CA4PRS: A DESIGN-TRAFFIC-CONSTRUCTION INTEGRATING ANALYSIS TOOL HIGHWAY RENEWAL PROJECTS

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ABSTRACT

Most state highways in the United States were built during the 1960s and 1970s and have exceeded their design lives. With mature and aging infrastructures, transportation agencies have shifted their focus from constructing new highways to rehabilitating existing facilities. One innovation in the effort to reduce highway construction time and its impact on traffic is software called *CA4PRS*, Construction Analysis for Pavement Rehabilitation Strategies. *CA4PRS* software is a decision-support tool for transportation agencies that helps in selection of the most effective and economical strategies for highway projects, especially when they are developing PS&E (Plans, Specifications, and Estimates) and TMP (Transportation Management Plans) packages. Funded through an USA FHWA (Federal Highway Administration) pooled-fund, *CA4PRS* was developed by the University of California at Berkeley's Institute of Transportation Studies. The CA4PRS (version 2.5 currently) program incorporates three interactive analytical modules: a Schedule-module that estimates project duration, a Traffic-module that quantifies the delay impact of work zone lane closures on the traveling public, and a Cost-module that compares project cost between design and construction alternatives. *CA4PRS* results can also be integrated with traffic simulation models to quantify the impact of work zone lane closures on the entire highway network. Results (outputs) of these three modules in *CA4PRS* integrates directly into formulation (inputs) of life-cycle cost analysis. These capabilities were confirmed on several large highway rehabilitation projects in states including California, Washington, and Minnesota. For example, *CA4PRS* played a crucial role in the concrete pavement reconstruction of Interstate 15 Devore near San Bernardino (CA), helping reduce agency cost by US$8 million and saving US$2 million in road user delays using continuous closures and 24/7 construction, compared with repeated nighttime (estimated about 1 year) traffic closures, the traditional approach. There is growing recognition of the capabilities of *CA4PRS* and the benefits of its use. For example, *CA4PRS* won a 2007 Global Road Achievement Award granted by the International Road Federation (IRF). The AASHTO Technology Implementation Group (TIG) is focusing on *CA4PRS* for nationwide promotion to its state members. FHWA also formally endorsed *CA4PRS* as a

“Priority, Market-Ready Technologies and Innovations” product in 2008, and recently acquired an unlimited *CA4PRS* group license for all 50 states DOT (Department of Transportation) to deploy the software nationally. Approximately 1,200 transportation engineers in about 20 state DOTs have received CA4PRS hands-on user training. On the academic side, approximately 10 U.S. universities currently use CA4PRS for highway research and teaching.

1. BACKGROUND

1.1 Highway Infrastructure Renewal

Most state highways in the United States were built during the 1960s and 1970s and have exceeded their design lives. Higher traffic volumes and heavier vehicles have accelerated highway network deterioration, especially in urban areas. Urban highway rehabilitation projects often create challenges to the state highway agencies, motorists, and commercial enterprises. Undesirable effects occurring during highway rehabilitation include congestion, safety problems, and limited property access. To mitigate these adverse impacts, highway planners, designers, and traffic managers try to expedite construction in a variety of ways (1). Balance must be achieved between the competing needs to minimize the costs of rehabilitation activities and to reduce the negative impacts of closures on road users, the economy, and the environment.

The State of California faces a large-scale deterioration of its highways. More than 90 percent of the state’s 80,000 lane-kilometer (50,000 lane-mile) highway system was built with a 20-year design life between 1955 and 1970. To deal with their deteriorating infrastructure, the California Department of Transportation (Caltrans) launched its Long-Life Pavement Rehabilitation Strategies (LLPRS) Program in 1999 (2). The purpose of the LLPRS program is to employ Caltrans’ “get-in, get-out, and stay-out” approach to providing “long-lasting, lower-maintenance pavement” for urban highways with high traffic volume. Based on a preliminary life-cycle cost analysis and evaluation of the agency’s future cash flow, approximately 2,800 lane-km (1,700 lane-mi) were selected as initial candidates for the program. Project selection criteria included poor pavement structural condition and ride quality, and a minimum of 150,000 average daily traffic or 15,000 heavy trucks. Most candidates were part of urban interstate highway networks in the Los Angeles and San Francisco Bay areas.

1.2 Tools for Highway Rehabilitation

The increase in highway maintenance and rehabilitation has exposed the need for further research into improved construction methods and ways to reduce the impact of construction on traffic flow. However, little research has aimed at integrating pavement materials and design, construction logistics, and traffic operations—all of which are essential to determine the most cost-effective rehabilitation strategies (3).

QuickZone was developed by the Federal Highway Administration (FHWA) as the key software component for the Strategic Work-Zone Analysis Tools (SWAT) program evaluating traveler delay due to construction work zones (4). The software provides a complete, realistic view of total construction costs based on estimation and quantification of work-zone delays and resulting user costs. However, users must provide input values for the construction schedules of different rehabilitation alternatives in terms of closure number and duration, crucial components in calculating traffic delay. Also, *QuickZone* relies on assumptions or users' personal experiences rather than quantified, analytical input data in defining lane closure duration.

