An Empirical Study on Pavement life cycle cost with Computer Programs

1priyesh gour, 2Dr. Shalini Yadav
1Ph.D. Scholar Department, 2Head Department of Civil and Environmental Engineering
Rabindranath Tagore University, Bhopal

***Abstract* - Development of the pavement network systems, which is inevitable due to the rapid economic growth, has increasingly become a topic of significant concern because of the severe environmental impacts of road expansion. For achieving the sustainable development goals (SDGs), the policies and actions towards the pavements' life cycle assessment (LCA) and life cycle cost analysis (LCCA) must be carefully assessed. Consequently, the purpose of this review is to present an overview of LCA and LCCA used in pavement engineering and management. Through the quality control of PRISMA, fifty-five most relevant documents were extracted for a thorough investigation. The state of the art review reveals that a limited number of the papers considered environmental impacts of the pavements. Consequently, to assess the environmental impact cost, a conceptual framework was developed to better consider the LCA and LCCA on various aspects of the pavement projects including the sustainability aspects. Besides, a case study was given to validate the literature review towards proposing a novel framework for the incorporation of environmental impact cost.**

***keywords* - Life-Cycle Cost Analysis (LCCA); Pavement management; LCCA software; Net Present Value (NPV)**

1. Introduction

Mobility networks are expanding in a fast paced. Sustainability and environmental aspects of the expansion of the road networks and pavements development have become the major concerns. In addition to the major attention towards pavement projects and economic growth, the severe environmental impacts had been widely neglected. Currently, the value of pavement projects is very immense, where not only the capital cost, but the operation, maintenance, and disposal cost also need consideration [1]. Likewise, with the immense growth of the pavement projects, the environment faces sustainability issue with toxic gaseous emissions, pollutant emissions, added fuel consumption, and noise pollution. Significant monetary procedures are required to overcome the issues of sustainability throughout the project life from the initial construction phase to the rehabilitation phase or end life to enhance serviceability. To maintain the proper functionality of the project, the user phase of the pavement project needs timely upgrading, as it has the longest duration in the life cycle [2–4].

Within 1950 the concept of benefit-cost analysis (BCA) was primarily applied as a range factor for various pavement design options. Then within 1970, LCCA principles started actuality applied in some key projects at the local and national state levels for pavement design and pavement type selection. "As presented in Fig. 1, the aim of LCCA represents the extent and details of the following steps"[20]. "All leaders and stakeholders should completely collaborate so that full effectiveness is achieved"[3].

Since the mostly inadequate funding under normal circumstances, road specialists are consistently challenged with funding projects thanks to resource insufficiency. Moreover, with the growing demand for brand new road infrastructure, the demand for efficient management of old and new roads is on the increase also, together with safety demands, accessibility and also the implementation of advanced traffic management systems for decreasing socio-economic costs by modifying maintenance-related environmental effects, traffic issues, and losses. Maintenance backlogs nonetheless increase too. "Road authorities thus emphasize more on better efficiency and lower expenses thanks to limited funds. Since maintenance overheads normally comprise half the annual road infrastructure funds, it's vital to rearrange efficiency in road maintenance"[5.6]. Thus, with relation to road objects, life-cycle costs (LCCs) are considered as having a higher priority than simply investments. Hence, road authorities are expected to appreciate the importance of LCCA and maintain a calculation system. LCCs are deemed to be a restraint in road design selection or the assessment of tenders. When calculating LCCs, both road authority costs and costs of socio-economic nature should be taken into consideration. Road agency (authority) costs comprise expenses for planning, construction, design, maintenance, and rehabilitation. These costs are usually the government's accountability to hide using tax earnings. Socio-economic costs comprise agency costs, user costs (e.g. delay costs, accident costs and automobile operation costs), and environmental costs.

