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Cost Estimate Modeling of Transportation Management Plans for Highway Projects

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RESEARCH BACKGROUND AND OBJECTIVE

With mature and aging infrastructure, transportation agencies have shifted their focus from constructing new highways to rehabilitating existing facilities. Because highway rehabilitation projects often cause congestion, safety concerns, and limited access for road users, agencies face a challenge in finding economical ways to renew deteriorating roadways in metropolitan areas. In 2010, a total of 576 fatalities were reported in work zones in the United States (USDOT 2011). Road users are also frustrated with the work zone delays and unexpected work zone road conditions. To better address the work zone issues, the Federal Highway Administration (FHWA) published updates to the Work Zone Safety and Mobility Rule. All state and local governments that receive federal-aid funding were required to comply with the provisions of the rule no later than October 12, 2007 (FHWA 2005).

One of the major elements of this rule is to develop and implement Transportation Management Plans (TMPs) for all road projects. Using well-developed TMP strategies, work zone safety and mobility can be enhanced while road user costs can be minimized. For better management of the impacts of California highway projects, the California Department of Transportation (Caltrans), in 2001, began requiring TMPs for all planned activities on the state's highway system.

The cost of a TMP is generally considered as one of the high cost items of a road project and is required to be quantified. During design, the project engineer with the support of the TMP engineers is in charge of the project cost estimate as part of the Plans, Specifications, and Estimates (PS&E) package. However, there are no tools or systematic modeling methods available to assist project engineers in the TMP cost estimating task. Therefore, a systematic modeling process for TMP cost estimation would be helpful to assist the district TMP team and project engineers in producing more accurate plans.

The overall objective of this research is to develop a systematic cost estimation modeling process for TMPs in order to assist Caltrans TMP engineers and project design engineers by automatically estimating TMP costs for highway projects using pre-established TMP elements grouped by TMP strategies.

RESEARCH METHODOLOGY

This research was performed by collecting TMP reports from Caltrans regarding state-of-the-art TMP practices and input from the district TMP managers and project engineers. In consultation with the district TMP engineers, highway project data (with regard to TMP cost estimating) was collected. Then, using Construction Analysis for Pavement Rehabilitation Strategies (CA4PRS) software, case studies were performed. Based on the outcomes of the case studies, a TMP cost estimate modeling process for Caltrans highway projects was proposed.

The proposed TMP cost estimate procedure consists of two major steps: 1) systematic method of selection of TMP strategies and 2) cost estimation for the selected TMP strategies. The TMP strategy selection process was performed using both the Performance Attribute Matrix (PAM) method and a TMP cost estimation method interacting with CA4PRS.

To validate the proposed model, an application for selecting TMP strategies and estimating TMP costs was demonstrated in this research. The I-15 Ontario rehabilitation project was used to test the proposed model's performance in order to validate the proposed method as a systematic model to be used for estimating TMP costs.

RESEARCH OUTCOMES

In this research, a detailed step-by-step TMP strategy selection and cost estimate (STELCE) model was developed considering various situations, including diversity of traffic conditions and construction schedules and resources. The TMP selection procedure model takes into account the CA4PRS analysis results as an input value to determine Intensity Level using the PAM method. The CA4PRS provides the major parameters to the TMP STELCE model. The resulting TMP cost estimates are then used as input into the CA4PRS so that they can be included in the agency's cost estimate.

The TMP STELCE model classifies the project into one of five Intensity Levels depending on the score earned through quantitative values for the project attributes. The TMP strategies in the TMP categories are determined by the resulting Intensity Level. The costs for TMP strategies, which are selected in the category's corresponding Intensity Level, are estimated by a function of Intensity Level and the base cost dollar amounts. The cost of each strategy is determined by using "what-if" analysis.

The TMP STELCE model was verified using the I-15 Ontario rehabilitation case study. The comparison results between the cost estimated by the model and the one estimated by the Caltrans TMP Report shows an acceptable difference (5 percent).

