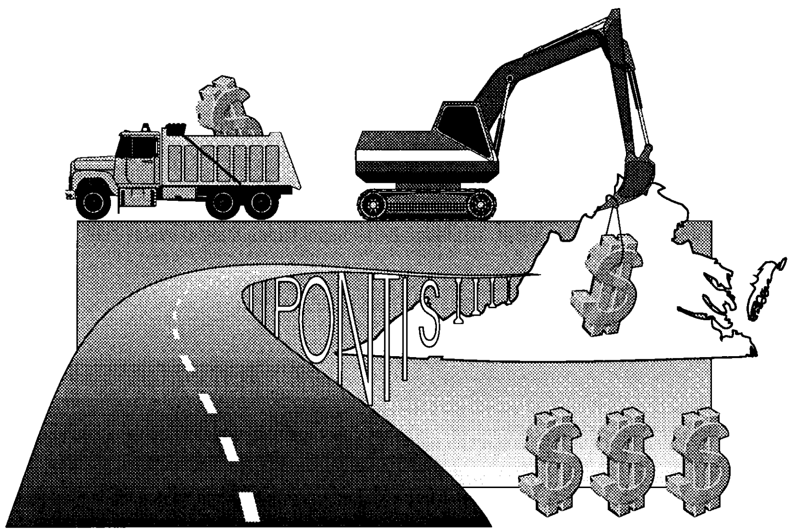
TECHNICAL
ASSISTANCE REPORT

MAINTENANCE, REPAIR, AND REHABILITATION UNIT COSTS FOR PONTIS



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(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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ABSTRACT

In the summer of 1993, the Bridge Management Task Force chairman requested that the Virginia Transportation Research Council begin a study of the maintenance, repair, and rehabilitation unit costs needed for the operation of the Pontis system. Because Pontis provides network-level analysis, implementing it requires a fundamental change in the business procedures of the Virginia Department of Transportation. The establishment of network-level cost data is one step in the implementation of Pontis. The shift from a bridge-specific focus makes existing data unsuitable, and alternatives need to be explored.

Since other states face similar problems, the Federal Highway Administration, the American Association of State Highway and Transportation Officials, and the National Cooperative Highway Research Program have initiated studies of these maintenance, repair, and rehabilitation costs. Rather than initiate a study of its own, the Virginia Transportation Research Council chose to follow these studies closely, and to make suggestions for implementing the findings from these studies within the Virginia Department of Transportation. This report provides the Task Force with a set of recommendations for implementing AASHTOWare™ Pontis™ Release 3.0.

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INTRODUCTION

The condition of the nation's bridges has recently received much attention, partly due to the age of the network, but also because the legal loads and traffic volumes carried by these bridges are increasing. Many bridges need maintenance, and maintenance funds are limited. Considering the overall condition of the bridge network, the available funds need to be used as efficiently as possible (National Highway Institute, 1994).

For efficiency, the maintenance needs of individual bridges need to be subordinated to service goals for the entire network. Bridge-by-bridge maintenance programs must be replaced by bridge management systems (BMSs) designed to help agencies develop network-level bridge programs by considering the economic costs and benefits of various policies.

When BMSs were mandated by the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), the Virginia Department of Transportation (VDOT) formed a Bridge Management Task Force. This Task Force was charged with developing and implementing a system that would meet the needs of the Commonwealth of Virginia and fulfill the federal mandates. One of the first Task Force recommendations was to use Pontis as the analytical engine for the BMS.

Because Pontis provides network-level analysis, while traditional methods have been project-level, a fundamental change in the business procedures of VDOT is necessary. The implementation of Pontis requires network-level cost data. The data should be an overall average and must incorporate location, economy of scale, and other variable factors. Existing project-level data are not suitable. Consequently, in the summer of 1993 the Task Force chairman requested that the Virginia Transportation Research Council (VTRC) begin a study of the maintenance, repair, and rehabilitation (MR&R) unit costs needed for the operation of Pontis.

To provide network-level analysis and project budget requirements, the system must include a predictive mechanism to model the future conditions of the bridge. Since the deterioration of bridges is a dynamic and uncertain process, a stochastic model provides a good representation. Each year, the Federal Highway Administration (FHWA) requires each state to submit National Bridge Inspection (NBI) component ratings of the deck, superstructure, and substructure. The condition assessments used by previous BMSs have been based on these component ratings. However, these components are a collection of various elements with distinct deterioration patterns. The developers of Pontis did not feel that deterioration could be best predicted using these components. To enable the best possible predictive methods, an alternate rating system was developed.

The element rating system uses individual elements of the bridge instead of components. The units of these elements were selected to allow the best predictive model to be developed and are often quite different from the traditional units used for project bids. While this causes some problems, the result provides the ability to make decisions based on life-cycle cost analysis.

Condition state language and the associated feasible actions are required for each of the elements used by an agency. Table 1 gives an example of this language for an unpainted steel closed web/box girder. This type of girder is element number 101, as indicated, and it is measured in units of linear feet (LF). As shown, this element has four allowable condition states. For each condition state, "do nothing" is a feasible alternative, and this action is 0. Condition states 2 and 3 have an additional feasible action labeled 1, "clean and paint". Condition state 4 has three feasible actions. These are "do nothing", which is 0, "rehab unit", which is 1, and "replace unit", which is feasible action 2.

Table 1: Condition State Language and Feasible Actions for a Sample Element.

Unpainted Steel Closed Web/Box Girder **101**
Units: LF

This element defines those steel closed web/box girders that are not painted or are constructed of weathering steel.

Condition States Descriptions

1	There is little or no corrosion of the unpainted steel. The weathering steel is coating uniformly and remains in excellent condition.			
	Feasible Actions:	(0) DN	(1) ------	(2) ------
2	Surface rust, surface pitting, has formed or is forming on the unpainted steel. The weathering steel has not corroded beyond design limits. Weathering steel color is yellow-orange to light brown.			
	Feasible Actions:	(0) DN	(1) Clean and paint	(2) ------
3	Steel has measurable section loss due to corrosion but does not warrant structural analysis. Weathering steel is dark brown or black.			
	Feasible Actions:	(0) DN	(1) Clean and paint	(2) ------
4	Corrosion is advanced. Section loss is sufficient to warrant structural analysis to ascertain the impact on the ultimate strength and/or serviceability of either the element or the bridge.			
	Feasible Actions:	(0) DN	(1) Rehab unit	(2) Replace unit

Pontis focuses its modeling around the elements of the bridge. Regardless of the bridges on which they are located, like elements are grouped to predict deterioration, and to predict the costs of actions taken on those elements. Traditional project-level estimates have typically accounted for the costs of the pre-engineering, material, labor, equipment, supervision, and traffic control, taking into consideration the location of the bridge, the accessibility of the work, the-magnitude of the work, knowledge about previous work done on the particular bridge, and the time frame for the work. Since network-level management focuses on the elements, it is impossible to estimate some of these factors. Averages must be considered. How best to account for the effect of each of these areas on repair costs is the problem posed by network-level estimating.

Table 2 illustrates some of the differences between network and project-level costs. Three network-level feasible actions within Pontis are compared with the project-level components that might be used for contract bidding purposes.

Table 2: Comparison of Network and Project-Level Actions

Element	Contract Information		Pontis Information	
	Action	Unit	Action	Unit
12 Concrete Deck	Latex/Silica Fume	Cubic Yards	Add protective system	Each
	Asphalt Concrete SM-2C	Ton		
12 Concrete Deck	Type A Scarifying	Square Yards	Rehab Deck	Each
	Type B Patching	Square Yards		
	Remove AC Overlay	Square Yards		
	Bridge Deck Grooving	Square Yards		
215 Abutment	Backwall Reconstruction	Linear Feet	Rehab Unit	Linear Feet
	Concrete Surface Repair	Square Yards		

To provide the network-level analysis, Pontis requires that each element used by an agency have a completed cost matrix for each allowable action in each condition state, for each of the four environments (Table 3). Table 3 is only for illustrative purposes, and the costs indicated are not meant to represent actual costs for the element. Costs are included for Action 0, Do Nothing, because Pontis assumes that a program of preventative maintenance is in place. An example of an action which might be incorporated into Do Nothing is washing. In this table, "action" is the feasible action and "state" is the condition state as described in Table 1. Benign, low, moderate, and severe are the four environments. When a condition state or feasible action does not exist, the space is left blank in this figure.