2. CA4PRS OVERVIEW

2.1 Software Capability

The need for a comprehensive analytical model that integrates construction schedule and traffic operations for highway rehabilitation projects drove the development of *CA4PRS* (Construction Analysis for Pavement Rehabilitation Strategies) software, the subject of this paper. The *CA4PRS* model was developed by the Institute of Transportation Studies at the University of California at Berkeley with support from the State Pavement Technology Consortium (California, Florida, Minnesota, Texas, and Washington), an FHWA pooled-fund program.

CA4PRS is a decision-support tool that helps planners and designers select effective, economical highway rehabilitation strategies. The analytical framework of *CA4PRS* consists of three modules: construction schedule estimate, work zone traffic delay calculation, and cost comparison for various what-if scenarios that incorporate different construction timing options, pavement design alternatives, and lane closure tactics. More specifically, the *CA4PRS* Schedule Module estimates the duration (total closure numbers) of highway rehabilitation based on the calculated optimized distance (lane-km) that can be completed during various types of closures. The schedule estimate, implemented in the initial version of *CA4PRS*, takes into account project parameters such as schedule constraints, pavement materials and cross sections, contractor logistics and resources, and lane closure tactics (5).

The *CA4PRS* Traffic Module, added to Version 2.0 in 2007, quantifies the impact of construction work zone closures on the traveling public in terms of road user cost and time spent in queue, using a demand-capacity model based on the *Highway Capacity Manual* (6). The *CA4PRS* Cost Module, a recent enhancement to Version 2.1, contains a built-in database (which can include the history of state DOT project bid items) that can search for the unit price of highway construction activities (mainly pavement-related items) with an automated material quantity calculation from basic dimension inputs (distance, width, and thickness). Cost Module users can also estimate the total project cost (so-called agency cost) as the sum of the costs of construction, traffic handling and management, engineering support, and other indirect costs.

2.2 Computational Platform

CA4PRS runs on Microsoft Windows 98/2000/XP/VISTA® or newer operating systems. It was developed in Microsoft *Visual Basic*® 6.0 and utilizes a Microsoft *Access*® *2000* database for data storage, but *CA4PRS* does not require *Access*® to be installed to run. *CA4PRS* utilizes a number of royalty-free third-party tools to enhance its user friendliness, the versatility of its user interface, and presentation quality. The software employs a multiple-document interface, similar to Microsoft *Excel*® or Microsoft *Word*®, which enables multiple projects and analyses to be opened, viewed, and compared simultaneously. Designed for project-level analysis, each project within the *CA4PRS* database receives a unique identifier that is the key to storing and retrieving relevant and related project information.

CA4PRS employs a systematic menu structure that groups items in an intuitive manner. The program also provides context sensitive online help and a user manual. *CA4PRS* provides extensive graphical and tabular outputs, and incorporates a report feature that documents the analysis input and output for printing or saving as an Adobe Portable Document Format (PDF) or Rich Text Format (RTF) file.

CA4PRS provides a dual analytical approach in dealing with input variables: deterministic or probabilistic modes. In the deterministic analysis approach, input parameters are treated as single values without any variability. The deterministic analysis is faster and has fewer input data requirements than the probabilistic analysis. In the probabilistic (stochastic analysis) approach, input parameters are treated as random variables and specified using the appropriate parameters for distribution of each variable selected. Any number of the scheduling and resource input parameters can be modeled as a probabilistic variable selected from a drop-down list. The probabilistic approach permits analysis of the likelihood of achieving different pavement rehabilitation production rates, utilizing Monte Carlo simulation.

3. ANALYTICAL MODELING FEATURES

3.1 Rehabilitation Strategies Modeled

The *CA4PRS* model was designed and programmed with inputs from the state departments of transportation (with Caltrans as the lead) in the consortium and from the American Concrete Pavement Association (ACPA) and the National Asphalt Pavement Association (NAPA).

The five most frequently adopted highway rehabilitation strategies, as listed below, are incorporated as individual analysis alternatives.

- ***Jointed plain concrete pavement (JPCP) rehabilitation***, in which the old pavement is rebuilt with a PCC slab and optional pavement base structure,
- ***Continuously reinforced concrete pavement (CRCP) rehabilitation*, ** which is similar to the JPCP rehabilitation but differs in that reinforced bars are installed in the new concrete slabs,
- ***Precast concrete (PCP) rehabilitation*, ** which is similar to the JPCP/CRCP rehabilitation with difference to place (assemble) prefabricated (in the plant) precast panels onsite to replace existing pavement (either flexible or rigid pavements),
- ***Crack, seat, and (AC) overlay (CSOL) rehabilitation***, in which the old pavement is optionally cracked/seated and overlaid with new asphalt concrete (AC) layers,
- ***Milling and AC overlay (MACO) rehabilitation***, in which the old AC pavement is removed with milling (cold-planning) and overlaid with new AC layers, and
- ***Full-depth AC (FDAC) replacement***, in which the old pavement (usually concrete) is removed and replaced with new full-depth AC layers.

3.2 Schedule Analysis Module

The input variables for the *CA4PRS* Schedule Module are schedule interactions, pavement design and materials, resource constraints, and lane closure schemes. The Schedule Module starts with a data entry form for user input with the following four input tabs: (i) Project Details; (ii) Activity Constraint; (iii) Resource Profile; and (iv) Schedule Analysis. Figure 1 shows a screen capture of the Schedule Analysis input for the “Milling and AC Filling” deterministic analysis. The interfaces for the Schedule, Traffic, and Cost modules are designed for a dual-unit system, English (US Customary) or Metric (SI) unit, so that inputs and outputs are automatically converted from one to the other when a user toggles the Unit menu.