As to the limitation of the model, the proposed TMP STELCE model was developed based on Caltrans TMP practices and strategies. Therefore, other state DOTs might need to make adjustments and modifications, reflecting their TMP processes, for their adoption of this model.

The proposed model is just a prototype process, a framework based on a limited number of TMP case study projects. The accuracy and reliability of the model can be improved with more TMP reference projects. Testing more case studies would be a next step. Prototyping the TMP STELCE model in Excel, using macro and Visual Basic functionalities, would also improve calculation reliability. Further, coding the model as a standalone Windows application with a user-friendly interface would greatly improve usability by professionals, making the model marketable.

Currently, this TMP STELCE model separately imports and uses traffic and construction information from CA4PRS to select TMP strategies and to estimate cost for the TMP strategies selected. With its own graphical user interface, this TMP STELCE module within

CA4PRS would enable engineers to estimate realistic agency costs, including reasonable TMP costs (along with the road user costs already embedded in CA4PRS).

I. INTRODUCTION

RESEARCH BACKGROUND

Minimizing disruption to the traveling public during construction has been a critical issue in the United States. According to the Federal Highway Administration's (FHWA) Rules on Work Zone Safety and Mobility (23 CFR 630 Subpart J) (called WZ Rule in this report), all state and local governments that receive federal-aid funding were required to comply with the provisions of the rule no later than October 12, 2007 (FHWA 2005). One of the major elements of the WZ Rule is to develop and implement Transportation Management Plans (TMPs) for all highway projects

A TMP traditionally has included temporary traffic control plans to manage mobility and safety impacts within a project work zone. For maintenance of traffic (MOT), estimating pay items and cost for the project MOT bid has already proven a difficult issue (Ellis 2008). With the implementation of the FHWA's WZ Rule, the TMP scope has expanded to include public relations, incident management, and system-level operational impacts, especially on significant projects.

The selection of TMP strategies for a highway project depends on factors such as project type and complexity, the project location (especially urban versus rural), construction staging plans, project agency cost (especially traffic budget), road user costs, agency lane closure policies, and particular aspects of the surrounding area (FHWA 2005). Therefore, to devise an effective TMP, it is imperative to take these influencing factors into consideration in a systematic process and model.

The California Department of Transportation (Caltrans) began requiring TMPs for all planned activities on the state highway system for better management of the impacts of highway projects in 2001. In California, typically (except some urban district areas) a delay of 30 minutes or longer during construction creates a significantly negative traffic impact (Caltrans 2009a). Caltrans has been implementing the required TMPs to alleviate or minimize "work-related traffic delays by the effective application of traditional traffic handling practices and an innovative combination of various strategies encompassing public awareness campaigns, motorist information, demand management, incident management, system management, construction methods and staging, and alternate route planning" (Caltrans 2009a). TMP strategies include: full facility closures, extended weekend closures, continuous weekday closures, performance-based traffic handling specifications, and so on (FHWA 2007). Using well-developed TMP strategies, work zone safety and mobility can be enhanced, and road user costs can be minimized.

In California, a summary of project cost estimates includes three major categories: 1) roadway, 2) structure, and 3) right-of-way. The TMP cost belongs to the traffic section as part of the roadway category. The cost of a TMP ranges from a small percentage of the overall project cost to more than 20 percent (AHMCT 2005). The TMP cost is included in the agency's construction cost and generally considered one of the high cost items. Therefore, the TMP cost is required to be quantified. The project design engineer, with the support of the TMP engineers, is in charge of the project cost estimate as part of the Plans, Specifications, and Estimates (PS&E) package. However, there are no tools or systematic modeling methods available to assist project engineers in estimating TMP costs. Therefore, it is necessary to develop a systematic modeling process for TMP cost estimation to assist a district TMP team and project engineers in producing more accurate plans.

RESEARCH OBJECTIVE

The overall objective of this research is to develop a systematic cost estimation modeling process for TMPs in order to assist Caltrans' TMP engineers and project design engineers by automatically estimating TMP costs for highway projects using pre-established TMP elements grouped by TMP strategies.

