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Implementing an Application Tool of Life Cycle Cost Analysis (LCCA) for Highway Maintenance and Rehabilitation in California, USA

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Abstract: Life-Cycle Cost Analysis (LCCA) for highway projects is known as an effective analytical technique that uses economic principles to evaluate long-term alternative investment options, especially for comparing the values of alternative pavement design structures and construction strategies. In the Unites States, the 2012 Moving Ahead for Progress in the 21st Century Act (MAP-21) amended the United States Code to mandate that the United States Government Accountability Office (GOA) conducts a study of the best practices for calculating life-cycle costs and benefits for the federally funded highway projects in 2013. The RealCost 2.5CA program was developed and adapted as an official LCCA tool to comply with regulatory requirements for California state highway projects in 2013. Utilization of this California-customized LCCA software helps Caltrans to achieve substantial economic benefits (agency cost and road user cost savings) for highway projects. Proper implementation of LCCA for roadway construction and rehabilitation would deliver noticeable savings of agency's roadway maintenance cost especially in developing counties where financial difficulties exist.

Keywords: Pavement Rehabilitation, Life Cycle Cost Analysis, Roadway Maintenance, Roadway Management, and RealCost

I. INTRODUCTION

Life-Cycle Cost Analysis is known as a technique helping the pavement designers make better decisions that balance initial cost of construction with projected future costs of maintenance and work zone delay to public due to maintenance activity in its life.

In 2002, the Federal Highway Administration (FHWA) first published an LCCA primer to provide sufficient background and demonstrations for transportation officials [1]. In addition, in 2004 the FHWA distributed an LCCA software tool, *RealCost* (version 2.5), to support practitioners performing LCCA for highway projects [2].

LCCA is implemented in California to compare design alternatives such as paving materials and cross-sections for the Caltrans highway projects since 2007, required by the State legislation [3],[4]. Based on the Caltrans *Highway Design Manual* (HDM) Topics 612 and 619, the Caltrans pavement designers and engineers evaluate the cost effectiveness of alternative pavement designs for highway new construction and reconstruction [5]. The Caltrans Office of Pavement Engineering published *Life-Cycle Cost Analysis Procedure Manual* in 2007 and modified it in 2013 to support them with the most updated information [6].

To achieve the goal of total cost comparison with equivalent benefits between competing design alternatives, LCCA requires extensive and project-specific information in its inputs, such as material volumes, material unit prices, agency supporting costs, traffic volumes, and lane closure schedules. Due to these complexity and diversity of LCCA, practitioners are overloaded and often prone to miscalculate total costs from inadequate and/or deficient input data.

Many researchers and practitioners have been developing LCCA concepts and computer tools to efficiently and properly execute LCCA to find the lowest cost alternative. Papagiannakis and Delwar developed a computer model to perform LCCA of roadway pavement, analyzing both agency and user costs. Their software accepts inputs from a pavement management database and carries out pavement LCCA on both network-wide and project-specific levels [7]. Rather than considering user delay and future maintenance and rehabilitation (M&R) costs, this software calculates the net annualized savings in user costs as the benefit that results from reducing pavement roughness (e.g., vehicle depreciation, maintenance, repair, tires, and cargo damage) from its current condition to that in the end year of the life-cycle.

Salem et al. introduced a risk-based probabilistic approach to predict probabilities of the alternative occurrence of different life-cycle costs on infrastructure construction and rehabilitation. Their model predicts probability of time of infrastructure failure for building alternatives [8]. Using the Florida and Washington State Department of Transportation (DOT) project databases, Gransberg and Molenaar developed best-value award algorithms of life-cycle cost for design/build highway pavement projects [9]. Labi and Sinha studied the cost effectiveness of different levels of life-cycle preventive maintenance (PM) for three asphalt concrete (AC) functional class families and presented a methodology to determine optimum PM funding levels based on maximum pavement life [10]. The Caltrans Office of Pavement Management and the University of California Pavement Research Center (UCPRC) have enhanced FHWA's *RealCost* software and customized it for California by adding new analytical capability for cost

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estimation, improving work zone traffic analysis, and developing automatic future M&R sequencing.

