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Abstract

Life Cycle Cost Analysis (LCCA) is increasingly gaining recognition by the transportation community as an indispensable practice, if the sustainability of its infrastructure systems is to be realized. This paper presents the product of a three-year study that assessed the LCCA practice within State Highway Agencies (SHAs). The study examined how LCCA practice changed in two decades, surveyed how LCCA is practiced currently at SHAs in the United States (US), and reviewed how this evaluation technique is deliberated by the academics and researchers in the engineering and economics domains. The results of this study prove noteworthy in the inspection of an observed gap between the state-of-the-practice and state-of-the-art of the LCCA. After all, this gap set up grounds for the noted mistrust in the credibility of LCCA. In addition to presenting the study results, this paper presents an analysis of the observed gap and its causes and concludes with recommendations on what can be done to bridge this gap; hopefully, it will prove valuable for practitioners conducting LCCA, for policy makers, and for researchers carrying out studies on various topics related to LCCA.
INTRODUCTION

Budget tightening, escalating costs for public-facility maintenance and increased populace censure of government-related expenditures have made all segments of our socioeconomic system tuned into the importance of effective management of resources and assets.

Transportation agencies especially are concerned because they rank among the top sectors in public spending, and the impacts of their investment decisions touch on every member of the society, making public scrutiny rather intense. Furthermore, an asset base of more than one trillion dollars (i.e., the value of the transportation system in the United States (US) as estimated by the Federal Highway Agency (FHWA) in 1999) is under the influence of many natural and man-made dynamics, which are often uncontrollable and/or uncertain.

Decision-making and effective asset management must be based on informed and conversant support. One of the most renowned techniques in the transportation domain for providing such informed support—when applied properly—is Life Cycle Cost Analysis (LCCA).

LCCA, as an evaluation technique, is predominantly considered necessary for appraising long-term public projects. Although this technique is based on well-founded principles of economics and engineering, many open questions about LCCA, as well as misconceptions about its applications, still linger. These open questions and misconceptions bring about certain mistrust in the LCCA outcome and doubt in its reliability. Open questions such as (1):

- Which costs should be included?
- Should benefits be included; if so, what type and in which form?
- What discount rate should be used?
- What is the reliability of the cost and benefit estimates?
- What is the length of the life cycle or the analysis period?
- What is the minimum acceptable or “trigger” level of serviceability of the infrastructure facility?

Resolving these open questions is not a straightforward matter. Many transportation societies, scientific research bodies, and State Highway Agencies (SHAs) embarked on research for developing guidelines that provide sufficient theoretical knowledge and directives to LCCA practitioners (2,3,4,5,6,7).

By the same token, in late 2000, the New Jersey Department of Transportation commissioned (to the authors of this paper) a research project to establish New Jersey State-specific guidelines for applying LCCA (8). An essential undertaking within the context of this research was to conduct a comprehensive survey of the current LCCA state-of-the-practice in the State Departments of Transportation (DOTs). The results of this survey were then 1) compared with the state-of-the-practice of LCCA that prevailed in 1984 and 2) compared with the state-of-the-art of LCCA. The resulting outcome was worthwhile and played a major role in the development of the LCCA guidelines as practical, applicable, consistent, and out-reaching to the major advancements taking place in this domain.

This paper presents the results of this study, which are valuable for LCCA practitioners, policy makers, and researchers. In the next section, the milestones of LCCA application are reviewed. Then, the research approach (a multi-stage survey) is described. The fourth section presents the survey results—the current state-of-the-practice—and compares it with the state-of-the-practice of LCCA in 1984.
The last three sections are dedicated to the main observations about LCCA practice, the differences between state-of-the-practice and state-of-the-art, and final conclusions.

LCCA MILESTONES

Although the 1998 Transportation Equity Act for the 21st Century (TEA-21), which replaced the 1992 Intermodal Surface Transportation Efficiency Act (ISTEA), had removed the requirement for SHAs to perform LCCA on NHS projects of $25 million or more, LCCA maintains its endorsement by the Federal Highway Agency (FHWA) uninterruptedly (2, 6).

Despite the relatively new interest in economic project evaluation tools such as LCCA, the concept of highway engineering economics was introduced as early as the end of the nineteenth century, when Gillespie issued his “Manual of the Principles and Practices of Road Making” in 1847. Gillespie characterized the most cost-effective highway project as one with the highest returns to the cost associated with its construction and maintenance (9).

