National Cooperative Highway Research Program

NCHRP Synthesis 227

Collecting and Managing Cost Data for Bridge Management Systems

A Synthesis of Highway Practice

Transportation Research Board
National Research Council

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Collecting and Managing Cost Data for Bridge Management Systems

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of interest to state DOT administrators and mid- to upper-level managers; researchers; cost estimators; bridge and general management system engineers; and bridge design, construction, inspection, and maintenance engineers; as well as to private industry professionals involved in developing bridge management system (BMS) software and collecting and analyzing BMS cost data. The state of the practice for collecting and managing cost data for BMS is described based on data obtained from a review of the literature and a survey of the state departments of transportation. The initial literature search revealed that the scope of the synthesis was new and had not been comprehensively addressed before.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

This report of the Transportation Research Board describes BMS cost data for work done by contract and in-house forces for state and local governments. It includes project-level cost estimation as well as the collection and management of data for network-level cost models. The various cost estimate methods for replacement; maintenance, repair, and rehabilitation; and emergency work are analyzed as are the special requirements of user costs and other special economic data.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the research in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

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COLLECTING AND MANAGING COST DATA FOR BRIDGE MANAGEMENT SYSTEMS

SUMMARY

The requirements stated in the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), and ongoing evolution in the understanding and implementation of bridge management systems (BMS) have focused renewed attention on cost data management and cost estimation, especially for the purpose of network-level analysis. This synthesis of the current practice in the collection and management of cost data for BMS captures a snapshot of the current state of the practice and outlines a potential future research agenda. A conclusion of this analysis is that few state departments of transportation (DOTs) have adequate data on which to base their bridge management system cost estimates, few monitor actual expenditures in order to validate their estimation procedures at the systemwide level, and many DOTs have no organizational mechanisms or systems in place to uncover and solve problems in cost estimation. These deficiencies affect the credibility of bridge management systems and of the planning process in general, and demand immediate attention as a high priority for future research at the national level and future management action at the department level.

Bridge management systems rely on cost models to predict, track, and report the costs of policy initiatives and projects, and to predict the cost savings to transportation agencies and to road users of preventive maintenance and functional improvements. The absence of accurate cost models can greatly diminish the effectiveness of BMS in analyzing the key tradeoffs in bridge policy and program decision making. As transportation agencies continue to implement enhanced bridge inspection programs and modern computerized decision support software, it is widely believed that the quality of cost data is now the greatest determining factor in improving bridge management systems.

The information presented in this synthesis is based on the combined results of a literature review and the 1995 Federal Highway Administration National Bridge Inventory, which surveyed state transportation agencies. A review of the literature shows that few agencies or researchers have yet focused attention on bridge cost or economic data as a subject for comprehensive attention; this is evident from the dearth of literature directly related to the subject. This conclusion was underscored in the survey, where cost data management practices were found to vary widely among the states, and no external sources in the literature were cited by any respondents either for unit costs or for cost data management methodologies. Most of the conclusions reached in this synthesis, therefore, draw from the 35 responses received to a detailed survey of state department of transportation practices for this report.

The survey found that most of the agencies are currently dissatisfied with their ability to provide unit costs to their BMS. A matter of great concern in these findings is that the least satisfied states are those that have established organizational mechanisms, such as a bridge management engineer and/or staff, to use cost data in a systemwide planning process.

Transportation agencies that have not yet established such a mechanism are likely to have major undiscovered deficiencies in their cost estimation procedures. These may be evidenced by "scope creep" (the tendency for project costs to increase during the planning process due to the late addition of project requirements), high contingency allowances, unwillingness of top management or elected officials to believe program plans, or lack of confidence in negotiating cost estimates with contractors.

While most agencies have reliable data on bridge replacement costs, only a small minority have reliable data on maintenance costs, especially in-house maintenance and work done on local bridges. North Carolina is the only state with its own source of user cost data. Exemplary systems can be found in states of all sizes and structures, but larger states and more centralized states tend to have more fully developed cost data management capabilities. The existence of maintenance management systems and contract management systems appears to be strongly correlated with better-quality cost data, but not all such systems cover bridge work.

For maintenance, repair, and rehabilitation (MR&R) work, only a handful of states collect work accomplishment data at a level of detail suitable for retrieval of unit costs at the bridge, element, and action levels. However, a majority of states believe that cost-effective collection of such data is possible, and most have plans to do so. State-of-the-art approaches that are planned include the use of client-server databases to collect work data in the field and distribute it to maintenance, pavement, bridge, and other management systems, and global positioning system receivers to accurately locate maintenance equipment and thereby associate work types with bridge identifiers. These technologies by themselves do not guarantee accurate cost estimation, but they do help to overcome barriers, especially headcount and training limitations, which stand in the way of better cost data collection and management.

A clear consensus emerged in the survey on the priorities for future research. At the top of the list are user cost models, MR&R unit costs (especially for unusual elements), project-level fixed costs (such as traffic control and mobilization), and local bridge costs. Even though costs tend to vary from one agency to another, the development of cost models for these activities is usually beyond the resources (in expertise and data) of individual states. A project of national scope could collect relevant data from multiple agencies and employ statistical analyses to develop network-level and project-level cost models. Such a project would require labor-intensive analysis of paper records kept by state and local governments, as well as a high degree of statistical and software capability. Since many of these factors apply to all infrastructure projects, not just bridges, great value could be added by extending this research and development to all types of asset and maintenance management. Models developed from this project could be interfaced with AASHTOWare™'s Bid Analysis and Management System (BAMS™) to significantly improve the planning capabilities of that system.

In order to to keep these models up to date over time and to provide a means of sharing cost data among departments, a national organization could establish a clearinghouse. The clearinghouse would collect contributions from the states, add value through data processing and analysis, and provide an infrastructure to make the data readily available and easily accessible to individual agencies. The distribution mechanism for the data, models, and documentation could be electronic, perhaps using public domain Internet facilities which are widely available. Work now underway at Clemson University for the Federal Highway Administration may form a basis for such a clearinghouse.

A demand for a standardization of BMS cost definitions is evident as well as for the development of guidelines that can be incorporated into new systems that might provide valuable cost data to a BMS. Both the survey and follow-up conversations reveal that departments of transportation vary widely in their understanding of how to collect work accomplishment data and how to re-engineer their work recording processes to serve the needs of project-level and network-level cost estimation. Frequently it is possible to improve the usefulness of cost data greatly without adding new data collection processes or costs, but top managers lack a practical source of guidance to identify such opportunities and exploit them. This need could be met by the preparation of an easy-to-use handbook, consisting of an overview accessible to top managers and covering the major organizational and system issues, along with sections of detailed information on the implementation of improved procedures and systems.

It is possible to extend this concept beyond bridges by recognizing and structuring the higher-level problem of work plan and work accomplishment data management for all types of projects. This is a major issue emerging in agencies that hope to integrate their management systems as a way of simplifying data collection and usage. A national program could sponsor original research and conceptual development of an integrated concept for the collection, management, and usage of economic data in management systems, to encompass the ISTEA management systems as well as maintenance and contract management systems, building on the results of the National Cooperative Highway Research Program Project 14–9(4), published in *NCHRP Report 363: The Role of Highway Maintenance in Integrated Management Systems.*

Top managers and cost estimators need guidance regarding the degree of accuracy possible in cost estimation; and there is a need for tools that departments can use to measure the accuracy of their own cost estimates and compare this accuracy with that of other states. An ongoing national effort could develop and publish aggregate statistics on the correlation between programmatic cost estimates and actual work accomplishment costs, as an index of the quality of cost estimation. Departments of transportation that are unable to calculate this quality index or that fare poorly relative to other states would be able to recognize their problem and develop measurable goals for improvement. This dynamic of healthy competition would spur the evolution of management decision making and bridge management system capabilities.

All of these initiatives are beyond the capabilities of individual departments. In fact, all of them reflect a shared federal, state, and local interest in improving the management of infrastructure, extending beyond bridges. Intergovernmental structures such as the Expert Technical Group on BMS Costs can identify and oversee such projects, and can provide the means to apply this work to pavements, highway maintenance, and other projects.

CHAPTER ONE

BRIDGE MANAGEMENT SYSTEMS COST DATA REQUIREMENTS

INTRODUCTION

The recent development of bridge management systems (BMS) enables transportation agencies to quickly and effectively analyze the costs of different options in maintaining, repairing, rehabilitating, or replacing bridge structures or elements thereof. Furthermore, this approach to cost analysis is consistent with the philosophy of the Intermodal Surface Transportation Efficiency Act of 1991 that is now being put into practice nationwide, focusing on the most economical strategy to maintain the transportation infrastructure in acceptable condition and working order. A key requirement in developing these cost estimates is to have access to unit costs of different actions in maintenance, repair, rehabilitation, and replacement of bridges or bridge elements, as well as unit costs borne by highway users to gauge the impacts of these actions. A good compilation of unit costs, or a good model to predict such costs, is of great importance no matter what the BMS analytic approach or methodology applied in a transportation agency.

Throughout the United States, methods to derive, compute, and update unit costs for bridge programs vary across agencies. To some degree this variation is the result of different agency practices regarding bridge design and construction, bridge maintenance and rehabilitation, approaches to cost estimation, methods of data collection and analysis, and management philosophy. While the recent growth in the number of bridge management systems has focused renewed attention on the structuring and application of cost data for management purposes, there is still a considerable divergence in what data are collected, how they are organized, and how they are applied.

The purpose of this synthesis is to document these various practices among states, as determined from a literature review and a special survey conducted for this study. A copy of the survey questionnaire, sent to each state Department of Transportation is included in Appendix A. The scope of the work includes activity done by contract and in-house forces, by state and local governments. It includes project-level cost estimation as well as the collection and management of data for development of network-level cost models. The variety of methods for replacement, maintenance, repair and rehabilitation (MR&R), and emergency work are analyzed, as are the special requirements of user costs and other special economic data.

The synthesis establishes a context for the application of cost models and the strict definition terms and assumptions inherent in economic quantities. The literature reveals that the scope of the synthesis is new, and has not been comprehensively addressed before. Discussion of the survey results follows the typical project development life cycle, from project initiation, to successively more detailed stages of project cost estimation, to the contract versus force account decision. (The term "force account" refers to work performed by in-house personnel.) Following the completion of bridge work, the survey results follow the recording of contract and force account accomplishments to gauge the extent to which these supply necessary raw data for network-level cost estimation in a BMS. This analysis of the economic data flows of bridge management highlights the weakest points and reinforces the survey respondents' nominations regarding areas most in need of improvements and research.

COST DATA REQUIREMENTS

The costs encompassed by bridge management fall into many categories. They not only result from the actions of several different functional areas within a DOT (e.g., design, construction, and maintenance), but they also represent economic components borne by others outside the road agency—in particular, by the motoring public. No standard, universally accepted breakdown of bridge management cost components is evident in the literature or in the practices of transportation agencies. The purpose of this section, therefore, is to organize bridge management costs within a structure, or taxonomy, that will provide a background reference for discussions and examples in later chapters. This cost structure serves several purposes:

- It defines an overall scope of bridge management costs. Current agency practices can be discussed within this scope to understand not only the components of costs that are addressed in each case, but also the level of detail to which costs are disaggregated.
- It provides a basis for comparing BMS cost practices among transportation agencies in the United States and internationally.
- It implicitly enables managers to relate bridge management cost practices to corresponding practices in other areas of highway facility management, particularly pavement management and maintenance management.
- It highlights areas where further research is warranted regarding data collection and analysis, database development, and model formulation addressing particular components of bridge management costs.

The cost structure is developed in several ways, reflecting the different purposes to which these costs are applied in management systems. These options in structuring cost information anticipate the variations in agency practices discussed in

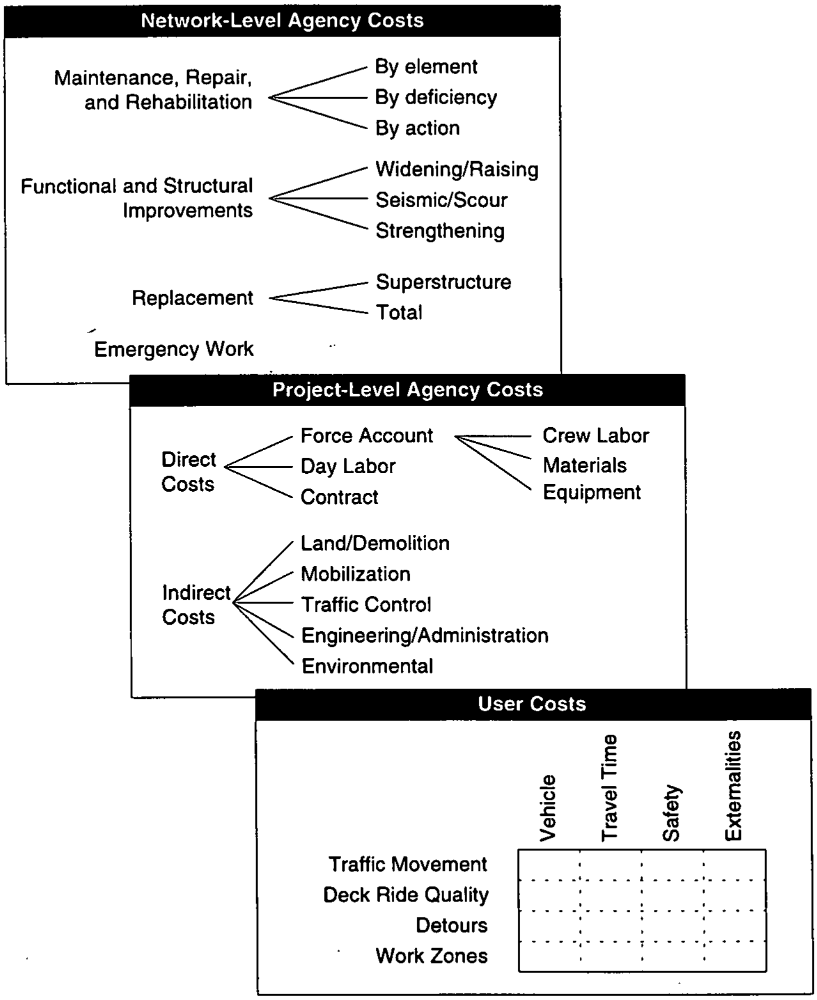

FIGURE 1 Structure of BMS cost data.

the literature review in Chapter 2. The overall structure of BMS cost data is illustrated in Figure 1, with each level explained below.

First, bridge management costs are discussed in terms of the *types of problems* to which they are applied. From an agency's perspective, for example, network-level versus project-level analyses of bridge investment needs imply cost data of different levels of detail. Similarly, user cost data are needed in several categories to fully address the impact of bridge investment actions on motorists.

Second, costs are discussed in terms of their *components*. These components do not necessarily reflect the practices of any given agency, but rather are an attempt to reduce bridge costs to the maximum level of detail likely to be needed for management purposes in the foreseeable future. Experience with, and current trends in, the development of pavement management and maintenance management systems (in addition to bridge management systems) has also informed this discussion.

Third, cost data are cast in terms of *desirable attributes of cost models*. These attributes are general, and are intended to suggest strategies that have been found to be useful in applying cost data to the several aspects of bridge management illustrated in Figure 2.

This structuring of BMS cost data is explained in more detail in the following sections. The discussion below employs terms commonly used in bridge management. A glossary of these terms is contained in the survey in Appendix A.

NETWORK-LEVEL AGENCY UNIT COSTS

Network-level analyses of costs are intended for department- or districtwide programmatic estimates, which typically extend over a future decade, and often several decades. Results of these analyses are of interest to middle- and upper-level managers and administrators in exploring scenarios and determining recommended bridge management or bridge investment strategies. This cost information is also useful for comparing predicted policy outcomes against actual results, as a way of helping managers to improve the decision process for bridge investments. The unit costs of agency actions for new bridge construction, rehabilitation or repair, maintenance, and replacement should be consistent with the objective, scope, and use of network-level analyses in the ways that follow.

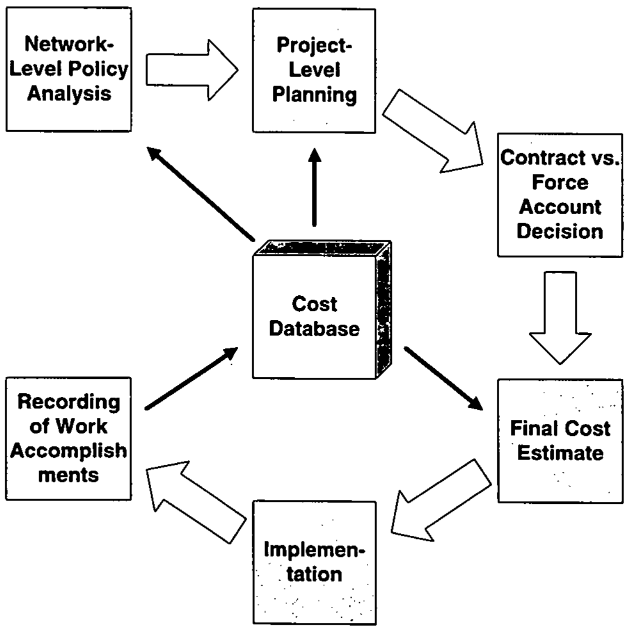

FIGURE 2 Life cycle of bridge cost data.