II. RESEARCH OBJECTIVE

The current FHWA's *RealCost* (*version 2.5*) is limited to analytical functions on calculating work zone user cost and net present values. It does not provide an analytical capacity to calculate agency costs. Similarly it does not have a capability to estimate pavement service lives for individual construction or rehabilitation activities, which should be input by users manually with their engineering judgment and agency's practices.

Firstly, for the LCCA enhancement in California, the improved traffic module was added into *RealCost* with four California representative traffic patterns generated through Caltrans traffic database system [11]. Secondly, cost estimate modules are developed for the initial construction and the subsequent maintenance and rehabilitation (M&R) of California highways, based on Caltrans historical contract cost data [12]. Thirdly, M&R sequencing automation is established and embedded with user-friendly menus to obtain active service life, maintenance frequency, and agency maintenance cost with given project constraints of climate region, final pavement surface, and design life. These new modules and functionalities enable the user to conduct more accurate LCCA with minimum of own inputs by relying on the most undated inputs values and standards. Especially, the automated M&R sequence selecting and cost estimating modules would reduce potential errors with multiple manual calculations and judgments through complicated LCCA procedure. The enhanced *RealCost* 2.5 California version will be distributed to Caltrans districts shortly.

The enhancement of the software includes the automated cost estimate of initial construction, customization of California-specific traffic data, the automated M&R sequence selection, and the automated cost estimate of future M&R. More details about each enhancement module are described in the following sections.

III. CONSTRUCTION COST ESTIMATE

A. Pavement Cost

Initial construction cost for highway projects in California is categorized into pavement cost, earthwork cost, drainage cost, specialty cost, and traffic cost. The pavement cost of each pavement item is calculated by a function of pavement item, thickness, lane width, length, and unit price. The traffic cost is calculated by using the specific inputs that includes traffic management plan, traffic handling, and moveable concrete barrier costs. Other non-pavement costs (four categorized items) are calculated by the certain proportions of the pavement cost; as a simplified procedure.

In pavement cost calculation, when a user selects each pavement item from the list and enters its thickness, lane width, lane length, and extra quantity, the software retrieves the corresponding unit cost from the database and calculates the cost for each pavement item. The pavement unit prices are periodically updated from the California construction contract cost database [12]. The software sequentially calculates total pavement cost and adjusts total pavement cost by contractor's resource cost multiplier. This automatic calculation procedure helps to; (1) avoid the input errors and calculation mistakes, (2) apply the California unified unit prices, and (3) save the engineering time.

B. Traffic Handling and Management Cost

Traffic cost consists of the cost related to traffic handling and management, which include construction zone enhancement enforcement program (COZEEP) cost, traffic handling cost, moveable concrete barrier cost, and public information cost.

The COZEEP cost is allocated for temporarily hiring the California Highway Patrol (CHP) officers to enhance enforcement on the work zone during construction. The software calculates the COZEEP cost from the user inputs: the highway patrol loaded rate ($/hour), the number of officers per shift, the closure hours, and the number of closure. The default rates of the CHP are $60 per hour per officer for daytime and $85 per hour per office for night time or weekend in the *RealCost* 2.5 California version. The numbers of officers per shift are zero to three for daytime closure, two to four for night time closure, and four to six for extended closure. The COZEEP cost is calculated by multiplication of hourly rate, closure hours, number of closure, and number of officers.

Traffic handling cost includes the costs for temporary fences, culverts, construction area signs, traffic striping, pavement marking, channelizing, portable changeable message signs, railing, flashing arrow signs, and temporary crash cushions. In Caltrans' LCCA procedure, the daily traffic handling cost is considered as the lump sum of the costs for the all traffic handling activities and supplies. The daily traffic handling cost varies from $2,000 to $2,800 by the range of the project cost (from less than $0.5 million to larger than $100 million). The traffic handling cost is calculated by multiplication of number of closures, closure duration, and daily traffic handling cost. The extra traffic management plan (TMP) cost ($120,000) applies $120,000 for the extended closure in addition to the general traffic handling cost because the extended closure requires more detour signs and restriping.

