, except that Region 4 (southern region) cannot do ROW, hydraulics, and signal design services. UDOT can outsource all PCS except advertisement for bids, evaluation of bids, and award of contract.

By dollar value, UDOT performs 25% PCS in-house, and 75% is outsourced. The main reasons it outsources PCS are staff availability and special expertise; the agency also chooses to outsource to strengthen the economy and expedite project delivery. It does not have a policy or regulations on how much it can or should outsource; however, it must always keep the in-house staff busy first. UDOT does not compare the cost of performing PCS in-house to consulting out as part of the outsourcing decision process; it is aware that this will cost more but is limited by staff levels. UDOT tries to decide early on whether the project will be outsourced or performed in-house so that it can set the budget early. PCS for simple projects will usually be performed in-house; this decision is made at the program level. Occasionally UDOT will put design staff to work with the consultant on an outsourced project to get experience. The staff level at UDOT has been reduced from 3,500 in 2000 to 1,530 at the time of this writing.

Table D-1. UDOT case study data information.

Project types	• Bridge – major structure • Emergency repairs • Enhancement • Grade and drainage • ITS and signals • Not applicable • Other • Railroad related • Reconstruction • Roadway • Roadway work • Safety • Sidewalk • Sign • Signal and light • Structural – minor structural rehab • Structures • Studies • Surfacing or resurfacing • Traffic and safety • Traffic management
Procurement methods	• CMGC • Design–build • Design–bid–build • Other • Procurement • Blank

The major influences on PCS cost for UDOT are:

- Complexity,
- Project type,
- NEPA classification, and
- Number of bridges.

The minor influences on PCS cost for this agency are:

- Highway classification,
- Construction costs,
- Number of plan sheets,
- Number of lanes, and
- Length of project.

The characteristics that have no influence on PCS cost for this agency are:

- Number of sub-consultants,
- Geographical, and
- Loss of design effort.

UDOT does not believe it sets out to make mistakes; therefore, it does not consider loss of design effort necessary in estimating PCS.

PCS estimate improvements: UDOT is already estimating PCS costs for all projects. To improve these estimates, the agency believes it needs to have more experience. New project managers do not have a good feel for the number of hours, required training, and time on the job needed to produce an accurate estimate. UDOT is happy with its current cost-estimating system, and it would prefer to refine its own system rather than adopt another system. UDOT believes that having more accurate PCS cost estimates could have some impact on the planning process and allow it to refine allocation of resources and negotiate with consultants better.

Researchers' observations: UDOT has a positive work environment that keeps it moving forward, which allows the agency to try new and innovative things and constantly push to get better results.

Case study information for the agency is contained in Table D-1.

APPENDIX E

Extract from *Guide to Project Management Strategies for Complex Projects*

The Second Strategic Highway Research Program

SHRP 2 Project R-10

Jennifer Shane, Kelly Strong, Douglas Gransberg, and David Jeong
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TRANSPORTATION RESEARCH BOARD

