A STATE-OF-THE-ART TOOL FOR SUSTAINABLE REBUILDING OF AGING INFRASTRUCTURE SYSTEMS

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Abstract

Agency efforts to deliver projects in a timely manner have been furthered by use of innovative software analysis programs and scheduling techniques like *CPM* (Critical Path Method) or *PERT* (Program Evaluation and Review Technique). A more recent tool arising from these efforts is a state-of-the-art tool called CA4PRS (Construction Analysis for Pavement Rehabilitation Strategies), which has come into use because of its ability to analyze schedules, costs, and work zone traffic impacts. In some innovative states like California, CA4PRS has been widely used as the main decision-support tool from the initial planning and design stages to implement the most economical rehabilitation strategies for the projects. This paper presents schedule and cost saving aspects of utilizing CA4PRS used to achieve faster project completion with less traffic disruption as applied on three experimental long-life highway pavement rehabilitation projects in California. The implementation of CA4PRS on the three urban large-scale projects has demonstrated its value on tremendous monetary savings in agency cost and road user cost by selecting the most economical construction strategy, geared to balancing schedule, cost, and traffic aspects. The CA4PRS's scheduling module estimates highway project duration (total number of closures), incorporating alternative strategies for pavement designs, lane-closure tactics, and contractor logistics. CA4PRS's traffic module quantifies the impact of construction work zone closures on the traveling public in terms of road-user cost and time spent in queue. Its greatest value lies in its capability of providing information to the planner/designer to optimally balance pavement design, construction constraints, traffic operations, and transportation agency budget — especially during the planning and design of rehabilitation projects. The schedule and cost saving benefits of CA4PRS addressed in this paper will promote the use of CA4PRS in the planning stage to develop the most economically feasible construction strategies in an attempt to maximize construction productivity and to minimize inconvenience to the traveling public during construction.

Key words: Highway rehabilitation, Computer-aided simulation, Infrastructure management, Scheduling, Project management

EMERGING NEEDS OF HIGHWAY INFRASTRUCTURE REHABILITATION

Over the past 20 years, highway traffic has increased by 75 percent. However, total number of new highways and bridges that are newly constructed take only 4 percent [1] (Figure 1). Traffic demand keeps increasing greatly over time, but capacity stays the same. Furthermore, most of the nation's highway system was built during construction boom between the 50's and 80's, with 20 years design life. Most of them already exceeded their original design life. For this reason, there are serious growing concerns about road user safety and inconvenience to the traveling public. To address the concerns, many states are now under increased pressure to rebuild aging highway infrastructure systems that need timely renewal within a few years.

In addition to the emerging need, the economy stimulus package calls for immediate, extensive rebuilding of the nation's existing infrastructure over the next few years to spark the economic growth as well as to respond to the emergent need for repairing the nation's aging infrastructure systems. $27.5 billion in federal stimulus money is being headed to state DOTs to achieve these purposes [2].

New Trend in High Impact Highway Rehabilitation Projects

Typically, highway renewal projects cause serious traffic disruptions for communities that use the freeways, and result in major inconveniences for commuters and businesses. It is estimated that the annual costs to drivers, businesses, and transportation agencies incurred by highway construction traffic delays total $43 billion, $21 billion of which is in extra fuel consumption [3]. The California Trucking Association estimates that the impact of early opening of freeways saves "their commercial operators more than $250 per truck trip or $500,000 per day" in trucking costs [4].

In responding to the budgetary need for more cost-effective construction and pressure to reduce the consequences of urban highway traffic disruptions due to construction, many state highway agencies (SHAs) have changed their focus from development and construction of new facilities to maintenance and renewal of existing facilities [5; 6]. It was reported that about 30 percent of highway maintenance and renewal projects in the United States were undertaken in heavily-trafficked urban areas [7].

Federal Rule Change in Safety and Mobility

As the frequency of U.S. highway reconstruction increases, improving the safety of work zones becomes an increasingly serious concern. In the year 2004, a total of 1,065 fatalities and more than 40,000 injuries resulted from work zone accidents [8]. In addition to the suffering caused by these accidents, traffic delays caused by the reduction in operational capacity at work zones increase road user costs and air pollution at a rapid rate.

To mitigate the problems caused by these work zone impacts, on September 9, 2004 the Work Zone Safety and Mobility Rule was published in the Federal Register by the Federal Highway Administration (FHWA). The rule states that all state and local governments receiving federal-aid funding are required to comply with the provisions of the rule no later than October 12, 2007. Under the new regulation, transportation agencies are required to consider work zone safety and mobility impacts broadly over project development stages and implementation stages. These provisions will help transportation agencies meet current and future work zone safety and mobility challenges.