Consistency with Network-Level Objectives

Given the primary objective of the network-level analysis—to help managers evaluate bridge program options quickly and efficiently—unit costs should represent, as closely as possible, the full costs of an activity or a project. Furthermore, they should reflect accurately the relative costs among a set of competing activities to address a problem or deficiency. (Both the absolute and the relative aspects of unit cost data are important.) Unit costs need to be of sufficient accuracy to investigate management and investment options, to assess tradeoffs among these options (such as "What is gained or what is lost by varying the funding level in a bridge program?"), and to compare total program costs against budget constraints. A comprehensive set of unit costs also contributes to a management system's ability to provide feedback on the effectiveness of policy decisions, as suggested in Figure 2. Trends in unit costs among different bridge activities can capture the effects of changes in local economic conditions, resource availability, engineering standards, regulatory requirements (as in safety), and advances in technology. Because network-level analyses often presume a life-cycle analysis (at least of agency costs), preventive as well as corrective treatments can be included in the definition of unit costs.

Scope of Unit Costs

Network-level unit costs of bridge maintenance, repair, and rehabilitation need to be broad in scope but how they satisfy this criterion depends on how bridge management or investment policies are represented, what types and levels of detail are captured in decision rules, and what mechanisms of deterioration are modeled.

One approach defined separate unit costs for activities to prevent or correct particular types of deficiencies, and materials-related problems (such as corrosion damage). Unit costs developed for the following activities are examples of this approach (units of measure may vary):

- Patching deck spalls, $/sq m;
- Sealing a deck or applying corrosion inhibitor, $/sq m;
- Replacing or reconstructing a deck, $/sq m;
- Painting bridge steel, $/sq m or $/kg of steel;
- Installing cathodic protection, $/sq m;
- Replacing bridge railing, $/m;
- Lubricating bearings, $/bearing.

A BMS predicated on this approach would need not only the unit costs of MR&R activities and projects to address individual deficiencies, but also corresponding decision rules and, if appropriate, models of impacts or consequences of these actions. For each activity in the examples above, decision rules are specified that govern when the activity should take place (e.g., at what extent and severity of spalling should the deck be patched), and the degree of repair. The impacts or consequences of these activities are expressed in both agency terms (i.e., the extended life afforded by each of the activities above, and reduced costs of future MR&R activities required), and user terms if appropriate (i.e., reduced costs of travel time and vehicle operation due to rough decks or bridge closure if deterioration progresses to an unacceptable level). While this approach requires work to develop the unit cost data and models for each activity, its advantage is the ability to evaluate a wide range of options and tradeoffs. For example, if unit costs are developed for each example listed above, a manager can analyze capital vs. maintenance options in developing priorities for bridge decks in the face of budget constraints.

A second approach is to choose one or two categories of deficiencies as the dominant ones, and to develop unit costs only for relevant preventive or corrective activities. This approach depends very much on an agency's design and construction practices, and on observations of historical performance of its bridge structures. For example, if an agency finds that the dominant mechanisms of deterioration on its bridges are deck corrosion and pier scour, then the activity unit costs it defines under this approach are deck MR&R, and scour protection. The advantage of this approach is greater simplicity in the development of activities and related unit cost data and models; however, there are correspondingly fewer tradeoffs that can be analyzed.

A third approach is to develop composite costs that represent a combined set of activities (e.g., structural and corrosion treatments) based on historical experience with particular combinations of bridge structure and materials. An example of this approach is the unit cost of deck work (e.g., $/sq m) that includes patching, overlaying, and corrosion prevention or repair in a single, composite cost. Another example is a cost of superstructure repair that includes painting (if appropriate), structural repairs (e.g., repairs of cracks in members), and repairs due to traffic damage. While this approach is likewise simpler in data collection and modeling (compared to the first approach described earlier), it reflects current practice, technology, and factors affecting bridge performance, and limits the tradeoffs that can be studied.

Similar considerations apply to the unit costs of functional improvements and replacement of the entire bridge. Given the requirements that govern the funding of these projects, a key question with respect to the unit costs of these projects is how the project scope is specified and controlled in testing different management strategies and scenarios. For example, current federal funding guidelines for functional improvements require an agency to bring all aspects of a bridge's functional performance up to standard, not just the single functional aspect that the agency might regard as deficient. Thus, the unit costs of a functional improvement project need to recognize the full costs of bringing a bridge up to federal standards in this scenario. As another example, with a relaxing of federal policy on spending federal dollars on maintenance, agencies that have developed unit cost data for individual maintenance activities (as in the first approach described above) are in a better position to evaluate the relative costs and benefits of maintenance vs. capital investments, and thus to apply federal dollars more efficiently under the new rules.

This comment applies more generally to bridge replacements, since replacements can be triggered by a number of reasons—structural deficiencies, need for functional improvements, safety deficiencies, site-related risks, or a combination of these factors. Again, the unit costs of a project need to reflect not only the direct need for the project, but also all other aspects needed to restore the bridge to current standard.

The examples illustrate an issue that DOTs face in balancing two aspects of bridge projects—their merits (in economic terms) vs. the availability and eligibility requirements of funding sources (a financial consideration). Whereas a BMS develops cost estimates and investment strategies based on projects that are optimal in terms of an economic criterion, funding policies can affect these recommendations. There is no question that bridge investments must be seen from both economic and financial perspectives. A BMS, based on solid unit cost data, can be a force to make project scoping decisions less dependent on funding policies, or at least to quantify the impact of financial requirements that lead to deviations from the recommended optimal investment strategy.

Effect of Bridge Inventory and of Deterioration

The structure of unit cost data for MR&R at the network level is affected by the composition of the bridge inventory itself and the active mechanisms of deterioration, which are represented in a BMS by deterioration models. Cost data need to be consistent with the representation of bridge structures in the inventory file; they also need to support the type and detail of deterioration models used. Two examples illustrate these points.

In the first example, the simplest case is a BMS that represents the network simply as a collection of structures. Various maintenance, repair, rehabilitation, and replacement activities are defined, with associated costs, to prevent or correct the structural or material deficiencies that are predicted by deterioration models. This approach is most suitable to populations of bridges of a very simple design and similar construction, environment, and use, where the types of deficiencies are well known, easily matched to preventive or corrective treatments, and small in number so that they can be treated as affecting the bridge overall. Unit costs in this case would reflect the cost per bridge to perform the respective project or activity.

The second considers bridge networks more typically as a complex combination of structural designs, span widths and lengths, construction materials and techniques, environmental zones, and traffic usage that render bridges too dissimilar to treat as a single population of structures. Moreover, even if a network were composed of a single type of bridge, any complexity in the design makes a cost-per-bridge approach infeasible, since the need for investment could arise in different components of the bridge over time. For these reasons, in most bridge management systems the structures are decomposed into simpler components, subcomponents, and elements that can be assembled within reasonable groupings or populations of similar items. This approach makes it possible to represent significantly different types of bridges (e.g., simple- or continuous-span girder, truss, arch, suspension, and so forth) within a single, consistent database and management system framework.

Most management systems developed for bridges are based on some level of disaggregation into components or elements. In the simplest cases, bridges may be decomposed into only a few components (e.g., superstructure, substructure, deck, and approaches). In its most detailed applications, this approach subdivides each structural component of a bridge into its constituent elements, to the level of footings, piers and pier caps; bearings and joints of various types; floor beams, stringers, and girders; deck structural slab, deck surface or membrane, and wearing course; truss diagonals and chords; suspension cables, suspender ropes, and towers and pylons, to cite a few examples. This decomposition has the advantage of reducing a set of diverse, complex structures to a set of items that are 1) identifiable across bridges of different design and construction that can be grouped into populations and treated in like fashion; and 2) amenable to a reasonably defined scope of work for maintenance or construction projects.

Network-level unit costs must follow not only the particular breakdown of bridge features described above, but also the scheme devised in the bridge management system to represent the condition and deterioration of these features. Two examples of different approaches that are used in bridge management follow.

The *continuous measurement scale of condition or deterioration* approach focuses on factors like percent of painted surface that has degraded, or percent of section loss due to corrosion. In this case it is useful to specify unit costs as, for example, a function of the surface area painted or the section loss restored. Furthermore, this approach is useful for each of the different types of activities that address the problem at some stage in its evolution (i.e., preventive or corrective routine maintenance, repair, rehabilitation, or element replacement). If applied correctly, the cost functions capture the benefits (if any) of prevention or early detection and correction of a deficiency; or, conversely, the penalties (if any) of deferred investments to correct the problem. (Refer to the section on assigning costs to deferred actions.)

The *discrete condition states* approach relies on Markov-process deterioration models. A Markov process describes the distribution of conditions among the population of bridge elements in terms of condition states. Changes among condition states are specified in terms of transition probabilities, reflecting processes of deterioration (in a negative direction), and MR&R (in a positive direction). The Markov process assumes that these transition probabilities, and the resulting distribution among condition states, are stationary from one period to another. Unit costs are defined on the basis of improving the current condition of some percentage of items in one condition state to another condition state. As stated above, if unit costs are specified correctly for different types of activities and for different combinations of state-to-state improvements, they can communicate the cost penalties of performing work before or after the optimal time, and above or below the optimal level of effort respectively for each activity.

In addition to consistency with the mathematical form of the deterioration models, network-level unit costs must represent projects, activities, or other actions that agree with the type of deterioration that is predicted to affect a bridge or its components. Thus, models of structural deterioration imply actions to prevent or correct these structural defects; the same reasoning applies to corrosion, risk of scour, or other forms of deterioration that require maintenance, repair, or rehabilitation. This does not prevent a user from defining actions that address multiple problems (e.g., several structural and materials defects simultaneously), but it does require clearly stated criteria and procedures to model this multiple effect correctly. Unit costs are then specified for the set of maintenance, repair, and rehabilitation activities or projects that are defined.

Level of Detail of Cost Data

Unit costs of bridge projects and activities used in a network-level analysis are established at an aggregate level, rather than in detail. They consolidate the many stages of a construction project or maintenance activity (e.g., mobilization, preparatory work, specific project items, traffic control, protective or mitigation measures, cleanup) within a single unit cost applicable to a population of bridges with similar characteristics. Relatively minor effects on costs due to such things as site variations and particular bridge construction details are not important for this type of analysis. Because network-level costs are applied to populations of bridges (or components thereof), a composite cost that works well on balance is satisfactory.

Assigning Costs to Deferred Actions

A problem of keen interest to the highway community in developing network-level strategies is how to reflect the "penalty" costs of deferring needed work. Good unit cost data and models help provide this information. Two examples will be given, for agency costs and for user costs respectively. Both examples are discussed in the context of a life-cycle cost analysis.

In dealing with agency costs, there are two components to the evaluation of deferred work. One is the presumed economic benefit to deferring an investment: i.e., the funding becomes available for some other purpose in that period. This implied benefit is captured by the discount rate: the higher the rate, the greater the benefit of postponing one project in favor of spending those funds on a higher valued project. The second component is the penalty associated with deferred work: i.e., the increased life-cycle costs due to greater degradation of the facility, the need to perform more expensive repairs in the future, and the potential costs associated with the risk of facility failure. A life-cycle cost analysis, properly performed, investigates the balance between these two competing trends. Deferring work can be shown to be a bad strategy *only if the real costs of deferral exceed the implied gain due to discounting*. The greater this cost penalty, the more urgent the project. BMS unit cost data and models can capture the penalty costs in two ways.

The first way is in the structuring of costs among activities, particularly across the range from maintenance to replacement. The more the unit costs of replacement exceed the unit costs of rehabilitation, and the more the unit costs of rehabilitation exceed the unit costs of maintenance (all other things being equal), the greater the incentive will be to perform work earlier rather than later. If, on the other hand, the disparity in costs among these activities is not large, an economic analysis will lean toward deferring maintenance and rehabilitation until the facility component needs to be replaced. This situation illustrates the point made at the beginning of this chapter, noting that the relative values of costs are as important a characteristic as their absolute values.

The second way to capture the penalty of deferral is in the behavior of models used to estimate agency costs. The more the models can reflect the greater expense of performing work later, the greater will be the incentive in an economic analysis to avoiding deferred work. One way to build in this behavior is to derive models as a function of the condition of the bridge element itself, and the degree of repair to be accomplished. Thus, if the cost of restoring a member to acceptable condition increases significantly as the current condition of the member declines, there is a strong incentive to perform work earlier rather than later. Conversely, if the unit cost models show no increase with declining condition or with greater repair needed, there is no penalty reflected in the model to deferring work. This discussion suggests that the form of the agency unit cost model is important, even if the model cannot be estimated precisely.

User costs provide another measure of the consequences of deferral decisions and user costs exhibit both positive and negative impacts. One positive impact of deferring investments derives from the congestion costs that are avoided if work is postponed. The negative impact is due to the declining condition of the bridge, and its consequences for travel time and for vehicle operating costs (the complicated relationships between operating costs and vehicle speed will be ignored for the time being). The total user impact will be the net result of these two effects, accounting for traffic volume and composition over time. As with agency costs, the future impacts are discounted by the discount rate, and the more significant the effects modeled, the greater their influence in the final analysis. In this context, user costs can become extremely significant if deferred work will lead ultimately to closure of the bridge and to lengthy detours due to the extent of the deterioration.

Combining agency costs and user costs within a life-cycle cost analysis yields the total set of economic considerations affecting the decision to perform work now or to defer it to a later time. An optimization procedure tied to life-cycle cost data can analyze this problem (particularly under budget constraints) to recommend what activities to perform, where to perform them, and when. In doing so, these analytic procedures identify where work can be deferred (or performed less expensively) while minimizing adverse impacts to the agency or to bridge users.

PROJECT-LEVEL AGENCY UNIT COSTS

Project-level analyses explore in detail the alternatives in performing major maintenance, repairs, rehabilitation, or reconstruction of a particular bridge. In contrast with the broad guidance that network results provide for the timing, location, and type of projects or activities to be undertaken in each program period, project-level analyses fill in the details and explore the most cost-effective way to conduct each action. These analyses are site specific, targeting individual bridges rather than groups of bridges or bridge elements. In addition to providing information on project alternatives per se, project-level analyses also contribute to other technical studies (which may not involve costs directly), e.g., predictions of remaining service life, data supporting structural capacity analyses (i.e., load ratings), or development of concepts and data to be used in project design. The characteristics of the unit costs needed to meet project-level analysis objectives are discussed below.

Consistency with Project-Level Objectives

Project-level unit costs are more focused, precise, and detailed than those at the network level. Unit costs are structured in terms of alternative approaches to projects or activities, which break the work down into phases or separate work or bid items. These unit costs also reflect site conditions and local economic factors. The organization of these unit costs enables managers to investigate various schemes or phasing options in building the project or conducting the activity, and to coordinate multiple projects that may be occurring at or near the bridge at the same time.

Scope of Unit Costs

Project-level unit costs are developed for each type of action or treatment to be considered. Categories of actions may include maintenance activities, repair or rehabilitation projects, replacement of bridge elements or components, or reconstruction of the entire bridge. In each category of actions, project-level unit costs involve one or more of the following considerations:

Disaggregation of unit costs. Whereas network-level unit costs capture the total costs of an action, individual project-level unit costs reflect only a particular phase of work, or bid item: e.g., mobilization, site preparation, traffic control, repair or rehabilitation of an existing structure, removal or demolition of an existing structure, replacement of an element, or reconstruction of a major component or of the entire bridge itself. One reason for this disaggregation is to enable managers to test different approaches to project execution (e.g., different methods of repair, or different schemes for traffic control). A second is to provide the precision required in these analyses. Although the unit costs are organized in disaggregate form, when taken collectively they should not only equal the anticipated total costs of an action to improve the bridge, but they should also be consistent in magnitude with the corresponding unit cost applied at the network level.

Site-specific information. Unit costs encompass site-specific information on the bridge and its environs, including 1) the design, construction, and material properties of the structure; 2) site characteristics such as topography, right-of-way limitations, approach characteristics, and type of crossing; 3) traffic volume, composition, peaking characteristics, potential detours, and other work zone implications; 4) local availability of labor, equipment and materials, and local costs; and 5) the history of the bridge itself, e.g., comparison in costs and performance with peer structures, noteworthy patterns of deterioration, ability to carry current and future loads, and any known limits on future bridge life.

Coordination of work. Unit costs reflect coordination of maintenance or project work, either on the bridge itself (i.e., if multiple project and maintenance needs have been identified for this structure within a time period), or in the proximity of the bridge (e.g., if projects on the bridge and its approaches require coordination in the establishment and operation of work zones).

Consistency with project-level review. Unit costs exhibit consistency with, and support of, an agency's analytic procedures for project-level review. For example, if an agency performs a life-cycle analysis at the project level to consider remaining service life versus cost of remedial treatments, then unit costs need to be developed to support this analysis.

Note that a project-level analysis deals with an individual bridge as an entity, and is therefore able to deal with its various components and elements in an integrated, coordinated way. This outlook is different from that which may have been applied in the network level analysis, which typically deals with populations of similar bridges, of bridge components (e.g., decks, superstructures, substructures, etc.), or elements (e.g., piers, pier caps, girders, bearings, deck slabs, etc.).