Construction Analysis for Pavement Rehabilitation Strategies (CA4PRS) software, funded through the FHWA, is a decision-support tool for transportation agencies that helps planners and designers select effective and economical rehabilitation strategies. There is growing recognition of the capabilities of CA4PRS and the benefits of its use. One of the expected contributions of this research is to utilize the outcomes of TMP cost estimate modeling to improve the process of and data for the CA4PRS cost estimating module.

RESEARCH SCOPE AND METHODOLOGY

To achieve the research objective, the following research tasks were performed:

- A comprehensive literature review of state-of-the-art practices for implementing TMP strategies and their cost estimate procedures for highway projects;
- A review of eight recent Caltrans highway projects implementing some typical TMP strategies, based on CA4PRS schedule and traffic delay analysis;
- Development of a cost estimate modeling process and framework, which automatically estimates TMP costs using pre-established TMP elements grouped by TMP strategies; and
- Application of the TMP cost estimate modeling framework on one of the case study projects to validate its logic.

For this study, the following approaches were used to develop a cost estimate model for TMPs for highway projects. First, the research team collected TMP reports of the selected case projects from Caltrans regarding state-of-the-art TMP practices. Second, the input values associated with the each TMP strategy were collected from the District TMP managers and project engineers. Third, highway project data were collected with regard to TMP cost estimating. Fourth, the research team performed case studies using CA4PRS software to estimate project duration, to quantify the delay impact of work zone lane closures on the traveling public, and to compare project cost (construction, traffic, and supporting costs) between alternatives. Finally, a cost estimate modeling process of TMPs for highway projects was developed by the authors, based on the outcomes of the case studies.

II. LITERATURE REVIEW

TRANSPORTATON MANAGEMENT PLAN

According to the 2011 Urban Mobility Report, $101 billion of road user costs were lost due to congestion on urban roadways in the United States (Schrank and Lomax 2011). Many urban corridors around the country experience high traffic volumes close to or greater than the available capacity (Pyeon 2010). Frequently, those demanding facilities need certain types of improvements to continuously serve the traveling public. Many state DOTs are paying attention to the urban "4R" projects, that is restoration, resurfacing, rehabilitation, and reconstruction projects (Herbsman and Glagola 1998).

Those 4R projects often have a negative impact on the road user's mobility and safety through construction work zones, requiring lane closures and/or shifting. It has been an important issue to minimize disruption to the traveling public during construction in the United States (Pyeon and Park 2010). According to the FHWA's WZ Rule for developing and implementing TMPs, all state and local governments that receive federal-aid funding were required to comply with the provisions of the rule no later than October 12, 2007 (FHWA 2005). TMPs contain various strategies dealing with the work zone impacts of highway projects.

A TMP lays out a set of coordinated transportation management strategies and describes how they will be used to manage the work zone impacts of a road project. Transportation management strategies for a work zone include temporary traffic control measures and devices, public information and outreach, and operational strategies, such as travel demand management, signal retiming, and traffic incident management. The scope, content, and level of detail of a TMP may vary based on local government transportation work zone policies and the anticipated work zone impacts of the project. Careful consideration in developing the TMP strategies for implementation should result in minimizing confusion and delays to motorists and pedestrians, as well as reducing traffic accidents, providing greater safety to the various parties involved in the project and improving the image of the construction industry (FHWA 2005).

TMP STRATEGIES

Many transportation facilities have already become obsolete or are not working properly. They need to be improved to provide the traveling public with a safe driving environment. The FHWA has also increased its emphasis on its new policies to accommodate non-motorized transportation modes, in addition to the multimodal transportation management system. As traffic demand steadily increases, work activities can create significant additional traffic delays and safety concerns during roadway closures on already congested highways. Planning work activities and balancing vehicular, bicycle, and pedestrian traffic demand with highway capacity also becomes more critical to prevent unreasonable traffic delays and queues. Thus, TMPs must be carefully developed and implemented in order to maintain acceptable levels of service and safety during all work activities on the highway system.