The Work Zone Safety and Mobility Rule encourages state and local agencies to seek systematic ways to consider and manage work zone impacts and to establish processes and procedures that implement and sustain work zone policies. The rule includes provisions for developing agency-level processes and procedures to manage work zone impacts systematically during the course of project development. The rule also calls for the development of project-level procedures to address the work zone impacts of individual projects. The project-level provisions require implementation of transportation management plans for all federal-aid highway projects. Lastly, the rule requires state agencies to develop project-specific procedures to access and manage the impacts of individual projects.

PROBLEMS IN CURRENT INDUSTRY PRACTICE

In current industry practice, the estimates of construction schedule, project cost, and traffic delay are done manually for the most part, so each aspect of planning, design, construction scheduling, and traffic management is evaluated separately using labor intensive means. The manual calculations are more prone to errors than automated methods partly in the process of making the calculation but for other reasons as well. For example, determination of contract times has relied to a great extent on the experience and judgment of the contracting agency engineers tasked with estimating the duration of project and realistic I/D rates [9]. Therefore, the accuracy of schedule estimates varies depending on a number of factors. Several limitations associated with existing traditional manual procedures are as follows:

- A limited number of alternatives can be developed and evaluated.
- Traditional methods are time consuming.
- Accuracy of manual procedures varies depending on a number of factors.

The time required for manual methods also makes it difficult to use innovative scenarios or to modify traditional approaches to achieve more economical solutions for specific project conditions.

In addition, there are no consistent, standardized methods and tools to integration of pavement materials and design, construction logistics, and traffic operations, which would provide more effective evaluation of highway rehabilitation alternatives. This inaccuracy using manual calculation often results in a monetary loss for SHAs through the overestimations of project schedule and cost.

RESEARCH OBJECTIVES

To address the aforementioned problems, a state-of-the-art tool called CA4PRS (Construction Analysis for Pavement Rehabilitation Strategies) was developed by the University of California Pavement Research Center under the FHWA pooled fund. It has come into use because of its ability to analyze schedules, costs, and work zone traffic impacts. This software tool can also perform the majority of the analyses required to comply with the recently updated FHWA rule governing safety and mobility in work zones. This software tool will automate the current manual methods and will enable the creation and evaluation of traditional as well as more innovative designs, construction schedules, and traffic management options by significantly increasing the number of "what-if" scenarios that engineers can examine.

The main objective of this paper is to introduce a new state-of-the-art computer tool that provides an integrated analysis of design, construction, cost, and traffic. This research study also demonstrates the power of utilizing CA4PRS in terms of schedule and cost savings that were achieved by faster project completion with less traffic disruption. Three experimental high impact urban highway rehabilitation projects that were completed in California over the past ten years are selected to compare the contractors' actual production performance with the CA4PRS-outlined schemes. Researchers including the author were present at the three construction sites to collect construction and traffic data, and to observe and document the construction process. This allowed the author to determine the influence of the varied activities on the overall project and to validate the accuracy of CA4PRS analysis results.

CA4PRS OVERVIEW

CA4PRS is a construction scheduling and traffic analysis tool that provides information to optimally balance pavement design, construction constraints, traffic operations, and budgets for transportation projects. CA4PRS assist the planning and design engineers in the evaluation of highway rehabilitation activities and selection of the optimal rehabilitation strategies under given constraints. The software's scheduling module estimates highway project duration (total number of closures), incorporating alternative strategies for pavement designs, lane-closure tactics, and contractor logistics. CA4PRS's traffic module (using the Highway Capacity Manual demand capacity model) quantifies the impact of construction work zone closures on the traveling public in terms of road user cost and time spent in queue.

It is a knowledge-based simulation model that allows "what if" evaluations by comparing the impact the following variables have on rehabilitation productivity [10]:

- Rehabilitation strategy: Portland Cement Concrete (PCC) reconstruction, crack-seat PCC and asphalt concrete overlay (CSOL), or full-depth asphalt concrete replacement (FDAC).
- Construction window: nighttime closures, weekend closure, continuous closure, or combinations.
- Lane closure tactic: number of lanes closed for rehabilitation (i.e., partial or full closures).
- Material selection: mix design and curing time for concrete or cooling time for asphalt.
- Pavement cross section: thickness of new concrete or asphalt concrete.
- Pavement base type: lean concrete base (LCB) or asphalt concrete base (ACB).
- Contractor's logistical resource: location, capacity, and numbers of rehabilitation equipment available (batch plant, delivery and hauling trucks, paving machine).
- Scheduling interface: mobilization/demobilization, traffic control time, and activity lead-lag time relationships and buffer sizes.