Table 3: Sample Screen from Edit MR & R Unit Costs (Source: Pontis Manual)

ELEMENT: 101 Steel Closed Web/Box Girder (Unpainted)

UNITS: LF along Girder

Action	State	Benign	Low	Moderate	Severe	Action
0	1	6	6	7	7	
0	2	6	6	7	7	Do
0	3	6	6	7	7	Nothing
0	4	6	6	7	7	
1	1					
1	2	387	345	388	416	Clean and Paint Unit
1	3	429	380	407	436	Clean and Paint Unit
1	4	414	360	411	385	Rehab Unit
2	1					
2	2					
2	3					
2	4	843	718	820	815	Replace Unit
Fail		1023	1043	1063	1083	Replacement cost from element failure

A completed matrix similar to the one shown in Table 3 is required for each of the commonly recognized (CoRe) elements (Cambridge Systematics, Inc., 1993), and any subelements or agency-specific elements the agency wishes to define.

PURPOSE AND SCOPE

This report makes recommendations to the Bridge Management Task Force about the MR&R unit cost data needed to implement Pontis. These recommendations result from monitoring ongoing activities in other states and at the national level. This phase of research addresses the agency-related MR&R costs and does not include the associated costs to the users.

APPROACH

Because Pontis was released only recently, a literature review revealed little that would be directly beneficial in establishing unit costs at the network level. (For an annotated bibliography see Appendix A.) While VDOT currently maintains several different types of cost data, some sort of conversion is necessary to use this data for network-level management. Since the definition of the CoRe elements, the associated feasible actions, the condition states, and the units of measure are very different from traditional practices, the data need to be manipulated extensively. There was no clear way to adapt or transfer the data from other systems used by VDOT. Early efforts in Minnesota and California developed preliminary databases, but in both cases, issues such as traffic control, geographical deviations, and economy of scale remained unresolved.

At the time of this study, three efforts-in-progress seemed to promise meaningful results for VDOT. The first was a project at Clemson University. The second was a synthesis study being conducted through the National Cooperative Highway Research Program (NCHRP). The third was the development of Release 3.0 of Pontis by the American Association of State Highway and Transportation Officials (AASHTO). Considering the magnitude of these efforts, it seemed best to cooperate with the national efforts already underway and then tailor the results for use in Virginia.

FINDINGS

When this project began, two states had addressed the issue of network-level MR&R costs. California had supplied data for the beta release of Pontis 1.0, and Minnesota had also gathered data from experienced personnel who were asked to estimate the unit costs. Subsequently, the South Carolina Department of Transportation contracted with Clemson University to develop a standardized cost database that can be used in Pontis, and Pontis 3.0 is being enhanced to improve the accuracy of the captured costs.

Minnesota

In the summer of 1992, the state of Minnesota developed a cost data base to use during their Beta Test of Pontis Release 1.0. The data was based on the expert judgement of five bridge maintenance engineers and one bridge estimator. Costs were developed for the moderate environment only.

In cases where the size of the element was not described by the unit, the bridge management engineer developed an average size to be used in the estimation. For example, open girders were to be considered a W36 beam, steel pier caps were to be 4' by 3', and the paint system specified as B was to be considered red lead.

Members of the Task Force reviewed this method, and had reservations about using it in Virginia. One major problem was how to account for the large variations in unit prices because of traffic control.

Clemson University

Clemson University and the South Carolina Department of Transportation have worked together on a BMS in South Carolina. Researchers at Clemson soon recognized the problems with developing the MR&R cost data, and prepared a proposal to create a standardized cost data base for Pontis. The three main benefits described in the proposal (Bell & Sanders, 1994) were:

1) The standardized database would provide each state with a starting point without labor-intensive individual collection efforts.

2) Standards would be established for what costs should be included.

3) A foundation for future cooperation and exchange between the states would be established.

Clemson developed a three-pronged approach to gather data in the Pontis format, and requested participation from each Pontis state. First, Virginia, California, Colorado, Minnesota, and Tennessee were visited to get expert opinion data. The general approach was very similar to that used in Minnesota: average sizes or projects were defined, and the respondent was asked to consider the described project. In cases where the size of the project was not defined, the respondent generally supplied a profile of a typical project. Also, the respondent was asked to list any factors that might significantly affect the price, such as related work or traffic control. In Virginia, this information was provided by a District Bridge Engineer from a rural area and by an assistant District Bridge Engineer from an urban area. (See Appendix B for a copy of this data.) The surveys were explained in a meeting with a researcher from Clemson, and then the surveys were completed at the convenience of the respondent.

The second and third approaches were surveys asking for historical and current data. A database of costs for the feasible actions of the CoRe elements assuming only one environment is being developed using results gathered from about 16 states, and will be made available with Release 3.0 of Pontis.

This is a starting point for further research on bridge management costs, by the Clemson team and others. Not all topics were addressed; for instance, how to determine the effect of environment on unit costs, how to assign these costs, and how to address the costing problems posed by such things as traffic control. The development of Release 3.0 of Pontis is expected to address some of these topics.

Task Force to Develop Pontis Release 3.0

Release 3.0 of Pontis is an enhanced version of the software originally developed through FHWA Demonstration Project 71. Based on findings from the beta test of the original software, and on developments in the philosophy of bridge management, significant changes are being made to the software. Two enhancements planned for Release 3.0 will directly influence the way VDOT and other agencies use Pontis cost data: the project-level module and the automatic cost updating capabilities.

Recognizing the importance of the cost models to Pontis, the AASHTOWare Task Force developing Pontis established a technical advisory group (TAG) specifically to advise the Task Force and the contractor on issues related to MR&R costs. The TAG worked with Pontis 3.0 and with Clemson to ensure that Clemson's work was compatible with 3.0. The TAG was composed of representatives from Colorado, Minnesota, South Carolina, and Virginia.

Project-Level Module

One of the many benefits of the project-level module will be in the cost area. The unique characteristics of a particular bridge can have a large impact on the cost of actions taken to that bridge, and the project-level module will be partially able to account for these. Costs that are very project- and bridge-specific, like traffic control, mobilization, and work zone user costs, are accounted for in the project-level module. Also, the project-level module allows specific characteristics that would affect the unit cost of the action, for example, the depth of a girder, to be included. (Thompson, 1994).

Updating of the Cost Model

Release 3.0 of Pontis will include an automatic process for updating the cost database. This feature will be very similar to the updating of the transition probability matrices found in earlier versions of Pontis. The process will use an initial database entered by the user, and then these costs will be updated using a Bayesian process as actions and costs are recorded.

The data from the research at Clemson University will be suitable for the initial database. If costs and actions taken can be captured and entered into the system when Release 3.0 is adopted, then by the time bridge programs are actually based on Pontis output, the costs will have been automatically updated based on Virginia data. For this reason, the process of recording maintenance actions and costs should begin soon, so the automatic updating feature of the cost database can be used to create the Virginia database, rather than having to rely on an intensive development of the database later.

DISCUSSION

It is important to understand the possible sources of error before the system is implemented. As research in bridge management costs increases, the magnitude of these errors will decrease. The Technical Advisory Group on Costs isolated four main areas that might contribute to the error of the cost estimation process:

1) *The actual unit cost may be different from the estimated unit cost.*

2) *The actual quantity of work may be different from the estimated quantity.*

3) *The actual actions taken may be different from what was planned.*

4) *The actual conditions found on the structure may be different from those on whose basis the actions were planned.*

While several of these sources of error cannot be avoided, practice with the system will refine the ability to project the actual work accurately. Also, based on past performance, adjustments may need to be made to the output.

The users of the output from the system also need to understand the purpose of the information. Though specific actions and associated costs are listed, the need for specific description of the work and a more detailed costs estimate has not been eliminated. Table 4 shows one of the problems with network-level actions. This example shows that the action of rehabilitating the deck is dependent on bridge-specific conditions. While the recommendation will be made to rehabilitate the deck, the specifics of that action still need to be considered as work is prepared for contract or state forces.