Detail of Unit Costs

To consolidate several points from the discussion above, the detail of unit costs that is required should respond to the following factors:

- Bridge components or elements requiring attention, for which costs need to be prepared,
- The stages of a maintenance activity or project that need to be estimated separately, particularly if variations in their execution form one objective of the project-level analysis,
- The cost estimation methodology used by an agency in project design and development,
- The analytic requirements of the project-level analysis itself.

AGENCY COST COMPONENTS

Agency costs encompass the total costs of performing bridge maintenance activities or construction projects, whether analyzed at the network or the project levels. The data components used to break down these costs in management system data files typify state agency practice in their cost estimation procedures. Agency cost components follow below.

Force Account Work

Force account work is work accomplished by an agency's own crews, and includes the following components:

- Crew labor, including not only direct wages, but also allowances for overtime, benefits, and other payroll burdens. Some management systems use an average crew wage applied to all members; others use the actual wage for each individual in the crew, retrieved from the payroll accounting system.
- Materials and supplies consumed in work performance. Some states determine materials prices annually from purchasing data; others maintain a continually adjusted price, based on stockpile calculations.
- Equipment operating costs, which may entail the fixed and variable operating charges of equipment owned by the agency, or charges for rental equipment (with or without an operator).
- Other costs, as for administration, travel time to and from the site, special equipment purchases, and overhead activities.

Contract Work

Work accomplished by contract is usually managed within a separate category in road management systems, not only to identify the portion of program costs performed by the private sector, but also because the information available through the contracting mechanism is different from that known for force account work. Contracts are used for 1) individual projects too large or too specialized to be done economically by force account, and 2) particular lines of work for which a decision has been made by an agency to perform through the private sector. Contract costs are typically broken down as follows:

- The direct and indirect costs of work performance by the contractor. An estimate of these costs is obtained initially through the contract successful bid, and many agencies analyze the costs of bid items each fiscal year. As work progresses, more refined data are obtained through actual contract payments. However, since contractors include indirect as well as direct costs in their bid item costs, and since these indirect costs may be distributed differently for several reasons, bid costs may vary by at least 20 to 30 percent for a given item in a year.
- Costs to administer the contract borne by the agency, including bid advertisement and award, and processing of invoices and contract changes. (Design and construction services are discussed in a later category.)

Site Costs

Site-related costs encompass the following items:

- Land acquisition for the right-of-way.
- Any mobilization and demobilization to be borne by the agency, including site preparation, establishment of batch plants or aggregate crushing plants, location and preparation of quarries, and utilities relocation.
- Traffic control, including warning signs, work zone identification and worker protection barriers, flaggers, and installation of special signals, warning lights, and message boards.
- Environmental mitigation costs: e.g., to prevent spread of lead paint dust, control excessive noise, and prevent water contamination from site runoff.

Project Support Costs

Costs of project support include agency costs for the following:

- Project planning and design; preparation of design plans and specifications; and preparation of contract documents.
- Construction supervision and inspection.

USER COSTS

The reductions in user costs achieved through a project provide a measure of benefits of that project. Conversely, incremental user costs caused by a project—whether in delays due to work zones during maintenance, repair, or rehabilitation; or in additional user costs incurred during operation (e.g., delays due to bridge openings or to a narrow deck width)—must be added to the agency costs of that project in the comparison of alternative actions. Recognition of the role of user costs is growing in the development of road management systems—for bridges, as well as for pavements and for road maintenance. The general categories of user costs applicable to bridge management are described in the following subsections.

Traffic Movements and Delays

Bridge design and operation affects the quality of traffic movement across it, much as would the design features affecting capacity along any other length of the highway. These aspects can be analyzed to estimate volumes, speeds, and travel times during different traffic demand periods—quantities which are then compared among project options in comparing relative costs and benefits. Factors to be considered in this analysis include the following:

- Geometric cross-sectional features such as lane width and side friction (e.g., location and height of curbs, and location of features such as luminaries, guard rail, and sign posts with respect to the edge of the travel way);
- Bottlenecks due to changes in numbers or widths of lanes (whether on the bridge itself, or at the transition between the bridge proper and its approaches);
- Operational features such as quality of lane signals and controls;
- Frequency and duration of bridge openings, if applicable.

Work Zone Restrictions and Detours

If all or part of a bridge must be closed for maintenance or repair, traffic must be channeled through the work zone or detoured around it. Additional travel time due to these restrictions is an additional cost incurred by road users that is added to the agency's project costs. These user costs can be applied, first, as part of the analysis of bridge design alternatives (i.e., comparing bridge designs that would require a project in mid-life—e.g., for scheduled maintenance or rehabilitation, or for expansion—versus a design option that did not entail such a project); and second, to analyze the best work zone and closure option itself, assuming that a project is required in any case.

Safety

Safety-related costs are typically measured in terms of accident reduction, where the social costs of accidents are tallied in three categories: property damage only, injury, and fatal. Accident frequencies in each of these categories are related to bridge design and operational characteristics, deck condition, traffic volumes, and environmental factors to provide a basis to estimate accident rates.

Bridge Deck Rideability

Bridge decks subject to structural and corrosion-related damage may exhibit spalls, delamination, or joint damage that inhibits rideability (affecting speed) and may introduce an additional accident risk. Incremental user costs can be related to deck condition to model these effects, much as user costs are related to pavement surface riding condition.

USER COST COMPONENTS

User cost components that are typically considered in road management systems include the costs of vehicle operation, travel time (and congestion), and safety. Each of these is described in the following sections.

Vehicle Operating Costs

Vehicle operating costs include the costs of fuel, oil, and tire consumption, plus allowances for incremental wear and tear due to road surfaces in poor condition. Costs such as vehicle ownership, insurance, license and registration fees, and the like generally are not quantified in road management systems (although they are considered in other types of transportation economic analyses), because they are fixed costs that do not vary with either the amount of road usage or the condition of the roads when driven—two of the primary variables in road management systems. Vehicle operating costs have been quantified with respect to road geometry, particularly horizontal curvature and vertical profile (grade). They are also dependent on vehicle speed, a function of running conditions.

Travel Time

Travel time as affected by volume-capacity relationships, congestion, detours, and closures for work zones is arguably the best researched component of user costs for application in road management systems—at least in terms of the behavioral component of the model. This behavioral component, which yields an estimate of speed of the traffic stream for different time periods and road conditions, is based on research that has been carried out in many theoretical and empirical studies of road operating conditions and the impacts of work zones. The other component of this effect, the estimate of the value of time itself as perceived by different classes of motorists, has also been researched, but estimates are subject to a wide variation. Nevertheless, it is possible to arrive at relative numbers that can serve economic analyses of bridge project options.

Safety

The social benefits of safety, in terms of accident risk reductions, have been quantified in three categories of accidents:

property damage only, injury producing, and fatal accidents. The prediction of accidents in these categories is often based upon empirical data, since accidents result from a complicated set of causes involving vehicle, driver, road design, current road condition, and ambient conditions (time of day, weather, wetness of the pavement or bridge deck surface, enforcement, distractions, etc.).

DESIRED ATTRIBUTES OF COST MODELS

There are characteristics that are desirable in the set of unit costs to be used in a management system, regardless of whether one is speaking about agency costs or user costs, at the network level or the program level. A summary of these characteristics follows:

- *Currency*. The capability to keep costs current through adjustments for inflation to define updated constant dollar figures; to account for differential inflation (in constant dollars) among labor, equipment, and materials factors; and to be able to reflect the costs of new practices, technologies, and materials as they become available to maintenance, repair, and rehabilitation. Published data sources are a particularly important tool in maintaining the currency of unit cost data. Other helpful procedures are agency internal cost analyses, and communication of experiences among agencies.
- *Consistency through the project development cycle*. A function of procedures in the project development cycle (Figure 2) to 1) provide initial cost estimates that are realistic and of high quality; 2) establish accountability for cost changes from initial projections and field assessments of needs through preliminary and final design, including documentation of reasons for cost adjustments that are well communicated; and 3) effective monitoring and management of project construction.
- *Reasonably economical updating of cost data*. Established through effective use of existing management tools and procedures, including data from other management systems: e.g., recording accurate costs of maintenance activities; tying cost reports into contract closeout procedures; sampling techniques to survey project or activity costs; and special studies of project costs (as are sometimes performed as part of a reorganization or reengineering effort).
- *Policy sensitivity*. A function of how costs are defined and derived, but including a sensitivity to (i.e., variation as the result of) factors such as the following: maintenance policy, level of effort, or frequency of activity performance; painting and washing cycles; deck joint repairs; rehabilitation techniques and procedures; design standards and alternatives, or standards of levels of service to be provided; use of contract versus force account resources to perform work; variations with project size (indicating any economies of scale).

CHAPTER TWO

SYNTHESIS DATA COLLECTION

LITERATURE REVIEW

A literature review was performed to gauge current practice in the availability and application of unit cost data to economic analyses of bridge maintenance and construction options. References that were reviewed included project reports, research surveys, and published journal articles on the subject. Many of these materials were available based upon past work in bridge management and correspondence with researchers and practitioners in the field, supplemented by a literature search conducted for this study using the Transportation Research Information System (TRIS) database. While many bridge management systems and other cost estimating procedures make use of unit cost data, the focus of this review was specifically on the availability or the estimation of the unit costs themselves. The review illustrates not only the divergence in practice nationwide in the derivation and application of these costs, but also the varying degree to which unit costs conform to the taxonomy outlined in Chapter 1. Both agency cost and user cost data are cited below.

Agency Costs

Unit cost data for maintenance or construction are either derived from statistical analyses and tabulations of existing bridge cost data, or are estimated using models that predict costs as a function of the type of action considered, the characteristics of the bridge, and other factors. Separate estimates or models may be developed for different road functional classes or other stratifying factors. Twelve examples of these developments are presented below.

Example 1—In a study conducted with PennDOT, bridge experts were organized in a group encounter session and asked their opinions on the initial cost and service life of various bridge maintenance and rehabilitation procedures *(1)*. These experts were chosen to represent different geographic, climatic, and other factors felt to affect costs. Expert opinion was gathered on the costs of 49 maintenance and rehabilitation procedures. These data were specified to comprise labor, materials, equipment, and overhead, consolidated to a single-value cost-per-unit basis. Site-specific considerations such as traffic control, profit, user costs, and economic impacts on the area served were excluded from the definition of cost. The resulting data were compared with reported costs from the PennDOT Contract Management Division and reduced to eliminate outliers, yielding estimated cost models for each of the activities investigated. These cost models are organized in three basic categories (superstructure, substructure, and approaches).

Example 2—Models and data to estimate agency unit costs have been developed as part of certain bridge management system designs. The North Carolina BMS includes regression models to estimate costs of bridge structure replacement, roadway construction, and engineering; and of bridge element rehabilitation *(2)*. Costs predicted by these models are total construction costs for the respective activity. The regression models represent functions of key parameters affecting total costs, such as maximum span length of the new bridge, and deck width of the new bridge. Models of preventive maintenance costs are also developed, as functions of the condition of the respective feature. These costs are quantified to the level of the entire activity (encompassing all labor, equipment, and materials), and are expressed in dollars per square foot or dollars per linear foot. (As metrication proceeds, DOTs will be converting data such as these to metric units.) Procedures are also described for updating cost data, using construction cost indices. Formulas for expansion factors are also included to account for the changing characteristics of bridges (e.g., the tendency toward longer spans and wider decks).

Example 3—Unit costs of initial construction for various bridge types and materials are developed for Texas as part of a BMS implementation plan *(3)*. These data are expressed in dollars per square foot of deck area for different improvement, rehabilitation, and replacement actions, and are derived from existing cost information in Texas data files.

Example 4—Saito *et al.* performed statistical analyses of bridge replacement cost data to develop cost estimation models as part of a continuing development of a bridge management system for the Indiana Department of Highways *(4)*. The analysis is stratified by major cost component (superstructure, substructure, approach, other) and by type of bridge component construction (e.g., the superstructure component is divided into various categories of slab, girder, and beam construction and materials type). Separate analyses of superstructure costs are performed for primary and secondary highways, based on consideration of data availability and characteristics for different highway functional classes. For each of the bridge components, models are developed in the form of an overall mean value and adjustment terms to account for key factors affecting costs (e.g., for superstructure, these terms include adjustments for highway and bridge type, an interaction between highway type and superstructure type, and an error term).

Example 5—A subsequent study by the same authors looks at the process of data recording by INDOT and the implications for accuracy of these costs (e.g., proper grouping and classification of rehabilitation activities; effects of contract packaging on apparent costs) *(5)*.

Example 6—The problem of whether to strengthen or replace a bridge with deficient load-carrying capacity is addressed by Wipf *et al.* *(6)*. As part of this effort, unit bridge replacement costs are surveyed from various states on a dollar-per- square foot basis, derived from bid prices for replacement structures that include removal of the existing bridge, construction of a new bridge, and traffic control costs. This paper also presents a curve of estimated bridge removal costs as a function of bridge length, and annual maintenance costs (dollars per bridge or dollars per square foot) for various types of bridges from five states.

Example 7—Agency cost data have been addressed in European practice, particularly within the context of life-cycle costs or "whole-life costing." For example, Brown and Owens report annual bridge maintenance costs, stratified by costs of direct maintenance work, traffic delay (a user cost component), and traffic management; by day versus night performance; and by type of bridge construction *(7)*. Based on these data, maintenance strategies are developed that yield the minimum total discounted cost. The authors emphasize the value of the whole-life approach, even for facilities (such as bridges) that have very long lives. Furthermore, the lowest first-cost approach does not necessarily yield the strategy with the lowest whole-life cost. This approach may force a greater consideration of maintenance and durability at the design stage.

Example 8—Data on maintenance costs and on capital costs for various bridge elements, expressed as a proportion of initial capital costs and whole-life costs, are presented by Leeming *(8)*. These costs are likewise developed within the context of a life-cycle analysis framework, which involves tradeoffs among bridge construction, maintenance, rehabilitation, operation, and replacement options. The authors take the opportunity to identify and respond to several problems with the life-cycle approach that have been raised in connection with long-lived structures such as bridges. Basically, their perspective is that a life-cycle cost analysis of bridge options cannot be viewed as an exact science, but rather must be seen as an analysis of relative courses of action. Furthermore, a life-cycle approach illuminates the role of maintenance as part of the decision process.

Example 9—Piringer examines life-cycle costs (cost per unit for various activities) for steel bridges *(9)*. His paper considers several cost elements, including costs of construction and protection against corrosion; recurring costs (e.g., inspection and renewal of corrosion protection); profit (toll earnings); irregular costs (wear and tear, material failure, effects of faulty design, and accidents after completion of construction); costs due to modified demands (represented as a statistical distribution, in some cases foreseeable), as for additional reinforcement or for widening; costs of eventual demolition; and profit from recyclable materials.

Example 10—Costs of project supporting activities have also been addressed. A review and analysis of the costs and safety impacts of traffic control strategies in work zones was conducted for the Federal Highway Administration (FHWA) *(10)*. This study is based on data from 51 bridge, pavement, and interchange projects of various types. Data are reported in terms of total costs for different types of traffic control measures and road geometric features at the project site.

Example 11—Reviews of bridge management system functions and data provide an overview of different methods of cost estimation, particularly as they relate to life-cycle cost concepts. Two such works are a review of bridge management prepared by the FHWA, *(11)* and,

Example 12—a series of papers on bridge management compiled by the Transportation Research Board *(12)*.

User Costs

User costs are applied to gauge the impacts of bridge actions on the motoring public, with reductions in user costs often constituting a major component of the benefits of an action. Several bridge management systems and other cost estimation procedures have been built on the premise of total life-cycle costs, and therefore have user costs incorporated directly in their framework. Examples of these implementations follow.

The Pontis BMS was developed through a federal-state partnership to establish a proof-of-concept of a network-level bridge management system. Conceived as a response to a series of 47 workshops conducted by the U.S. Federal Highway Administration (FHWA) in the mid 1980s, Pontis represented an effort by the FHWA to act as a catalyst for a group of states to develop jointly a network-level bridge planning model. In its developmental phase, Pontis was overseen by a Technical Advisory Committee consisting of representatives of the FHWA, the TRB, and the departments of transportation of California (which managed the effort), Minnesota, North Carolina, Tennessee, Vermont, and Washington. Release 1.0 of Pontis conclusively demonstrated the feasibility of a network-level optimization model for bridges, the acceptability of an expanded bridge inspection procedure, the suitability of a personal computer platform for this system, and characteristics of user-friendliness and flexibility to meet the needs of different DOT practices across the country.

Pontis generates incremental user costs mainly through level-of-service deficiencies, such as narrow width, low vertical clearance, poor alignment, and low load capacity *(13)*. User costs are computed as the sum of three components: vehicle operating costs, travel time costs, and accident costs. Incremental vehicle operating costs are computed on the percentage of vehicles that must detour around a bridge because of weight or height restrictions. The model is based on the posted bridge limits, the volume and composition of the traffic stream, and relationships between the weight or height limits and the estimated percentage of trucks that will need to detour. These latter relationships are developed for various types of trucks. Travel time is also tallied as an incremental cost related to a detour. Accident costs are estimated as a function of traffic, accident rates for property damage, injury, and fatal accidents, and adjustments for bridge deck width and approach alignment, based on work performed in North Carolina which is described next.