However, this concept was not used in highway projects until the 1950s. The works of the engineering economist Winfrey in the 1960s and the American Association of State Highway Officials (AASHO) “Red Book” (1960) ushered in the concept of Life Cycle Cost Analysis to the transportation domain (10, 11).

Realizing the impacts of considering the life cycle costs in the evaluation of transportation projects, extensive research began; it focused on issues like data gathering and integration but, for the most part, it aimed at quantifying the user cost and vehicle operating cost by conducting field experiments, such as the road test experiment that was initiated by the World Bank in Brazil in the 1960s and the development of empirical models of these costs (10).

In 1984 the National Cooperative Highway Research (NCHRP) commenced project number 20-5 FY 1983 with the aim of promoting LCCA (9). This project investigated the state-of-the-practice of LCCA in transportation agencies at the time and examined the different aspects and parameters of the process. The AASHTO, in its Pavement Design Guides of 1983 and 1993, endorsed the use of LCCA as a means for economic evaluation and as a decision support tool (12).

The 1992 ISTEA (sections 1024 and 1025) called for “the use of life cycle costs in the design and engineering of bridges, tunnels, or pavement” both for metropolitan and statewide planning. Federal Executive Order 12893, issued in 1994, outlined the principles of public investment and stressed the importance of including life cycle costs when making decisions regarding public infrastructure investments. Subsequently, the National Highway System (NHS) Designation Act of 1995 mandated the States to perform LCCA on NHS projects costing $25 million or more. In 1996, the FHWA released its Final Policy statement on LCCA (13).

In an effort to advance and regulate the application of LCCA in SHAs, the FHWA carried out Demonstration Project 115 “Life-Cycle Cost Analysis in Pavement Design” in 1998 and developed an instructional LCCA workshop that has since been presented many times in various states. In addition, a noteworthy technical bulletin, which outlined the best practice of LCCA methodology and discussed its related parameters, was published (2).

In 2000, within FHWA, the LCCA came under the charge of the Office of Asset Management (14). One of their recent products (late 2002) is the development of an LCCA instructional software package for pavement—FHWA Probabilistic LCCA. In the domain of bridges, National Cooperative Highway Research Program initiated project 12-43 in 1996. The resulting report 483 presents a comprehensive methodology for carrying out Bridge Life Cycle Cost Analysis (BLCCA) and accompanying software that automates the methodology (15).
The importance of LCCA is widely recognized in developed countries as well as developing countries. The introduction of the World Bank evaluation model “Highway Development and Management” (HDM-4) and its predecessors in the last decade (which focuses on the consideration of the life cycle costs of projects) had signaled a keystone in LCCA practice at the international level. Furthermore, the continuous training and promotion activities of this model managed by the World Road Association (PIARC) had lead to the global distribution of interest in this practice as evident from the 700 HDM-4 registrations in 106 countries; many of these registrations are in the developing countries and transition economies.

Research commissioned by the SHAs and other interested partners continues to be conducted on a broader scale. The research covers LCCA in the context of planning and management for transportation projects, as well as other contexts. It addresses issues such as data management and integration, treatment of the uncertainty in LCCA parameters, and the boundless topic of related user and social costs.

RESEARCH APPROACH

The brief history of LCCA presented above clearly demonstrates the efforts by both Federal and State governments in encouraging the use of LCCA as a project-level evaluation tool. The major question posed in this paper is two fold:

1. What is the current state-of-the-practice of LCCA in SHAs in the US today? How is the current state-of-the-practice of LCCA in SHAs different from the state-of-the-practice in 1984—when a comprehensive survey was first conducted on LCCA practice?

2. Given the acknowledged state-of-the-practice of LCCA in the US nowadays, what are the major differences between its current state-of-practice and state-of-the art?

The current state-of-the-practice of LCCA was determined by conducting a three-stage survey. Each stage had a distinct approach and was completed at different times. The approaches were designed to be diverse, complementary of each other, detail-oriented, and, at the same time, broad.

Stage One: This stage commenced in September 2000. It consisted of exploring the websites of State DOTs, reviewing published DOT reports, and making personal contacts with DOT personnel to inquire about the LCCA practice, in the general sense, within their respective departments.