Table 4: Comparison of Definitions of Feasible Actions

Element	Contract Information		Pontis Information	
	Action	Unit	Action	Unit
12 Concrete Deck	Type A Scarifying	Square Yards	Rehab Deck	Each
	Type A Patching	Square Yards		
	Type B Patching	Square Yards		
	Type C Patching	Square Yards		
	Bridge Deck Grooving	Square Yards		
12 Concrete Deck	Type A Scarifying	Square Yards	Rehab Deck	Each
	Type B Patching	Square Yards		
	Remove AC Overlay	Square Yards		
	Bridge Deck Grooving	Square Yards		

Research has not yet addressed how to develop unit costs based on the four environments that were designed to model the effects of operating practice and climatic exposure on deterioration. This is not a trivial area. To link these areas of deterioration and cost, the factors that contribute to the rate of deterioration and the factors that contribute to the cost of the feasible actions must be isolated. If these factors can be correlated, then the costs may be varied based on environment. The separate identification of costs in each of the four environments will improve the accuracy of the estimates at the network level. The linkage of these two areas will require both identification and quantification of the factors affecting deterioration and cost by each agency implementing Pontis. (For further discussion of the environments within Pontis see Wells, 1994; and Cambridge Systematics, 1993.)

This report focuses on the development of MR&R unit costs. The importance of these costs to transportation agencies cannot be overstated, because they determine how much can be accomplished with the money that is available to construct and maintain the bridge network. However, these costs are only part of the overall cost. This study has not explored the area of user costs. User costs are another very important part of the overall expense of the bridge program. These costs include the costs to the user of bridges that provide unsatisfactory levels of service: additional travel time, additional mileage, delay at work zones, etc. An accurate picture of the costs of bridge policies must consider the costs to the users. Some work has been done in this area (Chen & Johnston, 1987), but further research is needed to ensure that Virginia's needs are met.

CONCLUSION AND RECOMMENDATIONS

The MR&R Unit Costs are critical to the success of the Pontis system or any similar BMS that uses economic analysis as the core of its prioritization modeling. Considering the importance of these costs, this study recommends that the VDOT Bridge Management Task Force take the following actions:

1) Use the results from the Clemson University study as the initial cost database for Pontis. Virginia supplied both expert opinion and historical data to Clemson for this database. The data from Virginia should be checked against the national database and any necessary adjustments made. If VDOT has additional data that is applicable at the network level, this data should also be used to tailor the database to fit Virginia's needs. If a review of the database indicates that it is not suitable for use in Virginia, then a Virginia database can be developed using Clemson's methodology.

2) Encourage the Maintenance and Structure and Bridge Divisions to continue to change the recording procedures for capturing cost data and maintenance actions, so historical data will be available in the future. By October 1998, states are to begin using the output from the management systems in the development of their programs. The Clemson data-

base is a good starting point, but conditions in Virginia will require some modifications to that data. Recording actions in a way useful to the maintenance management systems and to Pontis will lead to more accurate and defendable costs in Pontis itself, which will make the management systems more defendable and better-tailored to Virginia's needs.

3) Recommend research into the impact of factors affecting deterioration on the cost of maintenance actions. Such findings would allow costs to be developed for the four environments used in Pontis. Getting the full use out of the environments in Pontis will allow more accurate modeling at the network level.

4) Recommend the investigation of user costs in Virginia. Work done at North Carolina State University has been the primary source of information on user costs. This research provides a solid foundation for future efforts in Virginia.

5) Continue to encourage and participate in national efforts to develop procedures for collecting and maintaining costs for BMSs.

REFERENCES

Bell, L. C., & Sanders, S. R. (1994). *Research Proposal: Standardized Cost Data Base for Pontis BMS*. Clemson, South Carolina: Civil Engineering Department, Clemson University.

Cambridge Systematics, Inc. (September 30, 1993). *Pontis Version 2.0 User's Manual.* Final Best Test Version. Cambridge, Massachusetts: Cambridge Systematics, Inc.

Chen, C., & Johnston, D. W. (1987). *Bridge Management Under a Level of Service Concept Providing Optimum Improvement Action, Time, and Budget Prediction.* (FHWA/NC/88-004). Raleigh: North Carolina State University Center for Transportation Engineering Studies.

National Highway Institute. (1994). *Safety Inspection of In-Service Bridges -- Participant Notebook.* (FHWA HI-94-031). Volume 1, pp. 5.5.7-5.5.9.

Thompson, P. (1994). *PONTIS Version 3.0: Reaching Out to the Bridge Management Community.* Cambridge, Massachusetts: Cambridge Systematics, Inc.

Wells, D. T. (1994). *Environmental Classification Scheme for Pontis* (VTRC Report No. 94-R20). Charlottesville, Virginia: Virginia Transportation Research Council.

Appendix A: Annotated Bibliography of Sources Related to the MR&R Unit Costs Needed by Pontis.

Bridge Deck Program. (August 1992). Washington State Department of Transportation: Program Development Division, Bridge and Structures Branch, Bridge Planning Unit.

> Gives an overview of the deck management program developed and used by the state of Washington. Presents selection criteria for ranking deck projects and for deciding the type of overlay to use. These decision criteria for overlay could be useful in a project-level bridge management system. Discusses the need to consider the cost effectiveness of actions when programming work. Includes some cost data for overlay systems.

Chen, Chwen-jinq, & Johnston, David W. (September 1987). *Bridge Management Under a Level of Service Concept Providing Optimum Improvement Action, Time, and Budget Prediction.* (FHWA/NC/88-004). Raleigh: North Carolina State University Center for Transportation Engineering Studies.

> Describes procedure for calculating backlog and future needs. Discusses various deficiencies in the management systems in use in 1987. These include failure to consider the level of service offered by the bridge. Very detailed description of available options and calculations of user costs.

Ellis, Ralph D., Jr., & Kumar, Ashish. (1993). Influence of Nighttime Operations on Construction Cost and Productivity. *Transportation Research Record 1389,* pp. 31-37. Washington, DC: Transportation Research Board, National Research Council.

> Discusses the overall costs of construction work done during the day versus that done at night. Discusses the four main types of costs that need to be considered: construction or owner costs, user costs, accident costs, and maintenance costs. Concludes that nighttime work is cheaper for the sample of projects used in their study. The differences because of user costs are significant. Only the unit price of concrete was found to be more expensive at night.

Infrastructure Woes: Going High-Tech to Diagnose Decaying Roads. (October 1990). *Scientific American*, 123.

> Brief review of some high-tech methods for detecting decay in road surfaces -- some statistics on maintenance costs.

Nickerson, R.L., & Veshosky, David. (September 1992). Life Cycle Cost vs. Life Cycle Performance: Decision Criteria for Bridge Selection. *Modern Steel Construction*, pp. 39-44.

> Veshosky asserts that there are not enough data available to use life cycle costing. Recent articles by Dunker and Rabbat, which claim that concrete is the best building material, are analyzed. The need to use life cycle performance to select between projects rather than life cycle costs is emphasized, but it is unclear exactly how life cycle performance should be measured.

McNeil, Sue, Markow, Michael, Neumann, Lance, Ordway, Jeffrey & Uzarski, Donald. (July/ August 1992). Emerging Issues in Transportation Facilities Management. *Journal of Transportation Engineering*, 118(4), 477-495.

General overview of the present status of infrastructure maintenance, rehabilitation and repair. Emphasis on various methods used for modeling, the importance of life cycle costs, and changes that need to be made in the near future.

Morrow, Tommy K., & Johnston, David W. (July 1993). *Bridge Maintenance Level-of-Service Optimization*. (Research Report No. FHWA/NC/94-004). Raleigh: Center for Transportation Engineering Studies, Department of Civil Engineering, North Carolina State University.

Suggests a method to be used to prioritize and select preventive and routine maintenance for bridges based on a modification of the Algorithm for Selection of Optimal Policy (ASOP). Method is based on level of service criteria and considers the trade-offs of various budget levels. This report continues the development of the North Carolina Bridge Management System and describes how this proposed methodology (MAINTBRG) fits into the overall system.

Moses, Fred. (July 1992). *Truck Weight Effects on Bridge Costs* (Report No. FHWA/OH-93/ 001). Submitted to the Ohio Department of Transportation. Cleveland, Ohio: Department of Civil Engineering, Case Western Reserve University.

Discusses the financial impact of allowing heavier trucks on bridges. Includes discussion of fatigue, the costs of new construction and rehabilitation to allow heavier loads, the calculation of permit fees, and the enforcement of weight limits.