Washington, D.C.
2015
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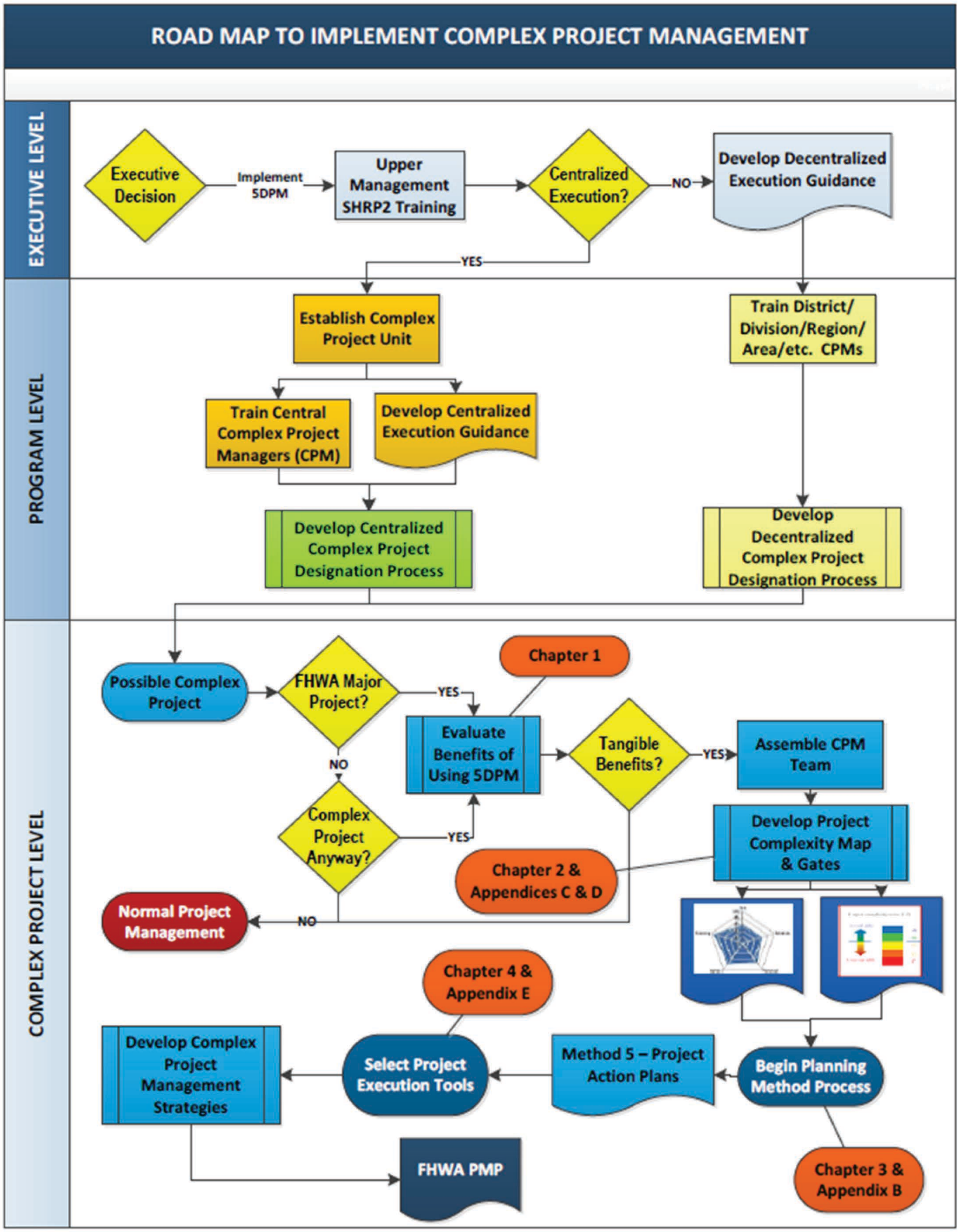
EXECUTIVE SUMMARY

This flowchart is the road map for a public agency to implement 5-Dimensional Project Management principles to develop project delivery strategies for complex projects.



Section 1: Five-Dimensional Project Management

1.1 Philosophy of the Guidebook

The guidebook's objective is to assist public agencies develop project management plans for complex projects. It focuses on practical tools and techniques designed to be immediately beneficial to transportation professionals. The content comes from the in-depth study of eighteen U.S. and international complex projects that identified strategies, methods, and tools that led to the successful delivery of those complex projects. It complements rather than replaces an agency's current project management practices, and as such, merely adds a different structure to the agency's existing project management planning (PMP) processes. The major change from routine project management is the sequence in which PMP tasks are accomplished with a strong emphasis to frontloading the PMP to address critical issues that create complexity as soon as practical instead of later in the routine project delivery process.

> "As the results of the SHRP 2 research are deployed, we will see more 'rapid renewal' tools developed for owners of the transportation system. ***The tools will lead to a fundamental change*** in how we approach rehabilitating our transportation system."
>
> ***Randell Iwasaki, P.E.***
>
> Chair SHRP 2 Renewal Technical Coordinating Committee

This section describes the five dimensions of complex project management, referred to as "5DPM" throughout the guide. To ensure a complete understanding, the reader must keep in mind that there are three primary components, to be explained in detail in the next section, to the 5DPM framework:

- Five project management dimensions,
- Five complex project planning methods, and
- Thirteen complex project execution tools.

The guide describes how the project team identifies, prioritizes, and quantifies the factors that create complexity in each dimension. The guide also provides instructions for developing complexity maps that visually represent the scope and nature of project complexity. Mapping complexity helps the project team rationally allocate available resources and determine requirements for additional or specialized resources. The maps also guide the application of the five complex project planning methods, as well as selection of complex project execution tools as shown in Figure 1.1, which shows three sequential phases:

1. Project analysis: The project team verifies that the given project is complex and develops the initial complexity map.

2. Project planning: Using the initial complexity map, the team applies the five complex project planning methods and develops the first nine sections of the PMP.
3. Project implementation: Based on the PMP, the team selects appropriate project execution tools and details their application in PMP sections 10 through 22.