Stage Two: This stage was completed in the five-month period between January 2001 and May 2001. A detailed questionnaire was sent to the members of the Research Advisory Committee (RAC) list serve, which includes representatives from the 52 State DOTs. It was anticipated that contacting the members of the RAC, who are in charge of research and development activities in each State DOT, would attract more illustrative responses—not restricted to one sector such as pavement—and ensure a higher response rate.

Stage Three: This stage was completed in September 2002. It consisted of a follow-up questionnaire to discern if any modifications in LCCA application had occurred within the department since the first two inquiries, as well as to solicit additional information.

Table 1 displays which State DOTs partook in our survey at each stage, also Figure 1 displays the geographical representation of the responses. The three-stage survey had obtained information from 39 State DOTs. The first stage (open inquiry) played a role mostly in the retrieval of published guidelines and manuscripts about the LCCA, as well as a number of LCCA
DOT customized software packages. The questionnaire in Stage Two contained 25 questions, each with a number of predefined answers and, yet, some space for subjectivity where needed. The questionnaire was formatted as such because of the indistinctive nature of the responses to our open inquiry in Stage-One and its low response rate (Table 1).

The 25 questions in Stage Two questionnaire were divided into four sections. The first section inquired about institutional and administrative aspects of the department. The second section had eight questions that covered the actual implementation of the LCCA—how long LCCA has been applied, which offices apply LCCA, on what type of projects, etc. The third section contained six questions that dealt specifically with the LCCA input parameters—what costs are considered in LCCA and how the discount rate and the inflation rate are decided on, as well as what analysis period is considered. The last section had six questions that investigated how LCCA is perceived by practitioners in general, what credence its outcome has—when performed—on the decision-making, whether any monitoring and/or feedback is ensued to assess LCCA application, and, finally, what practitioners recommend to achieve more efficient and credible LCCA practice.

In Stage Three, the follow-up questionnaire focused on some ever more deliberated issues in LCCA: the statistical approach used in performing LCCA (deterministic versus probabilistic), any modification in LCCA application specifically in the value of the discount rate used, the reconsideration of including the user costs, and the use of other evaluation tools besides LCCA and their effect on the decision-making in the respective State DOT.

Regarding the state-of-the-practice of LCCA in 1984, it was mainly determined from the results of a survey conducted by the Transportation Research Board in that period as part of a NCHRP research project and documented in NCHRP Synthesis No. 122, titled “Life Cycle Cost Analysis of Pavements” (9). This 1984 survey collected information about the LCCA practice from 49 State DOTs (including some Canadian DOTs). The questionnaire, at the time, focused on LCCA practice specifically in pavement projects; yet, several of its questions are reminiscent of the 2001 survey questions—such as what type of costs are included, what values are used for each economic input parameter, what the sources of data are, how computers are utilized in LCCA. This partial consistency between the two questionnaires provided a legitimate ground for the objective assessment discussed below.


Information obtained from the three-stage survey was compiled and analyzed thoroughly. The first noteworthy finding was that 18% of the respondents indicated that they currently are not using the LCCA (Figure 1). This shows that in 17 years, the percentage of State DOTs using LCCA increased to some extent when compared with the results of the 1984 survey, where 63% indicated the use of LCCA in some form. One respondent answered that “…they do not need to use it, since their capital investments are below the 25 million dollar threshold mandated by the Congress…” (even though this mandate was removed in 1998). The results and analyses from the responses of State DOTs that positively confirmed LCCA practice are described below.

**General Application of LCCA**

The 2001 survey revealed that LCCA practice in State DOTs goes back at least thirty years; the time-span of this practice varies between eight and thirty years with a mean value of sixteen years. Notwithstanding, the 1984 survey averaged the time-span of LCCA practice at the time as
One would anticipate that if in 1984 the average time-span was 17.5 years, then seventeen years later (in 2001), this time-span would be approximately 34 years. To illustrate this argument unequivocally, when asked in 1984 how long they have been using LCCA, representatives of one State DOT answered 10 years, whereas in 2001, the same DOT answered 10 years. Another State DOT indicated in 1984 that they have been using the LCCA since 1966, while in 2001 their answer was 10 years. This unexpected outcome can have one explanation; the proper documentation of LCCA actual practice—that assures the continuity and informs the new-to-the-job practitioners about previous practice—is inadequate in some State DOTs.

Needless to say, this deficiency has many adverse effects, principally the inability of the department to monitor and assess previous analyses and/or decision-making in a meticulous manner and, consequently, its inability to improve these two critical processes.