Moveable concrete barrier (MCB) cost is one component of traffic handling and management cost, applied only for the extended closure. The total MCB cost is computed by the barrier length, barrier usage month, barrier cost for each month, transformer cost for each month, and a training cost. Utilization of MCB costs $60 per meter with $30,000 of transformer fee and one-time training fee for the first month, and it costs $11 per meter per month with $15,000 of monthly transformer fee for the second month and thereafter.

Public information cost contains the costs for public outreach and information deployment, such as construction information website, media, brochure, and signage. The public information cost is applied usually for the extended closure ($30,000) but it can be applied for the nighttime closures as necessary.

C. Agency Supporting Cost

Supporting cost mainly covers agency (Department of Transportation) engineering cost, especially field engineers' time during construction. Either a user can simply estimate the supporting cost by using a certain proportion of the construction cost or compute the specific amount by using the detail information. The supporting cost is computed by the field engineer salary, number of engineers per day, overtime rate, extra preparation days in case of the extended closure and the engineering person-year (PY). In California general practices, the numbers of field engineers are three for the nighttime closures and four with three shifts for the extended closures. The overtime rates are used as 110 percent of the regular rate for the nighttime closures and 150 percent of the regular rate for the extended closure. The engineering PY ranges from four to eight PY for project.

IV. Work Zone User Cost

A. Automatic Traffic Data Inputs

Traffic data is required to calculate work zone user cost (delay cost) for each activity of every alternative. Traffic delay is calculated using lane closure parameters such as the number of closed lanes, duration of lane closure, work zone length, work zone capacity and speed limit change, and either annual average daily traffic (AADT) with hourly traffic distribution pattern or average hourly volumes for both directions.

The AADT on most California highways are updated every year [13] and the hourly traffic volumes are collected and released through the California Freeway Performance Measurement System (PeMS) for the major urban highways [11].

The default traffic hourly distributions in the FHWA RealCost 2.5 were taken from MicroBENCOST, software produced by the Texas Transportation Institute in the early 1990's [14]. These traffic distributions are inadequate for California implementation for both weekday and weekend analysis. The traffic patterns in California highways show more diverse types than the MicroBENCOST defaults. Traffic data were collected in 43 locations in statewide and analyzed for establishing California standard traffic hourly distribution patterns for weekdays versus weekends for efficient and accurate implementation.

Traffic data analysis indicates that weekday traffic patterns are different from weekend ones. The AADT for weekends are smaller than those for weekdays. The average of the weekend AADT conversion factor from weekday traffic was 0.84.

Four standard patterns; (1) 'weekday single peak', (2) 'weekday double peak', (3) 'weekend flat peak', and (4) 'weekend skew peak', were produced. Two dominant patterns are observed in the traffic data for weekdays. The 'weekday single peak' distribution shows a morning-peak period for one direction and an afternoon-peak period for the opposite direction. The 'weekday double peak' pattern shows one morning- and one afternoon-peak period for both directions. Two prevailing patterns were also observed in the traffic data for weekends. The 'weekend flat peak' shows a single flat afternoon-peak period the shape of the 'weekend skew peak' is a single, relatively sharp afternoon-peak period.

In addition to the four California standard traffic patterns, the customization function was created to allow users to input a site-specific traffic hourly distribution pattern with flexibility. Users can directly input either hourly proportions and directional split proportions or hourly volumes or inbound and outbound.

B. Work Zone User Cost

User costs include additional travel time (delay) cost and vehicle operating cost (excluding routine vehicle maintenance cost) incurred by the traveling public through the highway work zone. During construction work zone lane configuration decreases traffic capacity through reducing number of service lanes and roadway capacity due to interruption to traffic flow. The additional travel times of the traveling public are simply calculated by demand-capacity relation, based on queuing theory. The additional travel time values are considered as work zone user cost with the additional vehicle operating costs, associated with traffic delay during construction activity. As a policy, the dollar value of user time is different for each type of vehicle. The default value for passenger cars is $12.80 and the default value for single unit trucks and combination trucks is $31.70 in the *RealCost* 2.5 California version [15].

