REPORT OF THE
DEPARTMENT OF TRANSPORTATION ON

METHODOLOGIES FOR DETERMINING LIFE CYCLE COSTS FOR HIGHWAY SYSTEM MAINTENANCE AND FACILITIES

TO THE GOVERNOR AND
THE GENERAL ASSEMBLY OF VIRGINIA

SENATE DOCUMENT NO. 33

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PREFACE

Senate Joint Resolution Number 21 was enacted during the 1994 General Assembly. This resolution requests that the Commissioner of the Virginia Department of Transportation study appropriate methodologies for determining life cycle costs for highway system maintenance and facilities. Recommendations are to be developed for improving the effectiveness, efficiency and economy of that maintenance.

This interim report was jointly prepared by A. V. Bailey, II, State Maintenance Engineer, and K. K. McGhee, Research Scientist. Others from the Virginia Department of Transportation who provided support include staff from the Materials, Policy Analysis, and Management Services Divisions.

EXECUTIVE SUMMARY

Life cycle cost analysis (LCCA) refers to an economic evaluation or methodology for determining present and future costs of an investment action. Principles of engineering economics such as interest rates and cash flow analysis are applied to proposed investment alternatives, as well as determining what the costs for the life of the project will be, beginning with design and culminating with salvage.

Leading research authorities in the public transportation field have documented the benefits of life cycle cost analysis including cost savings and selection of more efficient alternatives. The Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO) encourage application of LCCA. Literature, seminars, and a national symposium have elevated the importance of the methodology while illustrating its applications. FHWA recently issued a policy statement which recognized that the initial costs of a project only represent a fraction of the total cost; economic analysis limited to the first costs will no longer be acceptable for comparing infrastructure investment alternatives. The Life Cycle Cost Symposium in 1993 acknowledged limitations, however, that may be imposed upon public agencies required to conduct LCCA such as an inability to react to technological evolution, incomplete cost information, and lack of reliable performance models.

The Virginia Department of Transportation (VDOT) has applied LCCA since 1984. Primarily used in the past for new construction and major pavement rehabilitation projects, VDOT is improving its own methodology and has added the cost of traffic delays to the analysis. With the advent of the Intermodal Surface Transportation Efficiency Act and supporting automated technology, improvements and further use of LCCA will be applied to bridges, other major structures, and other infrastructure and operating facilities maintained by VDOT. Impairing the widespread and effective use of LCCA is the lack of cost and benefit information. Improved data bases of inventory, condition information, and design through maintenance costs are essential. Efforts to create and/or improve data bases are underway and should be continued.

LCCA ideals were developed in Phase I. The second phase of this study will involve application of these ideals in order to identify maintenance activities best suited for analysis. A final report will be prepared for the Governor and 1996 Session of the General Assembly.

INTRODUCTION

Senate Joint Resolution 21 (SJR 21) requests that the Commissioner of the Department of Transportation (VDOT) investigate ways that Virginia's transportation systems and facilities might better implement the principles of life cycle cost analysis (LCAA). In particular, the resolution asks that the department look at methodologies for determining life cycle costs for its assets and provide recommendations as to how these principles might best be applied to improve the efficiency and effectiveness of VDOT's maintenance practices.

The Department's Maintenance Division has taken lead responsibility for this study with a co-principal provided by the Virginia Transportation Research Council. Additional support has been provided and will be provided as necessary from the Materials Division, Policy Analysis Division, and Management Services Division. The Maintenance Management Research Advisory Committee and the District Materials Engineers will provide much of the guidance for this initiative.

The study is being conducted in two stages. The first phase combines a literature review with a series of interviews to establish both the state-of-the-art and the state-of-the-practice for application of life cycle cost analysis for transportation systems and facilities. Phase II will apply the ideals developed in Phase I to identify maintenance activities that are best suited to benefit from the application of LCCA.

The remainder of this document constitutes an interim report on Phase I. The primary focus has been a literature survey with an ancillary look at the more limited interview findings. The literature search produced studies that ranged from a discussion of the fundamentals of LCCA to its application for specific projects to its incorporation into entire maintenance programs. Personal interviews, which have included representatives from the state and federal governments, as well as industry, have basically run the same gamut of issues.