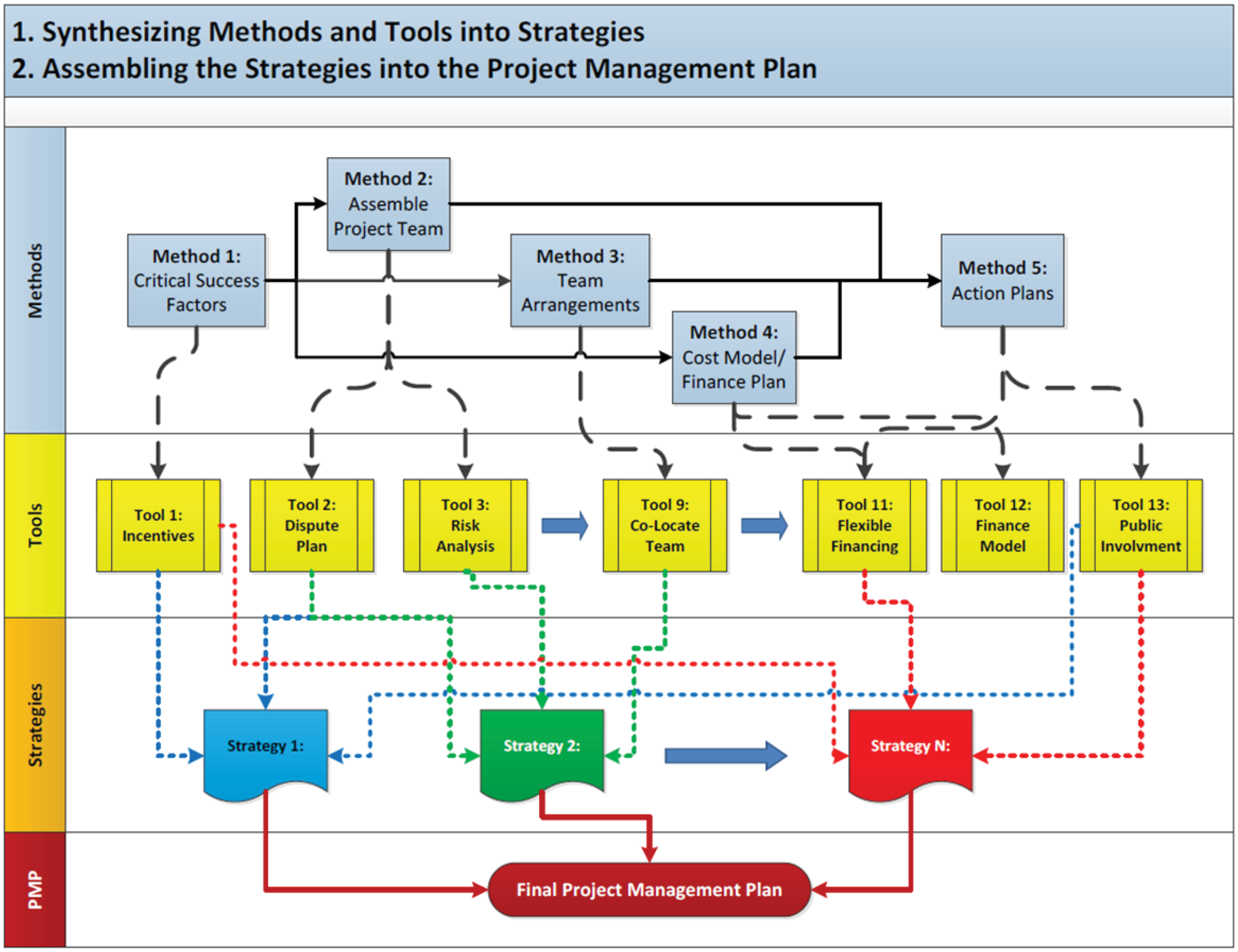


Figure 1.1. Overview of complex project management and 5DPM process flow to develop the FHWA Major Project Management Plan

The result is a complete PMP for the complex project. Figure 1.2 maps the contribution of 5DPM to the completion of the FHWA major project PMP development process and provides a graphical understanding of how the 5DPM process fits within the existing PMP process. The major addition to the current process is recognition that a complex project involves managing many more factors that are outside the project manager's direct control. Therefore, the PMP must identify and address external factors, like public opinion and innovative financing, as early as practical, and the project team must regularly update the project's complexity map to ensure that the tools chosen to manage complexity are performing as planned in the PMP. If they are, the area of the complexity map should shrink as complexities are successfully managed and the project will proceed as planned. The result is the successful integration of the project's design and construction team from concept to completion. Integrated planning and execution is 5DPM's key to manage complexity successfully across the complex project's life cycle.

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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
FAST	Fixing America's Surface Transportation Act (2015)
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
TDC	Transit Development Corporation
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

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