V. Automation of M&R Sequence Decision

After viable pavement design alternatives are selected for comparison in LCCA, a pavement M&R schedule, in terms of its sequence and timing, needs to be determined. The M&R sequences for the Caltrans highway projects are determined by the classification of four factors: (1) climate region, (2) pavement final surface type, (3) design life, and (4) maintenance service level, as defined in their HDM and the Caltrans *LCCA procedure manual* [5, 6]. The M&R decision tree is based on the California five climate regions. The pavement final surface type influences the M&R sequence selection. Hot mix asphalt (HMA), HMA with open graded friction course (OGFC), or crack-seat-and asphalt concrete (AC) Overlay are generally chosen for final surface in rigid pavement. Rubberized asphalt concrete (RAC), RAC with RAC Type-O, continuously reinforced concrete pavement (CRCP), and jointed plain concrete pavement (JPCP) are generally chosen for final surface in flexible pavement in California.

Maintenance service level (MSL) is the state highway classification used by the Caltrans Division of Maintenance for maintenance program purpose. MSL 1 and 2 results more frequent M&R sequence with higher maintenance priority than MSL 3.

VI. M&R Cost Estimate

Procedure of the cost estimate for future M&R varies by pavement types: rigid or flexible pavements. Maintenance is often called as capital pavement maintenance (CAPM) in order to separate out from annual routine maintenance activity in California. As the pavement ages, its condition will gradually deteriorate to a point where some type of maintenance or rehabilitation treatment is warranted. CAPM consists of work performed to preserve the exiting pavement structure utilizing strategies that preserve or expend pavement service life. Rehabilitation includes placement of additional surfacing and/or shoulders and the partial or complete removal and replacement of the pavement structure.

A. Maintenance (CAPM) Cost

CAPM cost for rigid pavement consists of concrete pavement restoration (CPR) cost, traffic cost, indirect (non-pavement) cost and supporting cost. The CPR cost is calculated by function of concrete pavement area, concrete shoulder area, asphalt shoulder area (there often existing either concrete or asphalt shoulder area or both with concrete mainline), existing Portland cement concrete (PCC) slab thickness, and treated base thickness. When the area of random slab replacement is less than two percent, it is called as CPR Type C. It falls in CPR type B when the area is about two to five percent, and it falls in CPR Type A when the area is about between five and seven percent. It requires rehabilitation when the area of random slab replacement is over seven percent. The material of rapid strength concrete (RSC) of different curing times: 4-hours, 12-hours, 24-hours, and 28-day conventional RSC. Depending on the RSC type selection, the corresponding unit price is retrieved from the database mentioned earlier [12]. Traffic cost is calculated by function of the work zone duration, daily traffic handling cost, and daily COZEEP cost like in cost estimate of initial construction. Indirect cost consists of the costs for earthwork, drainage, safety, road side, right of way, and administrative costs. It is generally calculated by the proportion of the CPR and traffic cost. The default value of indirect cost uses 35 percent of the pavement cost, which is an average indirect cost in four case studies on cost evaluation of pavement rehabilitation in California [16].

The proportion of supporting cost is determined by construction type and project size and ranges from 13 percent of the project cost for a large project (over $5 million) to 19 percent of the project cost for a small project ($0.75~2 million). The proportion of supporting cost for rehabilitation ranges from 19 percent of the project cost for a large project to 35 percent of the project cost for a small project.

CAPM cost of flexible pavement consists of overlay, milling, sacrificial course, traffic handling, indirect, and supporting cost. The pavement structure of the overlay cost is determined by the international roughness index (IRI) in California pavement design practice.

In a case of the IRI less than 170, the pavement material for overlay may be chosen from either hot-mix asphalt (HMA) or rubberized hot-mix asphalt (RHMA). When the IRI is over 170, the construction segment needs rehabilitation instead of CAPM in California general practices. Sacrificial course has five options (HMA Type-A, HMA Type-O, RHMA-G, RHMA-O, and nothing) in pavement material selection. The calculation procedure for traffic handling, indirect, supporting cost is same as in rigid pavement. Figure 1 shows the procedure of CAPM cost estimate for flexible pavement. The total cost of the CAPM project becomes a lump sum of overlay, milling, sacrificial course, traffic handling, indirect, and agency supporting costs.