To help traffic engineers and managers at state and local government levels understand the provisions for implementing the WZ Rule, the FHWA has developed a suite of guidance documents that address four topics. First is the Overall Rule Implementation (FHWA 2005), which provides an overview of the WZ Rule and general guidance for implementing the rule, lays out fundamental principles, and presents ideas for implementing the rule's provisions. Second is the Work Zone Impacts Assessment (FHWA 2006), which addresses the traffic impact. Third is the Work Zone TMP (FHWA 2005), which provides guidance on developing TMPs for managing work zone impacts of projects. And the fourth is the Work Zone Public Information and Outreach strategies (FHWA 2005), which provides guidance on developing communications strategies to inform affected audiences about construction projects, their expected work zone impacts, and the changing conditions on project sites.

The final WZ Rule's overarching goal is to reduce traffic accidents and congestion in and around work zones. Provisions in support of this goal encourage expanding work zone planning beyond the project work zone itself to address corridor, network, and regional issues. This updated WZ Rule also advocates expanding work zone management beyond the basics of traffic safety and control to address the need for continued mobility.

The WZ Rule provides guidance on identifying "significant projects" and developing and implementing TMPs. Simply stated, significant projects are those expected to cause a relatively high level of disruption to safety and mobility in the area (FHWA 2006). For all projects, the TMP must include a Temporary Traffic Control (TTC) plan that addresses traffic safety and control throughout the work zone. For significant projects, the TMP must also contain both a Transportation Operations (TO) component and a Public Information Officer (PIO) component. However, the rule encourages transportation engineers and practitioners to consider including transportation operations and public information components in all TMPs, as appropriate, regardless of whether or not a project is considered significant.

CALTRANS TMP IMPLEMENTATION

Based on the FHWA's TMP requirements, in 2001 the California Department of Transportation (Caltrans) began requiring and implementing all planned activities on the state highway system to help manage the impacts of work zones. Implementation of TMPs in California has helped to significantly reduce delays in work zones. On the I-10 Long-Life Pavement Project in Caltrans District 7 (Los Angeles Basin), the TMP helped reduce traffic demand by an estimated 57 percent, queue lengths to two miles from the originally projected 44 miles, and delays to 16,000 from the originally projected 1,000,000 total vehicle hours (FWHA 2008).

California is one of the few states that has a specific policy on TMPs, and has spent years improving it. In 1993, Caltrans initially developed the TMP Effectiveness Study (FHWA 2005). Since then, the Office of Operations within Caltrans Headquarters has continuously improved the guidelines based on their experience. Caltrans has focused primarily on improving guidelines on the most effective mitigation strategies (Caltrans 2009a). The most recent version of California's TMP guidelines was published in June 2009.

Caltrans defines a TMP as "a method for minimizing activity-related traffic delay and accidents by the effective application of traditional traffic handling practices and an innovative combination of public and motorist, bicyclist and pedestrian information, demand management, incident management, system management, construction strategies, alternate routes and other strategies" (Caltrans 2009a).

CALTRANS TMP COST ESTIMATING PROCEDURES

Caltrans TMPs are categorized into three levels based on the expected impact on traffic: 1) Blanket TMP, 2) Minor TMP, and 3) Major TMP. The three levels of TMPS and their conditions are listed in Table 1. A Major TMP is generally required for a high-impact project, and should be developed by a Traffic Management Team, which consists of "Caltrans representatives from Public Information, Project Development, Construction, Traffic Operations, Public Transportation, Maintenance, Structures, California Highway Patrol, FHWA, and other involved agencies" (Caltrans 2009a).

Table 1. Three Levels of TMPs Based on the Expected Impact on Traffic

Level of TMP	Types of Conditions
Blanket TMP	No expected delays. Work done at off-peak hours. Low volume roads. Moving lane closures.
Minor TMP (majority of projects)	Minimal impacts caused by work. Lane closure charts required. Some mitigation measures required.
Major TMP	Significant impacts caused by work. Multiple traffic management strategies required. Multiple contracts involved.

Source: Caltrans 2009a.