Phase I discussion begins with an overview of LCCA basics. A large portion of the discussion will address relevant activities by the federal government and the American Association of State Highway and Transportation Officials (AASHTO) to encourage application of LCCA by the states. A short discussion on the degree to which VDOT has applied LCCA will be followed by some preliminary conclusions and recommendations.

FUNDAMENTALS OF LIFE CYCLE COST ANALYSIS

In the interim policy statement issued by the Federal Highway Administration (FHWA) (Federal Register, July 1994), LCCA is described as "...an economic evaluation of all current and future costs associated with investment alternatives." In order to conduct any sort of economic alternative analysis that appropriately accounts for all costs encountered over the life of each option, a methodology has to be applied that establishes an "economically level playing field." The process of doing this is known as conducting cashflow discounting. Three of the most often used methods are discussed in a National Highway Research Program (NCHRP) Synthesis of Practice 122 [1]. These are:

Present Worth - convert all present and future expenses to a base of today's costs, total, and compare same with alternatives.
Annualized - convert all present and future expenses to a uniform annual cost. Smallest total annual cost is preferred.
Rate of Return - identify the discount rate at which two different alternatives have annual costs or present worths that are equal. Requires the calculation of rates of return on a large number of projects and on alternatives within projects (a trial-and-error solution).

An adequate treatment of discounted cashflow analysis cannot be carried out without a discussion of the *discount rate* and *analysis periods* used to affect this discounting. The discount rate is that interest rate used to reduce future costs or benefits to present-day terms. Likewise, it is also necessary to represent present and future costs and benefits in equivalent annual costs. There is general agreement that the discount rate should reflect the difference between the market interest rate and the inflation rate. The intention is to portray the real cost of capital, or the opportunity cost of money invested versus that earning interest or spent on an alternative. Of course, to truly weigh one alternative against another, the analysis periods over which these opportunity costs are applied are also critical. Although alternatives will almost certainly have dissimilar cost streams over different service lives, the analysis periods must be appropriately long and equivalent if legitimate comparisons are to be made. Even when annualized methods are used, short and/or disparate analysis periods can eclipse significant cash flows and skew an analysis.

The principles of engineering economics that describe interest rates, analysis periods and discounted cash flow analysis are, for the most part, well established. What continue to be subjects of great debate, however, are those costs that constitute the agency, user and other relevant costs incurred over the life of an investment alternative. Again, NCHRP 122 suggests that the following cost factors are those most relevant to analysis of state highways and facilities:

Design Costs - includes materials, site evaluation, traffic analysis, engineering design, plans and specifications.
Construction Costs - costs to construct in accordance with plans and specifications.
Maintenance Costs - includes corrective and preventive maintenance (whatever it takes to maintain above a predetermined level-of-service).
Rehabilitation Costs - rehabilitation or restoring to acceptable performance.
User Costs - may represent delay, increased operating, and denial-of-use costs incurred by traveling public.
Salvage Value - value at end of life cycle or analysis period. May be positive or negative depending on whether facility maintains some economic value or cost of demolition and removal exceeds value.

Energy Use - relative energy consumption, may fall under construction, maintenance, or rehabilitation costs. Very appropriate when considering items such as lighting, ventilation, and movable bridge span systems.

Of the above-mentioned factors, user costs are the least quantifiable and correspondingly the most controversial. As the upcoming discussion on national activities will point out, along with using appropriate analysis periods and applying suitable discount rates, calculation of user costs is a paramount issue on the agendas of state and federal highway officials.

NATIONAL ACTIVITIES INVOLVING LCCA

There have been several national/federal activities recently that address many of the issues pertinent to SJR 21. In December 1993, FHWA and AASHTO co-sponsored a symposium to learn more about states' activities in life cycle cost analysis. An important contributor to that meeting was a survey of state LCCA practices that had been distributed by AASHTO in June 1993. In January 1994, Executive Order 12893, "Principles of Federal Infrastructure Investment," was issued to speak to the need for infrastructure investment decisions to appropriately measure and discount all benefits and costs of an investment over its full life cycle. Finally, in July 1994, FHWA posted an interim policy statement to both fulfill the federal requirements of the Executive Order, and to confront the issues raised at the symposium of December 1993.