CA4PRS INPUTS AND OUTPUTS

CA4PRS Inputs

CA4PRS starts with a prompt for user input with the following four input tab windows: (1) project details window, (2) scheduling window, (3) resource profile window, and (4) analysis window, as described in detail below (see Figure 2).

- Project Details Window: The user enters basic project information, including analysis identifier, project descriptions, route name, post (station) miles, location, etc. The user also specifies project scope by entering total lane-km to be rehabilitated. This scope acts as the baseline to compute total number of closures required based on the computed rehabilitation production rates for each closure.

- Activity Constraints Window: The user enters in minimum times required for mobilization and demobilization purposes such as site preparation, clean-up, and, more importantly, traffic control for the construction. Activity lead-lag relationship and minimum time interfaces among major operations need to be specified. Three alternative time frames (construction windows) are available to the user: nighttime, weekend, and continuous closures. Continuous closure has two sub-options: daytime operations, with one or two crew shift(s) for a limited number of weekdays while the freeway remains closed throughout the whole period of rehabilitation; and continuous closure with continuous (round-the-clock) operations using two or three rotating crew shifts.

- Resource Profile Window: Contractor logistics and resource constraints to be specified here are two of the most decisive factors in rehabilitation production, especially in urban highway rehabilitation where space and access for construction equipment are often limited. Resource inputs require prior knowledge, experience and/or personal judgments of the user.
- Analysis Window: The user selects and controls construction time, rehabilitation sequence with respect to lane closure tactics, concrete curing time, pavement cross-section changes, and truck lane width.

CA4PRS Outputs

Agency engineers, contractors, and consultants can use CA4PRS to determine the duration of project and to estimate the probability of project accomplishment within a given project duration. The former is called the deterministic analysis and the latter is referred to as the probabilistic analysis. More specifically, the deterministic analysis determines (a) the duration of project, (b) maximum production rate, (c) critical resources, and (d) material volumes. It provides answers to the following management questions:

- How many lane-km could be finished within a closure?
- How many closures in total are needed to finish the whole project, and what is the total duration of the closures?

In comparison, the probabilistic analysis estimates the likelihood of completing the project within given activity durations, generated with Monte Carlo simulation. The probabilistic analysis produces the likelihood of the maximum possible production rates (lane-miles per closure) in three different probable scenarios:

- Pessimistic production rate
- Most likely production rate, and
- Optimistic production rate.

For practical application, it is more appropriate for major contractors, who have some previous proven records, to apply the optimistic production rate.

BENEFITS OF CA4PRS

CA4PRS can be used through the entire project implementation phases. In the planning stage, it helps agencies select the most feasible construction scenario by comparing several candidate scenarios in terms of construction schedule, project total cost, and traffic delay. In the design stage, it can be used to develop PS&E (Plans, Specifications, and Estimates) package and transportation management plans. In the construction stage, it helps validate contractor's work plan and evaluate contractor's request of change orders (Figure 3). CA4PRS also helps agencies, contractors, and consultants prepare strategies (including the PS&E package) for highway rehabilitation projects in:

- Estimating working days and CPM schedules,
- Developing construction staging plans,

- Supplementing traffic management plans, and
- Outlining incentives and cost (A) + schedule (B) contracts.

Other benefits are summarized as follows:

- Reduced engineering time: the use of CA4PRS to automate traditional manual procedures will shorten the time required for engineers to develop designs, construction schedules, and traffic management options. Fewer errors that occur as a result of this more accurate automated approach will reduce the time required for error checking and will enable more focus on inputs and evaluation of outputs for potential improvements. Overall efficiency will be enhanced because more "what-if" scenarios are evaluated and an optimal alternative can be selected in a shorter time during project development.
- Reduced work zone delay: a reduction in work-zone delay includes evaluating alternative scenarios for construction staging plans and traffic management plans. Like the planning and design phases of project development, the construction phase will benefit from an integrated approach, which will overcome the limitations of manual procedures. Lowering work-zone delays results from the power of the automated approach to evaluate more alternatives (leading to an optimized project) and to ensure better accuracy. As a standardized, knowledge-based expert system used throughout Caltrans, the software will ensure the use of best practice statewide in construction scheduling and staging as well as development of effective management plans. The integrated tool will reduce delays for projects carrying high passenger volumes in urban locations as well as those carrying heavy freight on rural routes.
- Reduced time in project development and planning: a reduction in project development time is based on less staff time to evaluate more alternatives in project scoping, planning, environmental documentation, and the time required to develop plans, specifications, and estimates (PS&E). An automated and integrated tool for optimizing project development will replace the time consuming, labor intensive, subjective, and inaccurate manual method typically used.