The Major TMP requires the Traffic Management Team to develop multiple TMP strategies in order to manage impacts on traffic. Examples of multiple TMP strategies and their elements are shown in Table 2 (Caltrans 2009a). A complete version of TMP strategies and elements with subcategories is organized in Appendix A.

Prior to approval of the Project Initiation Document (PID), a TMP cost estimate should be developed for each alternative being considered. A typical procedure to develop the TMP is as follows (Caltrans 2009a):

1. The project engineer sends conceptual geometrics to the District Traffic Manager or District TMP Coordinator for evaluation.

2. The District Traffic Manager or TMP Coordinator estimates the extent of the TMP required and determines whether potential traffic delays are anticipated that cannot be mitigated by traditional traffic handling practices or well-planned construction staging.

3. The District Traffic Manager or TMP Coordinator must sign-off on the “TMP Data Sheet” to be included in the PID.

In California, the estimated cost of a TMP could range from a small percentage of the overall project cost up to more than 20 percent. For instance, $1 million of the TMP cost estimates can be planned for a $9 million project (approximately 11 percent of the project budget) as shown in Table 3. (AHMCT 2005) In general, the cost of the TMP is considered as one of the high cost items of a project and is required to be quantified.

Table 2. TMP Strategies and Their Elements

TMP Strategies	Elements
Public Information	Brochures and Mailers, Media Releases (including Minority Media Sources), Paid Advertising, Public Information Center, Public Meetings/Speaker’s Bureau, Telephone Hotline, Visual Information (videos, slide shows, etc.), Total Facility Closure Information, Local Cable TV and News, Traveler Information Systems (Internet), Internet, Notification to Targeted Groups (bicycle, organizations, schools, organizations, representing people with disabilities)
Traveler Information Strategies	Electronic Message Signs, Changeable Message Signs, Extinguishable Signs, Ground Mounted Signs, Commercial Traffic Radio, Highway Advisory Radio (fixed and mobile), Planned Lane Closure Web Site, Caltrans Highway Information Network (CHIN), Radar Speed Message Sign, Bicycle and Pedestrian Information, (e.g., detour maps)
Incident Management	Call Boxes, Construction or Maintenance Zone Enhanced Enforcement Program (COZEEP or MAZEEP), Freeway Service Patrol, Traffic Surveillance Stations (loop detectors and CCTV), 911 Cellular Calls, Transportation Management Centers (TMC), Traffic Control Officers, CHP Officer in TMC (during construction), Onsite Traffic Advisor, CHP Helicopter, Traffic Management Team
Construction Strategies	Incentive/Disincentive Clauses, Ramp Metering, Lane Rental, Off-peak/Night/Weekend Work, Planned Lane/Ramp Closures, Project Phasing, Temporary Traffic Screens, Total Facility Closure, Truck Traffic/Permit Restrictions, Variable Lanes, Extended Weekend Closures, Reduced Speed Zones, Coordination with Adjacent Construction, Traffic Control Improvements
Demand Management	HOV Lanes/Ramps, Park-and-Ride Lots, Parking Management/Pricing, Rideshare Incentives, Rideshare Marketing, Transit Incentives, Transit Service Improvements, Train or Light-Rail Incentives, Variable Work Hours, Telecommute, Shuttle Service Incentives
Alternate Route Strategies	Ramp Closures, Street Improvements, Reversible Lanes, Temporary Lanes or Shoulder Use, Freeway to Freeway Connector Closures, Temporary Bicycle or Pedestrian Facilities
Other Strategies	Application of New Technology, Innovative Products, Improved Specifications, Staff Training/Development

Source: Caltrans 2009a.

SUMMARY OF LITERATURE REVIEW

In general, TMP policies, processes, and requirements have been informal so far and rely mostly on engineering judgment. Each state has some policy provisions for work zone planning and management, but they differ in their names and their nature. Despite these differences, each agency is trying to minimize work zone impacts during the pre-construction planning phase. For instance, mitigation strategy reports developed by the different agencies will be referred to as TMPs, although they might differ from the definition of TMP in the updated final WZ Rule.