2. Literature review

2.1 Historical background

The American Association of Highway Officials (AASHO) introduced the concept of life-cycle cost-benefit analysis in its "Red Book" in 1960. The LCCA was introduced for highway investment decisions, and intrinsically, formed the notion of the economic evaluation of highway upgrades during the look stage. The subsequent progress step was made by Winfrey [2] who combined data available on the price of auto operations in an exceeding system to be utilized when highway planners are developing life-cycle costing processes. Moreover, two projects within 1960 introduced the use of LCC principles for pavement type selection and pavement design. Within the first project, the Centre for Highway Transportation Research and therefore the Texas Transportation Institute (TTI) developed the Flexible Pavement System (FPS), a computer-based approach for analyzing and rating alternative flexible pavement designs through the life-cycle cost. The second project was by the National Cooperative Highway Research Program (NCHRP), which examined the promotion of the LCCA concept. Subsequently, the Rigid Pavement System (RPS) was developed by Texas DOT, which is the image of FPS concerning how Life-Cycle analysis of rigid pavements is administered. RPS also ranks alternative designs per their total life-cycle costs.

The use of the LCC concept is supported in the different AASHTO Pavement Design Guide editions, which also include detailed discussions regarding costs that should be considered in LCCA. The current study presents an overview of the basic life-cycle costing theories, with explanations of the various user and agency costs associated with highway pavement projects, as well as the discount rates and economic feasibility of systems.

2.2 Literature review

- Dayong Wu et al., having an academic background Case study on risk-in China, based on optimization of pavement maintenance preventive measures When it comes to the practise of pavement preservation management (PPM), the need to justify decisions and get money has grown, even as it has become more frequent in engineering practises.
- Dan M. Frangopol et al., significant research has been done on the design of deteriorating structures and their life cycle costs. An innovative approach to inspecting and fixing ageing infrastructure is unveiled and shown in this research. Based on the total cost of ownership and the permissible life expectancy, optimization is carried up.
- Virginia transportation research council report, in-depth investigation of the economic and cost components of the life cycle cost analysisOther strategies for maintaining pavements, such as asphalt concrete repair and rehabilitation of rigid pavements with overlays as well as installation of a continuous reinforced concrete pavement with wide lanes and AC shoulders were also highlighted in the research.
- Omkar et al., For rigid, flexible, and composite pavement types, a connection was made between the IRI and the current serviceability rating (PSR). PSR is a 0–5 scale used by a user panel to rate a vehicle's readability.
- Pradhan Mantri Gram Sadak Yojona, Life-cycle cost analysis of both the original investment and maintenance led to a cost-effective pavement type. The price of both stiff and flexible pavement construction was also mentioned. Bituminous pavement's life cycle costs may be compared to concrete pavement's at twenty to twenty-five percent lower costs.
- Udaykumar et al, proposed a method for determining the most critical parts of pavement in need of repair. Pavement condition metrics are used as a basis for determining a ranking for each individual stretch of pavement. A numerical weight is assigned to parameters such as distress, which is quantified by determining their density and severity. The severity and scope of a person's distress determines how much of a deduction they receive.
- Horak and Emery, In South Africa, researchers have created a semi-mechanistic empirical analytic tool for rehabilitation design using the cumulative difference sums method. For comparative benchmarking, the deflection bowl parameters produced from the FWD bowl data are combined with a standardized visual survey procedure.

2.3 Problem statement

The primary goals of suppliers to end users are to reduce costs and boost profits. As a result, the major objective is to reduce the predicted overall life cycle cost while accounting for all expenditures associated with road life. No consideration for continuous operating, maintenance, and energy costs are taken into account while making the decision. This is a major flaw. A cost-effective solution to the road's construction must be implemented early on, so that we may use LCC as a starting point for our calculations. Using this study, we will be able to lower the LCC of our structure and save money over the life of the road.

In this study, a pavement design and condition optimization model was built. It is possible to think of the pavement as a type of generic pavement. Low traffic increase had been taken into account when selecting the pavement. The weather was deemed to be of a moderate severity. As a result, rainfall in the area has an average effect. Development and urbanization in the area were likewise regarded to be on the lower end of the scale.

3. Initial Strategy and Analysis Decisions

Certain baseline decisions, estimates and assumptions are needed in order to establish the parameters under which a LCCA can be carried out. These decisions, estimates and assumptions can be broadly categorized as follows:

- Alternative pavement design strategies. A "pavement design strategy" is the combination of initial pavement design and necessary supporting maintenance and rehabilitation activities. LCCA is most often used to evaluate two or more different pavement design strategies and determine their relative value.