IMPLEMENTATION EXPERIENCE

Since 1999, the capabilities of CA4PRS have been confirmed on several major highway rehabilitation projects in states including California, Washington, and Minnesota (Figure 4). The software was validated on the 2.8-lane-km I-10 Pomona Project, which used fast-setting hydraulic cement concrete and was completed in one 55-hour weekend closure. The software was also used to develop a construction staging plan for the I-710 Long Beach Project, where 26 lane-km of asphalt concrete were reconstructed in a series of eight 55-hour weekend closures—two weekends ahead of schedule.

More recently, CA4PRS was used with traffic simulation models to select the most economical rehabilitation scenario for the I-15 Devore Project. The 4.5-km concrete reconstruction project, which would have taken 10 months using traditional nighttime closures, was completed over two 9-day periods using one-roadbed continuous closures and around-the-clock construction. Implementing continuous closures rather than repeated nighttime closures in this project resulted in significant savings: $6 million in agency costs and $2 million in road user costs (see Table 1).

Alternative strategies enabled by use of CA4PRS led to an accelerated project process dubbed "Rapid Rehab" that was praised by professionals.

Other sponsoring state transportation departments have also used CA4PRS for analyses of corridor rehabilitations. The Washington State DOT used it to analyze reconstruction of Interstate 5 through Seattle. The Minnesota DOT used it to analyze the rehabilitation of interstates 394 and 494 in St. Paul.

CONCLUSION

CA4PRS is designed to predict the maximum amount (distance) of freeway rehabilitation or reconstruction in various closure times and durations under the given project constraints of pavement design, lane closure tactics, schedule interfaces, and contractor's logistics and resources. The software is a useful tool for constructability analysis that allows road agencies evaluate "what-if" scenarios at each stage of the pavement rehabilitation project: feasibility/planning, design, and construction.

It provides a schedule baseline for the integrated analysis of design, construction, and traffic, all essential for selecting economical pavement rehabilitation strategies. When combined with a traffic model, CA4PRS software can help determine which pavement structures and rehabilitation strategies maximize on-schedule construction production without creating unacceptable traffic delays.

For urban freeway rehabilitation and reconstruction, CA4PRS has wide applicability for the entire transportation industry.

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LIST OF TABLE

Construction Scenario	Schedule Comparison		Cost Comparison ($M)			Max. Peak Delay (Min)
	Total Closure	Closure Hours	User Delay	Agency Cost	Total Cost	
One Roadbed Continuous (24/7)	2	400	5.0	15.0	20.0	80
72-Hour Weekday	8	512	5.0	16.0	21.0	50
55-Hour Weekday	14	770	14.0	17.0	31.0	80
10-Hour Night-time Closures	220	2,220	7.0	21.0	28.0	30

Table 1. Analysis Summary Integrating Construction Schedule, Cost, and Traffic Aspects.

LIST OF FIGURES

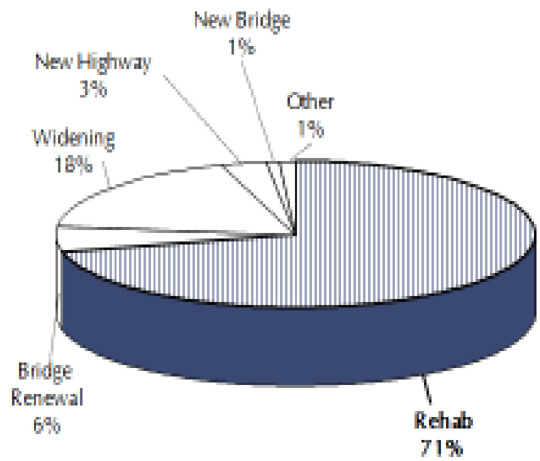

Figure 1. Breakdown of 6,000 infrastructure projects completed between 2000 and 2008 in California