The North Carolina BMS considers accident costs and vehicle operating costs. Accident relationships are derived from experience with bridge-related accidents specifically, which are more severe than other accidents. The model predicts directly the number of accidents per year, without differentiating among types or severity of accident, and uses an average accident cost based on the average distribution of type and severity of injuries in bridge-related accidents. The model is a function of the average daily traffic (with a separate model to estimate traffic growth rate), the length of the bridge, and the difference in width between the "goal clear deck width" for an acceptable level of service (a function of the goal number of lanes and lane width) and the actual clear deck width. Vehicle operating costs are scaled on a linear curve between two extremes: the operating costs for a vehicle weighing three tons or less, and the operating costs for a vehicle weighing the maximum legal load; estimated operating costs (dollars per mile) are thus a function of the vehicle weight.

The proposed Texas BMS has procedures to estimate accident costs related to deck width and alignment deficiencies, and accident, travel time, and vehicle operating costs associated with detours. Accident rates for the three categories of accident severity, which are associated specifically with bridge characteristics, are presented as a function of bridge type, number of lanes, bridge width, and shoulder reduction. To these rates are applied accident unit costs, stratified by accident severity and urban versus rural location. Costs of travel time at detours are based on FHWA recommended values; vehicle operating costs are estimated using models developed by Zaniewski, updated to 1990 *(14)*. These latter models represent vehicle operation in a detailed speed profile, accounting for idling, speed change cycles, and uniform speed regimes. The framework for accounting for accidents in detours is also presented, including accident unit costs by urban and rural highways and type of highway (freeway, divided, and undivided). The Texas approach also includes a formula, modified from the Highway Performance Monitoring System (HPMS), to account for adjustments in travel speed due to bridge deck roughness; separate corrections for operating costs due to deck roughness are also included, adapted from Zaniewski's models.

Work performed for the Strategic Highway Research Program also considered the effects of deck condition and construction projects on user costs *(15)*. Two basic situations were addressed: 1) increases in user costs due to travel time, vehicle operation, and accident risk with worsening deck condition; and 2) delays during deck treatments due to work zone restrictions or detours. Regarding the first effect, this study noted that for typical road surface conditions in North America, operational characteristics of traffic volume and congestion have a much greater effect on user costs than do surface conditions, and that road surface condition does not begin to have a major effect on user costs until the condition becomes very bad. Thus, bridge deck condition was judged not to have a significant effect on user costs unless the deck is allowed to deteriorate to a high degree of spalling (the study addressed corrosion-related deterioration of the deck surface).

A model was proposed to capture this relationship in which user costs are represented by an aggregate figure, in dollars per vehicle, covering the increments in travel time, vehicle operation, and accident risk costs. Regarding the second effect, a volume-capacity model was proposed to handle the additional costs of either detours around the construction zone, or congestion due to restricted capacity across the bridge because of the work zone. BRIDGIT is bridge management system (BMS) software that includes cost estimation procedures and is intended to meet the needs of state, local, and other bridge agencies by providing guidance on network-level management decisions and project-level actions. BRIDGIT was developed under the AASHTO-sponsored National Cooperative Highway Research Program (Projects 12–28(2)A and 12–28(2)B) and is a microcomputer-based system that is easy to use, easy to implement, and responsive to all FHWA requirements (now optional) for BMS. Maine DOT currently uses BRIDGIT.

Version 1.0, released in 1995 to all the state DOTs, is a fully functional system, meeting FHWA and AASHTO guidelines for bridge management systems. Although enhancements are being made to BRIDGIT under NCHRP Project 12–28(2)B, the current system is fully operational and meets both immediate and long-term needs of a highway agency.

A very detailed treatment of user costs in analyses of transportation alternatives for Florida was developed by McFarland *et al.* *(16)*. In looking at bridge widening versus replacement as a case study, this approach developed a set of detailed calculations developed from data and relationships from multiple sources. For example, excess operating and travel time costs are tied to speed changes, reduced speeds, and lateral movements that occur on an existing, narrow bridge, in dollars per 1,000 vehicles. Accident costs were related to bridge width based on separate data from Colorado *(17)* and from another study *(18)*.

Work zone effects on user costs have been studied as individual research efforts. An FHWA study analyzes accident rates and road user costs for vehicle operation and travel time as a function of traffic volume, work zone capacity, and (for accidents) the traffic control strategy (single lane closure or two-lane, two-way operations) *(10)*. Road user costs for both vehicle operation and travel time are reduced to a set of curves for non-saturated and saturated (i.e., queued) flow, expressing these user costs in dollars per work zone mile per hour for the entire traffic stream for non-saturated flow, or dollars per hour (as a function of queue length) for saturated flow conditions.

SURVEY

A survey was developed and executed to gain an accurate view of the current state of the practice of collecting and managing cost data for BMS. (Appendix A.) This 20-page questionnaire was distributed in March of 1994 to 52 departments of transportation in the 50 states, the District of Columbia, and Puerto Rico. Given the number of topics addressed by the survey and the lack of a central "clearinghouse" of cost data in most agencies, it was common for portions of the questionnaire to be distributed simultaneously to different people in the agency. The topics covered were the following:

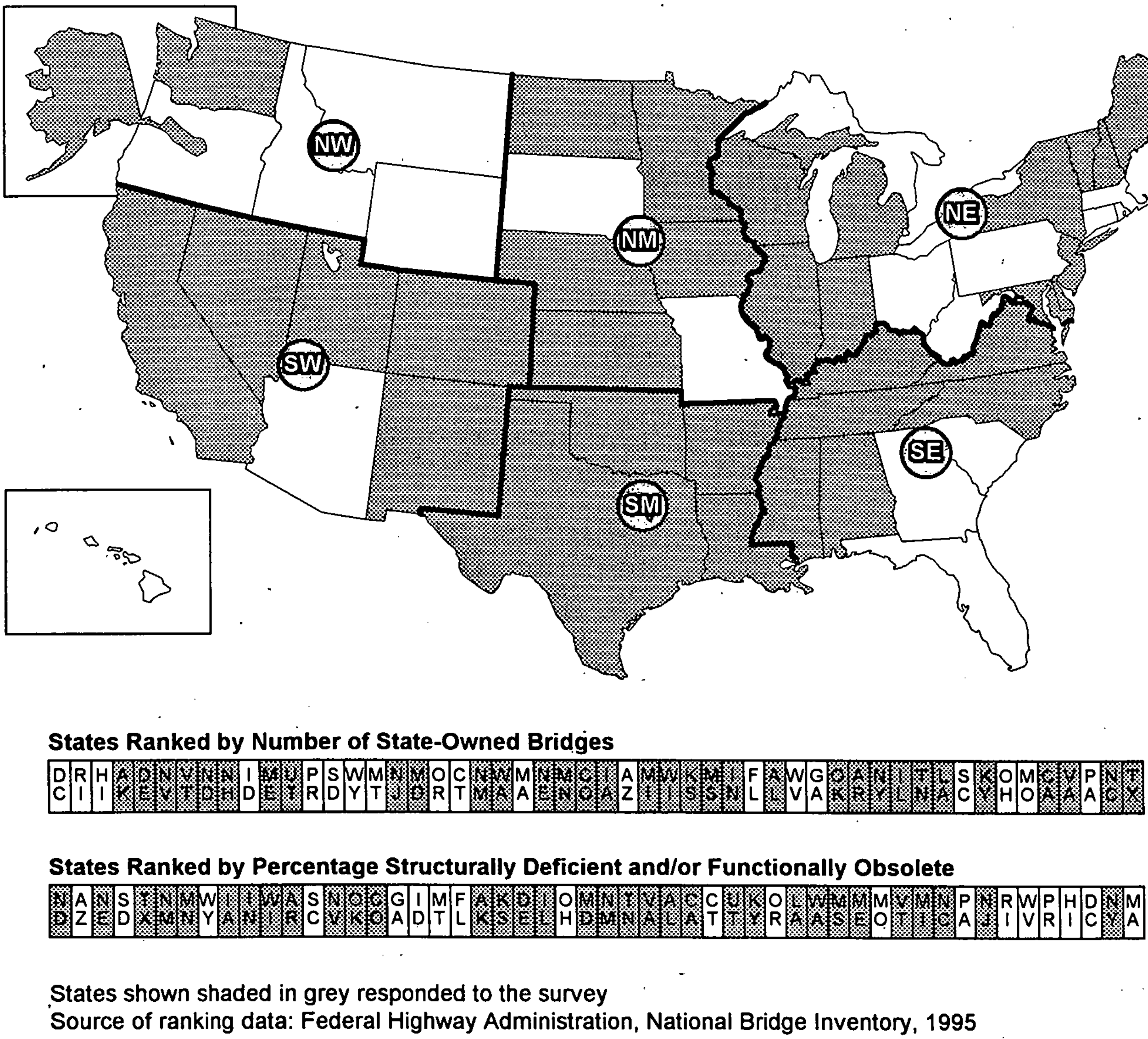

FIGURE 3 Distribution of responses.

- Identification of the agency and its plans for implementation of a network-level BMS;
- General information about the agency's program size, decentralization, and means of implementing bridge work;
- Project development process, including responsibility for project initiation and cost estimation;
- Contracting, and the level of detail of contract cost data;
- Level of detail, and units of measurement, of cost data on force account and day-labor work;
- Ability to estimate other types of agency costs;
- User costs;
- Local bridges; and
- Overall appraisal of the suitability of the agency's cost data for a bridge management system.

Thirty-five state DOTs responded to the survey, with 33 providing usable responses. As shown in Figure 3, the usable responses represent a fair cross-section of the nation, reflecting all geographic regions, inventory sizes, and degrees of bridge needs. Responses to the survey were tabulated in spreadsheets and analyzed for patterns related to region, size, percent deficient, and centralization, as well as interrelationships among the questions in the survey. The responses to each question, when

TABLE 1

PROGRAM SIZE

Type of Work	Percent of Inventory Acted On	Cost per Bridge Acted On ($000)
Replacement	0.9	833
Functional/Structural	1.3	606
Maintenance	5.6	27
Emergency	0.2	
Total	7.0	202

(Question 1b, 27 responses)

expressed as percents, are adjusted for the number of usable responses to that question. There was no common pattern to the states that were able to respond; they covered a complete range of sizes, locations, and degrees of centralization.

Twenty-five of the responding states, or 76 percent, indicated that they are implementing Pontis, four are developing their own systems (of which one is also implementing Pontis), and three are undecided. Maine DOT uses BRIDGIT and a few others are evaluating it in conjunction with Pontis. Sixteen of the respondents, or nearly half, described their own job titles as "Bridge Management Engineer" or "BMS Engineer," while the rest of the respondents have more general responsibilities over bridge design, maintenance, or inspection. This indicates a strong trend of institutionalization of bridge management as an organizational function in state DOTs. Although this title is found somewhat more commonly in states with centralized bridge program development processes and states in the west, it is evident in states of all sizes across the country.

The survey asked each respondent to characterize the size of their bridge program by number of bridges and cost of replacement, functional and structural work, maintenance, and emergency work. Only 18 agencies were able to fully respond to this question. Of the remainder, five agencies were able to respond to all but the maintenance questions. Of the 18 agencies with complete responses, four were able to provide only estimates. This outcome suggests that many of the states would benefit from easier access to these basic pieces of information.

Table 1 summarizes the program size results of the survey. The project types listed in the table are:

TABLE 2

CENTRALIZATION OF BRIDGE PROJECT DEVELOPMENT AND COSTING

					Centralization of Project Development			
					Replacement		Maintenance	
State	State Owned Bridges	Region		Percent of Insp. in HQ	Initiation	Estimate	Initiation	Estimate
High Centralization								
AK	688	N	W	100	1	2	0	2
AL	5419	S	E	12	1	2	0	2
CA	11236	S	W	100	1	1	1	1
CO	3401	S	W	100	-1	2	-1	2
DE	733	N	E	100	1	2	-1	0
IA	3871	N	M	44	0	2	0	2
KS	4609	N	M	19	1	2	1	2
MD	2343	N	E	100	0	2	0	2
ME	1487	N	E	100	1	2	-1	2
NC	15393	S	E	100	2	2	2	2
ND	1066	N	M	3	1	2	1	2
NH	1242	N	E	25	1	2	1	2
NJ	2301	N	E	98	1	2	-1	1
NV	871	S	W	38	1	2	0	0
UT	1649	S	W	100	1	2	-1	1
VT	1057	N	E	100	1	2	1	2
WA	2897	N	W	100	1	2	1	2
Medium Centralization								
IL	7424	N	E	10	-1	0	-1	2
KY	8629	S	E	5	1	0	-1	0
LA	7665	S	E	4	1	2	-1	-2
MI	4206	N	E	86	0	1	0	-2
MS	5000	S	E	27	0	0	-1	2
NE	3366	N	M	67	0	2	-1	0
NM	2888	S	W	0	1	2	-1	-2
OK	6641	S	M	11	1	2	-1	1
TN	7480	S	E	9	0	0	0	0
Low Centralization								
AR	6775	S	M	4	-1	2	-2	-2
IN	5053	N	E	14	-1	2	-1	-2
MN	3399	N	M	3	-1	1	-1	-2
NY	7358	N	E	0	-1	-	-1	-2
TX	30700	S	M	14	0	-1	-1	-2
VA	11356	S	E	0	-1	0	-2	0
WI	4544	N	E	25	-1	-2	-1	-1

• Replacement of whole bridges,

• Functional and structural, including major repair, rehabilitation, widening, raising, rail replacement, seismic retrofit, and scour mitigation.

• Maintenance, which is smaller work including painting, concrete patching, deck overlays, and joint and bearing rehabilitation; and not including annual routine maintenance.

• Emergency (unplanned work caused by natural disasters, traffic accidents, etc.).

Appendix A shows the full definitions used. The survey results indicate significant differences among states in the definitions used for these terms. As a result, even though most of the states providing data were able to observe the definitions given, a significant number noted that their data were based on different definitions. The definition of "maintenance," in particular, varies considerably.

In all, the responding states work on seven percent of their state-owned inventories each year, spending an average of $202,000 per project. (Since a few states responded only with total expenditures rather than the breakdown by type of work, the totals do not necessarily agree with the breakdown.) Spread over the entire state-owned inventory, the states spend an average of $14,000 per bridge per year, or 1.5 percent of the average replacement cost. These averages exhibited considerable variation from state to state. These variations show no significant correlation with inventory size, location, centralization, or percent of substandard bridges in the inventory. States with high bridge replacement costs tend to perform maintenance on a larger fraction of the inventory, and tend to incur higher costs for emergency work. However, this does not imply a cause-and-effect relationship.

Table 2 shows that responsibilities for bridge project development and cost estimation are centralized in some states and decentralized in others. Centralization tends to be greater in smaller states and in northern and western states. Bridge replacement decisions tend to be more centralized than maintenance decisions. (Functional and structural decisions follow the same patterns as replacement, while emergency decisions tend to follow the same patterns as maintenance.) In Table 2, negative numbers in the initiation and cost estimation columns indicate responses that are less centralized, and positive numbers more centralized. Zeroes typically indicate responses where both districts and headquarters participate in decisions. Six states indicated that initial replacement cost estimates are performed in the districts, then finalized in the central office. Three indicated that maintenance cost estimates follow this pattern. In general, the degree of centralization of bridge decision making does not necessarily follow the level of centralization of non-bridge activities of a department of transportation.

CHAPTER THREE

PROJECT-LEVEL COST ESTIMATION BASED ON SURVEY RESULTS

Since project-level cost estimation capabilities of some kind exist in every state DOT, they are the most obvious source of cost models for bridge management systems. States that have well-developed automated capabilities to keep their cost estimation procedures up to date are most likely to have the procedures, systems, and staff resources in place to keep bridge management system models up to date. Because accurate cost estimation is of great importance in every transportation agency, states that have not been able to implement effective cost data collection in the past will find bridge management systems to be one more strong reason to consider improving their capabilities now.

The concept of network-level bridge management is relatively new, and most cost estimation capabilities now in existence in transportation agencies work at the project level. These have evolved gradually, in response to particular needs of the project development process. In agencies where automated means of collecting, managing, and applying network-level cost data have been developed, these have generally evolved from project-level tools, especially bid tracking systems.

Cost estimates follow a continuum of detail, ranging from long-range estimates used for multi-year programming, to shorter-range program estimates used for resource planning, to planning, design, and construction budget estimates, to engineer's estimates used for letting of contracts, and cash flow estimates for tactical management of in-house forces. Most of these types of estimates are useful in a bridge management system, with the first two used in network-level analysis and the rest used in project-level analysis. All of these types of estimates can benefit from the same data sources, though the latter ones need more detail and rely more heavily on bridge-specific analysis and field checking.

FIELD IDENTIFICATION AND SCREENING OF NEEDED WORK

Most bridge inspectors in the responding states are non-engineers based in district offices. In states that use engineers for bridge inspection, most are based in headquarters. Table 3 shows the distribution of inspectors. The deployment of inspectors is not correlated with the size or condition of the inventory, but does show interesting correlations with location and centralization. Most states use a combination of engineers and non-engineers to perform inspections; only three use solely engineers, and only three use solely non-engineers. The survey did not include questions regarding the productivity of the inspectors or the distribution between full-time and part-time assignments.