Table 3. Sample TMP Costs for a Highway Project

TMP Elements	Costs ($)
TV Commercial (local)	4,000+
Permanent Changeable Message Sign	300,000
Portable Changeable Message Sign	10,000
Ground-Mounted Sign	300
Radio Ad	800 / minute
Newspaper Ad (1/2 page, color)	14,000 / day
Billboard	3,500 / month
Open House	3,000
Extra Enforcement (CHP)	1,000 / night
Moveable Concrete Barrier (transport machine rental)	100,000 / 6 months
Temporary Signal	30,000
Consultants to Develop TMP	250,000+

Source: AHMCT 2005.

Although some state transportation agencies require all construction or maintenance projects to be accompanied by a TMP, which may range from a single-page datasheet to a comprehensive report, many agencies do not have TMP policies covering major work zone issues typically found during construction, nor do they have TMP policy and methodology to develop TMPs (Maze, Burchett, and Hochstein 2005). TMP cost estimating for budgeting purposes has become an issue for successful TMP implementation. Over the years, highway engineers have devised and implemented strategies and innovative practices for minimizing the disruption caused by work zones, while ensuring successful project delivery. But the existing research and literature have focused more on traditional traffic management techniques rather than TMP cost estimates.

Although the cost of the TMP is required to be quantified, there are no automatic tools or systematic modeling processes currently in use to assist project engineers and planners in the task of estimating TMP costs. Therefore, it is helpful to develop a systematic modeling process for TMP cost estimation to assist the District TMP team and project engineers in producing plans with more accurate estimates.

III. CASE STUDIES

A total of eight Caltrans construction projects, recently completed between 2007 and 2010, were selected for the TMP case studies. Their project data were collected from Caltrans transportation engineers of the Caltrans district offices. The selected projects implemented some typical TMP strategies developed, based on the results of the CA4PRS schedule and traffic delay analysis. The TMP cost estimates for the selected projects were performed using Caltrans' typical estimating procedures based on the CA4PRS analysis outcomes, such as schedules and delay costs with closure strategies. Table 4 shows the list of case study projects with a brief description of project scope.

Table 4. List of TMP Case Study Projects

Project Title	District	County	TMP Year	Project Scope
I-80 Dixon	4	Solano	2010	Resurfacing the existing pavement of the entire traveled way, shoulders, and rams with gap-graded rubberized asphalt concrete (RAC).
I-680 Alameda	4	Alameda/ Contra Costa	2010	Rehabilitating with PCC surface and Crack-Seat Asphalt Concrete (CSAC).
US 101 Doyle	4	San Francisco	2009	Environmental mitigation and plans, private utility relocation, rebuilding connectors and ramps.
US 101 Tully	4	San Mateo	2010	Removing and constructing median barrier and pedestrian overcrossing (POC).
SR 37 Sonoma	4	Sonoma and Solano	2009	Bridge Asphalt Concrete (AC) rehabilitation.
SR 9 Santa Clara	4	Santa Clara	2010	Erosion control work on slopes uphill.
SR 17 Santa Cruz(1)	4	Santa Cruz	2010	Improving median drainage and rehabilitating pavement.
I-15 Ontario	8	San Bernardino	2007	Replacing two outside truck lanes with Portland Cement Concrete (PCC) slab and AC base.

Note: (1) Although Santa Cruz County is in District 5, the TMP report was prepared by the TMP office in District 4.

I-80 DIXON PROJECT

The project scope consisted of resurfacing the existing pavement of the entire traveled way, shoulders, and ramps with gap-graded rubberized asphalt concrete (RAC) on Interstate 80 (I-80) in Solano County, between the cities of Dixon and Davis, from Post Mile (PM) 38.35 to PM 47.22 (8.87 center-line miles). It also included installation of metal barrier guard railing (MBGR) at certain locations on the freeway and construction of approach slabs along with joint seal (Caltrans 2010a).