FHWA and AASHTO Life Cycle Cost Symposium

Participants of the Life Cycle Cost Symposium included representatives from state and federal government, academia, and industry. The symposium agenda included both general sessions and break-out discussion groups. The joint sessions were used for general discussion and the presentation of papers, among those being an overview of the AASHTO survey. The break-out sessions consisted of smaller working meetings where one group focused on LCCA applications for pavements, another on bridges, another on policy/planning/programming, and a fourth on the technical aspects of life cycle costing.

The break-out groups were responsible for the majority of the substantive conclusions and recommendations of the symposium. Although priorities varied slightly, depending on group backgrounds, there were a number of common themes. First, there was general support for LCCA for application in infrastructure investment, although there were mixed opinions regarding its definition. The desire to dissolve the widely recognized barriers between planning, design, construction, maintenance, and operations was another popular issue. A number of the participants, particularly the pavement and bridge people, saw the advantages of making maintenance eligible for federal funding. And lastly, it was agreed that performance models, costs, analysis periods, discount rates and user costs were critical issues in the implementation of LCCA.

Federal Executive Order 12893

The "Principles of Federal Infrastructure Investment" calls for every state agency to develop plans for infrastructure investment and management consistent with the following principles:

1. Systematic Analysis of Expected Benefits and Costs
2. Efficient Management
3. Private Sector Participation
4. Encouragement of More Effective State and Local Programs

A particularly pertinent stipulation involving the analysis of benefits and costs strongly suggested that the (benefits and costs) "..... should be measured and appropriately discounted over the full life cycle of each project..." in order to "...enable informed tradeoffs among capital outlays, operating and maintenance costs, and nonmonetary costs borne by the public."

Federal Highway Administration Interim Policy Statement

Essentially in direct response to this directive, the Federal Highway Administration is preparing a policy statement to establish the economic principles to be applied to infrastructure investment analyses. Although the statement is focused primarily on life cycle cost strategies for state bridge and pavement management systems, the fundamentals can be applied to the entire spectrum of assets maintained, or expended by a state agency. The general issues that the policy will address include what level of detail should be included in an analysis and what discounting methodologies are appropriate. For example, it is suggested that more detailed analysis is warranted when conducting LCCA on National Highway System (NHS) projects as opposed to non-NHS projects. It is also recommended that more attention would be appropriate for a reconstruction alternative analysis than when weighing maintenance options.

More specific items covered by the policy will include guidelines for selecting *analysis periods*, incorporation of *user costs*, and application of *discount factors*. The following are the major points concerning these items:

Analysis Periods: In general terms, the policy will suggest that analysis periods cover life of facility and account for all foreseeable future actions. Guidelines for analysis period lengths can be expected for major bridges, tunnels, hydraulic systems, and pavements.

User Costs: These costs will likely be associated with increased vehicle operating and delay costs anticipated over the life of the facility. They will include those costs incurred by the user due to decreased levels of service, as well as for delays around and through maintenance and construction work zones.

Discount Factors: Discount rates should be consistent with the guidance provided in OMB Circular A-94.

Perhaps the most significant element of the policy statement was the formal recognition by the FHWA that first costs of a project may only represent a fraction of its total life cycle cost (TLCC). Presumably, therefore, future projects can openly propose reduced maintenance costs and increased service lives to justify larger initial capital outlays without risking federal participation. Further, it may also represent some lenience towards the use of federal monies in facility maintenance. The essence of the policy is that economic analyses which consider only first costs will no longer be generally acceptable for comparing infrastructure investment alternatives. Appropriate proposals should also be accompanied by a thorough evaluation of expected current and future costs for all alternatives being considered.

VDOT STATUS ON LCCA

For approximately 10 years, The Department has been using life cycle cost analysis to compare various new construction and rehabilitation alternatives for pavement projects. The Department uses a Lotus spreadsheet to incorporate a 30-year analysis period, a four percent discount rate, and a salvage value of fifty percent of initial cost to conduct analyses. As of April 1994, pavement officials have also begun to address traffic delay costs.