In the Project Details tab, the user enters basic project information, including project identifier, project descriptions, route name, etc. The user also specifies project scope in terms of total lane-km (lane-mi) to be rehabilitated.

In the Activity Constraints tab, the user defines basic time constraints between rehabilitation activities, including required minimum mobilization and demobilization time for contractors and the lead–lag time relationship between predecessor and successor activities. The Activity Constraints tab includes four alternative time frames for lane closures (or construction windows), including nighttime, weekend, daytime-shift, and continuous closures, with user specifiable closing and opening hours and number of days. The user can set up lane closure hours for each construction window, such as 7-hour nighttime closures, 55-hour extended weekend closures, 8-hour daytime closures, or continuous 3-day closures.

In the Resource Profile tab, contractor logistics and resource constraints are specified. Major resources with production rates for the schedule analysis include: (1) demolition hauling trucks (size and hourly truck numbers), (2) delivery trucks (size and hourly truck numbers) for base, PCC, or AC, (3) milling machine (for AC), (4) PCC or AC paving machine, (5) rebar cage installation (CRCP), (5) PCC or AC production batch plants, and (6) crew numbers. To help users find realistic ranges of input values for major parameters, a tool tip appears displaying construction data from previous case studies when the cursor hovers over a selected entry. Clicking the INFO- button provides users with additional constructability information.

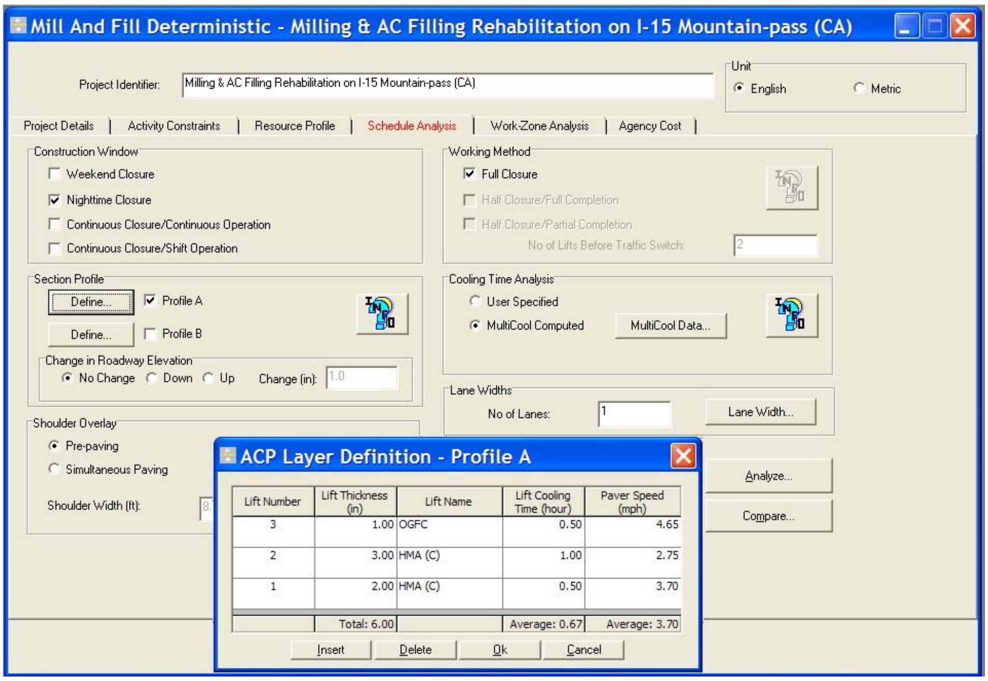

Figure 1 - *CA4PRS* Schedule Module screen capture shows scheduling inputs for the I-15 Mountain-pass project.