Table 2 summarizes the survey responses regarding the particular offices or divisions where LCCA is conducted. Of the design and research offices in State DOTs, 68% perform the LCCA. This high percentage shows the potential for a wide-ranging application of the LCCA (eg, not only in pavement projects). On the other hand, it is important to ensure that the outcome of LCCA, when performed by Design and Research offices, is integrated in the decision-making process; this provision might be easier-said-than-done for certain DOTs. Materials and pavement offices ranked second in the use of LCCA, both representing 37.5% of the respondents; whereas bridges offices had the lowest percentage in the use of LCCA at 12.5% of the respondents.

Another question asked about the type of projects that is evaluated using LCCA. All of the respondents, indicated pavement projects, whereas only 25% pointed out bridge projects. Intelligent Transportation System (ITS) projects—an emerging type of transportation project that make use of advanced technologies and communications to better manage the transportation system—was listed in the possible answers. However, only the California Department of Transportation (CALTRANS) reported positively the use of LCCA in evaluating them. On the other hand, according to the Stage-One investigation, research work in ITS evaluation by means of cost-benefit (B/C) analysis is increasingly reported—LCCA is considered a restricted form of B/C analysis (3, 16). At present, these ITS B/C analyses are conducted or sponsored by a few State DOTs to establish the feasibility of such projects, but the pertinent incorporation of ITS evaluation within State DOT practice is yet to come.

About 60% of the State DOTs indicated that they already have formal guidelines for the application of LCCA. Nevertheless, when reviewing the publications and reports of these guidelines, the levels of detail vary widely from well-established procedures involving every aspect of LCCA application to a two-page summary of the LCCA technique incorporated in the pavement design manual. Most of the State DOTs opted to focus their guidelines on one or two aspects of the LCCA that mainly concerned them. The focus of these reports was categorized into three areas. The first category contains the majority of State DOT LCCA guidelines or reports. These guidelines were issued as an “instructional guidebook.” It explains the LCCA process, theory, purpose, and parameters (ie, economic indicators, formulas, and input parameters) and might recommend the use of previously collected information (ie, timing of future rehabilitation and unit cost of items) in their databases. An illustrative example of such reports is the Colorado DOT report on LCCA (5). The second category involved LCCA reports (two reports) that used pavement performance models to estimate some of the LCCA components more efficiently—mainly, the timing of activities and user costs (10). The last category expanded the use of the LCCA more resourcefully; it incorporated the LCCA as part of
other practiced agency processes, such as value engineering or interfacing the LCCA project-level evaluation with the network-level evaluation and programming. The number of LCCA documents in the last two categories is, in fact, minimal, and such reports mostly are the result of a collaborated research effort between State DOTs and academic institutions. No specific question was posed about the presence of State-specific LCCA guidelines in the 1984 surveys. Nevertheless, the synthesis (9) included three reports or examples of how LCCA was perceived at the time; these consisted of a concise economic analysis section incorporated within the pavement selection procedure.

One question in the survey asked about any preset criteria (eg, amount of investment or project classification) that warrant the use of the LCCA. The findings revealed no common criteria among all the DOTs; each agency had set its own norm derived from its general policies. About 25% of these agencies had no preset condition whatsoever for using LCCA—and it was executed on a case-by-case basis—whereas 20% of the agencies applied the LCCA only to new construction projects. Other criteria considered interstate highway or federally funded projects, projects with more than one design alternative, or projects with an initial cost of more than one million dollars.

With the recent advancements in the Information Technology (IT) arena, it is useful to understand the effects of the widespread deployment of computers—hardware and software—on the use of LCCA in State DOTs. In 1984, the survey results, as expected, indicated that only 10% of the agencies were using computers in their analysis; half of these agencies had developed a simple program for the LCCA. The 2001 survey asked if the agencies were using any specific software package to perform the LCCA; 50% of the respondents answered positively. Out of these, more than half had already developed their own customized programs, and the remaining agencies were using the LCCA module in DARWin, a pavement design system developed by AASHTO. The survey findings, in addition to the information obtained from personal interviews with LCCA practitioners, underline two important features desired in the LCCA software: minimalism, directness yet customizability. The recently introduced FHWA Probabilistic LCCA software package as such—even though it is only applicable to pavement projects—is expected to be of great value to any LCCA practitioner (18).