- Determine performance periods and activity timing. Because LCCA is performed in advance of actual pavement construction, estimates of pavement performance (e.g., how will a pavement deteriorate over time) and maintenance and rehabilitation effort timing (e.g., when should maintenance and rehabilitation activities be scheduled) need to be made so that an appropriate analysis period can be chosen and appropriate cost estimates made. Often, agencies can use past local experience to estimate these parameters.
- Analysis period. The time period over which alternate design strategies are analyzed. The LCCA analysis period should be sufficiently long to reflect long-term cost differences between alternatives. For instance, if one pavement design alternative requires rehabilitation at the 15-year point and the other requires rehabilitation at the 25-year point, an 20-year analysis period would not provide a fair comparison between the two alternatives since it would include rehabilitation costs for one alternative but not for the other. In general, the selected analysis period should include at least one rehabilitation activity for each alternative. In the above case, a more appropriate analysis period might be 30 years or even 50 years depending upon the rehabilitation activity timing. The FHWA recommends an analysis period of at least a 35 years.

It is important to realize that the nature of these initial decisions, estimates and assumptions can be critical to the outcome of a LCCA. As input parameters are changed, the cost-effectiveness of alternatives will change.

3.1 Costs

- Agency Costs

Agency costs are all those costs incurred by the owning agency over the life of the project. Items common to all alternatives need not be considered because their costs will cancel one another out. Agency costs include:

Preliminary engineering Costs associated with preliminary items such as feasibility studies of alternative designs, permitting, engineering design and consultation for each alternative. For instance, one alternative may involve significantly more wetland mitigation which could be reflected in additional permitting and engineering costs.

Contract administration Costs associated with contract administration.

Initial construction. Construction costs associated with each alternative. For instance, each alternative's different roadway sections and material quantities should be accounted for in the analysis. Costs which are unique to each alternative should be included in the analysis.

Construction supervision Costs associated with construction inspectors, construction management consultant costs, materials testing costs, or other costs associated with construction supervision.

Maintenance costs Costs associated with maintaining the pavement surface at some acceptable level. Routine reactive-type maintenance cost data are often difficult to obtain. However, these costs are generally small and do not vary greatly from alternative to alternative. They have a negligible effect on NPV and can generally be ignored. When maintenance costs are available for the alternatives considered, they should be incorporated into the life-cycle cost analysis.

Rehabilitation costs Costs associated with each rehabilitation alternative (typically they are resurfacing costs). They are computed in a manner consistent with the initial construction costs.

Administrative costs Any other administrative or overhead costs unique to each alternative.

Salvage value. The value of an investment alternative at the end of the analysis period. This is usually included as a negative agency cost (an agency benefit) and is comprised of two major components:

Residual value. The net value from recycling the pavement. The differential residual value between pavement design strategies is generally not very large, and, when discounted over long periods of time (e.g., 35 years) tends to have little effect on LCCA results.

Serviceable life The remaining life in a pavement alternative at the end of the analysis period. Serviceable life accounts for the differences in remaining pavement life between different alternatives. For instance, suppose alternative a reaches terminal serviceability at year 30, while alternative B requires a rehabilitation at year 25 that will extend its life for another 10 years. If a 30-year analysis period is used then alternative A has no remaining serviceable life at the end of the analysis period while alternative B has 5 years of remaining service life. This additional serviceable life must be accounted for in LCCA and is usually done so under the "agency cost" category. In this example, alternative B would be credited with a monetary value equivalent to 5 years of service life. Often this is done by calculating this 5 years as a percentage of design life remaining (5 years remaining on a 10-year rehabilitation design life would give 50%) and then multiplied by the cost of alternative B's rehabilitation at year 25.

- User Costs

User costs are those costs that are accrued by the user of the facility during the construction, maintenance and/or rehabilitation and everyday use of a roadway section. User costs should be included in a LCCA because they tend to be several orders of magnitude larger than agency costs and can often be the major driving force in life-cycle cost. User costs can be divided into two basic categories:

1. Normal operation. Roadway user costs associated with using a facility during periods free of construction, maintenance, and/or rehabilitation activities that restrict the capacity of the facility. These costs are generally driven by pavement roughness.
2. Work zone. Roadway user costs associated with using a facility during periods of construction, maintenance, and/or rehabilitation activities that generally restrict the capacity of the facility and disrupt

normal traffic flow. These costs are influenced by the level, duration, and character of capacity restriction (e.g., number of closed lanes, length of closure, traffic during closure, amount of stopping and starting, etc.).