Two-thirds of the responding states have one or more engineers who are assigned primarily to bridge maintenance. On average, there is one engineer for every nine inspectors, equally divided between districts and headquarters. There is a heavy reliance on inspectors for initial identification and screening of projects, especially in maintenance and emergency work, as shown in Table 4. Interestingly, states that use relatively large numbers of engineers for inspections are not significantly more likely to use inspectors for project initiation. However, they are more likely to have a centralized project initiation process. For maintenance work, smaller states tend to use maintenance crews and managers to initiate work, while larger states rely on inspectors. The less centralized states rely more heavily on inspectors for replacement projects, while the more centralized states rely on planners.

TABLE 3
DEPLOYMENT OF BRIDGE INSPECTORS

	Districts	Headquarters	Other	Total
Non-engineers	55	9	1	65
Engineers	15	19	1	35
Total	70	28	2	100

(Question 1a, 31 responses)
Percentages of the total number of inspectors

By Region		By Degree of Centralization	
Northern USA	64	High	73
Southern USA	30	Medium	28
		Low	30

Engineers as a percentage of all inspectors

PROJECT DEVELOPMENT PROCEDURES

There is a wide variation among the states in the organizational procedures used for cost estimation, as shown in Table 5. Although designers and engineers are most responsible for final cost estimation, which is performed just before advertising a project or issuing a work order, the initial cost estimates may be produced by a variety of people. Generally, the groups that perform the initial cost estimate are the same groups that introduce the project into the project development process. For replacement projects, three states use inspectors to perform initial cost estimation (two of them use only engineers to perform inspections), 12 use planners, and seven use managers. Ten states perform initial cost estimation in district offices, but five of them then turn the projects over to headquarters for final estimates. For maintenance projects, many have their initial cost estimates done by inspectors, but most of these states then turn the projects over to designers or engineers for final

TABLE 4
PROJECT INITIATION

Group	Replacement	Functional/ Structural	Maintenance	Emergency
	Classification of Work			
Inspectors	14	17	25	26
Maintenance Crews	2	2	18	16
Planners	15	12	2	1
Designers	4	6	1	1
Engineers	17	19	15	15
Special Surveys	2	4	4	4
Safety Planners	0	4	0	0
BMS Users	4	5	2	1
Managers	18	17	10	8
Others	1	1	0	2

Number of states indicating the involvement of each group of staff
(Question 2a, 32 responses)

Districts	20	20	27	27
Headquarters	30	29	17	18
Consulting Firms	0	0	1	2
Other	2	1	0	0

Number of states indicating the involvement of each level of the department
(33 responses)

TABLE 5
COST ESTIMATION PROCEDURES

Group	Classification of Work							
	Replacement		Functional/ Structural		Maintenance		Emergency	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final
Inspectors	3	0	3	0	11	1	8	1
Maintenance Crews	0	0	1	0	5	7	3	2
Planners	12	1	11	1	3	0	2	0
Designers	5	14	7	15	4	8	4	6
Engineers	11	16	11	16	13	14	15	14
Special Surveys	0	0	0	0	0	0	1	0
Safety Planners	0	0	2	0	1	0	0	0
BMS Users	2	0	2	0	1	0	1	0
Managers	7	2	6	2	5	5	5	4
Others*	2	3	2	3	0	0	0	2

* MN and NE mentioned Bridge Estimation Unit
Number of states indicating initial and final estimates performed by each group
(Question 2b, 31 responses)

Districts	10	5	10	5	16	16	15	10
Headquarters	25	29	25	29	20	20	20	21
Consulting Firms	6	6	8	8	3	3	3	4
Other	0	0	0	0	0	0	0	0

Number of states indicating initial and final estimates performed by each level of the department
(32 responses)

estimates. Half of the states perform their initial maintenance cost estimates in district offices, with only three turning the final cost estimation over to headquarters.

MEANS OF IMPLEMENTATION

The survey results show that cost data management procedures vary greatly depending on whether the work is done by contract or by the agency's own forces. This complicates the problem of cost estimation for a bridge management system, because program cost figures are generally needed long before a contracting decision can be made. Often, contracting decisions are made by the organizational unit responsible for completing the work, which may be different from the group responsible for the cost estimate. In the survey, 13 states indicated that contracting decisions are made in headquarters, seven in districts, and six in both. In three states this result was completely different from the location of most of the project development process. The most common reasons given for deciding to contract a project are as follows (the parenthetical number indicates the number of states mentioning each reason):

Type of work, such as complexity and magnitude (9);

- Cost (11);
- Capability of state forces (10);
- Funding (8); and
- Urgency (1).

After the contracting decision is made, 16 states say they revise the cost estimate, while eight states say they do not. The reasons for not revising the cost estimate may include a belief that the cost estimate does not change, or the unavailability of a suitable estimation procedure. Table 6 summarizes the use of contracting in the responding states. These figures have been normalized according to the total number of bridges worked upon in each state to avoid biases resulting from wide variations in the number of bridges. The table shows that contracting is very widely used, especially for bridge replacement; six of the states indicated that practically all bridge work is done by contract.

ESTIMATION PROCEDURES

Project cost estimation procedures in most of the states are informal and manual at the beginning of the programming process, then become more formalized as the project proceeds toward the design stage. An important milestone occurs in over half of the states when the contract versus in-house decision is made, especially for maintenance work. In nearly all of the states, procedures and systems are in place that permit the development of contractor and contract administration cost estimation procedures, especially for major projects. This capability is not as well developed for in-house work. Many of the states have access to contract cost data for use in preparing engineers' estimates and for bid checking. The dissemination of this information is almost universal for bridge replacement and functional/structural projects, but is much more limited for maintenance and emergency projects. Some of the larger states have computerized contract management systems, and a few states have other computerized sources of this information. None of the smaller states have full computerized access to detailed contract maintenance data. Table 7 summarizes the availability of data for contract cost estimation. The levels of detail in the table are:

- Project. Data about the cost of a project that does not distinguish individual structures, elements, or actions.
- Bridge. Data that can distinguish individual structures.
- Element. Data that can be applied separately to elements of a structure, such as the Commonly-Recognized (CoRe) elements.
- Element/State. Data that can be applied separately to different condition states of individual elements.
- Action. Data that can distinguish one of the levels listed above, and can also distinguish different kinds of actions.

Only two states indicate that they do not have this information available for replacement projects by bridge. Since a majority of the states use contractors to do all bridge replacements, this indicates a nearly universal capability to estimate replacement costs at the bridge level.

For contract maintenance, just over half of the responding states *(17)* have the ability to estimate costs at the project or

TABLE 6
USE OF CONTRACTING FOR BRIDGE WORK

	Classification of Work			
Performer	Replacement	Functional/ Structural	Maintenance	Emergency
Force Account	1	5	35	27
Day Labor	0	4	17	7
Contract	99	91	48	66
Total	100	100	100	100

Percentage of bridges in each work category
(Question 1c, 27 responses)

TABLE 7

DATA FOR CONTRACT COST ESTIMATION

	Classification of Work			
Detail	Replacement	Functional/ Structural	Maintenance	Emergency
Project	22	22	11	10
Bridge	29	28	17	18
Element	13	15	10	10
Project/action	7	7	3	2
Bridge/action	10	10	7	7
Element/action	4	4	4	4
Elem/state/action	0	0	0	0

Number of states indicating availability at each level of detail
(Question 3a, 31 responses)

TABLE 8

AVAILABILITY OF WORK ORDER ESTIMATION DATA

	Classification of Work			
Detail	Replacement	Functional/ Structural	Maintenance	Emergency
Project	3	4	12	7
Bridge	5	5	15	13
Element	4	3	12	8
Project/action	0	1	6	3
Bridge/action	1	2	7	4
Element/action	2	2	6	4
Elem/state/action	0	0	1	1

Number of states reporting availability at each level of detail
(Question 4b, 30 responses)

bridge level. Of these, nine also have these data available at the element level. All of these are larger states and all of them have computerized contract management systems, though not all of them rely on a contract management system for cost data. Three additional states have access to contract maintenance data at the project level, but not at the bridge or element levels. None of the remaining 11 states indicates the availability of any contract maintenance cost estimation data at all. None of the states has access to cost estimation data at the element/state/action level. In all, 26 of the responding states have computerized contract management systems, but only 20 have computerized access to contract cost estimation data for bridges. These data are almost always available uniformly across the agency, without variation among the districts. One-third of the states have access to this information for virtually 100 percent of their state-owned bridges, and half have access for at least 75 percent of their bridges. Two of these states do not have contract management systems but do have other computerized sources of the information.

For work done by force account or day labor, capabilities for maintenance cost estimation are not as good as those for contracts. Fifteen states have data to estimate these costs at the bridge level, and 12 states have data for cost estimation at the element level. Eight states have force account/day labor maintenance cost estimation data at both the bridge level and the element level. Only North Carolina has access to these data at the element/state/action level, and 36 percent of the states do not indicate access to any of these data. Confidence in agencies' abilities to estimate force account costs is low: only 23 percent of the respondents feel that they are able to estimate costs accurately at least three-fourths of the time. Computerized maintenance management systems exist in 16 of the responding states, but only 11 have computerized access to force account/day labor cost data. Computerization is not at all correlated with inventory size, location, or degree of centralization. Availability is much more variable than for contract data, with only 11 of the respondents (mostly larger inventories) reporting uniform availability across the agency. Nearly all states that have quantity estimation data also have cost estimation data. Table 8 summarizes the availability of force account/day labor data.

The availability of data is another area in which survey responses vary widely. Twenty-three of the states report that they have written guidelines for estimating costs, while seven do not. Most often, the estimation procedures are manual, even if based on automated data. A few states have regular annual procedures to update the cost estimation factors, but most do it on an "as-needed" basis. Three states report using AASHTO's BAMS software as a source of data for cost estimation factors. Four states (Arkansas, Kansas, Louisiana, and Maryland)

TABLE 9

AVAILABILITY OF MAINTENANCE COST DATA FOR STATE-OWNED BRIDGES

	Contract Maintenance					Force Account and Day Labor				
State	Pct	Bridge	Elem	Action	Comp	Pct	Bridge	Elem	Action	Comp
AK	0					100	x			
AL		x	x	x	x			x	x	x
AR		x	x	x	x		x	x		
CA	19	x	x	x	x	81	x	x	x	x
CO					x		x	x	x	
DE					x					
IA	100	x			x	0				
IL	62				x	38	x		x	x
IN	100	x	x		x	0	x			x
KS	100	x	x	x	x	0	x	x		x
KY		x					x			
LA	0	x	x	x	x	100	x	x	x	
MD	100		x	x		0				
ME	2				x	98				
MI	20					80				
MN					x		x	x	x	x
MS	100	x				0				
NC	1					99	x	x	x	x
ND	100					0				
NE	88	x	x		x	12	x			
NH	4	x		x	x	96				
NJ					x		x		x	x
NM	8					92				
NV	0					100	x	x		
NY		x	x		x			x		x
OK	7	x		x		93	x		x	x
TN					x					
TX	33				x	67			x	
UT	100	x		x		0				
VA	66	x		x	x	34		x	x	x
VT		x			x			x		
WA	50	x	x		x	50				
WI					x					

Pct = Percent of bridges for which the data are available
Bridge = Bridge-level data available
Elem = Element-level data available (not necessarily AASHTO Commonly-Recognized (CoRe) elements)
Action = Action-level data available
Comp = Data available in computerized form

describe the use of bid databases which they maintain specifically for contract cost estimation and bid checking. Maryland has found it valuable to develop separate indexes of contract costs for different geographic areas of the state, to fine-tune its cost estimates. Washington state has found it helpful to occasionally vary its bidding procedure to ask contractors for unit costs.

Overall, the availability of data to estimate bridge replacement and rehabilitation costs is very well developed across the country, but the availability of maintenance cost data is not. There are significant differences among the states in the types of data available, and significant differences even within states between contract work and force account work. If these data are to be viewed as a potential source of unit costs for bridge management systems, few states have a complete capability to do it. Table 9 summarizes each responding state's availability of detailed cost estimation data, indicating the level of detail and the computerization for contract work and force account/day labor work.

CHAPTER FOUR

DEVELOPING NETWORK-LEVEL MODELS

One conclusion to be drawn from the survey is that the states are not satisfied with their current cost estimation capability, that they feel it is cost-effective to improve the level of detail of cost data, and that they have plans to do so. Table 10 summarizes the opinions expressed by the respondents about their own ability to supply cost data to their bridge management systems. Interestingly, 12 of the 16 states having Bridge Management Engineers as the respondents were dissatisfied. It could be that the increased emphasis on bridge management in these states has uncovered cost estimation problems that other states have not discovered. Most states, however, express plans to improve their capabilities to a level where they will be satisfied, and many believe that the improvements will make their capability superior to other states. Twenty-one states believe that the planned improvements will be adequate to support their bridge management systems, while five doubt that they will be adequate.

TABLE 10

SATISFACTION WITH COST DATA

	Now	Future
Very satisfied	0	2
Satisfied	6	18
Neutral	4	5
Unsatisfied	17	1
Very unsatisfied	5	0

(Questions 8a and 8c)
Number of states indicating satisfaction now, and after current plans for improvement are implemented.

Most of the states believe that it would be cost-effective to increase the level of detail in their data gathering. These results are highly consistent between functional/structural projects and maintenance, and between contract and in-house work. Twenty-five states believe that it would be cost-effective to increase the level of detail beyond their current cost estimation capability, and most indicate that they have plans to do so. Table 11 summarizes the respondents' opinions regarding the highest cost-effective level of detail.

TABLE 11

COST-EFFECTIVE LEVEL OF DETAIL FOR MAINTENANCE ACCOMPLISHMENT DATA

Detail	Contracts	Work Orders
Project	25	23
Bridge	27	28
Element	25	26
Project/action	21	19
Bridge/action	23	24
Element/action	22	22
Element/state/action	13	15

Number of states indicating each level of detail to be cost-effective. (Question 8d, 30 responses)

RECORDING OF WORK ACCOMPLISHMENTS

To a great extent, the accuracy and precision of bridge management system cost estimates are limited by the level of detail of work accomplishment data collected. States that do not have regular procedures in place to record the costs of work accomplished seldom are satisfied with either their bridge management system cost estimates or their project development cost estimates. For this reason, states that are now implementing bridge management systems generally take a close look at their cost data collection procedures. These may be closely tied to project completion recording in contract management or maintenance management systems.

Based on the survey results, 26 of the 29 responding states have automated management of historical contract replacement cost data, and more than two-thirds of them can retrieve this information at the bridge level. Nearly all the states with automated bridge-level data have computerized contract management systems and computerized project cost estimation capabilities. Only six states have paper records at a higher level of detail than the automated records. All but one of the states that collect completion and quantity data also collect cost data. Table 12 summarizes the availability of automated contract completion cost data.

For contract maintenance, only 20 states have automated work accomplishment data collection, of which all but one includes cost data. Twelve states collect bridge-level data, and seven collect element-level data. Only five have automated data at the bridge/element/action level, but two others can access this information on paper. One state (Alabama) has data at the element/state/action level. Nearly all of the states with automated bridge-level data collection have computerized contract management systems and computerized contract maintenance cost estimation. Functional and structural projects follow the same pattern as replacement projects, with a slightly lower level of data availability. Emergency projects follow the same pattern as maintenance projects, again with a slightly lower level of data availability. Almost all of the states with automated cost data collection store actual costs, and a few also store estimated costs. Paper records, on the other hand, more typically store estimated costs.

TABLE 12

CONTRACT COMPLETION COST DATA

Detail	Classification of Work							
	Replacement		Functional/Structural		Maintenance		Emergency	
	Auto	Paper	Auto	Paper	Auto	Paper	Auto	Paper
Project	23	18	21	15	13	11	16	11
Bridge	21	18	19	16	12	13	14	13
Element	11	10	8	9	11	7	7	9
Project/action	9	6	9	7	6	6	4	2
Bridge/action	9	5	9	6	7	7	5	3
Element/action	4	4	3	3	3	4	2	2
Element/state/action	0	0	0	0	1	0	1	0

Number of states indicating availability of data at each level of detail.
(Question 3d, 29 responses)

TABLE 13

WORK ORDER COMPLETION COST DATA

Detail	Classification of Work							
	Replacement		Functional/Structural		Maintenance		Emergency	
	Auto	Paper	Auto	Paper	Auto	Paper	Auto	Paper
Project	4	6	7	7	10	11	5	8
Bridge	4	6	6	8	8	12	8	10
Element	3	3	4	3	8	5	6	4
Project/action	1	2	2	3	5	4	2	3
Bridge/action	1	2	3	2	6	5	4	4
Element/action	1	1	2	1	4	2	3	2
Element/state/action	0	0	0	0	1	1	1	1

Number of states indicating availability of data at each level of detail.
(Question 4c, 27 responses)

Force account maintenance costs are very important and only a few states have complete automated data. Although five states collect data on force account bridge replacement costs, this combination is relatively unusual. Fifteen of the 27 responding states have automated maintenance work order accomplishment data, of which all but one have cost data. Eight states collect bridge-level data (four more can access it on paper), eight collect element-level data, and only four collect bridge/element/action-level data on computers. North Carolina alone collects automated maintenance work order data at the element/state/action level. (One more state, Colorado, collects data at this level on paper.) Only a third of the states have complete and accurate bridge-specific quantity or cost data anywhere in the agency. Table 13 summarizes work order accomplishment data for all types of actions.