**LCCA Input Parameters**

This section presents the findings regarding LCCA input parameters. The 1984 survey revealed the lack of a general consensus about the choice of LCCA input parameters—particularly the economic parameters, such as the discount rate, inflation rate, and analysis period. An on-going dispute was (and is) ensuing about the proper values for the economic parameters to obtain reliable and reasonably acceptable analysis results. In 2001 about 85% of the survey participants responded that their agencies specify values or guidance for the LCCA input parameters (Figure 2).

Figure 3 displays the responses regarding the choice of the discount rate. In 1984 the discount rate ranged between 0 % and 10% with a mean of 4.3 % (Figure 3), whereas the 2001 survey results showed that the applied discount rate ranged between 3% and 5% with a mean of 3.9 %. Examining Figure 3 carefully indicates that the responses of 1984 are more dispersed over a wider range, while the 2001 responses are more clustered signaling a better consensus among State DOTs; furthermore, the 2001 responses introduced the choice of the annually published Office of Management and Budget (OMB) rates as the discount rate in LCCA. Regarding the inflation rate, in 1984 was used by only 19% of the agencies and ranged between 4.1% and 6%
with a mean of 5.3%. Similarly, the inflation was considered in 2001 by only 18% of the agencies but it had lower value that ranged between 2% and 3%.

The analysis period is one more uncertain input parameter in LCCA. The State DOTs were asked what analysis period they consider in their LCCA. Figure 4 illustrates the results for the two surveys, the 1984 and the 2001. Comparing both results shows that State DOTs are moving towards longer analysis periods in their evaluations. And similar to the discount rate parameter, the responses of State DOTs exhibited more agreement on the choice of the analysis period. In 2001, this parameter ranged from 30 to 50 years with 44% indicating that this period varied between projects, while in 1984 the analysis period varied between 20 and 40 years with a mean of 29.7 years. It has to be noted that the above mentioned values for the analysis period are reported for the evaluation of pavement projects. For bridges projects, there was no specific value for the analysis period, and agencies reported that this period varied on case-by-case basis. The higher analysis period—for pavement projects—results from the aspiration for a longer pavement lifetime, as well as the continuous introduction of improved materials and construction techniques.

The incorporation of user costs in the analysis significantly differs between agencies. In 1984, none of the State DOTs (except Maryland) incorporated any type of user costs. Of the 2001 respondents, 69% stated that they did not consider these costs in their analysis at all (Figure 2). The most common explanation for this (high percentage) is the complexity of the procedure, and, as one agency engineer answered, “We do not include the user costs…the user costs overwhelm the process…but one day we’ll bite the bullet.” On the other hand, 36% of the agencies that consider user costs in their analysis have developed systematic approaches for calculating these costs (17). Understandably, these approaches are only employed where specialized software is used. On the whole, when respondents reported the inclusion of the user costs in their analysis, they referred to the user delay cost only during major rehabilitation activities. One specialized program for calculating user delay costs during work-zone activities, QueWZ, is recognized by many State DOTs. The FHWA Probabilistic LCCA package also has incorporated a module for calculating these costs, but this software is yet to be used on a broad scale (18). The respondents made little suggestion that other types of user costs—such as vehicle operating costs during normal operation in pavement projects or the cost of failure in bridge projects—are actually considered in LCCA as applied in State DOTs. None of the State agencies considered any type of encountered social costs in their analysis except the California DOT, which indicated the possible inclusion of such costs.

The final statement on the input variables refers to the statistical approach used in the LCCA. Most of the input variables of LCCA are uncertain in nature (eg, the discount rate varies during the analysis period, and the time for rehabilitation activity may occur over a range of years). This uncertainty can be treated either by using risk analysis (the probabilistic approach) or by performing sensitivity analysis. In the actual LCCA practice, the uncertainty is well understood, to the point that this uncertainty, at times, causes the mistrust in the efficacy of the LCCA. On the other hand, most State DOT analysts treat this uncertainty by applying sensitivity analysis in its simplest form. Commonly, this process consists of applying LCCA for a range of discount rates. In Stage Three of the survey (late 2002), the authors specifically explored if this treatment of uncertainty had advanced between early 2001 and late 2002, especially with the publications of the FHWA Interim Technical Bulletin on LCCA, which fostered the application of Monte Carlo Simulation in 1998 (2) and the introduction of the FHWA Probabilistic LCCA software in 2002 (18, 19). The responses indicated that, at the time, barely any State DOTs had
actually expanded their treatment of this uncertainty through the application of the probabilistic approach (i.e., Monte Carlo simulation). Alternatively, almost all respondents expressed their intention of doing so in the near future.