Often times, normal operation user costs are assumed to be equal for all alternatives involved and only work zone user costs are analyzed. In general, user costs are an aggregation of three separate cost components:

Vehicle operating costs (VOC) Includes all costs associated with operating a vehicle including fuel, oil, part replacement, upkeep and maintenance.Vehicle operating costs will vary depending upon roadway condition (Figure 1 shows the relationship between VOC and roughness for a stretch of roadway in Washington State).

User delay costs The costs associated with highway users' time. User delay costs help quantify costs associated with slow downs due to construction and maintenance activities and denial-of-use. User delay costs are the most difficult and most controversial life-cycle cost to accurately calculate because they involve assigning a dollar value to individuals' delay time.

Crash costs The costs associated with highway accidents. Generally crash costs are categorized into fatality, non-fatal injury and property damage only.

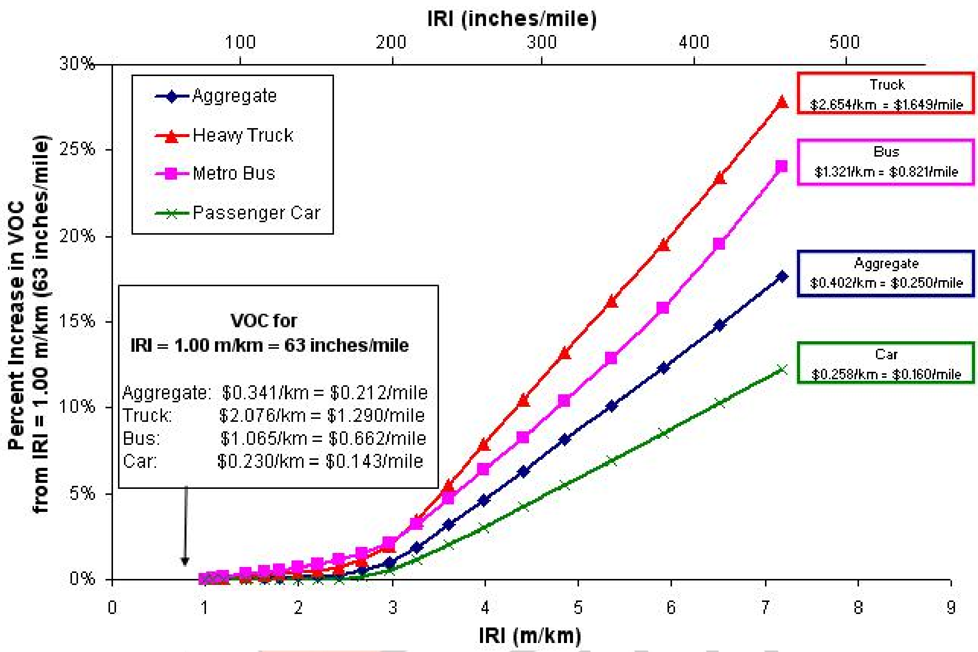

Figure 1. Percent Increase in Vehicle Operating Costs (VOC) for Various Vehicle Types as a Function of Roughness.

4. LCCA Assessments & Alternative Comparison

Once the performance period, activity timing, and costs associated with each alternative have been established, they must be compared over the chosen analysis period. This is typically done in one of two ways: net present value (NPV) or equivalent uniform annual costs (EUAC).