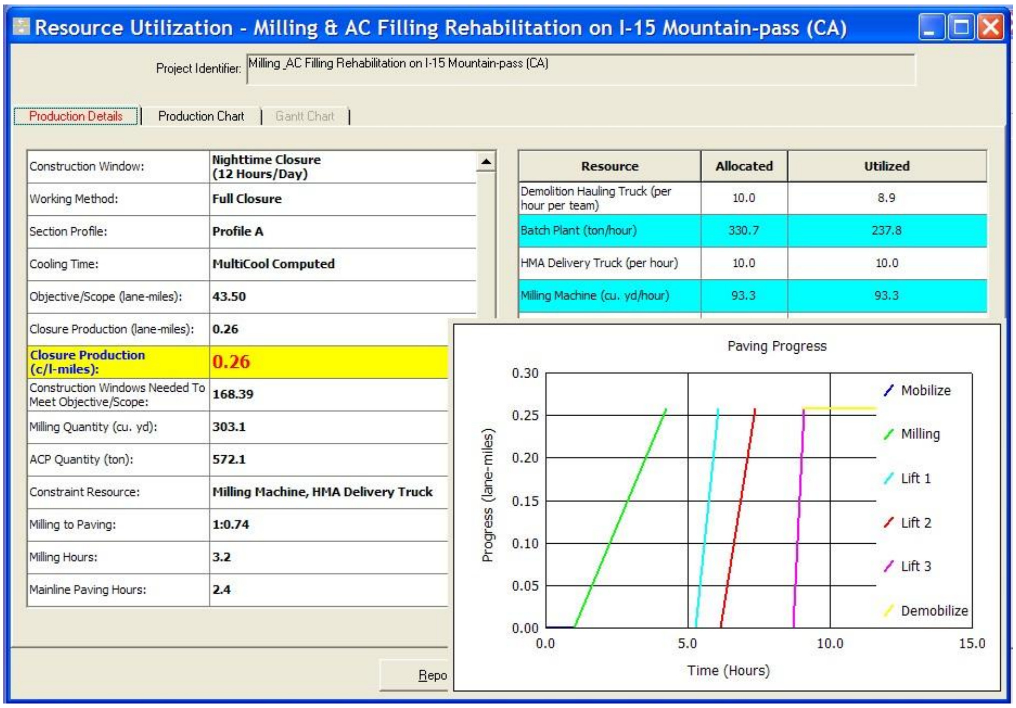

Figure 2 - *CA4PRS* Schedule Module output screen capture shows production rates and closure numbers for the I-15 Mountain-pass project.

In the Schedule Analysis tab, the user selects and controls the following input categories: construction window, construction process (concurrent or sequential) with respect to lane closure tactics, concrete curing or AC cooling time, pavement cross-section changes, and truck lane width. The user can select from the predefined concrete pavement cross sections or input a project-specific cross section, such as AC layer profile and new base thickness. Schedule Analysis takes into account any longitudinal elevation change after the pavement rehabilitation with the Elevation Change menu: No, Down, or Up. For example, oftentimes milling and AC filling rehabilitation on rural highways removes 1-2 inches of existing AC pavement and places 3 to 6 inches of new HMA. In other cases, full-depth AC replacement on urban freeways is designed to include additional demolition thickness to lower the longitudinal elevation underneath a local overpass bridge for better clearance on the mainline.

CA4PRS provides extensive graphical and tabular outputs and incorporates a reports feature that allows input and output information to be saved in PDF or RTF file. *CA4PRS* Schedule Analysis allows more than one selection from each of the four input categories for analysis and side-by-side comparison, and generates multiple analyses showing the combined result of the selections. The schedule analysis output present the maximum production of each rehabilitation scenario, analyzed in terms of lane-km, and the total number of closures required to complete the project based on the maximum production of each scenario (see Figure 2). The output identifies the minimum required resources that maximizes production and the optimally balanced duration of demolition and paving activities within a given closure window.

3.3 Work-zone Traffic Analysis Module

A work zone (WZ) is defined in the *Highway Capacity Manual (HCM)* as an area of a highway where construction operations impinge on the number of lanes available to traffic and affect the operational characteristics of traffic flowing through the area. Lane closure strategies for work zones should include estimates of the number of days the work zone will last, the hours of the day it will be in place, and the anticipated traffic control operations. Work zone characteristics modeled in *CA4PRS* include factors such as work zone length, number and capacity of lanes open, timing and duration of lane closures (hours of the day, days of the week, season, etc.), posted speed limit, and the availability of alternative routes for diversion, as illustrated in Figure 3.

The Demand-Capacity concept is utilized in the Traffic Module to calculate work zone traffic delays and road user cost (RUC) during highway rehabilitation. The basic work zone delay calculation compares hourly traffic demand and available capacity of the roadway analyzed over a 24-hour period. Where demand exceeds capacity, the total road user delay measured in vehicle-hours can be estimated with geometric relationships comparing the two (demand and capacity) curves (detailed delay formulas can be found in Chapter 29 of *HCM 2000).* RUC refers to the dollar values assigned to three user cost components: (1) user delay (including detour delay) costs; (2) vehicle operating costs (VOC), and (3) crash costs incurred by highway users resulting from lane closure in work zones for construction, maintenance, or rehabilitation. RUC is a function of (1) the timing, duration, frequency, scope, and characteristics of the work zone; (2) the volume and operating characteristics of the traffic affected; (3) and the dollar cost rates assigned to vehicle operating, delay, and crashes.

User costs are calculated by multiplying the quantity of the various work zone–related user cost components (user delay, VOC, and crash) by the unit cost for those components. User delay cost is obtained by multiplying the total delay in vehicle-hours by a dollar value of time, a user input that may be based on state, regional, or national values. As an example, the 2007 guidelines from Caltrans (CA) Traffic Operations recommended $11.51/hour for passenger cars and $27.83/hour for commercial trucks.

The Traffic Demand button shown in Figure 3 opens a sub-form for inputting hourly traffic demand on the roadway segment during construction. The user can adjust (reduce) demand through work zone during construction, as a percentage of the hourly traffic flow, to account for no-show (trip cancel) and detours (diversion). Construction year traffic demand is adjusted using the annual growth rate and the time gap between the traffic data year and construction year specified by the user.

CA4PRS computes work zone–induced RUC as the difference in delay cost between that during work zone and normal operating conditions, and requires the roadway capacity under normal operating and work zone conditions. The user can input capacities for the Before- and During-construction conditions, if project-specific values are available, as shown in the RUC input tab. Alternatively, the built-in calculator available via the "Capacity Adjustment" button can be used to calculate and adjust the roadway capacities for Before- and During-construction. The roadway calculator is based on the *HCM 2000,* and the major parameters taken into account are basic capacity, truck percentage (H) in conjunction with geographic terrain (roadway grade), lane width (W), and shoulder and lateral clearance (S).