**LCCA in Combination with Other Processes**

The credibility of LCCA results largely relies on the source of data used. The values of most of the input parameters should be based on the actual practice in the agency. As the engineering results are imperative in determining the alternative design strategies, the previously practiced rehabilitation and maintenance procedures of the agency represent a key factor in predicting the future actions of the agency. A systematic documentation of agency projects—from the initial construction of highways to routine repairs and reconstruction with detailed expenditures and timings—ensures the availability of data required for LCCA. The majority of the State DOTs in 2001 had already set up their pavement management systems. However, only a few agencies had implemented a simple routine for retrieving the required information in an acceptable format for project-level evaluation. The 1984 survey and its resultant synthesis had pointed out the importance of well-designed pavement management systems; at the time, some agencies had some form of a pavement management system, but none of these systems had progressed far enough for use in the pavement selection process.

The response to a question about the sources of the data used in the LCCA indicated that all of the State DOTs have their own databases. In addition to their data, 13% of DOTs use consultant data, and 25% may employ other sources of data. Some State DOTs obtained the information needed for the LCCA inputs from their PMS and published it in their LCCA guidelines.

Stage One of our survey revealed that many of the DOTs employ LCCA as part of their value engineering (VE) system; this finding called for further investigation about the extent of this employment. Of the State DOTs, 57% confirmed the use of LCCA in combination with VE in the design stages, whereas 25% of the DOTs answered that although they do not practice this at the present time, they plan to in the future. None of the respondents indicated using LCCA in combination with VE principles in the bidding stage. The remaining 13% answered negatively about applying LCCA in combination with VE.

**Implementation of LCCA Results**

In addition to its main objective of choosing the most cost-effective alternative for an investment, LCCA may be applied to other domains, such as the selection of bidders, using the breakdown analysis to establish the pay schedules for contractors, or program planning. The survey contained three questions investigating the prospects of using LCCA results in other procedures.

According to the survey, none of the State DOTs use LCCA in their project contracts—except for the New York State DOT, which indicated that it has a special provision in their contracts for applying LCCA. Moreover, only two State DOTs, Michigan and New York, responded that they make use of LCCA outcome in the process of selecting bidders. None of the participating State DOTs indicated using the breakdown analysis of LCCA outcome in determining pay schedules; only the Iowa State DOT exhibited the intention of doing so in the future. The 1984 survey did not include any inquiries about other uses of LCCA.
Evaluating LCCA Application

The last part of the Stage-Two questionnaire was designed to evaluate the actual application of LCCA techniques based on the experiences of the DOT analysts. The survey respondents were asked to identify the purpose of applying LCCA in their agencies and to comment on the actual implementation of this process. The most common statement by the respondents was that LCCA is the proper tool for choosing between different alternatives. Another analogous reason given for its use was that the LCCA could assist in achieving economically sound decisions and implementing cost-effective investments of taxpayer money. Other motives included the interest of the agency to account for user costs, which could only be achieved by applying LCCA. One State indicated FHWA requirements as the main drive behind applying the LCCA, whereas another State DOT indicated the necessity for a better management of the annual maintenance costs.

The respondent’s ratings of LCCA confirmed mixed views regarding LCCA application. Of the respondents, more than 43% rated their LCCA application to be neither successful nor unsuccessful. On the other hand, the remaining 57% indicated the successful application of the LCCA and their approval of the outcome. Moreover, 50% of the respondents openly recognized the benefits of LCCA and recommended its more frequent use; the remaining 50% expressed their satisfaction with their current application and suggested maintaining the current application level.

MAIN OBSERVATIONS

In addition to the direct results of the survey, which were discussed earlier, other noteworthy observations were made from the study of the state-of-the-practice of LCCA. This section summarizes the main points of these observations:

- In the transportation sector, LCCA is acknowledged as a robust evaluation technique for choosing between different types of pavements (ie, flexible vs rigid) or between different types of pavement rehabilitation. The potential benefits of the LCCA and the applicability of this technique to evaluate other types of investment in the transportation domain is yet to be fully recognized despite the amount and quality of academic research conducted in this domain.