Purvis, Ronald L.; Babaei, Khossrow; Clear, Kenneth C.; & Markow, Michael J. (1994). *Life-Cycle Cost Analysis for Protection and Rehabilitation of Concrete Bridges Relative to Reinforcement Corrosion*. (Report No. SHRP-S-377). Washington, DC: Strategic Highway Research Program, National Research Council.

Includes step-by-step method for determining quantitative measure of corrosion. Presents method for calculating user costs before, during, and after construction for bridge-related closures or partial closures. Discusses two methods of calculating life-cycle costs -- 1) capitalized cost approach and 2) salvage value approach. Includes factors to be included in costs for various deck and structural treatments. Discusses the need to consider remaining service life when selecting most cost efficient life-cycle strategy. Discusses compatible treatments and need to consider the total structure when selecting treatments. Demonstrates example for calculating the optimum treatment and time of treatment using life-cycle analysis. (Computer program is included.)

Saito, Mitsuru, & Sinha, Kumares C. (May 31, 1990). *Data Collection and Analysis of Bridge Rehabilitation and Maintenance Costs.* Paper presented at 6th Maintenance Management Workshop.

Discussion of importance of proper data collection to bridge management and to life cycle costing. Proposes how data should be collected and specified. Very technical discussion with useful general conclusions. One main point is that the data currently available will make accurate bridge management difficult.

Saito, M., & Sinha, K. (1990). Data Collection and Analysis of Bridge Rehabilitation and Maintenance Costs. *Transportation Research Record 1276*, pp. 72-75. Washington, DC: Transportation Research Board, National Research Council.

Analysis of the record keeping procedures for rehabilitation and maintenance as they relate to an effective, efficient BMS. Examples from Indiana. Discusses methodology as could be applied generally, and points out shortcomings of current methods.

Skeet, James A., & Kriviak, Gary J. (1994). *Service Life Prediction of Protective Systems for Concrete Bridge Decks in Alberta*, (ABTR/RD/RR-94/01), Prepared for Alberta Transportation and Utilities; Bridge Engineering Branch/Research and Development Branch by Reid Crowther & Partners.

Gives the following definition for environmental factors: *Those deterioration characteristics which are unique to a particular bridge site and are not related to design or construction.* Discusses life cycle calculations, saying that their accuracy depends on three things:

* reasonable alternative choices for deck repair or replacement of deck superstructure or the entire bridge
* accurate costs for alternative choices
* accurate service life predictions for each alternative

Presents a method for predicting service lives using half cell tests. The following factors influence service life: ADT, freeze/thaw cycles, structure type, structure flexibility.

Veshosky, David, & Beidleman, Carl R. (July 1992). Life-Cycle Cost Analysis Doesn't Work for Bridges. *Civil Engineering*, 62(7), 6.

Discussion and explanation in the Forum section concerning why the life cycle costing required in the 1991 Intermodal Surface Transportation Efficiency Act is impractical. Mentions data is not available and that life cycle costs are very dependent on the level of maintenance performed.

Weissmann, Jose, Reed, Robert L. & Feroze, Ahmed. (1994). I*ncremental Bridge Construction Costs for Highway Cost Allocation.* Preprint for the Transportation Research Board, 73rd Annual Meeting, January 9-13, 1994, Washington, DC, TRB 940706.

Weyers, R.E., Cady, P.D. & Hunter, J. M. (1988). Cost-Effective Bridge Maintenance and Rehabilitation Procedures. *Transportation Research Record 1184*, 31-40. Washington, DC: Transportation Research Board, National Research Council.

Discusses actual economic development of the Pennsylvania DOT's BMS. Gives some background as to how they obtained their information, and details methods used.

Weyers, Richard E.; Cady, Philip D.; & McClure, Richard M. (1984). Cost-Effective Decision Models for Maintenance, Rehabilitation, and Replacement of Bridges. *Transportation Research Record 950*, Vol. 1, 28-32. Washington, DC: Transportation Research Board, National Research Council.

Argues that failure to account for inflation in traditional engineering economics impacts decisions affecting future costs of bridges. From this a computer model is described which determines whether a bridge should be rehabilitated or replaced.

Weyers, Richard E., Fitch, Michael G., Larsen, Erin P., Al-Qadi, Imad L., Chamberlin, William P., & Hoffman, Paul C. (1994). *Concrete Bridge Protection and Rehabilitation: Chemical and Physical Techniques, Service Life Estimates.* (Report No. SHRP-S-668). Washington, DC: Strategic Highway Research Program, National Research Council.

Discusses the need to consider service life when identifying life cycle costs and selecting appropriate treatments. Discusses environmental factors that could be expected to affect performance of bridge components. Concludes that the factors influencing the residence time and concentration of chloride salts have the most impact on service life. Because of this, environmental severity on specific bridges was measured using mean annual snowfall and average annual daily traffic. (Considerations: (1) frequency of snow may be more accurate indicator of chloride applications that the total snowfall and (2) heavy traffic may rid the roads of snow, and therefore the applications of chlorides may be less.) Discusses the performance of various types of overlays, a method to map deck damage by digitizing photos of the deck. Developed a model for time to rehabilitate the deck and piers based on condition information, characteristic information (e.g., age, ADT, speed), total damage of various areas, and aggregates of the damage. Concludes that rehabilitation of the substructure is often determined by when the deck is rehabilitated rather than the condition of the substructure.

Wipf, Terry J., Erickson, Donald L., & Klaiber, F. Wayne. (1987). Cost-Effectiveness Analysis for Strengthening Existing Bridges. *Transportation Research Record 1113*, 9-17. Washington, DC: Transportation Research Board, National Research Council.

Presents an analysis method for choosing the most cost effective alternative for improving deficient bridges. Emphasizes that first cost analysis is not appropriate since the initial cost represents less than half of the total cost of the structure. Method uses equivalent uniform annual cost.

Wonsiewicz, Thomas J. (1988). Life Cycle Cost Analysis: Key Assumptions and Sensitivity of Results. *Transportation Research Record 1191*, 113-117. Washington, DC: Transportation Research Board, National Research Council.

Discussion of life cycle cost analysis. Issues include the inclusion of inflation, the discount rate, design life, and sensitivity analysis.

Yanev, B., & Chen, Xiaoming. (1993). Life-Cycle Performance of New York City Bridges, *Transportation Research Record 1389*, 17-24. Washington, DC: Transportation Research Board, National Research Council.

Discusses the possibility of using life-cycle performance in bridge management systems. Performs analysis of data of bridge maintained by New York City and State Departments of Transportation. Concludes that bridges that have undergone "capital rehabilitation" have a steeper deterioration slope than new bridges. Could be analytical evidence to refute the use of Markovian modeling for bridge deterioration.

Appendix B: MR & R Unit Cost Data for Viginia Provided to Clemson University

Core Elem. No.	Core Element Description	Units	Cond. State	Feas. Act. No.	Feasible Action Description	Data from No. Va.	Data from Culpeper
12	Concrete deck-bare	each (1)	1	2	Add a protective system	$250	$250
			2	2	Repair spalled/delam area	$60	$50
			2	3	Add a protective system	$310	$280
			3	2	Repair spalled areas	$225	$115
			3	3	Repair spalled areas and add protective system	$475	$310
			4	2	Repair spalled areas	$500	$262
			4	3	Repair spalled areas and add protective system	$750	$395
			5	2	Repair spalled areas and/or add protective system	$1,050	$670
			5	3	Replace deck	$6,500	$1,830
13	Deck-unprotected with AC overlay	each (1)	2	2	Repair potholes and substrate	$70	$60
			3	2	Repair potholes and substrate	$275	$125
			3	3	Repair substrate and replace overlay	n/a	$250
			4	2	Repair potholes and substrate	$500	$275
			4	3	Repair substrate and replace overlay	$400	$100
			5	2	Repair substrate and replace overlay	$750	$650
			5	3	Replace deck	$6,500	$1,830
14	Concrete deck-protected with AC overlay	each (1)	2	2	Repair potholes	$80	$40
			3	2	Repair potholes	$300	$60
			3	3	Replace overlay	$100	$125
			4	2	Patch potholes	$900	$90
			4	3	Replace overlay and protective system	$200	$110
			5	2	Replace overlay and protective system	$300	$140
			5	3	Replace deck	$6,500	$1,830
18	Concrete deck -protected w/thin (<1 inch) overlay	each (1)	2	2	Repair spalls/delams	$20	$50
			3	2	Repair spalls/delams	$35	$115
			4	2	Repair spalls/delams	$75	$262
			4	3	Replace overlay	$75	$575
			5	2	Replace overlay	$35,000	$625
			5	3	Replace deck	n/a	$1,830
22	Concrete deck protected w/rigid overlay	each (1)	2	2	Repair spalls/delams	$45	$50
			3	2	Repair spalls/delams	$200	$115
			4	2	Repair spalls/delams	$400	$262
			4	3	Replace overlay	$400	$610
			5	2	Replace overlay	$555	$670
			5	3	Replace deck	$6,500	$1,830
26	Concrete deck-protected w/coated bars	each (1)	2	2	Patch spalls/delams	$60	$50
			3	2	Repair spalled areas	$180	$115
			3	3	Repair spalled areas and add/replace overlay	$250	$310