The primary outputs from the work zone traffic analysis include maximum delay and queue length per closure in the work zone and road user costs (daily, per closure, total per direction, and grand total for both directions). In addition to comparing alternative closure strategies (discussed in subsequent sections), this information can be useful for estimating nominal incentive (or disincentive) amounts to the contractor for early completion of lane closures, which are commonly used in urban freeway rehabilitation.

The results are given by direction of travel under Before and During Construction and as the difference between Before and During Construction. For illustrative purposes, the secondary traffic output also graphically shows traffic hourly inputs such as hourly traffic flow (demand) in comparison with roadway capacity by direction of travel.

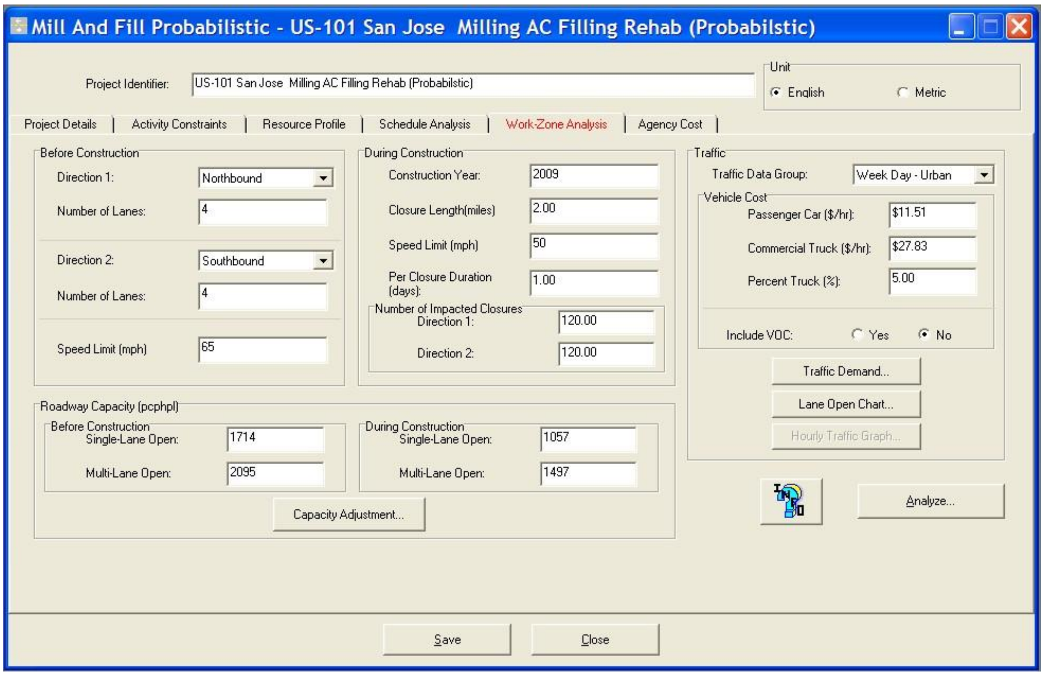

Figure 3 - *CA4PRS* Traffic Module input screen capture shows work zone impact analysis for the US-101 AC Rehabilitation Project.

3.4 Project Cost Estimate Module

The *CA4PRS* Cost Estimate Module is intended to assist state DOT engineers in comparing rehabilitation alternatives from the agency total cost perspective at the level of the engineer's estimate. Based on consultation with state DOT engineers, the Cost Module follows typical cost estimation procedures: (1) calculation of material quantities for major pavement items, (2) estimation of pavement costs based on the unit prices of typical pavement items searched from the historical bid database, (3) estimation of traffic handling and management item costs, (4) estimation of the agency's engineering supporting cost, and (5) estimation of roadway and project costs by factoring the costs of pavement and traffic items with multipliers to cover non-pavement items and indirect costs.

The Agency Cost input tab contains five input groups (sections): Closure Details, Construction Cost, Roadway Cost, Project Total Cost, and Adjusted Project Cost, as shown in Figure 4. The cost estimation follows a step-by-step process for each input group.

Closure Details, the first group of inputs, represents the lane closure information for rehabilitation and consists of closure type and closure number estimated from the schedule analysis. Construction Cost, the second group, starts with defining the pavement items costs accessible from the "Sum (∑)" button in its Pavement subsection. The pavement item costs are developed by selecting relevant bid items from the built-in cost database, including unit price, or by manually adding them. In the case of Caltrans, the unit price of major pavement items are extracted from the Caltrans contract cost database, an online application that allows querying and retrieval of contractors' historical bids (6). After selecting a pavement bid item, the user can input the material quantity directly or use the built-in calculator to compute quantities based on predefined pavement section dimensions (such as distance, width, and thickness).

Total cost for each pavement line item is calculated from the quantity and the unit price and, after all pavement bid items involved in the rehabilitation project are entered, the Total Pavement Cost is calculated as the sum of the cost of all pavement line items. The total pavement cost for the highway rehabilitation project is adjusted based on the closure hours and numbers, primary factors in determining the duration of the project. This adjustment reflects contractor overhead in their bid to secure resources (especially equipment and labor) on site, compared to the standard (nominal) duration of the project with 8-hour closures.