- Net Present Value (NPV)

NPV is determined by discounting all project costs to the base, or present, year (usually the present year, year of construction or year of authorization). Thus the entire project can be expressed as a single base year, or present year, cost. Alternatives are then compared by comparing these base year costs. NPV is a common economic calculation and, for roadways, can be expressed by the following equation:

$$NPV = \text{initial cost} + \sum_{k=1}^{N} \text{Rehab cost}_k \left[\frac{1}{(1+i)^{n_k}} \right]$$

where :

i = discount rate

n = year of expenditure

$$\left[\frac{1}{(1+i)^{n_k}} \right] = \text{present value (PV) factor}$$

- Equivalent Uniform Annual Costs (EUAC)

EUAC is determined by converting all project costs to a uniform recurring annual cost over the analysis period. Whereas NPV discounts all costs to a single base year costs and then compares these costs, EUAC discounts all projects to a recurring yearly cost and then compares these costs. EUAC is a useful indicator when budgets are established on an annual basis. Typically, EUAC is determined by first figuring the NPV and then using the following formula to convert it to EUAC:

$$EUAC = NPV\left[\frac{(1+i)^n}{(1+i)^n - 1}\right]$$

where :

i = discount rate

n = analysis period (i.e. the number of years into the future over which you wish to compare the projects)

Analysis

Once initial NPV's have been calculated for all alternatives they should be analyzed to determine the relative effects of inputs, the distribution of likely input values and the probability distribution of resultant NPVs. This analysis helps in determining which alternatives are better in which situations and also where improvements can be made to each alternative to make it more cost effective. Generally, analysis should involve a sensitivity analysis and a risk analysis.

Sensitivity Analysis

Sensitivity analysis involves looking at how variations in key input parameters affect its NPV. For each major input parameter (the determination of which input parameters are "major" or "significant" is somewhat subjective but can include discount rate, traffic volume, hourly value of user delay, agency costs, pavement performance life and rehabilitation costs) all other parameters are held constant while the parameter in question is varied over a reasonable range (either within some percentage of the initial value or over a range of values). The resultant NPVs should give a feel for the impact of input parameter variability on overall LCCA. The major disadvantage to sensitivity analysis is that no credit for the relative likelihood of input values. Therefore, equal weight is given to all input value assumptions regardless of their occurrence likelihood.

Probability Analysis

"Probability analysis" (sometimes called "risk analysis") is a term that describes an analytical method used to account for the potential variability of input parameters. Basic LCCA analyses that determine life-cycle costs based on the most likely input parameters (e.g., the most likely labor costs, material costs, construction times, rehabilitation intervals, etc.) are called deterministic. Based on the assumed input values there is one and only one output value. Deterministic LCCA does not account for two vital items:

Potential variability of input parameters. Typically, it is not possible to predict the exact value of an input parameter. Therefore, it is better to describe input parameters by a range of probable values rather than one single most likely value. LCCA results based on input parameters described this way will give a range of life-cycle costs.

Likelihood of occurrence for an input parameter value. Although sensitivity analysis can show how the final LCCA result varies as input parameters are varied, it does not account for the relative likelihood of each one of these variations. Therefore, input parameters are best described as a probability distribution, which accounts for a range of values and their relative likelihood. LCCA results based on input parameters described in this way will give a probability distribution of life-cycle costs.

Probability analysis is important to perform because it can a range of potential life-cycle costs and their associated probabilities of occurring. With this level of information, an agency can assess the risks associated with a particular probability distribution of life-cycle costs and make the most informed decision possible. Furthermore, if probability analysis is not performed and left to an evaluator's intuition, this type of subjective risk analysis can be wrong for any number of reasons including incomplete data, incorrect data or a poor perception of the risk.

5. LCCA Assessments by Computer programmes

5.1 LCCA packages

Agencies and other anticipations. Some have indeed developed computer programs for his or her LCCA approaches so as to further extend the analysis. Other pavement companies use different LCCA computer software and methodologies, including styles for Alabama, Pennsylvania, andnon-automated methodologies. Trace work zone lane closures are estimated using the QUEWZ model.