The state of the practice of work accomplishment data collection is relatively undeveloped at present. Although replacement costs are widely available, only three states (Minnesota, California, and North Carolina) collect a complete automated set of maintenance costs, for contracts and work orders, at the bridge/element/action level. Only North Carolina currently collects automated maintenance costs at the bridge/element/state/action level, but Alabama is about to begin doing so. Table 14 lists the responding states with the status of their data collection programs for maintenance costs, and Table 15 summarizes the current state of the practice of work accomplishment data collection. Well-developed data collection is not correlated with inventory size, location, or degree of centralization.

The cost of work accomplished on local bridges is even more difficult to access, especially for work done by local agencies with their own forces and funds. Table 16 summarizes the availability of such data, and Table 17 lists each state's status with local bridge cost data. In all, 16 of the states, more than half of those responding, plan to develop bridge management system cost models to be offered to local agencies for their own use. Four states plan to require local agencies to report their cost experience to the state, and nine plan to encourage it.

For both locally and state-owned bridges, the most common cost data collection and management strategy is to use contract management systems and maintenance management systems. Only two or three states have extensive manual systems to accomplish this purpose; most states do not have the

TABLE 14

AVAILABILITY OF MAINTENANCE ACCOMPLISHMENT COST DATA

	Contract Maintenance					Force Account and Day Labor				
State	Pct	Bridge	Elem	Action	Comp	Pct	Bridge	Elem	Action	Comp
AK	0	x	x			100				
AL		x	x	x	x			x	x	x
AR		x					x	x		
CA	19	x	x	x	x	81	x	x	x	x
CO		x	x		x		x	x	x	x
DE										
IA	100	x			x	0	x			
IL	62					38	x		x	
IN	100	x	x		x	0				
KS.	100	x	x		x	0	x	x		x
KY										
LA	0	x	x	x	x	100				
MD	100		x	x	x	0				
ME	2					98	x			
MI	20	x		x		80				
MN		x	x	x	x		x	x	x	x
MS	100	x				0				
NC	1					99	x	x	x	x
ND	100					0				
NE	88	x	x	x	x	12	x			x
NH	4	x	x	x		96	x			
NJ		x		x	x		x		x	x
NM	8					92				
NV	0					100	x	x		
NY			x		x			x		x
OK	7	x		x	x	93	x		x	x
TN					x					
TX	33			x	x	67				x
UT	100	x	x	x		0	x	x	x	
VA	66		x	x	x	34		x	x	x
VT										
WA	50	x				50	x			
WI		x			x					

Pct = Percent of bridges for which the data are available
Bridge = Bridge-level data available
Elem = Element-level data available (not necessarily AASHTO Commonly Recognized (CoRe) elements)
Action = Action-level data available
Comp = Data available in computerized form

TABLE 15

STATE-OF-THE-PRACTICE WORK ACCOMPLISHMENT COSTS

Contract replacement, bridge-level	21 out of 29
Contract maintenance, bridge/element/action level	5 out of 29
Work-order maintenance, bridge/element/ action level	4 out of 27

Number of states which collect each type of data in automated form, compared to number responding.

resources necessary to maintain a manual system and use it effectively over a long period of time. Other automated systems that also yield useful data to one or more states include:

- BAMS—AASHTO's Bid Analysis and Management System;
- Project Management and Tracking System;
- Accounts Payable;
- Contract Administration System (separate from Contract Management in two states);
- Construction Bid Letting System;
- Construction Management System;
- Project Finance System;
- Payroll Timesheet System;
- Pavement Management System;
- Financial Management System; and
- Capital Program Management System.

In all, seven states indicate that they have systems other than their Contract Management System that are potential sources of contract cost data, and nine states indicate that they have systems other than their Maintenance Management System which are potential sources of force account work accomplishment data. All of the states with definite plans for their Bridge Management Systems envision some means of capturing historical cost data in the BMS and using it to improve cost estimation.

In many states, however, manual recording of cost data in the BMS may not be the most cost-effective approach, especially

TABLE 16

AVAILABILITY OF LOCAL BRIDGE WORK ACCOMPLISHMENT COST DATA

	Replacement	Functional/Structural	Maintenance	Emergency
Contract costs	20	13	3	3
In-house work costs	3	3	5	2

Number of states indicating availability of each type of data.
(Question 7, 30 responses)

TABLE 17

STATUS OF LOCAL BRIDGE COST DATA

State	Cost of Contract Replacement	Cost of Contract Maintenance	Cost of In-House Maintenance	Limitations	Offer Cost Models to Locals	Local Reporting of Costs
AK						
AL						Yes
AR	x			3		Yes
CA	x			1		
CO	x				Yes	Yes
DE				2		
IA	x	x			Yes	Yes
IL	x				Yes	Yes
IN	x				Yes	
KS	x				Yes	Yes
KY						
LA	x		x	2	Yes	No
MD						
ME	x			2	No	No
MI	x				Yes	Yes
MN	x	x				
MS	x			1	Yes	No
NC				2		
ND	x		x		Yes	
NE	x			1		No
NH					Yes	Yes
NJ			x		Yes	Yes
NM						
NV						
NY		x	x	3		
OK	x				Yes	Yes
TN	x			1	No	Yes
TX	x				Yes	
UT	x		x		Yes	No
VA						
VT	x				No	Yes
WA	x				Yes	Yes
WI					Yes	

Limitations:
1 — Only if state or federally funded
2 — State administers all local bridge activities or owns nearly all bridges
3 — Only contracts let by the state

if the same data are also recorded manually in other systems. In the past, building interfaces between management systems as a means of avoiding duplicative data entry has been technically difficult. Now, the availability of client-server systems is making system integration much easier. Several states in the process of re-developing their Maintenance Management Systems are in a position to take advantage of this new technology, including Iowa, Maryland, Michigan, Nevada, and South Carolina. In a client-server architecture, a software program for work recording can capture data at its source, and directly feed all systems needing the data through an appropriate data-sharing mechanism. This is simpler, more reliable, and more flexible than the more centralized systems of the past. As it becomes more cost-effective to equip maintenance crews with computers and even with Global Positioning System receivers, data collection costs should fall and accuracy should increase.

TABLE 18

COST FACTORS AVAILABLE IN BRIDGE-SPECIFIC COST DATA

Employee Labor	16
Day Labor	7
Materials	18
Equipment Usage	17

Number of states indicating the availability of each factor
(Question 4e, 27 responses)

TABLE 19

ABILITY TO ESTIMATE OTHER AGENCY COSTS

Land Acquisition	19	8
Mobilization	23	12
Traffic Control	23	11
Environmental	16	7
Planning	14	5
Design	29	10

Number of states indicating the ability to estimate each cost (state bridges), and
Availability of cost estimation data (local bridges)
(Question 5, 30 responses)

ACCUMULATION OF ACTUAL COST FACTORS

Most of the states have capabilities to estimate cost components of projects, but very few have ongoing procedures to track and update cost factors that might be used for network-level or project-level cost estimates. As Table 18 shows, about half of the responding states have bridge-specific cost data for employee labor, materials, and equipment usage. However, only a third of the states report using this information to periodically update the cost estimation assumptions and factors used in project-level estimates. The latter situation is even more pronounced for other types of agency costs. Table 19 shows that more than half of the states have the capability to estimate land acquisition, mobilization, traffic control, environmental, and design costs at the bridge level. Most states report using rules-of-thumb or subjective agency experience, rather than analyzing historical data, to develop the necessary cost factors. Exceptions are California, Maryland, Minnesota, Mississippi, Nebraska, New York, Texas, Washington, and Virginia, which systematically track costs developed in their design processes and periodically update their models. A few of these states also track and update other cost factors, including contract administration (CA), construction engineering (DE, ME), utilities (DE), and miscellaneous and contingency costs (IN). Table 19 also indicates that most of the responding states do not have access to local cost data which can be used to estimate cost factors for local bridges. When systematic tracking and cost model development are available, it is usually done by means of design/construction information systems, contract management systems, and maintenance

TABLE 20

QUANTITY UNITS USED IN ACTION RECORDING

	Painting	Concrete Patching	Deck Overlay or Replacement
Cubic Feet	0	7	3
Square Feet	13	20	24
Linear Feet	0	0	0
Tons	9	0	1
Gallons	5	0	0
Each	4	6	3
Hours	1	3	0

Number of states indicating each type of unit.
(Question 4d, 29 responses)

management systems, as a by-product. The developers of those systems usually are not in the same part of the agency as the bridge management staff. It is important for bridge management staff to be aware of this and to encourage the inclusion of data that can support the calculation of bridge cost factors.

DEVELOPMENT OF ELEMENT-LEVEL UNIT COSTS

It is almost universally reported by the states that the most difficult BMS unit costs to develop are maintenance, repair, and rehabilitation costs at the element level. It is important for maintenance management systems to be developed with careful attention to the needs of bridge management so that maintenance activity codes can map easily onto bridge elements or BMS feasible actions. A similar consideration exists for contract maintenance bid items. Even units of measurement may differ, as summarized in Table 20. None of the states has completely overcome this problem, but the states with the longest history of experience in bridge management systems have made the most progress. These states include Alabama, California, Minnesota, and New York.

Although none of the states indicated the current use of metric units, this fact is expected to change quickly over the next few years.

DEVELOPING USER COST MODELS

User costs in bridge management systems are most often used as a means of prioritizing functional improvement actions, but in some cases are also used in choosing among project alternatives or implementation strategies. They provide a systematic way of weighing the various user benefits—and sometimes non-user social benefits—of a project (such as accident reduction, avoidance of the extra travel time and expense of detours, risk factors, pollution costs), and of incorporating the severity of functional deficiencies and the number of people affected. In practical applications, user costs saved by a functional improvement are often much larger than the agency cost of the improvement. As a result, user costs are not often

TABLE 21

USE OF USER COST MODELS

Bridges	DE, IN, LA, ME, NC, NY
Pavements	AK, CO, IN, LA, MD, ME, WA
Roadside maintenance	OK
Safety programs	AK, CA, CO, IN, MD, ME, WA
Increased traffic capacity	IN
Vehicle operating costs	CA, CO, DE, IN, LA, MD, ME, NC, UT, WA
Travel time costs	CA, DE, IN, ME, NC, NY, UT, WA
Accident/risk costs	AK, CA, DE, IN, MD, ME, NC, ND, WA
Pollution costs	CA, CO, IN, MD, ND
Impact to businesses	DE

States indicating that they use user cost models for each type of facility need.
(Question 6b, 27 responses)

TABLE 22

TYPES OF USER COST-RELATED DATA

Truck height distributions	IL, KS, NC
Truck weight distributions	CO, IL, KS, LA, ME, MI, MS, NC, UT, VA, VT
Average hourly costs of truck operations	NC, WA,
Average per-mile cost of truck operations	CO, NC, WA
Legal claims due to traffic accidents	AR, CA, CO, IA, IL, KS, LA, MI, NC, ND, UT, VA, WA
Cost to agency of fatal accidents	CA, CO, MI, ND, OK, UT, VA, WA
Cost to agency of injury accidents	CA, CO, MI, ND, OK, UT, VA, WA
Cost to agency of property-damage-only accidents	CA, CO, IL, KS, MS, OK, UT, VA, WA
Accident costs specifically related to bridges	AR, CA, IA, IL, MS, NC, OK, UT, VA
Number of bridge-related accidents	AK, CA, IA, IL, ME, NC, OK, UT, VA, WA
Number of accidents associated with specific bridges	CA, IA, IL, MD, NC, OK, VA, WA
Severity of accidents associated with specific bridges	CA, IA, IL, MD, OK, UT, VA, WA
Size of monetary claims associated with specific bridges	UT, WA

States indicating the availability of each kind of data.
(Question 6c, 27 responses)

used as a means of assessing the absolute economic viability of a project. Another emerging use of user cost models is in assessing the impact of construction activity on road users. In a bridge management system, this impact can be added to the agency cost in a benefit/cost ratio calculation to increase the priority of less disruptive projects. A few states (notably California) are beginning to use user cost models to develop contract incentives or penalties for construction time and lane closures. At the present state of the practice, with implementation of bridge management systems just starting, only a minority of states employ user cost models to analyze facility needs, as shown in Table 21. These states have a variety of studies and procedures which they view as reliable sources of user cost data (see Table 22).

The user cost components that have the greatest impact in bridge management systems are truck detours and automobile accidents. As many states begin to design freight movement networks and automated commercial vehicle licensing, the quality of truck data is likely to improve. Bridge management personnel can monitor these developments and take advantage of them in many cases to access detailed, reliable data. A few states are also beginning to collect truck data to support their congestion, safety, traffic monitoring, and intermodal management systems. Of all the responding states, only North Carolina reports having conducted a thorough study of user costs related to bridges. The models developed by North Carolina are widely used in bridge management systems across the country.

ADJUSTING COST MODELS FOR GEOGRAPHY, TIME, AND OTHER FACTORS

A few of the states (notably California and Maryland) have routine capabilities in place to adjust their cost estimates to account for geography. The effectiveness of this approach depends on developing cost indexes accumulated over many years in order to build sufficient sample size in each geographic area, and both states are pleased with the results.

A few of the states also develop time-based cost indexes; these help them make effective use of historical data in the development and updating of cost models. For current-period cost indexes, the most common sources are the U.S. Bureau of Labor Statistics and the construction industry journal Engineering News Record, which both publish specialized cost indexes.

None of the states indicate any in-house capability to forecast external macroeconomic trends that influence costs, such as future inflation and future construction industry business climate. These factors are likely to set a practical limit on the accuracy of BMS cost estimates for the foreseeable future.

CHAPTER FIVE

CONCLUSIONS

The collection and management of bridge cost data can be improved by approaching it in a comprehensive way—this conclusion, drawn from both the survey and the literature, reveals bridge management systems importance in providing the first opportunity for a complete economic analysis of the life cycle of bridges at the network level. The survey strongly indicates that state DOTs see BMS as a catalyst, both in making BMS results more meaningful and in solving long-standing problems relating to cost estimation, project scoping, maintenance planning, and bid evaluation.

Exemplary systems can be found in states of all sizes and organizational structures, but larger states and more centralized states tend to have cost data management capabilities that are more fully developed. The existence of maintenance management systems and contract management systems appears to be strongly correlated with better quality cost data, but not all such systems provide the needed coverage of bridge work. To be useful in developing bridge unit costs, these systems should routinely associate all bridge related costs with bridge identifiers and BMS-relevant activity codes. Further, for maintenance, repair, and rehabilitation (MR&R) actions, all variable costs should also be associated with bridge elements. Most states do not have these capabilities. States that have had the most successful experience in developing unit costs for their BMS are usually the states that have devoted special effort to project-level cost estimation.

Project-level costs can vary substantially depending on whether the work is performed by an agency's own forces or by contract. Contracting is used about twice as often as force account (work performed by in-house personnel) and day labor hired by the agency combined. Half of the states are able to revise their cost estimates after making the decision whether to perform work by contract. However, this decision is generally made late in the project development process, so it is not available for most programming purposes. Historical data on contract costs are more readily available than data on in-house work.

Cost estimation capabilities are most highly developed for larger projects like bridge replacement; nearly every state has a cost estimation capability. Almost all states are able to estimate the costs of functional and structural improvements. For contract maintenance, just over half of the states are able to estimate costs at the bridge level, and only a quarter are able to estimate costs at both the bridge and element levels. These numbers are slightly lower for in-house maintenance. Most of the states have written guidelines for cost estimation, which are generally used manually and updated periodically from accumulated agency experience. (See Appendix D for an example from Caltrans.) Some of the best examples of these guidelines include cost indexes based on time or geography.

The requirements of a network-level BMS for unit cost data are somewhat more demanding than those for project-level purposes. They would therefore benefit from automated storage and analysis of work accomplishment data. More than half of the states surveyed have automated management of historical contract replacement cost data at the bridge level, but only 13 percent have automated contract maintenance data at the bridge/element/action level, and only 10 percent have in-house maintenance data at this level. The pattern of availability of functional and structural improvement work accomplishment data is about the same as for bridge replacement, while the pattern of data for emergency work is about the same as for maintenance. Nearly all of the surveyed agencies that are able to retrieve project completion and quantity data are also able to retrieve cost data at the same level of detail.

Work accomplishment and cost data on local bridges are very difficult to acquire. The states with the best databases are those that take an operational role in conducting the work by providing funding, inspections, maintenance crews, or contract administration services.

North Carolina is the only state identified in the research that has conducted any special studies on user costs. As a result, all of the states that apply user cost models in their BMS are currently relying on the research conducted by North Carolina. A minority of states have their own sources of data on certain user cost factors, such as vehicle operating costs, travel time, and accidents.

A majority of states characterize themselves as dissatisfied with their current capability to collect and manage cost data, and nearly all of them foresee improvements that will raise their level of satisfaction. The areas receiving greatest emphasis are MR&R unit costs, user costs, and project-level fixed costs. A substantial majority of states believe it would be cost-effective to increase the level of detail of MR&R work accomplishment data, at least to the level of bridge/element/action. Of the states surveyed, only North Carolina collects MR&R cost data at the bridge/element/state/action level of detail. For the design of bridge management systems, this implies that having procedures to generate the additional level of detail from input at the bridge/element/action level, is perhaps a necessity and could be accomplished by matching actions to condition states.

In most departments of transportation, the ability to collect and manage cost data is the biggest impediment to the agency's ability to successfully implement a bridge management system, and is therefore among the most substantial barriers to achieving a more systematic and strategic approach to managing bridges. Accuracy in cost estimation is central to the credibility of project programming and, network-level bridge management system analyses; however, few agencies are able to measure the accuracy of their cost data.