The user estimates the lump-sum costs of non-pavement roadway items, including Earthwork, Drainage, and Specialty items such as a Storm Water Pollution Prevention Plan (SWPPP), as percentages of the Construction Cost, or by inputting the total lump-sum cost of those items directly. The breakdown analysis of cost estimate data for typical pavement rehabilitation for Caltrans projects shows that the Earthwork cost is about 3%, Drainage cost is about 1%, and Specialty cost is about 10% of the Construction Cost.

Traffic handling and management cost consist of the Transportation Management Plan (TMP) and the contractor's traffic-handling cost. TMP cost includes the incident management cost to provide highway patrol service for work zone safety, so-called Construction Zone Enhanced Enforcement Program (COZEEP) costs, incentives/disincentive cost, public information cost, and Extra TMP cost to cover such items as Freeway Service Patrol (towing service). The Traffic Handling costs covers contractor's daily traffic cost items such as signs, barriers, and strips. Moveable concrete barrier (MCB) is covered as a special traffic handling cost, typically for full lane closures such as extended weekend construction.

The Roadway Cost input section includes costs for project mobilization, supplemental, contingency, and other minor costs specified as agency standard percentages of the total construction cost. An itemized cost estimate is provided to cover the agency's supporting costs, mainly engineering staff time, so-called person year (PY) from planning, design, traffic, and construction.

The final Project Cost is computed as the sum of the Roadway (which includes Construction) and Structure, Right of Way, and Supporting costs. Using a discount rate input, the estimated project cost for future construction is converted to a present value for use in LCCA.

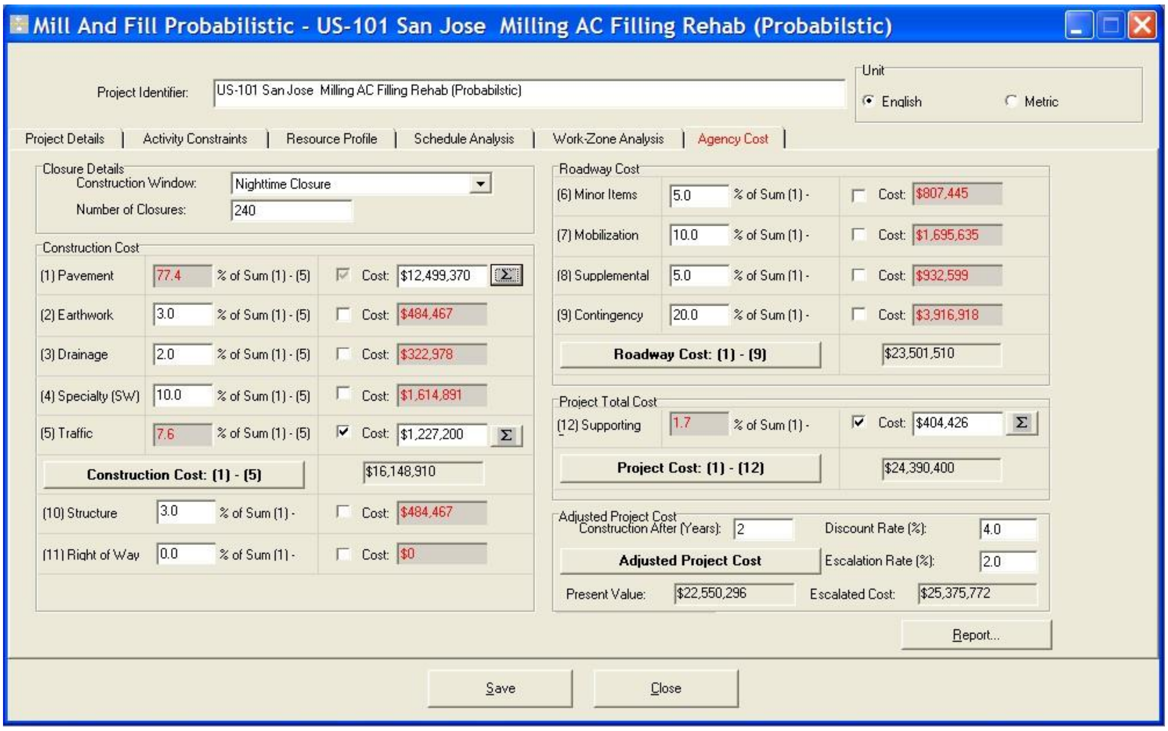

Figure 4 - *CA4PRS* Cost Module screen capture shows agency cost estimate for the US-101 AC project.

4. IMPLEMENTATION CASE STUDIES

4.1 Validation Projects

Since the initiation of the LLPRS program, Caltrans has completed several case study projects for validation and implementation of *CA4PRS*. The first project was on Interstate 10 (I-10) in Pomona, California. The existing 20 lane-km of old concrete pavement was rehabilitated with 4-hour fast-setting hydraulic cement concrete during several 10-hour or 7-hour nighttime closures, except for a 2.8 lane-km stretch of demonstration section that was replaced over a 55-hour weekend closure. In the preconstruction analysis, *CA4PRS* predicted the production rate of the 55-hour weekend closure would be 2.9 lane-km (1.8 lane-mi). As-built data from a construction monitoring study confirmed that the prediction was close to the actual production of 2.8 lane-km completed in the 55-hour weekend closure (8).