LCCA has not been integrated as thoroughly into the bridge maintenance program. It is anticipated, however, that the traditional positions by the FHWA that would tend to encourage consideration of first costs only for alternative analysis will now be supplanted by suggestions that DOTs start examining future streams of costs for maintaining bridge joints, bearings, paint systems, etc. that can be significantly influenced at the earlier stages of design (e.g., continuous beam bridges have fewer joints and bearings than simple span structures, and prestressed concrete beam bridges do not have paint systems to maintain)[2].

Information Management Systems

The application of LCCA and improved inventory data bases will, in part, be facilitated by the Department's actions to meet ISTEA mandates for management systems. Both the Bridge Management and Pavement Management Systems' enhancements will include the history and type of construction, rehabilitation, and maintenance data. Physical features of the structure and roadway network collected, stored, and retrieved will include identification, location, referencing, type, dimensions, condition, etc.

The Bridge Management System enhancements include procurement and application of analytical software, "Pontis". Pontis provides bridge engineers and managers the capability for cost/benefit analysis. Optimization routines will be applied and used to select the best alternative treatment strategies. The analytical capabilities of the new Pavement Management System software will offer similar tools that decision makers need at the project level such as information which outlines the costs and benefits of alternatives in a simple format.

An Integrated Maintenance Management System (IMMS) is also being developed. Ultimately it will facilitate the Department to establish, update and maintain an inventory of maintainable items; plan, forecast, and budget resources; identify and schedule work; monitor and analyze outcomes; incorporate historical factors into future planning efforts; and develop a comprehensive program to continually review and update the business process. IMMS will not duplicate existing data bases or analytical software, but will improve automated access and interfacing. Enhancements may be necessary, however, to improve efficiencies and effectiveness.

String vs. Mast Signal Light Systems

Outside the areas of pavement and bridge, there are other LCCA activities underway. One example worthy of note originates in the Northern Virginia District (NOVA) to address the problem of selecting and justifying signal light installation systems:

> There are two fundamental alternatives at the disposal of traffic engineers for installing signal light systems. These are the traditional, although unsightly, string lighting option, and a newer system that uses heavy aluminum poles and cantilevered masts. The first option, where the lights are fastened to wires and cables and strung above the roadway, is relatively inexpensive to install ($50,000 - $70,000). The second option is more expensive to install ($70,000-$90,000). However, this option will allow the light unit to enjoy a relatively fixed state, relieving it of the wear and tear experienced by the strung unit that is subject to swing and bounce when exposed to strong winds. Another factor that is much less difficult to quantify, but perhaps just as influential, is that of aesthetics. Fairfax County, after seeing the difference in appearance of the two options, was all but insistent that the Northern Virginia District use, in every case possible, the mast system instead of the string. NOVA officials were able to apply life cycle costing methodologies to demonstrate that the reduced signal unit maintenance costs observed in the fixed mast system would recover the additional first costs of the mast over a reasonable analysis period.

PRELIMINARY CONCLUSIONS AND RECOMMENDATIONS FOR VDOT

The AASHTO/FHWA Symposium expressed significant concern for perceived limitations that may be imposed upon agencies that are required to conduct life cycle cost analyses. Examples of limitations included an inability to react to economical and technological evolution. Changes in user requirements were also recognized as a source of variability that could, for example, render a five year-old LCCA worthless.

In response to this, questions are raised: How do state agencies account for unforeseen technological advances in the analyses presently conducted? If these unanticipated changes are not addressed now, why expect to be able to accurately represent them with new economic analysis methods? The best that can be done is attempt to account for everything that is known; factor in those parameters that studies have shown may also contribute; initiate LCCA in workplanning; and fine-tune the LCCA process as life cycle costs are actually incurred, recorded and used in future analysis.

Agencies and agency officials should take advantage of the tools offered by life cycle costing, and take responsibility for developing and collecting those costs. This is not to say that these analyses should not include room in them for those shifts in the future that will affect the life cycle cost of a facility. Life cycle cost analyses should be a dynamic/temporal entity that accompanies a project, program, or network throughout its lifetime. Analyses should be updated annually and maintained indefinitely. In a comprehensive management system, life cycle costs of assets should be reviewed, primarily in an automated mode, with every inspection cycle.