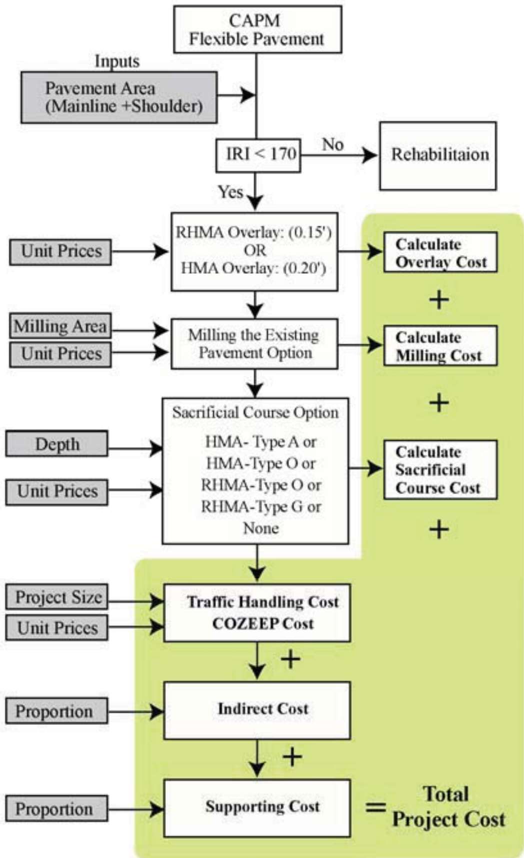

Figure 1. Procedure of CAPM cost estimate for flexible pavement

B. Rehabilitation Cost

Rehabilitation cost contains pavement cost (mainline pavement cost, base repair cost, shoulder cost), non-pavement cost, traffic cost, indirect cost, and supporting cost. Mainline pavement cost is calculated by the length of mainline and pavement material and thickness. The pavement structure alternatives are determined by the classification of climate region, subgrade soil type, traffic index, and lateral support existence. The software identifies the pavement structure alternatives, satisfying four classifications selected, from the California HDM [5]. The mainline pavement cost is calculated by the function of the pavement item, thickness, length of mainline, and the unit prices for pavement items.

When the pavement structure is chosen for rigid pavement for rehabilitation, the volume of each pavement item is determined by the given thickness of the pavement item and the pavement length (lane-mile). The unit price for each pavement item is retrieved from the pavement unit price database and the total pavement cost is automatically calculated for the chosen pavement structure.

The non-pavement item is determined by the proportion of the pavement cost of mainline, base repair, and shoulders and traffic cost is calculated by the same calculation in CAPM cost estimate. The indirect cost is then calculated by the proportion of the lump sum of the pavement cost, non-pavement cost, and traffic cost. The supporting cost is calculated by the different proportion of the project cost with the project size like the supporting cost calculation in CAPM cost estimate.

VII. Summary and Future Directions

The LCCA tool, *RealCost* 2.5 California version was developed with enhancement on functionality and user interfaces, especially for the cost estimate procedures and M&R sequence selection for California implementation. This software integrated the essential information (traffic data, pavement unit prices, and pavement structures) from the different database sources. The automated pavement structure selection and M&R sequence selection allows user to compare the realistic pavement design alternative.

The fully-automated cost calculation process of construction activity reduces the errors and mistakes from the manual calculation and usage of inappropriate input values. Utilization of the *RealCost* 2.5 California version saves engineering time and increases accuracy of LCCA result.

For future version, pavement performance-based dynamic design procedure, utilizing mechanistic-empirical (ME) pavement design technology, would be incorporated in M&R sequence selection. In addition to agency and road user cost analysis, the environmental impact cost analysis needs to be included in decision-making of pavement alternatives. The environmental cost analysis would include comparison and carbon dioxide emission increase due to construction activities and traffic interrupts and would find the most environmental friendly pavement alternative for life cycle analysis period.

Proper implementation of LCCA for roadway construction and rehabilitation would deliver noticeable savings of agency's roadway maintenance cost especially in developing counties where financial difficulties exist.

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