CA4PRS was also used to evaluate contractor's staging plans for the Caltrans long-life rehabilitation of Interstate 710 (I-710) in Long Beach (CA), where a 4.4 centerline-km (26.4 lane-km) stretch of old PCC pavement (200 mm (8 inch) slabs and 100 mm (4 inch) cement-treated base) was rehabilitated in a series (eight) of 55-hour weekend full closures. The project consisted of three full-depth asphalt concrete (FDAC) replacement sections ([1.6 km (1 mi) total) under freeway overpasses, and two sections (2.8 km (1.7 mi) total)] with crack, seat, and overlay (CSOL) of existing PCC slabs with asphalt concrete. *CA4PRS* was used to develop the project construction staging plan based on its schedule estimate. The contractor's measured actual production—with noticeable improvements and a learning curve effect as the construction progressed—was within 5 percent of the *CA4PRS* production estimates (9).

More recently, *CA4PRS* was used for a Caltrans project that rebuilt a heavily trafficked 4.5 centerline-km (2.8 mi) concrete truck lanes on Interstate 15 (I-15) in Devore (CA), which was the first large-scale concrete LLPRS implementation project with an innovative fast-track reconstruction approach. *CA4PRS* was used in the preconstruction analysis to select the optimal rehabilitation scenario for the project. Four construction closure scenarios were compared: 72-hour weekday, 55-hour weekend, extended continuous (24/7), and 10-hour nighttime closures. The project was completed in two 210-hour extended closures (about 9 days for each closure), using counter-flow traffic and 24/7 continuous construction operations. According to the preconstruction schedule estimate with *CA4PRS,* this project would have taken ten months using traditional nighttime closures. The use of this "Rapid Rehab" approach on the I-15 Devore project reduced agency costs by $6 million, and saved $2 million in road user delay costs, compared to nighttime closures. The production estimate by *CA4PRS* was consistent with the contractor's actual measured production performance (10).

CA4PRS was used by the Washington State Department of Transportation (WSDOT) to compare rapid rehabilitation strategies to lengthy traditional reconstruction strategies on two projects: one on I-5 in Federal Way and one beneath the Seattle Convention Center. The WSDOT *CA4PRS* evaluation was performed on a complex, heavily constrained, downtown Seattle partial reconstruction of about 3.57 lane-km (2.22 lane-mile) of Interstate 5, using a four-weekend closure scheme. Results showed that *CA4PRS* can be successfully used during early scoping and design for alternative evaluation and post-award preconstruction to verify the contractor's schedule (11).

During the 2004 construction season, the Minnesota Department of Transportation (MNDOT) implemented *CA4PRS* on two asphalt resurfacing (milling and AC overlay) projects on freeways near the Twin Cities (Minneapolis and St. Paul). Both projects involved milling and bituminous paving: one was a nighttime operation on I-494, and the other involved a combination of night and complete weekend closures on I-394.

4.2 Pre-Construction Analysis Example: I-280 PCC Rehabilitation Project

CA4PRS is being used in ongoing LLPRS projects in California, including the I-15 Ontario PCC reconstruction and I-710 Compton AC rehabilitation projects, to develop construction staging and traffic management plans to complete work as quickly as possible with the least impact to traffic (both of these projects are designed for 55-hour weekend closures over several months).

Recently, project teams in Caltrans urban districts (such as the San Francisco Bay Area) have modified lane closure schemes for their rehabilitation projects based on *CA4PRS* use. Several upcoming pavement rehabilitation projects, including a San Jose AC project on US 101, a Santa Clara PCC project on I-280, and a San Ramon Precast and CSOL project on I-680, all in their final design stage, were changed from short nighttime closures (e.g., 6 hours) to longer closures (e.g., 7 or 8 hours), based on the *CA4PRS* sensitivity analyses. As an example, the traffic operations team recommended 6-hour nighttime closures to the design team for the PS&E (Plans, Specifications, and Estimates) of the I-280 Santa Clara (south of San Jose) project to minimize work zone traffic impact. However, *CA4PRS* schedule estimate indicated that the 6-hour short nighttime construction strategy would require about four times more closures (370) compared with 8-hour nighttime construction (100) for the approximately 4.8 lane-km (3 lane-mi) PCCP rehabilitation project.

In addition to the scheduling advantage of a longer nighttime closure that yields more efficient productivity and consequently reduces the total closure duration, the *CA4PRS* integration analysis also illustrated that the longer closure might also help reduce construction costs, as it is likely that the contractor will incur lower overhead costs given reduced construction duration. It was also shown that other agency costs, such as traffic handling and TMP (Transportation Management Plans) and field engineers' supporting costs, can be reduced substantially with the longer closure strategy, as they are proportional to the total duration (and number) of the lane closures. For example, one of the major TMP cost components in Caltrans' nighttime construction in urban networks is the cost of a highway patrol service, the so-called COZEEP, which is part of FHWA's work-zone incident management. This cost is estimated at $0.7M for 370 six-hour closures compared to $0.3M for 100 eight-hour nighttime closures.

During the design stages of a recent Caltrans I-280 PCC rehabilitation project, the extended weekend closure (55-hour) strategy was considered as the best one as it has the advantage of reducing overall construction duration (closure time) and agency cost significantly compared with nighttime closures. The schedule analysis indicated that the entire PCC rehabilitation project could be completed in about six weekend closures instead of two years of short (6-hour) nighttime closures. However, the *CA4PRS* work zone traffic analysis showed that the maximum delay per weekend closure would be over the Caltrans practical threshold (30 minutes) due to high traffic demand in the Silicon Valley area during weekends. In addition, the Caltrans district management had concerns about changing to extended weekend closure for two reasons. First, the change represented a major deviation from the initial construction strategy of conventional nighttime closures, which would require preparation of a more comprehensive PS&E package. If this were to occur it would lead to delays in the project implementation schedule. Finally, based on the *CA4PRS* preconstruction analysis (as summarized in Table 1) the project team became more flexible, changing from the initial plan to use short (6-hour) nighttime closures to longer nighttime closures (mostly of 8 hours, with several of 7 hours, depending on locations).