- A clear misconception about the LCCA is that it accounts for agency or real costs only. This misconception blurs the difference between economic analysis and financial analysis—a very profound oversight that must be avoided; otherwise, the rationale behind including only agency cost must be clearly stated (ie, proved to be equal for all alternatives).

- Governmental guidelines and reports on LCCA (or any evaluation technique) can impact its actual implementation in SHAs significantly. This is obvious from the recent consensus about many aspects of the state-of-the-practice of LCCA in 2001. For example, the values used for the discount rate and the analysis period, the inclusion of the user delay cost during rehabilitation activities, and the intention of adopting the probabilistic approach are all based on the recommendations provided by the FHWA in the Interim Technical Bulletin of LCCA (2). Therefore, any guidance must be evenhanded and based on proven scientific research. Transportation practitioners generally tend to follow FHWA reports unreservedly, and one can expect that any FHWA recommendation for a specific situation might be applied mistakenly to all cases if not
clearly warned against that. For instance, the above-mentioned report does not promote the inclusion of the vehicle operating cost component during normal operation. This exclusion is justified as long as the serviceability level of the pavement is above the acceptable threshold (which is likely on interstate highways). However, other arterials may not enjoy this level of performance. The latest published “Highway Statistics” by the US DOT in 2001 reported that about 30% of the miles-traveled under the functional classification “Other arterials” were pavements with an international roughness index (IRI) more than 170 in/mile, whereas 15% of miles traveled under the interstate highway system had an IRI more than 170 in/mile. According to transportation research, not considering user costs in during normal operation in the LCCA is a serious shortcoming. In brief, any general guidelines must address all possible conditions and be as comprehensive as possible. Otherwise, the long-term implications might be difficult to remedy (20).


When the current state-of-the-practice of LCCA in State DOTs was established, it was compared with the state-of-the-art. The state-of-the-art of LCCA is based on the literature review of academic research (20, 21, 22, 23, 24), and national and international guidelines—governmental and nongovernmental such as the FHWA and the World Bank publications (2, 13, 16, 25). The existence of a gap between practice and the well-established theory of LCCA was evident from our assessment. Figure 5 illustrates systematically this observed gap in the context of the general procedure for conducting LCCA. The gap is the result of four basic disparities in the practice:

- **The statistical nature of the uncertain input parameters**—In the state-of-the-practice, virtually all analysts assume discrete values for the uncertain input parameters, whereas in the state-of-the-art, uncertain parameters are represented by probability distributions that best describe the possible variability in the value of the parameter.

- **The determination of the timing of future rehabilitation activities**—In general, State DOTs rely on their expert opinion and past practices to establish the life cycle strategies for the alternatives, which specify the timing of rehabilitation, upgrading, and reconstruction. On the other hand, research in academia has utilized facility performance prediction models to predict the time when rehabilitation activities must take place in accordance with a preset minimum threshold for the facility serviceability (i.e., each type of distress or a composite index of distresses).

- **The inclusion/exclusion of user and social costs**—The general tendency of State DOTs is to exclude some components of the costs encountered by the users (especially during normal operations) from the LCCA of transportation projects based on the assumption that such costs are common to all alternatives. However, the research on how to quantify and monetize such costs—VOC, comfort, risk and reliability, noise, health effects, etc—continues to grow as these cost components are proven to be significant based on years of empirical and theoretical research results. More importantly, LCCA practitioners tend to exclude user costs in their analysis based on the unfounded argument that user costs are not real costs, let alone the difficulty in monetizing these externalities.

- **The treatment of uncertainty**—State DOTs usually have overlooked the uncertainty factor when applying LCCA. Generally, the outcome of LCCA is a point-estimate; at best, a
simple sensitivity analysis—on the effects of different discount rates—is conducted. Risk analysis via the probabilistic approach is gaining enormous acceptance, and easy-to-use programs that perform this analysis is being introduced continuously (18, 26). State-of-the-art is advancing clearly on the use of probabilistic techniques based on Monte Carlo simulation to treat uncertainty in LCCA.

CONCLUSIONS

Establishing the current state-of-the-practice of LCCA using our three-stage survey approach had achieved several objectives; among them are: 1) determining the level of appreciation of LCCA by the decision-makers in the transportation sector at State DOTs; 2) recognizing the key points that determine the success or failure of LCCA application; 3) identifying how practitioners deal with the open questions of LCCA—mentioned in section 1; and most importantly, 4) recognizing the major road blocks that practitioners face in LCCA application.