Effective collection and use of work accomplishment data provide the raw numbers needed to compare actual costs against program costs, and to update program cost estimation procedures to keep them in agreement with actual experience. The research uncovered few agencies that are currently able to collect the necessary data, even though most respondents to the survey expressed an intention to do so in the future. There is opportunity for large organizations such as AASHTO, FHWA, and departments of transportation to work cooperatively on tools and research to substantially improve this situation.

The same issues that have been uncovered in this synthesis specifically related to bridges in the United States also exist internationally and apply to all types of infrastructure. Maintenance management planning in general would benefit greatly from improved cost tracking and estimation capabilities at the network level. Program managers in state, local, and foreign transportation agencies all complain of the unquantified but questionable accuracy of cost estimates, as evidenced by "scope creep" (the tendency for project costs to increase during the planning process due to the late addition of project requirements), high contingency allowances, unwillingness of top management or elected officials to believe program plans, or lack of confidence in negotiating cost estimates with contractors. Agencies that are simultaneously developing all of the previously mandated ISTEA management systems along with maintenance and contract management systems, are recognizing that there is an immediate need to solve these problems in the same way in all management systems.

Respondents to the survey and the Topic Panel members for this synthesis have identified a large number of potential research efforts that would be of value and have national significance. These ideas were described as too large or complex for an individual department of transportation to accomplish, but feasible for cooperative projects. Most of the departments view joint projects as a way of developing better capabilities than they would otherwise achieve on their own.

At the top of the list is the development and maintenance of cost models that can be customized and applied by individual agencies. The types of cost models receiving special interest include:

- User Costs. Many respondents listed this as a priority research topic, many of them placing extra emphasis on it as a top priority. The research could develop national models, with regional or state-level adjustments, for truck height and weight distributions, truck operating costs (per mile and per hour), accident costs, and accident rates as a function of bridge characteristics. Work zone user costs could also be included.
- Maintenance, Repair, and Rehabilitation Costs. Respondents listed the development of unit costs at the element, state, and action level, which could be adjusted by region or according to state characteristics. The research now being undertaken by Clemson University may begin to address this need. Of special interest is the cost of unusual elements (e.g., cables).
- Project-Level Fixed Costs. This research could include the development of cost models for traffic control, mobilization, environmental mitigation, and other project fixed costs. It is important for the level of detail of these models to be low enough so they operate effectively with BMS data, without requiring special data collection efforts to be routinely used. It would be useful to associate these costs with bridge elements, to improve the consideration of them in network-level models.
- Local Bridge Costs. Several respondents mentioned the difficulty of developing suitable cost models for local bridges, which typically represent the greatest level of need. This calls for the development of procedures that can specifically address the differences between state-managed bridges and locally managed bridges.

Even though costs tend to vary from one agency to another, the development of cost models for these activities is usually beyond the resources (data and expertise) of individual states. A national project could collect relevant data from multiple agencies and employ statistical analyses to develop network-level and project-level cost models. Such a project would require labor-intensive analysis of paper records kept by state and local governments, as well as a high degree of statistical and software capability. Since many of these factors apply to all infrastructure projects, not just bridges, greater value could be added by extending this research and development to all types of asset and maintenance management. Models developed from this project could be interfaced with AASHTOWare™'s Bid Analysis and Management System (BAMS™) to greatly improve the planning capabilities of that system.

To keep these models up to date over time, and to provide a means of sharing cost data among departments, a national organization could establish a clearinghouse. The clearinghouse would collect contributions from the states, add value through data processing and analysis, and provide an infrastructure to make the data readily available and easily usable by individual agencies. The distribution mechanism for the data, models, and documentation could be electronic, perhaps using public domain Internet facilities which are widely available. Work now underway at Clemson University for the Federal Highway Administration could form the basis for such a clearinghouse.

Several states suggested various ways of standardizing definitions and procedures in order to make the sharing of cost data among states more practical. One way of accomplishing this is to prepare a set of guidelines for Bridge Management System cost data collection and management. The project could include broad-based state participation (such as what went into the AASHTO Bridge Management System Guidelines) to develop something close to a national consensus. The results could then be implemented uniformly in AASHTOWare's bridge products, and would be of great help to individual states in designing new Maintenance and Contract Management Systems.

It is evident from the survey and from follow-up conversations that departments of transportation vary widely in their understanding of how to collect work accomplishment data and how to re-engineer their work recording processes to serve the needs of project-level and network-level cost estimation.

Frequently it is possible to greatly improve the usefulness of cost data without adding new data collection processes or costs, but top managers lack guidance in identifying and using such opportunities. An easy-to-use handbook could meet this need; it could provide top managers with an overview and cover the major organizational and system issues, and also contain sections of detailed information on the implementation of improved procedures and systems. A possible outline of this document is given in Appendix C.

It is possible to extend this concept beyond bridges by recognizing that all types of projects need a solution to the problem of managing work plans and work accomplishment data on a high level. In agencies that hope to integrate their management systems as a means of simplifying data collection and usage, this is an emerging issue. A national program could sponsor original research and conceptual development of an integrated concept for the collection, management, and usage of economic data in management systems, to encompass the management systems detailed in ISTEA, as well as maintenance and contract management systems, building on the results of NCHRP Project 14–9*(4)*.

Top managers and cost estimators need guidance in knowing the level of accuracy to expect in cost estimation; and there is a need for tools that departments can use to measure the accuracy of their own cost estimates and compare this accuracy with that achieved by other states. An ongoing effort could develop and publish aggregate statistics on the correlation between programmatic cost estimates and actual work accomplishment costs, as an index of the quality of cost estimation. This information would be valuable to departments of transportation in evaluating their cost data collection and management procedures, and in developing measurable goals for improvement. This would establish a healthy competitive dynamic from which management decision making and bridge management system capabilities could improve and evolve.

Several states suggested various refinements to cost models, some of which have not yet been attempted by any states. These include:

- Economic quantification of risk in bridge management decisions;
- Cost indexes for inflation and other macroeconomic factors;
- Cost factors for projects involving small quantities of work or materials;
- Cost factors to distinguish union from non-union labor;
- Estimation of the cost of bridge inspections;
- Estimation of the cost of routine maintenance, such as deck patching;
- Cost factors to distinguish the requirements of different funding sources;
- Development of automated cost data recording and gathering systems; and
- Development of approximation procedures that can work with less detailed data.

Such research often leads to useful insights, products, or even breakthroughs in new techniques having wide applicability. The subject of risk quantification and management is especially timely for original research: as departments of transportation become adept at developing and using the life-cycle models typically included in asset management systems, they will begin to understand the role of risk factors in decision making and will be ready to use quantitative tools to address risk within an overall economic framework.

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APPENDIX A

Questionnaire

Name ______________________________

Title ______________ Division ______________

Organization ______________________________

Address ______________________________

Phone ______________ Fax ______________

Internet address ______________

Please describe your responsibilities related to the questionnaire subject.

____

____

____

____

Please indicate the current status of your organization's network-level BMS (check all that apply).

Status	System
☐ Already implemented	☐ Packaged program, specify: ______________
☐ Currently developing	☐ Custom/in-house
☐ Planned	☐ Undecided

Thank you very much for agreeing to participate in this study. The results of this survey will be compiled, along with the results of a literature review, into an NCHRP synthesis on the state-of-the practice of collecting and managing cost data for bridge management systems (BMS). With the widespread implementation of bridge management systems now underway, this subject is widely regarded as one of the most important and difficult unresolved issues. This synthesis will provide a valuable early means of sharing a comprehensive picture of existing practice and future plans, at a time when transportation organizations are actively searching for organizational and technical approaches which they can implement with reasonable confidence. Because the field is embryonic, the survey results are expected to identify opportunities for high-value research and development which can be undertaken in the coming years.

Many of the questions and tables explore capabilities which may be rare or non-existent in transportation agencies. The presence of these questions should in no case be interpreted as a suggestion or opinion on the part of the researchers or NCHRP that such capabilities are needed, or that they justify their cost. The survey is intended strictly to catalog in a comprehensive manner what capabilities currently exist or are planned in the transportation community.

NCHRP Project 20-5

Topic 25-06

Collecting and Managing Cost Data for Bridge Management Systems

All of the questions are intended mainly to address cost estimation at the network level, not at the project design level. This means that we are interested in cost factors that you would use for pre-engineering estimates, such as would be used for needs identification, multi-year programming, and your Bridge Management System (BMS). If you have tools which you use for project-level purposes but which may be applicable to the network level (e.g. bid-checking systems), then these are of interest to us also. Network-level cost estimates are not generally expected to be as precise or accurate as project-level estimates, but they are expected to give an accuracy appropriate for planning and budgeting purposes when used over a whole group of bridges in a bridge program.

A particular requirement of a network-level BMS is a set of average unit costs for maintenance, repair, and rehabilitation for each type of bridge element in the inventory (e.g. typical cost per linear foot or area to spot blast, clean, and paint a steel girder; typical cost to rehab a concrete column; typical cost per linear foot to replace a deck joint). Procedures to develop such unit costs could be based on comprehensive records of actual expenditures, could be developed from cost allocation procedures which may have been based on judgment or on special studies, or could be estimated from special studies of a sample of bridge projects designed to provide a representative range of conditions and actions. We are interested in any of these methods or others which you have used or plan to use.

If you are not sure of the answers to some of the questions, we would appreciate it if you could check with others in your organization who might know. We understand that some of this information will be difficult to supply; we would appreciate your best efforts to fill in whichever parts of the questionnaire you can.

Questionnaire Instructions

1. In answering the following questions, please clearly indicate whether each response describes actual routine practice, experimental results, or future plans.

2. Please be sure to enter zero in all questions which you know to be zero, and leave blank all questions where you do not know the answer. If you are sure that no one in the organization knows the answer for a particular cell in the tables, please write "unknown" in that cell. You may supply ranges if necessary, since we do not require a great level of precision. Please clearly indicate answers which are estimates. On multiple-choice questions, if you know the answer but it is not any of the choices given, please write in your answer.

This questionnaire is divided into sections to reflect different aspects of cost estimation, which may be addressed by different people within your agency.

The sections are:

1. General Information
2. Project Development Process
3. Contracting
4. In-House Work
5. Other Agency Costs
6. User Costs
7. Overall Appraisal

Definitions

Some of the questions may use terminology with which you may not be familiar, or which may be ambiguous. In order to have a set of results which are reasonably consistent and comparable from state to state, we have established a few key definitions of terms which are used in the questionnaire. If you are unable to provide answers in a form consistent with these definitions, please indicate your own assumptions where applicable.

Unless specifically stated otherwise, all of the questions apply to state-owned bridges. Question 7 can be used to indicate practices or plans which apply to local bridges. Cost data for the structure itself are of interest, as are data about approach slabs, slope paving, and other adjacent elements related to bridges. We are more interested in the typical structures representing the bulk of most states' inventories, rather than monumental or unusual bridges.

Classification of Work

General Work Categories. These are distinguished from each other because this affects the way in which work is performed (use of contractors, need for special skills or equipment, assignment of responsibility within the agency) or the methods used for estimating costs or recording accomplishments.

- **Replacement.** All bridge replacement projects, whether programmed individually or as part of larger highway projects
- **Functional Improvements.** All widening, raising, replacement of substandard railings, seismic retrofit, or scour mitigation, whether programmed individually or as part of larger highway projects
- **Structural Repairs.** All major repair and rehabilitation projects which are exclusively structural in nature, including replacement of individual members on a bridge.
- **Functional and Structural.** Combination of functional improvement and structural repairs.
- **Maintenance.** All smaller programmed work which does not fit in the above categories, including painting, concrete patching, deck overlays, joint and bearing rehabilitation, etc. For this survey, exclude all annual maintenance such as cleaning gutters, washing, pothole repair, etc.
- **Emergency.** Unplanned work of an urgent nature made necessary by natural disasters, traffic accidents, etc.

Means of Accomplishment

Force Account. Work is performed by permanent employees of the agency.

Day Labor. Work is performed by laborers hired only for the specific job.

Contractor. Work is performed by an outside firm under a contract.

Level of Detail of Data

Project-Level Detail. The ability to associate work accomplishment or a specific cost with a project that may involve multiple bridges. In this questionnaire, the term "usable project-level detail" means that the BMS bridge identifiers of all bridges involved in the project can be determined, that all identified needs on all of the bridges have been met, and that the cost of the bridge-related work can be separated from all non-bridge work, such as pavement work.

Bridge-Level Detail. The ability to associate a specific work accomplishment or cost number with a specific BMS bridge identifier, including the ability to separate the cost of one bridge from the costs of other bridges which may have received work as part of the same project.

Element-Level Detail. The ability to associate a specific work accomplishment or cost number with a specific type of element on a specific BMS bridge identifier, including the ability to separate the cost of one element from other elements on the same bridge or other bridges. This level of detail is relevant only for maintenance, repair, and rehabilitation (MR&R) actions. Element-level data collection is described in the Federal Interim Final Rule on Management Systems, and the Commonly-Recognized element definitions published by FHWA.

Project/Action Detail. The ability to distinguish detailed action types (such as replacement, widening, seismic retrofit, girder replacement, spot-painting, spall patching, joint rehabilitation, deck patching, etc.) without the ability to distinguish individual bridges in a multi-bridge project.

Bridge/Action Detail. The ability to distinguish both the action types and the individual bridges.

Element/Action Detail. The ability to distinguish both action types and specific element types on specific bridges.

Element/State/Action Detail. This is the highest usable level of detail, which distinguishes specific elements of specific bridges, and is also able to distinguish the quantities or costs of specific actions on different parts of elements which are in different condition states. For this purpose, condition states refer to the definitions of Commonly-Recognized Elements published by FHWA.

1. General Information

a. Please complete the following table by entering the number of employees in each cell:

Staffing	Districts	Headquarters	Other
Bridge Inspectors (non-engineers)	______	______	______
Bridge Inspectors (engineers)	______	______	______
Engineers assigned primarily to bridge maintenance	______	______	______

b. Please indicate in the following table the number and cost of bridges with work performed in the most recent year for which such information is available, whether programmed or not. Total cost includes contracts, administration, site-related costs, planning, and design.

Program Size	Replacement	Functional & Structural	Maintenance	Emergency
Number of bridges	______	______	______	______
Total cost	______	______	______	______
Year: ______				

c. For the most recent available year, please indicate the number of bridges in each work category, performed by each type of agent.

Bridges by Performer	Replacement	Functional & Structural	Maintenance	Emergency
Force account	______	______	______	______
Day labor	______	______	______	______
Contract	______	______	______	______

Who decides whether to contract? ____________________

What criteria are used in this decision? ____________________

Is cost estimate revised if contracted? Y/N ______

d. Please provide an overview of your existing and/or planned capability to provide agency bridge cost data for your network-level BMS, addressing the following aspects:

- Types of costs which you can reasonably estimate.
- Limitations on the types of projects for which the cost estimation procedures can be used.
- Which parts of the organization routinely use the procedures?
- Are the procedures periodically updated?
- What kinds of data are used in updating the procedures?
- What are the sources of data and updating procedures?
- How much confidence do various levels of management have in the resulting estimates?

You do not need to repeat the information given in the questions below. The purpose here is to provide an overview and context to help us fully understand the more detailed information in the later questions.

2. Project Development Process

a. Initiation. Who initiates a bridge need into the programming process? Please check all that apply in each column. If you check more than one in a column, please circle the one which is responsible for initiating the largest number of bridges.

Initiators	Replacement	Functional & Structural	Maintenance	Emergency
Inspectors	☐	☐	☐	☐
Maintenance crews	☐	☐	☐	☐
Planners	☐	☐	☐	☐
Designers	☐	☐	☐	☐
Engineers	☐	☐	☐	☐
Special surveys	☐	☐	☐	☐
Safety planners	☐	☐	☐	☐
BMS users	☐	☐	☐	☐
Managers	☐	☐	☐	☐
Other	☐	☐	☐	☐
Location				
Districts	☐	☐	☐	☐
Headquarters	☐	☐	☐	☐
Consulting Firms	☐	☐	☐	☐
Other	☐	☐	☐	☐

b. Cost Estimation. Who performs the initial (when needs identified) and final (before advertising or work order) cost estimates in the programming process? In each column, identify the group with:

I if the group does initial cost estimates

F if the group does final cost estimates

M if the group does cost estimates in the middle of the process

If you write the same letter in more than one row in a column, please circle the one which is responsible for estimating the largest number of bridges.

Estimators	Replacement	Functional & Structural	Maintenance	Emergency
Inspectors	______	______	______	______
Maintenance crews	______	______	______	______
Planners	______	______	______	______
Designers	______	______	______	______
Engineers	______	______	______	______
Special surveys	______	______	______	______
Safety planners	______	______	______	______
BMS users	______	______	______	______
Managers	______	______	______	______
Other	______	______	______	______

Location	Replacement	Functional & Structural	Maintenance	Emergency
Districts	______	______	______	______
Headquarters	______	______	______	______
Consulting Firms	______	______	______	______
Other	______	______	______	______

c. Please describe any additional review processes your agency has, to develop or refine cost estimates for program planning.

____

____

____

____

____

d. **Procedures.** Does your agency have any written manuals or guidelines for estimating costs for program planning for any of the work categories given above?