Table 1 - Comparison of Schedule, Traffic, and Cost with *CA4PRS* for the I-280 PCC Project

Construction Schedule			**Work-zone Traffic Impact**		**Direct Agency Cost ($Millions)**			
Closure Hours		Closure Number	User Cost ($M)	Max Delay (min)	Pavement Items	Traffic Handling	Field Engineers	Total Agency
Nighttime	6-hour	370	0	0	$8.20	$1.30	$0.60	$10.10
	7-hour	165	$0.5	15	$6.60	$0.60	$0.30	$7.60
	8-hour	100	$1.0	25	$5.50	$0.40	$0.20	$6.10
	9-hour	70	$3.0	45	$5.50	$0.30	$0.10	$5.90
Weekend Extended	55-hour	6	$6.0	120	$3.60	$0.70	$0.10	$4.40

5. DEPLOYMENT EFFORTS

5.1 Potential Payoffs

The use of *CA4PRS* by state DOTs since its release in 2000 has shown it to be a valuable tool in any project phase. It is particularly useful to state DOTS when implemented during the planning and design stages of project development, the time when the analysis results can be used to balance pavement design, construction logistics, traffic operations, and agency budget. *CA4PRS* can provide additional benefits when its results are integrated with readily available traffic simulation modeling tools to quantify the impact of work-zone lane closures on the entire highway network, including local arterials and neighboring highways. When combined with these traffic simulation models, *CA4PRS* can help identify pavement structures and rehabilitation strategies that maximize on-schedule construction production without creating unacceptable traffic delays. The *CA4PRS* outputs also provide useful information for public outreach activities. This information is vital in balancing the three competing goals of longer-life pavement, minimizing agency cost, and minimizing traffic delay during closures.

During the estimation and execution stages of highway rehabilitation projects, *CA4PRS* can also assist engineers from design, construction, and traffic operations develop a schedule baseline to determine reasonable productivity goals. In addition, paving contractors and consultants may find this tool useful for checking construction staging plans, identifying critical resources that constrain production, and quantifying the probability of meeting incentives/disincentives and cost-plus-schedule contracts.

5.2 Nationwide Deployment

A new federal work zone regulation requires the implementation of project-level procedures to assess and manage the impacts of highway construction projects on safety and mobility in work zones (Work Zone Safety and Mobility Rule [23 CFR 630 Subpart J]) (12). The regulation requires any project receiving federal-aid highway funding to develop a Transportation Management Plan (TMP, a part of the PS&E package) to assess and mitigate work zone traffic delays. *CA4PRS* can assist in a majority of the analyses required for compliance with the new federal rule.

The Technology Implementation Group (TIG) of the American Association of State Highway and Transportation Officials (AASHTO) selected *CA4PRS* along with traffic simulation models as a market-ready technology for adaptation by state agencies through the project titled “Construction Analysis Software Tools” (CAST). In 2008, *CA4PRS* was also endorsed by FHWA as a “Priority, Market-Ready Technologies and Innovations” product for nationwide deployment. In early 2009, a *CA4PRS* group license was acquired by FHWA and has been made freely available to all fifty states.

6. CONCLUSIONS

Urban highway rehabilitation projects often create challenges for state highway agencies, motorists, and commercial enterprises. To mitigate these adverse effects, highway planners, pavement designers, and traffic managers seek to expedite construction in a variety of ways.

CA4PRS software is designed to help highway agencies, consultants, and paving contractors identify highway rehabilitation strategies that balance on-schedule completion, disruption to traffic, and agency cost. *CA4PRS* is most useful to transportation agencies as a planning and design tool to identify highway rehabilitation strategies that meet project goals and eliminate unwarranted constraints in achieving those goals. The *CA4PRS* model, with its seamlessly integrated schedule, traffic, and agency cost analysis modules, can also facilitate what-if type analysis and communication among engineers from design, construction, and traffic operations to arrive at a mutually optimal solution in their decision-making processes. It can also be a valuable tool in developing quantified information on important topics such as construction duration, lane closure tactics, and use of local resources for communication with local communities affected by rehabilitation operations.

The validation and implementation of *CA4PRS* on urban freeway rehabilitation projects in sponsoring states, including I-710 Long Beach and I-15 Devore projects, has shown that its predictions are consistent with observed construction performance and demonstrated its value in cost savings to both agencies and road users.

Additional benefits may be realized when *CA4PRS* results are integrated with macroscopic and microscopic traffic simulation tools for estimating road user costs due to construction work zone closures, especially on high traffic volume urban networks. *CA4PRS* can benefit transportation agencies during the planning and design stages of highway rehabilitation and reconstruction projects by assisting in the development of construction staging plans, establishing design-level CPM construction schedules, estimating working days for cost (A) + schedule (B) contracts, checking contractor contingency plans, and calculating user costs for incentive/disincentive specifications.

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