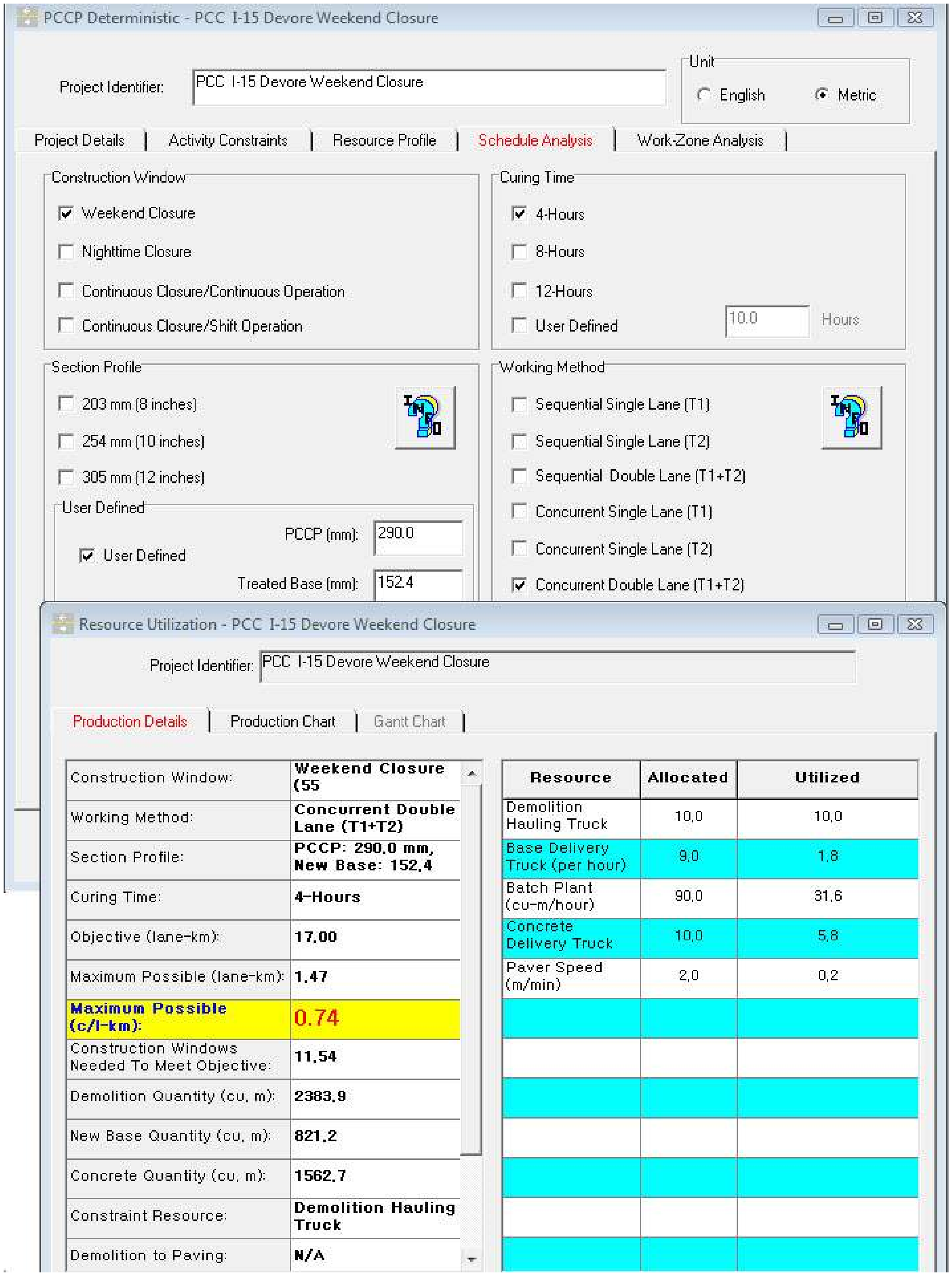

Figure 2. Input and Output Screen Example of the CA4PRS Schedule Estimate

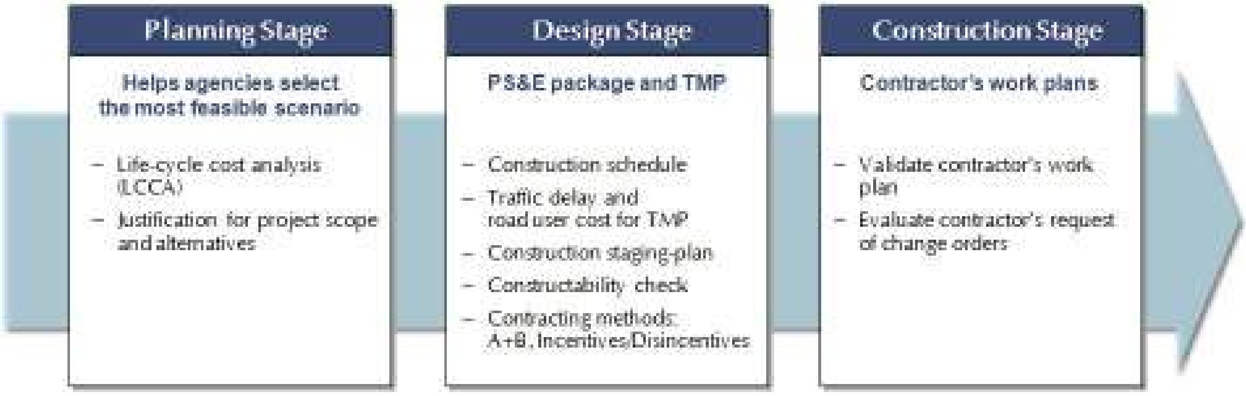