Notes

Core Elem. No.	Core Element Description	Units	Cond. State	Feas. Act. No.	Feasible Action Description	Data from No. Va.	Data from Culpeper
			4	2	Repair spalled areas	$400	$262
			4	3	Repair spalled areas and add/replace overlay	$400	$350
			5	2	Repair spalled areas and add/replace overlay	$555	$400
			5	3	Replace deck	$6,500	$1,830
27	Concrete deck-protected w/cathodic protection	each (1)	2	2	Patch spalls/delams	n/a	$50
			3	2	Repair spalled areas	n/a	$115
			3	3	Repair spalled areas and add/replace overlay	n/a	$310
			4	2	Repair spalled areas	n/a	$262
			4	3	Repair spalled areas and add/replace overlay	n/a	$350
			5	2	Repair spalled areas and add/replace overlay	n/a	$400
			5	3	Replace deck	n/a	No Data
28	Steel deck-open grid	each (1)	2	2	Surface clean	n/a	n/a
			3	2	Surface clean and restore top coat	n/a	n/a
			3	3	Rehab connectors	n/a	n/a
			4	2	Spot blast, clean and paint	n/a	n/a
			4	3	Rehab connectors	n/a	n/a
			5	2	Rehab connectors and replace system	n/a	n/a
			5	3	Replace unit	n/a	n/a
29	Steel deck-concrete filled grid	each (1)	2	2	Surface clean	n/a	n/a
			3	2	Surface clean and restore top coat	n/a	n/a
			3	3	Rehab connectors and concrete filler	n/a	n/a
			4	2	Spot blast, clean and paint	n/a	n/a
			4	3	Rehab connectors and concrete filler	n/a	n/a
			5	2	Rehab connectors & concrete filler & replace paint	n/a	n/a
			5	3	Replace unit	n/a	n/a
30	Deck-Corrugated/Orthotropic/etc.	each (1)	2	2	Seal cracks and/or repair potholes	n/a	n/a
			3	2	Surface clean and restore top coat of paint	n/a	n/a
			3	3	Repair potholes and cracks	n/a	n/a
			4	2	Spot blast, clean, paint, repair potholes	n/a	n/a
			4	3	Repair potholes and cracks	n/a	n/a
			5	2	Rehab/replace paint system, replace surfacing	n/a	n/a
			5	3	Replace unit	n/a	n/a
31	Wood deck (bare)	each (2)	2	2	Rehab and/or protect deck	$125	$10
			3	2	Rehab deck	$315	$15
			3	3	Replace deck	$1,250	$50
			4	2	Replace deck	$1,250	$50
32	Wood deck-with AC overlay	each (2)	2	2	Repair potholes	$50	$5
			2	3	Rehab and/or protect unit	$125	$12

Notes

Core Elem. No.	Core Element Description	Units	Cond. State	Feas. Act. No.	Feasible Action Description	Data from No. Va.	Data from Culpeper
			3	2	Rehab deck and repair/replace surfacing	$375	$23
			3	3	Replace deck and surfacing	$1,340	$58
			4	2	Replace deck and surfacing	$1,340	$58
38	Concrete slab-bare	each (3)	1	2	Add a protective system	$390	$175
			2	2	Repair spalled/delam area	$45	$30
			2	3	Add a protective system	$435	$200
			3	2	Repair spalled areas	$178	$75
			3	3	Repair spalled areas and add protective system	$568	$230
			4	2	repair spalled areas	$400	$150
			4	3	Repair spalled areas and add protective system	$790	$325
			5	2	Repair spalled areas and/or add protective system	$555	$275
			5	3	Replace deck	$945	$2,500
39	Concrete slab-unprotected w/AC overlay	each (3)	2	2	Repair potholesand substrate	$55	$35
			3	2	Repair potholes and substrate	$145	$80
			3	3	Repair substrate and replace overlay	$145	$180
			4	2	Repair potholes and substrate	$400	$155
			4	3	Repair substrate and replace overlay	$425	$250
			5	2	Repair substrate and replace overlay	$555	$300
			5	3	Replace deck	$6,500	$2,500
40	Concrete slab-protected w/AC overlay	each (3)	2	2	Repair potholes	$20	$40
			3	2	Repair potholes	$60	$60
			3	3	Replace overlay	$192	$130
			4	2	Patch potholes	$92	$90
			4	3	Replace overlay and protective system	$192	$250
			5	2	Replace overlay and protective system	$192	$250
			5	3	Replace deck	$6,500	$2,500
44	Concrete slab Protected w/thin overlay	each (3)	2	2	Repair spalls/delams	$56	$35
			3	2	Repair spalls/delams	$168	$80
			4	2	Repair spalls/delams	$475	$160
			4	3	Replace overlay	$810	$425
			5	2	Replace overlay	$1,030	$475
			5	3	Replace deck	$6,500	$2,500
48	Concrete salb protected w/rigid overlay	each (3)	2	2	Repair spalls/delams	$60	$35
			3	2	Repair spalls/delams	$172	$80
			4	2	Repair spalls/delams	$479	$160
			4	3	Replace overlay	$814	$500
			5	2	Replace overlay	$1,035	$550
			5	3	Replace deck	$6,500	$2,500

Notes

Core Elem. No.	Core Element Description	Units	Cond. State	Feas. Act. No.	Feasible Action Description	Data from No. Va.	Data from Culpeper
52	Concrete salb-protected w/coated bars	each (1,3)	2	2	Patch spalls/delams	$56	$35
			3	2	Repair spalled areas	$168	$80
			3	3	Repair spalled areas and add/replace overlay	$505	$325
			4	2	Repair spalled areas	$400	$160
			4	3	Repair spalled areas and add/replace overlay	$785	$400
			5	2	Repair spalled areas and add/replace overlay	$940	$450
			5	3	Replace deck	$6,500	$2,500
53	Concrete slab-protected w/cathodic protection	each (1,3)	2	2	Patch spalls/delams	$56	$35
			3	2	Repair spalled areas	$168	$80
			3	3	Repair spalls and overlay (add or replace)	$505	$325
			4	2	Repair spalled areas	$400	$160
			4	3	Repair spalls and overlay (add or replace)	$785	$400
			5	2	Repair spalls and overlay (add or replace)	$940	$450
			5	3	Replace deck	$6,500	$2,500
54	Timber slab	each (2, 49)	2	2	Rehab and/or protect deck	$140	
			3	2	Rehab deck	$375	
			3	3	Replace deck	$1,240	$600
			4	2	Replace deck	$1,240	$600
55	Timber slab-with AC overlay	each (2, 49)	2	2	Repair potholes	$40	$5
			2	3	Rehab and/or protect unit	$160	
			3	2	Rehab deck and surfacing (repair or replace)	$395	
			3	3	Replace deck and surfacing	$1,340	$650
			4	2	Replace deck and surfacing	$1,340	$650
101	Unpainted steel closed web/bos girder	LF	2	2	Clean and paint	n/a	n/a
			3	2	Clean and paint	n/a	n/a
			4	2	Rehab unit	n/a	n/a
			4	3	Replace unit	n/a	n/a
102	Painted steel closed web/box girder	LF (4)	1	2	Surface clean	$380	n/a
			2	2	Surface clean	$720	n/a
			2	3	Surface clean, restore top coat	$2,880	n/a
			3	2	Spot blast, clean and paint	$5,600	n/a
			4	2	Spot blast, clean and paint	$7,200	n/a
			4	3	Replace paint system	$8,640	n/a
			5	2	Major rehab unit	$18,000	n/a
			5	3	Replace unit	$90,000	n/a
104	P/S Conc closed web/box girder	LF (4)	2	2	Seal cracks minor patch	$600	$10
			3	2	Clean steel and patch and/or seal	$900	$25
			4	2	Rehab unit	$1,500	$150