Trying to capture the progress of LCCA practice in the last two decades (1984-2002) and comparing it with the current state-of-the-practice were necessary because these years were decisive for LCCA implementation. This can be attributed mostly to the advancement in computing technology, which made the most complicated algorithms readily solvable in a short time, and to the notable consideration the federal government is paying to LCCA, which is obvious in the number of laws encouraging, mandating, or guiding the application of LCCA in the evaluation of the transportation system, as discussed in the LCCA Milestones section. As a result, this comparison helped in 1) identifying the consequences of publishing legislation and federal guidelines on the actual practice and 2) discovering if the attained computing power had any effect on the proper deployment of LCCA. Still, a significant gap between the practice and theory of LCCA is observed. To bridge this gap and to apply the LCCA more reliably in SHAs, a few key considerations can be listed below:

- the founding of a protocol for LCCA application in the transportation sector that specifies the course of action in choosing the economic parameters, costs, and/or benefits to be included in the analysis for all types of projects, as well as treatment of uncertainty.
- ensuring the development and maintenance of high-quality databases of state-specific LCCA parameters (unit costs of items/procedures, rehabilitation treatments and timings, inventory of facilities/segments, updated condition assessment, etc).
- development and/or calibration of state-specific models for predicting future conditions or performance of transportation facilities
- incorporation of systematic validation, monitoring, and documentation procedures of ex-ante (prior to implementations) evaluation analysis.
- the continuous development of training and technology-transfer activities of the LCCA procedures to ensure that the policy-makers and decision-makers accept LCCA as an indispensable evaluation technique that helps them make more reliable and effective management decisions.

It is evident that the long-term and short-term benefits of applying the LCCA—as undoubtedly understood and scientifically shown by the academic community—are not as clearly observed in practice. According to our survey results, questions and doubts about various
components and results of LCCA still remain among practitioners. Besides the stated objective of choosing the alternative with the least net present cost (incurred by the agency), far-reaching benefits, such as optimizing life cycle costs, competent asset management systems, cost-effective resource allocation—as well as the immediate benefits, such as using LCCA in establishing pay schedules and minimizing the intangible costs encountered by the users and the society—are only gradually infiltrating into the actual practice of the transportation industry. However, the use of LCCA for transportation projects as an efficient decision support tool will undoubtedly continue to grow as long as the public and policy-makers demand better management of scarce resources in the long run.

ACKNOWLEDGMENT

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References

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### TABLE 2  Offices Conducting LCCA in State DOTs

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FIGURE 1 Geographical Representation of Responses in the 3-Stage Survey
Ozbay, Jawad, Parker, Hussein

FIGURE 2: LCCA Input Parameter Guidance in State DOTs

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Paper revised from original submittal.
FIGURE 3: Discount Rate as Employed by State DOTs in 1984 and 2001
FIGURE 4: Analysis Period as Employed by State DOTs in 1984 and 2001
FIGURE 5: State-of-the-Practice vs State-of-the-Art of LCCA

1) Establish Alternative Design Strategies

2) Define General Economic Parameters:
   Discount Rate, Inflation Rate, Analysis Period

3) Generate Future Rehabilitation Activities for Each Alternative:
   Nature & Timing

4) Estimate all Differential Costs for each alternative:
   Agency, User, Societal

5) Establish Expenditure Stream Diagrams for each alternative

6) Compute the differential Economic Worth (i.e. NPV) for each alternative

7) Analyze Results and Reevaluate design Strategies

State-of-Practice LCCA Approach

- Use Discrete Values for each variable based on the average
- Nature and Timings are based on Previous Practice within agency & expert judgment
- User & Societal Costs are Excluded (User costs/work zone are sometimes considered)
- Compute a Point Estimate of Results, Simple Risk Analysis can be performed

Advanced LCCA Approach

- Use Probability Distribution for each Uncertain Variable
- Nature and Timings are based on Facility Performance Models for the controlling factors
- User & Societal Costs are considered by utilizing empirical performance models of the facility with cost models
- Perform Monte Carlo Simulation of the model & Present Final Results as Probability Distribution of possible outcomes

User & Societal Costs are considered by utilizing empirical performance models of the facility with cost models