Figure 3. Use of CA4PRS throughout project life cycle

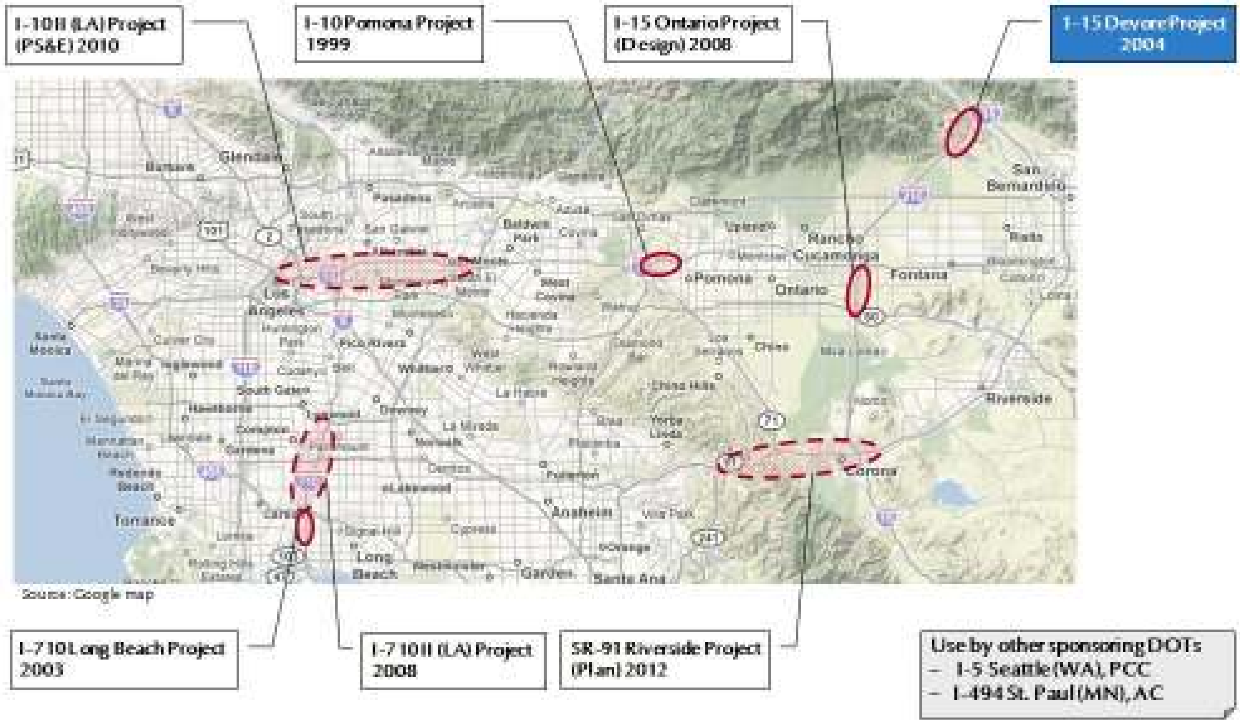

Figure 4. CA4PRS implementation and validation on several large-scale urban infrastructure rehabilitation projects