Notes

Core Elem. No.	Core Element Description	Units	Cond. State	Feas. Act. No.	Feasible Action Description	Data from No. Va.	Data from Culpeper
			4	3	Replace unit	$17,300	$250
105	Reinforced concrete closed webs/box girder	LF (5)	2	2	Seal cracks minor patch	$1,120	n/a
			3	2	Clean rebar and patch and/or seal	$2,250	n/a
			4	2	Rehab unit	$7,000	n/a
			4	3	Replace unit	***********	n/a
106	Unpainted steel open girder	LF (6)	2	2	Clean and paint	n/a	$60
			3	2	Clean and paint	n/a	$60
			4	2	Rehab unit	n/a	
			4	3	Replace unit	n/a	$500
107	Painted Steel open girder	LF (7)	1	2	Surface clean	$10	
			2	2	Surface clean	$15	
			2	3	Surface clean and restore top coat	$50	$35
			3	2	Spot blast, clean and paint	$75	$100
			4	2	Spot blast, clean and paint	$100	$125
			4	3	Replace paint system	$140	$180
			5	2	Major rehab unit	$220	$250
			5	3	Replace unit	$240	$500
109	P/S Conc open girder	LF (8)	2	2	Seal cracks minor patch	$25	$50
			3	2	Clean steel and patch and/or seal	$50	$75
			4	2	Rehab unit	$75	$100
			4	3	Replace unit	$296	$200
110	Reinforced conc open girder	LF (9)	2	2	Seal cracks minor patch	$25	$30
			3	2	Clean rebar and patch and/or seal	$50	$60
			4	2	Rehab unit	$65	$100
			4	3	Replace unit	$270	$250
111	Timber open girder	LF	2	2	Rehab and/or protect unit	n/a	n/a
			3	2	Rehab unit	n/a	n/a
			3	3	Replace unit	n/a	n/a
			4	2	Rehab unit	n/a	n/a
			4	3	Replace unit	n/a	n/a
112	Unpainted steel stringer	LF (10)	2	2	Clean and paint	n/a	$20
			3	2	Clean and paint	n/a	$20
			4	2	Rehab unit	n/a	
			4	3	Replace unit	n/a	$35
113	Painted steel stringer	LF (10)	1	2	Surface clean	$2	
			2	2	Surface clean	$4	
			2	3	Surface clean and restore top coat	$8	$12
			3	2	Spot blast, clean and paint	$15	$30

Notes

Core Elem. No.	Core Element Description	Units	Cond. State	Feas. Act. No.	Feasible Action Description	Data from No. Va.	Data from Culpeper
			4	2	Spot blast, clean and paint	$25	$35
			4	3	Replace paint system	$35	$50
			5	2	Major rehab unit	$70	
			5	3	Replace unit	$75	$35
115	P/S Conc stringer	LF	2	2	Seal cracks minor patch	n/a	n/a
			3	2	Clean steel and patch and/or seal	n/a	n/a
			4	2	Rehab unit	n/a	n/a
			4	3	Replace unit	n/a	n/a
116	Reinforced conc stringer	LF	2	2	Seal cracks minor patch	n/a	n/a
			3	2	Clean steel and patch and/or seal	n/a	n/a
			4	2	Rehab unit	n/a	n/a
			4	3	Replace unit	n/a	n/a
117	Timber stringer	LF	2	2	Rehab and/or protect unit	n/a	n/a
			3	2	Rehab unit	n/a	n/a
			3	3	Replace unit	n/a	n/a
			4	2	Rehab unit	n/a	n/a
			4	3	Replace unit	n/a	n/a
120	Unpainted steel bottom chord through truss	LF (50)	2	2	Clean and paint	n/a	$5
			3	2	Clean and paint	n/a	$5
			4	2	Rehab unit	n/a	
			4	3	Replace unit	n/a	
121	Painted steel bottom chord through truss	LF (11, 50)	1	2	Surface clean	$2	
			2	2	Surface clean	$3	
			2	3	Surface clean and restore top coat	$6	$4
			3	2	Spot blast, clean and paint	$8	$8
			3	3	Spot blast, clean and paint	$8	$8
			4	2	Spot blast, clean and paint	$10	$8
			4	3	Replace paint system	$28	$15
			5	2	Major rehab unit	$45	
			5	3	Replace unit	n/a	
125	Unpainted steel thru truss (excluding bottom chord	LF (51)	2	2	Clean and paint	n/a	$25
			3	2	Clean and paint	n/a	$25
			4	2	Rehab unit	n/a	
			4	3	Replace unit	n/a	
126	Painted steel thru truss (excluding bottom chord)	LF (12, 51)	1	2	Surface clean	$240	
			2	2	Surface clean	$360	
			2	3	Surface clean and restore top coat	$600	$20
			3	2	Spot blast, clean and paint	$800	$40

Notes

Core Elem. No.	Core Element Description	Units	Cond. State	Feas. Act. No.	Feasible Action Description	Data from No. Va.	Data from Culpeper
			4	2	Spot blast, clean and paint	$1,000	$40
			4	3	Replace paint system	$1,680	$75
			5	2	Major rehab unit	$2,400	
			5	3	Replace unit	n/a	
130	Unpainted steel deck truss	LF	2	2	Clean and paint	n/a	n/a
			3	2	Clean and paint	n/a	n/a
			4	2	Rehab unit	n/a	n/a
			4	3	Replace unit	n/a	n/a
131	Painted steel deck truss	LF (12)	1	2	Surface clean	$280	n/a
			2	2	Surface clean	$400	n/a
			2	3	Surface clean and restore top coat	$640	n/a
			3	2	Spot blast, clean and paint	$840	n/a
			4	2	Spot blast, clean and paint	$1,040	n/a
			4	3	Replace paint system	$1,720	n/a
			5	2	Major rehab unit	$2,440	n/a
			5	3	Replace unit	n/a	n/a
135	Timber truss/arch	LF	2	2	Rehab and/or protect unit	n/a	n/a
			3	2	Rehab unit	n/a	n/a
			3	3	Replace unit	n/a	n/a
			4	2	Rehab unit	n/a	n/a
			4	3	Replace unit	n/a	n/a
140	Unpainted steel arch	LF	2	2	Clean and paint	n/a	n/a
			3	2	Clean and paint	n/a	n/a
			4	2	Rehab unit	n/a	n/a
			4	3	Replace unit	n/a	n/a
141	Painted steel arch	LF	1	2	Surface clean	n/a	n/a
			2	2	Surface clean	n/a	n/a
			2	3	Surface clean and restore top coat	n/a	n/a
			3	2	Spot blast, clean and paint	n/a	n/a
			3	3	Replace paint system	n/a	n/a
			4	3	Replace paint system	n/a	n/a
			4	2	Spot blast, clean and paint	n/a	n/a
			5	2	Major rehab unit	n/a	n/a
			5	3	Replace unit	n/a	n/a
143	P/S Conc arch	LF	2	2	Seal cracks minor patch	n/a	n/a
			3	2	Clean steel and patch and/or seal	n/a	n/a
			4	2	Rehab unit	n/a	n/a
			4	3	Replace unit	n/a	n/a