☐ Yes

☐ No

If so, please describe them, indicating the users and the types of projects to which they apply. Are the procedures used uniformly across the agency, or does their usage vary by district?

______

______

______

______

______

Who is responsible for keeping these procedures up-to-date? By what process do they accomplish this?

______

______

______

______

3. Contracting

The following questions are intended to provide an indication of the availability, completeness, and detail of contract accomplishment and cost data. We are trying to determine the degree of automation of contract data in each work category, and the type and quality of information managed by manual and automated means.

a. In each column below, please check all levels of detail of data that are available for engineer's estimates and bid checking. If you check more than one level of detail, please circle the one which is predominant.

Bid Data	Replacement	Functional & Structural	Maintenance	Emergency
Project	☐	☐	☐	☐
Bridge	☐	☐	☐	☐
Element	☐	☐	☐	☐
Project/action	☐	☐	☐	☐
Bridge/action	☐	☐	☐	☐
Element/action	☐	☐	☐	☐
Element/state/action	☐	☐	☐	☐

For what percentage of your inventory is this information available? ______

Availability	Computerized?
☐ Across the agency	☐ Yes
☐ Varies by district	☐ No

b. Does your agency have a computerized contract management system which tracks the obligation and completion of contracts?

☐ Yes

☐ No

c. **Contract Administration.** Does your agency have procedures for estimating or tracking contract administration costs?

☐ Yes

☐ No

Please describe them, and indicate what, if any, contract administration cost data are available in your contract management system.

______

______

______

______

d. **Contract Completion.** The following table provides a means for you to describe the information available to you about the completion of contracts. It is set up in a way which allows you to show how the levels of detail of your contract and maintenance data may vary. Many agencies enter only summary data in the contract management system, while keeping the more detailed paper records in file cabinets; in such cases, you may indicate for paper data a greater level of detail than for automated data. In each blank in the table, please enter one or more of the following letters:

- C Work completion data are available (i.e. bridge identifier and/or action code)
- Q Quantity data are available (measured or estimated for a specific bridge and action)
- $ Cost data are available (measured or estimated for a specific bridge or action)
- N No data are available at this level of detail

If you enter more than one letter in a column, please circle the ones whose level of detail is available for the largest number of bridges.

	Replacement		Functional & Structural		Maintenance		Emergency	
Contract Data	Auto	Paper	Auto	Paper	Auto	Paper	Auto	Paper
Project	____	____	____	____	____	____	____	____
Bridge	____	____	____	____	____	____	____	____
Element	____	____	____	____	____	____	____	____
Project/action	____	____	____	____	____	____	____	____
Bridge/action	____	____	____	____	____	____	____	____
Element/action	____	____	____	____	____	____	____	____
Element/state/action	____	____	____	____	____	____	____	____

Of all the bridges which had contract work done on them in the most recent year, for what percentage does your agency have accurate bridge-specific **quantity** data? ______

Of all the bridges which had contract work done on them in the most recent year, for what percentage does your agency have accurate bridge-specific **cost** data? ______

Do the quantity and cost data available represent actual quantities (calculated during or after the work) or estimated quantities (calculated before the work is done)?

☐ Actual

☐ Estimated

e. Other than bid checking and contract management systems, does your agency have any other systems which it uses, or which you believe it could in the future use, to provide contract cost data to your bridge management system?

☐ Yes

☐ No

Please describe the system(s).

____

____

____

____

____

4. Force Account and Day Labor

The following questions are intended to provide an indication of the availability, completeness, and detail of in-house work accomplishment and cost data. We are trying to determine the degree of automation of such data in each work category, and the type and quality of information managed by manual and automated means.

a. Does your agency have a computerized maintenance management system which tracks the maintenance of bridges?

☐ Yes

☐ No

b. Please indicate in each blank the type of work order estimation information available for each work category at each level of detail as follows:

Q Quantity estimates can be generated

$ Cost estimates can be generated

N No data are available at this level of detail

If you indicate more than one level of detail in a work category, please circle the one which represents the level of detail available for the largest number of bridges.

Work Order Estimation	Replacement	Functional & Structural	Maintenance	Emergency
Project	____	____	____	____
Bridge	____	____	____	____
Element	____	____	____	____
Project/action	____	____	____	____
Bridge/action	____	____	____	____
Element/action	____	____	____	____
Element/state/action	____	____	____	____

Of all the bridge work orders issued in the most recent year, for what percentage was your agency able to accurately estimate the total cost? ______

Availability	Computerized
☐ Across the agency	☐ Yes
☐ Varies by district	☐ No

c. **Work Order Completion.** The following table provides a means for you to describe the information available to you about the completion of work orders. It is set up in a way which allows you to show how the levels of detail of your data may vary. Many agencies enter only summary data in the maintenance management system, while keeping the more detailed paper records in file cabinets; in such cases, you may indicate for paper data a greater level of detail than for automated data. In each blank in the following table, please enter all of the following letters which apply:

C Work completion data are available (i.e. bridge identifier and/or action code)

Q Quantity data are available (measured or estimated for a specific bridge and action)

$ Cost data are available (measured or estimated for a specific bridge or action)

N No data are available at this level of detail

If you enter more than one letter in a column, please circle the ones whose level of detail is available for the largest number of bridges.

	Replacement		Functional & Structural		Maintenance		Emergency	
Work Order Data	Auto	Paper	Auto	Paper	Auto	Paper	Auto	Paper
Project	____	____	____	____	____	____	____	____
Bridge	____	____	____	____	____	____	____	____
Element	____	____	____	____	____	____	____	____
Project/action	____	____	____	____	____	____	____	____
Bridge/action	____	____	____	____	____	____	____	____
Element/action	____	____	____	____	____	____	____	____
Element/state/action	____	____	____	____	____	____	____	____

Of all the bridges for which work orders were issued in the most recent year, for what percentage does your agency have accurate bridge-specific quantity data? ______

Of all the bridges for which work orders were issued in the most recent year, for what percentage does your agency have accurate bridge-specific cost data? ______

d. When you record quantities of work performed, what units do you use (check all that apply)?

	Painting	Concrete Patching	Deck Overlay/Replace
Cubic Feet	☐	☐	☐
Square Feet	☐	☐	☐
Linear Feet	☐	☐	☐
Tons	☐	☐	☐
Gallons	☐	☐	☐
Each	☐	☐	☐

e. If your agency records bridge-specific cost data, which cost factors are you able to include (check all that apply)?

☐ Employee labor

☐ Day labor

☐ Materials

☐ Equipment usage

f. Other than a maintenance management system, does your agency have any other systems which it uses, or which you believe it could in the future use, to provide unit cost data (in units suitable to a network-level BMS) to your bridge management system?

☐ Yes

☐ No

Please describe the system(s)

____

____

____

____

____

5. Other Agency Costs

What other kinds of bridge-related agency costs is your agency able to estimate on a significant number of bridge projects? (Please check all that apply)

☐ Land acquisition

☐ Mobilization

☐ Traffic control

☐ Environmental protection and mitigation

☐ Planning

☐ Design

☐ Discount rate (for time value of money calculations)

☐ Other: ____________________

For each item you checked in the preceding question, please briefly describe any procedures you may have in place, or have planned, to calculate them for program cost estimates. At what level of detail do you perform this analysis?

____

____

____

____

____

6. User Costs

a. Please briefly describe any special studies or routine data collection your agency has conducted to estimate bridge-related user costs.

______
______
______
______
______

b. Do you currently apply user cost models in your analyses of facility needs (check all that apply)?

Facility Need Types	User Cost Types
☐ Bridges	☐ Vehicle operating costs
☐ Pavements	☐ Travel time costs
☐ Roadside maintenance	☐ Accident/risk costs
☐ Safety programs	☐ Pollution costs
☐ Transit	☐ Other ______
☐ Other ______	

c. Do you have any special studies or routine procedures that would be a source of reliable data on any of the following (check all that apply)?

☐ Truck height distributions (e.g., % trucks passing various vertical clearance restrictions)
☐ Truck weight distributions
☐ Average hourly costs of truck operations
☐ Average per-mile costs of truck operations

☐ Legal claims, judgments, and settlements against the agency due to traffic accidents
☐ Cost to the agency of fatal accidents
☐ Cost to the agency of injury accidents
☐ Cost to the agency of property-damage-only accidents
☐ Accident costs specifically related to bridges

☐ Number of bridge-related accidents in a given time period
☐ Number of accidents associated with specific bridge identifiers
☐ Severity of accidents associated with specific bridge identifiers
☐ Size of monetary claims associated with specific bridge identifiers

7. Local Bridges

Of the different kinds of cost data described in the preceding questions for state-owned bridges, which are also available for a significant number of local bridges (check all that apply)?

Local Bridge Data	Replacement	Functional & Structural	Maintenance	Emergency
Contract work completion	☐	☐	☐	☐
Contract work quantities	☐	☐	☐	☐
Contract costs	☐	☐	☐	☐

Local Bridge Data	Replacement	Functional & Structural	Maintenance	Emergency
In-house work completion	☐	☐	☐	☐
In-house work quantities	☐	☐	☐	☐
In-house work costs	☐	☐	☐	☐

☐ Land acquisition
☐ Mobilization
☐ Traffic control
☐ Environmental
☐ Planning
☐ Design

☐ User costs
☐ Truck size/weight
☐ Accident costs
☐ Accidents associated with bridge identifiers

Does your agency plan to develop bridge management system cost models which will be offered to local agencies for their use?

☐ Yes
☐ No
☐ Undecided

Does your agency plan to require or encourage local agencies to report their cost experience to the state as part of the local participation in the state bridge management system?

☐ Require ☐ Encourage ☐ No reporting ☐ Undecided

8. Overall Appraisal

a. Considering the problem of adequately providing cost data to your bridge management system in general, to what extent are you satisfied that your current capability provides the accuracy and coverage that you need?

☐ Very satisfied ☐ Satisfied ☐ Neutral ☐ Unsatisfied ☐ Very unsatisfied

b. How would you compare your own cost estimation capability to that of other states with which you are familiar?

☐ Much better ☐ Better ☐ Similar ☐ Worse ☐ Much worse

c. If the capabilities which you have described above as planned, but not yet in place, are fully implemented, how would you change your answers to the preceding two questions?

☐ Very satisfied ☐ Satisfied ☐ Neutral ☐ Unsatisfied ☐ Very unsatisfied

☐ Much better ☐ Better ☐ Similar ☐ Worse ☐ Much worse

Would you then have an adequate capability to operate your BMS?

☐ Yes

☐ No

d. If you could improve your agency's data gathering capability, to routinely collect and manage all cost data for which you would consider it cost-effective to do so, what level of detail would you have available? Please check all that apply.

Cost-Effective Data Collection Detail	Contract Functional & Structural	Contract Maintenance	In-house Functional & Structural	In-house Maintenance
Project	☐	☐	☐	☐
Bridge	☐	☐	☐	☐
Element	☐	☐	☐	☐
Project/action	☐	☐	☐	☐
Bridge/action	☐	☐	☐	☐
Element/action	☐	☐	☐	☐
Element/state/action	☐	☐	☐	☐

e. Please go back now and check each answer to be sure that you have indicated all capabilities which are planned, rather than existing. It is important that we distinguish these two, in order to have a true picture of the state of the practice.

☐ Done

f. If joint-development projects of national or regional scope, or Federal research and development projects, were to be initiated for the purpose of improving the quality of BMS cost estimation, what would you consider to be the highest priorities for such projects?

____

____

____

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What types of cost data do you believe would be impractical for your own agency to collect, but would be practical in a project of larger scope involving multiple agencies?

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g. The subject of cost estimation for bridge management systems is a new and difficult field which can greatly benefit from creative thought and original work by BMS users. Your thoughtful comments and ideas on how the state-of-the-art can be improved would be greatly appreciated.

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Thank you for your assistance.

Please send your questionnaire to:

Paul Thompson
Cambridge Systematics, Inc.
222 Third Street
Cambridge, MA 02142
Phone: (617) 354-0167
Fax: (617) 354-1542

We would appreciate your response by: April 30, 1994

APPENDIX B

Research and Development in Progress

The following is a partial list of major projects underway as of this writing, which address the topic of the collection and management of bridge cost data.

- Federal Highway Administration and Clemson University, development of a national database of bridge management system unit costs for maintenance, repair, and rehabilitation.
- Pennsylvania Department of Transportation, Bridge Management System development and ISTEA management system business plan.
- North Carolina Department of Transportation, Continuing enhancement of the Bridge Management System.
- New York Department of Transportation, Development of Bridge Management System.
- Alabama Department of Transportation, Development of Bridge Management System.
- Ohio Department of Transportation, Development of Bridge Management System.
- Michigan Department of Transportation, Development of Transportation Management System, including a Bridge Management System.
- Federal Highway Administration, development of a bridge management training course.
- American Association of State Highway and Transportation Officials, Development of Pontis Release 3.0.
- National Cooperative Highway Research Program 12-28(2)A, Development of the Bridgit Bridge Management System.
- Swiss Federal Highway Administration, Development of the KUBA-MP Bridge Management System.
- Swedish National Road Administration, Continuing enhancements to the SAFE Bridge Management System.
- Finnish National Road Administration, Continuing enhancements to the SIHA Bridge Management System.
- Danish Road Authority, Continuing Enhancements to the DanBro Bridge Management System.
- Federal Highway Administration, Development of the National Bridge Investment Analysis System.

APPENDIX C

Possible Outline for A Set of Guidelines for Bridge Management System Cost Data Collection and Management

One of the suggestions of the study is the development of guidelines to help transportation agencies to implement improved collection and management of BMS cost data. The following is a possible outline for this suggested document. The guidelines would not be intended to be all-inclusive, and each state would need to consider the appropriateness of the suggested guidelines to its organizational structure and capabilities.

Executive summary, describing the scope of the problem and the major management issues needing to be addressed.

1. Introduction

2. Management agenda for improving cost data management
   - Identifying problems
   - Diagnosing the cause of problems
   - Organizational structures and responsibilities
   - Computer system requirements
   - What to ask from computer systems
   - Resource requirements
   - Phased implementation strategies

3. Applications and requirements for cost data
   - Catalog of applications requiring cost data (project-level and network-level)
   - The structure and life cycle of cost data
   - Levels of detail and dimensions of access required

4. Principles of cost data management
   - Cost data management differences between contracts and maintenance work orders
   - Cost data management differences among types of work
   - Work planning data requirements
   - Work accomplishment data requirements
   - Guidelines for establishing definitions and action codes suitable for all purposes

5. Data collection and automation
   - Database structures and schemas
   - Data collection strategies, including new technologies
   - Re-engineering agencywide data collection procedures to avoid duplication
   - Sampling and other cost-saving strategies for cost data collection

6. Conclusions

APPENDIX D

EXAMPLE COSTING PROCEDURES

CALIFORNIA DEPARTMENT OF TRANSPORTATION

DIVISION OF STRUCTURES

CONSTRUCTION STATISTICS BASED ON BID OPENINGS

1993

The following tabular data describes the structure work for which bids were opened in 1993, and the scope of bridge work since 1966.

Compiled by
Ed Yomogida
Tom Ruckman
David Liu

Cover Design by
Vinh Giang

Reviewed by
Dolores Valls

CALTRANS

DIVISION OF STRUCTURES

BRIDGE SQUARE FOOT COST SUMMARY

1993

TYPE OF BRIDGE	NUMBER OF BRIDGES	AMOUNT	SQ FT. OF DECK	WT.AVG. COST/SQ FT
RC SLAB	15	$9,123,648	86,685	$105.25
RC T-BEAM	3	$6,342,851	57,487	$110.34
RC BOX GIRDER	7	$16,556,027	183,646	$90.15
CIP/PS SLAB	3	$1,096,379	8,090	$135.52
CIP/PS BOX GDR	71	$122,365,862	1,949,547	$62.77
PC/PS "1" GDR	15	$9,154,639	104,334	$87.74
PC/PS SLAB	2	$1,384,295	18,986	$72.91
PC/PS T-GDR	1	$1,327,639	24,050	$55.20
PC/PS BOX GDR	1	$5,116,898	59,940	$85.37
STEEL GIRDER	4	$35,135,945	261,927	$134.14
TOTALS	122	$207,604,183	2,754,692	$75.36

THE TRANSPORTATION RESEARCH BOARD is a unit of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. It evolved in 1974 from the Highway Research Board, which was established in 1920. The TRB incorporates all former HRB activities and also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society. The Board's purpose is to stimulate research concerning the nature and performance of transportation systems, to disseminate information that the research produces, and to encourage the application of appropriate research findings. The Board's program is carried out by more than 400 committees, task forces, and panels composed of more than 4,000 administrators, engineers, social scientists, attorneys, educators, and others concerned with transportation; they serve without compensation. The program is supported by state transportation and highway departments, the modal administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation.

The National Academy of Sciences is a nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Bruce Alberts is president of the National Academy of Sciences.

The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encouraging education and research, and recognizes the superior achievements of engineers. Dr. William A.Wulf is interim president of the National Academy of Engineering.

The Institute of Medicine was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences, by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Kenneth I. Shine is president of the Institute of Medicine.

The National Research Council was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Bruce Alberts and Dr. William A. Wulf are chairman and interim vice chairman, respectively, of the National Research Council.

Transportation Research Board
National Research Council
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