As federal officials begin to enforce LCCA mandates, those mandates must be extremely flexible in examining the parameters, or cost elements, it accepts. For example, administering officials should expect to see figures placed on non-conventional factors accounting for inputs like political benefits and costs and long range planning speculations. They should expect to see numbers placed on items that have in the past only been implicitly included in decisions. To put it bluntly, administering officials will have to get used to seeing numbers assigned to some very "soft" things.

An ability to apply the tools made available through LCCA pivot exclusively on the ability to supply these tools with the cost and benefit information upon which there analyses are based. Hence, the most appropriate measures that VDOT can take are any that improve our ability to inventory, manipulate, and report this kind of information about assets. The *Inventory of Maintainable Items*, first introduced in "An Experimental Maintenance Management System,"[3] is an option that could be revisited, but any of the efforts underway to improve existing inventory data bases should be continued.

Appendix A of this report includes "How to Conduct The Roadway Maintenance Log Inventory". It recommends that an inventory include the following items:

1. Pipes (inlet & outlet ditches) - size and direction of flow
2. Box Culverts - size and number
3. Bridges - structure number
4. Entrances - with or without pipe
5. Signs - number and type on each post
6. Guardrail - length
7. Ditch Miles - ditchable areas
8. Shoulder Type - sod, gravel, or paved
9. Mowable Swaths - 1, 2,....n
10. Paved Ditches and Flumes - length
11. Curb and Gutter - length
12. Sidewalk - length
13. Drop Inlets - number
14. Waysides - number
15. Lights - number and type

To restore, update, and maintain this type of inventory would be a formidable task. Data collection, storage, and retrieval technologies have improved considerably in the last 15 years, however dedicated resources to successfully accomplish the tasks would be imperative.

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[1] Peterson, Dale E. 1985. *Life-Cycle Cost Analysis of Pavements.* NCHRP Synthesis 122. Washington, D.C.: Transportation Research Board.

[2]Conversation with State FHWA Structural Engineer.

[3]Hall, John H., McMillan, Glenn A., and Lisle, Frank N. 1979. *An Experimental Maintenance Management System.* Charlottesville, Virginia. Virginia Highway & Transportation Research Council.

SENATE JOINT RESOLUTION NO. 21

Requesting the Commonwealth Transportation Commissioner to study appropriate methodologies for determining life cycle costs for maintenance of the Commonwealth's highway system and facilities and to develop recommendations for improving the effectiveness, efficiency and economy in the maintenance of its systems and facilities.

Agreed to by the Senate, February 14, 1994

Agreed to by the House of Delegates, February 25, 1994

WHEREAS, the costs of improving, operating and maintaining the nation's third largest highway system continue to increase even though the unit costs for improvement, operation and maintenance remain low; and

WHEREAS, the Virginia Department of Transportation has undertaken value engineering and other cost-saving initiatives to reduce the costs of improvement, operation and maintenance; and

WHEREAS, the Department of Transportation currently uses life cycle cost analysis in the development, comparison and selection of project alternatives for improvement projects and maintenance replacement projects; and

WHEREAS, the use of life cycle cost analysis has resulted in reduced costs for improvement and maintenance replacement projects; and

WHEREAS, the potential for the use of life cycle cost analysis into other areas of maintenance and operation planning and implementation may provide additional economies, efficiencies and cost savings; now, therefore, be it

RESOLVED by the Senate, the House of Delegates concurring, That the Commonwealth Transportation Commissioner be requested to study appropriate methodologies for determining life cycle costs for maintenance of the Commonwealth's highway system and facilities and to develop recommendations for improving the effectiveness, efficiency and economy in the maintenance of its systems and facilities. The Commissioner is further requested to adopt procedures that show the greatest potential for ensuring that the most cost-effective methods are used in highway and facility maintenance; and, be it

RESOLVED FURTHER, That the Commonwealth Transportation Commissioner report his findings to the Senate Transportation Committee and the House Committee on Roads and Internal Navigation prior to the 1995 and 1996 Regular Sessions of the General Assembly.

The Commonwealth Transportation Commissioner shall complete his work in time to submit an interim report in 1995, if appropriate, and a final report to the Governor and the 1996 Session of the General Assembly as provided in the procedures of the Division of Legislative Automated Systems for the processing of legislative documents