Notes

Core Elem. No.	Core Element Description	Units	Cond. State	Feas. Act. No.	Feasible Action Description	Data from No. Va.	Data from Culpeper
144	Reinforced Conc arch	LF (13)	2	2	Seal cracks minor patch	$75	n/a
			3	2	Clean rebar and patch and/or seal	$200	n/a
			4	2	Rehab unit	$1,300	n/a
			4	3	Replace unit	$3,350	n/a
146	Cable (not embedded in concrete)	Each	2	2	Clean and paint	n/a	n/a
			3	2	Clean and paint	n/a	n/a
			4	2	Rehab unit and replace paint system	n/a	n/a
			4	3	Replace unit	n/a	n/a
151	Unpainted steel floor beam	LF (14)	2	2	Clean and paint	$30	$30
			3	2	Clean and paint	$40	$30
			4	2	Rehab unit	$125	
			4	3	Replace unit	$200	
152	Painted steel floor beam	LF (14)	1	2	Surface clean	$12	
			2	2	Surface clean	$15	
			2	3	Surface clean and restore top coat	$45	$24
			3	2	Spot blast, clean and paint	$50	$48
			4	2	Spot blast, clean and paint	$60	$48
			4	3	Replace paint system	$84	$72
			5	2	Major rehab unit	$125	
			5	3	Replace unit	$200	
154	P/S Conc floor beam	LF	2	2	Seal cracks minor patch	n/a	n/a
			3	2	Clean steel and patch and/or seal	n/a	n/a
			4	2	Rehab unit	n/a	n/a
			4	3	Replace unit	n/a	n/a
155	Reinforced conc floor beam	LF (52)	2	2	Seal cracks	n/a	$50
			3	2	Clean rebar and patch and/or seal	n/a	$75
			4	2	Rehab unit	n/a	$100
			4	3	Replace unit	n/a	
156	Timber floor beam	LF	2	2	Rehab and/or protect unit	n/a	n/a
			3	2	Rehab unit	n/a	n/a
			3	3	Replace unit	n/a	n/a
			4	2	Rehab unit	n/a	n/a
			4	3	Replace unit	n/a	n/a
160	Unpainted steel pin and/or pin and hanger assembly	each (15)	2	2	Clean and paint	n/a	n/a
			2	3	Rehab element	n/a	n/a
			3	2	Rehab unit	n/a	n/a
			4	2	Rehab unit	n/a	n/a
			4	3	Replace unit	n/a	n/a

Notes

Core Elem. No.	Core Element Description	Units	Cond. State	Feas. Act. No.	Feasible Action Description	Data from No. Va.	Data from Culpeper
161	Painted steel pin and/or hanger assembly	each (15)	2	2	Surface clean	$110	n/a
			3	2	Spot blast, clean and paint	$210	n/a
			4	2	Replace paint system	$350	n/a
			4	3	Repair, replace paint system	$400	n/a
			5	2	Major rehab unit	$1,200	n/a
			5	3	Replace unit	$3,800	n/a
201	Unpainted steel column or pile extension	each (16)	2	2	Clean and paint	n/a	n/a
			3	2	Clean and paint	n/a	n/a
			4	2	Rehab unit	n/a	n/a
			4	3	Replace unit	n/a	n/a
202	Painted steel column or pile extension	each (16)	1	2	Surface clean	$90	n/a
			2	2	Surface clean	$120	n/a
			2	3	Surface clean and restore top coat	$360	n/a
			3	2	Spot blast, clean and paint	$750	n/a
			4	2	Spot blast, clean and paint	$900	n/a
			4	3	Replace paint system	$1,260	n/a
			5	2	Major rehab unit	$1,750	n/a
			5	3	Replace unit	$6,000	n/a
204	P/S Conc column or pile extension	each (17, 53)	2	2	Seal cracks minor patch	$150	$500
			3	2	Clean steel and patch and/or seal	$450	$1,000
			4	2	Rehab unit	$1,250	$5,000
			4	3	Replace unit	$6,000	$20,000
205	Reinforced conc column or pile extension	each (18, 54)	2	2	Seal cracks minor patch	$150	$500
			3	2	Clean rebar and patch, and/or seal	$450	$1,000
			4	2	Rehab unit	$1,800	$5,000
			4	3	Replace unit	$4,500	$25,000
206	Timber column or pile extension	each (19)	2	2	Rehab and/or protect unit	$1,250	
			3	2	Rehab unit	$1,600	
			3	3	Replace unit	$3,700	
			4	2	Rehab unit	$2,500	
			4	3	Replace unit	$3,700	
210	Reinforced conc pier wall	LF (20)	2	2	Seal cracks minor patch	$25	$50
			3	2	Clean rebar and patch and/or seal	$90	$100
			4	2	Rehab unit	$225	$300
			4	3	Replace unit	$2,220	$500
211	Other pier wall	LF (21)	2	2	Rehab unit	$490	$50
			3	2	Rehab unit	$550	$100
			4	2	Rehab unit	$612	$200

Notes

Core Elem. No.	Core Element Description	Units	Cond. State	Feas. Act. No.	Feasible Action Description	Data from No. Va.	Data from Culpeper
			4	3	Replace unit	$1,330	$400
215	Reinforced conc abutment	LF (22)	2	2	Seal cracks minor patch	$55	$50
			3	2	Clean rebar and patch and/or seal	$285	$100
			4	2	Rehab unit	$410	$300
			4	3	Replace unit	$890	$900
216	Timber abutment	LF (23)	2	2	Rehab and/or protect unit	$45	?
			3	2	Rehab unit	$95	?
			3	3	Replace unit	$270	$250
			4	2	Rehab unit	$130	?
			4	3	Replace unit	$270	$250
217	Other abutment	LF (24, 55)	2	2	Rehab unit	$210	$50
			3	2	Rehab unit	$410	$100
			4	2	Rehab unit	$612	$200
			4	3	Replace unit	$1,500	$700
220	Reinforced conc submerged pile cap/footing	each	2	2	Seal cracks minor patch	n/a	n/a
			3	2	Clean rebar and patch and/or seal	n/a	n/a
			4	2	Rehab unit	n/a	n/a
			4	3	Replace unit	n/a	n/a
225	Unpainted steel submerged pile	each	2	2	Place cathodic protection	n/a	n/a
			3	2	Place cathodic protection	n/a	n/a
			4	2	Rehab unit and place cathodic protection	n/a	n/a
			4	3	Replace unit	n/a	n/a
226	P/S Conc submerged pile	each (25)	2	2	Seal cracks minor patch	$1,100	n/a
			3	2	Clean steel and patch and/or seal	$1,650	n/a
			4	2	Rehab unit	$2,500	n/a
			4	3	Replace unit	$3,900	n/a
227	Reinforced conc submerged pile	each (26)	2	2	Seal cracks minor patch	$1,500	n/a
			3	2	Clean rebar and patch and/or seal	$1,800	n/a
			4	2	Rehab unit	$3,000	n/a
			4	3	Replace unit	$4,500	n/a
228	Timber submerged pile	each (27)	2	2	Rehab and/or protect unit	$1,000	n/a
			3	2	Rehab unit	$2,500	n/a
			3	3	Replace unit	$5,000	n/a
			4	2	Rehab unit	$2,500	n/a
			4	3	Replace unit	$5,000	n/a
230	Unpainted steel cap	LF (28)	2	2	Clean and paint	n/a	$25
			3	2	Clean and paint	n/a	$25
			4	2	Rehab unit	n/a	

Notes

Core Elem. No.	Core Element Description	Units	Cond. State	Feas. Act. No.	Feasible Action Description	Data from No. Va.	Data from Culpeper
			4	3	Replace unit	n/a	$600
231	Painted steel cap	LF (29)	1	2	Surface clean	$16	
			2	2	Surface clean	$20	
			2	3	Surface clean and restore top coat	$40	$20
			3	2	Spot blast, clean and paint	$65	$40
			4	2	Spot blast, clean and paint	$80	$40
			4	3	Replace paint system	$112	$60
			5	2	Major rehab unit	$235	
			5	3	Replace unit	$500	$600
233	P/S conc cap	LF	2	2	Seal cracks minor patch	n/a	n/a
			3	2	Clean steel and patch and/or seal	n/a	n/a
			4	2	Rehab unit	n/a	n/a
			4	3	Replace unit	n/a	n/a
234	Reinforced conc cap	LF (30)	2	2	Seal cracks minor patch	$120	$20
			3	2	Clean rebar and patch and/or seal	$260	$40
			4	2	Rehab unit	$750	$200
			4	3	Replace unit	$2,350	$750
235	Timber cap	LF (31, 56)	2	2	Rehab and/or protect unit	$85	
			3	2	Rehab unit	$110	
			3	3	Replace unit	$250	$100
			4	2	Rehab unit	$175	
			4	3	Replace unit	$300	$100
240	Steel culvert	LF (32)	2	2	Rehab unit	Do Nothin	n/a
			3	2	Rehab unit	$95	$200
			4	2	Rehab unit	Do Nothin	n/a
			4	3	Replace unit	$150	$1,000
241	Concrete culvert	LF (33)	2	2	Rehab unit	$50	n/a
			3	2	Rehab unit	$95	
			4	2	Rehab unit	$130	
			4	3	Replace unit	$280	$1,100
242	Timber culvert	LF	2	2	Rehab unit	n/a	n/a
			3	2	Rehab unit	n/a	n/a
			4	2	Rehab unit	n/a	n/a
			4	3	Replace unit	n/a	n/a
243	Other culvert	LF (34)	2	2	Rehab unit	$95	n/a
			3	2	Rehab unit	$300	n/a
			4	2	Rehab unit	$600	n/a
			4	3	Replace unit	$3,300	n/a