- Graces and limitation of LCCA methodologies and software packages

LCCA models are subject to certain limitations. stoner cost rejection is one of the limitations in analysis. Highway druggies dodge these costs, which include detention costs, vehicle operating costs similar as energy, tires, machine oil painting, and vehicle conservation) and any other accident costs. stoner cost is barred in several LCCA styles and software as quantification is difficult and there are disputed values associated with stoner

Table 1*: Comprehensive LCCA packages*

LCCA packages	Year	Producer	Life-cycle Costs				Descriptions
			Initial Construction	Rehabilitation	User Cost	Salvage Value	
DARWin	N/A	AASHTO	*	*		*	Project level valuation
TEXAS DOT RPS/FPS	1968	Centre of Highway	*	*		*	Latest version consists of user cost
HDM	1977	World Bank	*	*	*		The HDM updated new versions
LCCP/LCCPR	1987	University of Maryland			*		The programs comprise of user operating costs associated with
EXPEAR	1989	University of Illinois[2]	*	*			Project level assessment
PRLEAM	1991	University of Waterloo	*	*	*	*	Most focus on cost-effective rehabilitation improvement approach
LCCOST	1991	Asphalt	*	*	*	*	Routine maintenance (optional) is also
MicroBENCOST	1993	Texas Transportation	*	*			Under the NCHRP Project 7-12
ACPA	1993	ACPA	*	*	*	*	Risk analysis is used to make sure a
CAL-B/C	2000	California Department of	*	*	*		A first spreadsheet format (MS Excel)
REALCOST	2004	FHWA	*	*	*	*	First Probabilistic and comprehensive
D-TIMS	2006	Indiana Department of	*	*	*		Provides the recommendations for the treatment for the specific distresses
IDAHO DOT LCCA	2008	Idaho Transportation	*	*			Units across the English and metric system can also be converted
APA LCCA	2011	APA	*	*	*	*	The software using the work zone

Stoner cost rejection is one amongst the constraints in analysis. LCCA models are subject to certain limitations. Highway druggies dodge these costs, which include detention costs, vehicle operating costs (similar as energy, tires, machine oil painting, and vehicle conservation) and the other accident costs. Stoner cost is barred in several LCCA styles and software as quantification is difficult and there are disputed values associated with stoner cost. Pavement LCCA models suffer from the limitation of not considering preventative conservation treatment within strategy expression. LCCA experimenters and interpreters argue that preventative conservation could be a new preservation strategy for pavements and data on long- term benefits still must be collected. Presently, only certain models are ready to quantify the long- term effective- ness of preventative conservation treatment. This can be tired the shape of service life extension or a performance jump. Hence, it's putatively grueling to incorporate preventative conservation in LCCA. it's also observed that druggies find the account of LCCA input parameters complicated, which is why they're doing not consider it during the system. The LCCA models treat the input variables independently and thus the single deterministic result's reckoned through the best- conjecture process of the fixed values for every input parameter. The varied input parameters affect the model results, which is why evaluation is done with perceptivity analysis. The uncertain areas that may be crucially affecting the decision- making process aren't shown as part of the perceptivity analysis. Hence, it's difficult to observe which option consists of the smallest true LCC. The query problem can be managed by LCCA through the threat analysis procedure. This would allow decision makers to weigh the probability of any implicit outgrowth. In discrepancy to utmost LCCA packages, the current FHWA package includes LCCA probabilistic approaches.

6. Conclusions

Data are available for some aspects, but other data must be anatomized and proved by the agencies themselves. Use of LCCA must be distributed meetly and data employed must be from being records that are accurate in terms of original costs, salvage value, recuperation timing and costs further as reduction rates. It’s essential to know that LCCA is simply a tool and also the results mustn't be taken as opinions. Several other factors but LCCA must be taken into consideration when deciding which type of pavement should be considered. The LCCA process comprises several assessments, prognostications and hypotheticals. Differences in inputs can vastly impact judges confidence with the LCCA results. Input delicacy is pivotal for all aspects. The precise estimation of pavement performance, business for relatively 30 times within the long run and future costs by judges determines the trust ability of LCCA results. In managing cast misgivings, the probabilistic threat analysis approach is gaining fissionability. It allows to quantitatively landing input parameters, helping to supply LCCA results. an outsized an element of literature also states that LCCA perpetration is as complicated as opting the correct reduction rate and agency costs, quantifying on-agency costs as stoner costs, securing believable supporting data including business data, estimating the salvage value and useful life, modelling asset deterioration, and estimating conservation costs, effectiveness and trip demand throughout the analysis period. During major recuperation and construction conditioning, the inviting maturity of LCCA only use detention costs as part of stoner costs

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