Notes

Expert Opinion MR&R Cost Data for Pontis

Core Elem. No.	Core Element Description	Units	Cond. State	Feas. Act. No.	Feasible Action Description	Data from No. Va.	Data from Culpeper
300	Strip seal expansion joint	LF (35)	2	2	Patch/reset/clean/joint	$15	
			3	2	Replace gland and patch concrete	$55	$75
			3	3	Replace joint	$165	$350
301	Pourable joint seal	LF (36)	2	2	Clean joint and replace seal	$25	$10
			3	2	Clean joint; patch spalls and replace seal	$125	$25
302	Compression joint seal	LF (37)	2	2	Remove and reinstall seal	$45	$35
			3	2	Replace seal and/or patch spalls	$145	$50
303	Assembly joint/seal	LF (38)	2	2	Rehab unit	$110	$50
			3	2	Rehab unit	$180	$300
			3	3	Replace unit	$275	$500
304	Other expansion joint	LF (39)	2	2	Rehab unit	$90	$50
			3	2	Rebuild unit	$170	$300
			3	3	Replace unit	$270	$500
310	Elastomeric bearing	each (40)	2	2	Reset bearings	$2,500	$500
			3	2	Reset bearings	$2,500	$500
			3	3	Replace unit and reset girders	$3,800	$1,000
311	Moveable bearing (roller, sliding, etc.)	each (41)	2	2	Rehab supports and/or reset bearing devices	$2,100	$700
			3	2	Rehab supports	$2,600	$1,000
			3	3	Replace unit	$3,900	$1,500
312	Enclosed/concealed bearing or bearing system	each	2	2	Rehab unit	n/a	n/a
			3	2	Rehab unit	n/a	n/a
			3	3	Replace unit	n/a	n/a
313	Fixed bearing	each (42)	2	2	Clean & paint or reset bearings and/or rehab suppo	$2,000	$700
			3	2	Rehab supports or bearings	$2,300	$1,000
			3	3	Replace unit	$3,200	$1,500
314	Pot bearing	each (43)	2	2	Rehab supports or bearing devices	$3,000	n/a
			3	2	Rehab bearing devices	$3,500	n/a
			3	3	Replace unit	$4,800	n/a
315	Disk bearing	each	2	2	Rehab supports or bearing devices	n/a	n/a
			3	2	Rehab bearing devices	n/a	n/a
			3	3	Replace unit	n/a	n/a
320	P/S Concrete approach slab	each	2	2	Perform mudjacking operations	n/a	n/a
			3	2	Place overlay	n/a	n/a
			3	3	Replace unit	n/a	n/a
			4	2	Replace unit	n/a	n/a
321	Reinforced concrete approach slab	each (44)	2	2	Perform mudjacking operations	n/a	$5,000
			3	2	Place overlay	$1,600	$1,000
			3	3	Replace unit	$14,000	$15,000

Notes

Expert Opinion MR&R Cost Data for Pontis

Core Elem. No.	Core Element Description	Units	Cond. State	Feas. Act. No.	Feasible Action Description	Data from No. Va.	Data from Culpeper
			4	2	Replace unit	$15,000	$15,000
330	Metal bridge railing	LF (45)	2	2	Clean and paint	$20	$10
			3	2	Clean and paint	$35	$10
			4	2	Rehab unit	$60	$25
			4	3	Replace unit	$150	$50
331	Concrete bridge railing	LF (46)	2	2	Rehab unit	$35	$25
			3	2	Rehab unit	$60	$35
			3	3	Replace unit	$150	$100
332	Timber bridge railing	LF (47, 57)	2	2	Rehab and/or apply surface treatmen3DN	$15	$10
			3	2	Replace unit	$35	$35
333	Miscellaneous-Bridge railing	LF (48)	2	2	Rehab unit	$30	$20
			3	2	Rehab unit	$50	$30
			3	3	Replace unit	$130	$125

Notes

(1) 200' long, 45' wide, no joint costs; multiple bridges, unit of 100 sf.
(2) 24' wide, 30' long, one span, unit of 100 sf.
(3) 3 spans, 140' long, 45' wide, 27" depth of concrete, unit of 100 sf.
(4) 3' wide x 4' high x 60' long (720 sf)
(5) Multiple cells (4-5); 8 - 10' wide; 4' high; multiple span; may be curved; 200' long; 2 lane; scaffolding suspended from bridge
(6) Includes plate girders; multiple span; 48" depth; hang scaffolding from bridge
(7) Includes plate girders; multiple span; 48" depth; hang scaffolding from bridge; working on entire bridge; 200' long
(8) 200'; 3-4 spans; 45" depth; hang scaffolding from bridge
(9) 200'; 4 beams; multiple spans; 30" depth; hang scaffolding from bridge
(10) stringer/floor beam system; 12" depth; 20' span
(11) 100' L truss (2 sf per lf)
(12) 100' L truss (120 sf surface per lf)
(13) 100' long by 30' wide
(14) 24" depth; 200' length; multiple (3-4) spans; (6 sf surface per lf)
(15) 4' deep; not in conjunction with other work
(16) 12" HP x 53; 60' length; multiple columns; 15' exposed; done in conjunction with other work; no restrictions due to traffic; i.e., can stay set up all day
(17) 15' exposed length; 12" x 12" size; 60' pile (4 sf per lf)
(18) 15' exposed; 3' diameter
(19) 12" diameter; 15' exposed
(20) 50' wide; #2 - 4lf of crack / lf of wall; 20' high
(21) rubble masonry walls; 24' wide x 12' high
(22) 45' wide; 8' high, exposed; in conjunction with other work; bridge closed
(23) 24' wide by 10' high with 12" by 12" timbers
(24) rubble abutments; 24' wide by 12' high
(25) 24" by 24" by 40' long (40 piles)
(26) 36" diameter column; 40' long (40 piles)
(27) 12" diameter by 40' long (40 piles)
(28) 36" box by 50' length
(29) 36", no box; scaffoling hung from bridge; 50' long steel beam bridge
(30) 3 columns, 3' wide, 4' deep, 45' long; one stage from ground, no done in conjunction with other work
(31) County bridge, 30' wide
(32) triple line 60" C.M. per lf of pipe (2' fill)
(33) 2 cell 10' x 10' x 50' length (2' fill over box)
(34) rubble masonry arches (20' span, 12' height, 50' length)
(35) 40' wide roadway; gland <= 4"; < 5 bridges
(36) 40' wide roadway, using high early strength, fast cure
(37) 40' roadway; done in conjunction with other work or 10 or more bridges (3" sealer)
(38) Sliding plate; 40' roadway width; can be placed with 4" strip seal

Notes

(39) Work on multiple bridges or activities; 40' wide (80' of joint)
(40) Elastomeric pad 20" by 12" x 1.5"; replacing 10 or more pads
(41) 8" x 16" x 4" with lubricated bronze
(42) Curved plate with 2 plates without elastomeric pads; 10" x 14"; > 8 bearings, jacking with slab in place
(43) 16" diameter
(44) 24' by 20'
(45) Metal posts on 10' spacings with 18" metal guardrail; brush paining. (50' length)
(46) J-barrier, setting on slab; 2'-4" high, multiple bridge or activities
(47) 4" x 6" post; 4" x 10" railing
(48) Concrete base with 2' metal rail
(49) 24' wide x 25' long
(50) surface area equals 1 sq. ft. per linear ft.
(51) surface area equals 5 sq. ft. per linear ft. of truss
(52) 12" x 24" beam at 5 sq. ft. per linear ft.
(53) 24" square x 20' long
(54) 3' diameter x 20' long
(55) rubble; 24' x 10' high
(56) County bridge, 24' x 10' (12" x 12" members)
(57) 2" x 8" timber posts at 6'; timber curb (4" x 6")