The basic TMP strategies were of a general nature and mitigated the overall level of congestion. The four TMP strategies identified as applicable to this project were Public Information, Motorist Information, Incident Management, and Construction Strategies. Public Information and Motorist Information objectives were accomplished with both an aggressive public notification campaign in advance of construction, as well as through effective notification of the motoring public during construction (Caltrans 2010a).

The main TMP components included highway advisory radio (HAR) broadcasts, fixed and portable changeable message signs (PCMS), and other appropriate signage. These provided uninterrupted directional traffic flow during construction through the preparation of stage construction plans and traffic detours to maintain continuous clear passage through the project area (Caltrans 2010a).

CA4PRS software was utilized to determine the most economical construction strategy between different closure scenarios. Half-closure of the one direction of the freeway during 10 hours at nighttime was determined to be the best closure scenario, with tolerable delays of less than 15 minutes to motoring public (Caltrans 2010a).

The Caltrans District 4 TMP office recommended a total of 225 nighttime closures, including both eastbound and westbound directions. To minimize the traffic impact to the area, it was recommended in this project that overlay of ramps, approach slab work, placing of Jersey barriers (called “K-rails” within Caltrans), and reconstruction of MBGR should be performed concurrently. Total TMP cost estimated was $1,626,550 (Caltrans 2010a).

I-680 ALAMEDA (SAN RAMON) PROJECT

Interstate 680 (I-680) PM 0.0 to PM 12.8 Rehabilitation Project was recently completed for both southbound and northbound directions. The main scope of the rehabilitation was concrete (PCC) pavement rehabilitation from PM 0.0 to PM 7.5 and crack-seat asphalt concrete (CSAC) overlay from PM 7.5 to PM 12.8 (Caltrans 2010b).

The PCC replacement was continuous for the entire length of the project, from Alcosta Boulevard to Diablo Road, (PM 0.0 to PM 7.5, both directions) through the city of San Ramon. A combination of cast-in-place PCC replacement and precast PCC replacement were implemented, depending on the lane number and location (Caltrans 2010b).

The CSAC overlay was adopted for the northern portion between Diablo Road (PM 7.5) and Rudgear Road (PM 12.8), at the south end of the city of Walnut Creek. The CSAC overlay work included the reconstruction of the freeway and its ramps, where rehabilitation was necessary. This information was documented in the Construction Documents for the Highway 680 PM 0.0 to 12.8 PCC and AC Pavement Rehabilitation Project (Caltrans 2010b).

The traffic lane closure strategy was to close lane 4 (the outermost lane) to be reconstructed entirely behind a fixed temporary K-rails. This work occurred during the standard work day since it did not have any significant impact on the public. The current four lanes of travel were shifted and narrowed to maintain four lanes of travel while the existing fourth lane was being reconstructed. Concurrently, temporary nighttime lane closures occurred to allow lane 2 and lane 3 to be reconstructed. The use of precast-concrete slabs and the CSAC overlay method allowed the construction to proceed quickly, which gave the contractor sufficient flexibility to work within the constraints of the traffic demands that existed in the work area (Caltrans 2010b).

The Caltrans Performance Measurement System (PeMS) data were used with CA4PRS to analyze traffic volumes on a Friday, Saturday, Sunday, and the high volume periods on weekdays. As the heaviest traffic volume was anticipated to be concentrated between Stone Valley Road and Highway 24, three equidistant points of interest (PM 10.25, 11.80, and 13.7) were chosen for the volume analysis for this segment, and one point of interest (PM 4.71) chosen at a midpoint within the remaining segment of the project. The traffic growth rate of four percent was chosen to estimate the delay time (Caltrans 2010b).

For the I-680 project, the TMP strategies for mitigating construction-related traffic delays were identified and described. The TMP strategies were designed to mitigate the overall level of congestion. The strategies identified in this plan were grouped into six broad transportation management strategies: Public Information, Motorist Information System, Incident Management System, Construction Strategy, Demand Management, and Alternate Routes. The total TMP cost estimated for this project was $470,280 (Caltrans 2010b).

US 101 DOYLE PROJECT

The US Route 101 (US 101) Doyle project, completed recently, is located in the Presidio area in San Francisco and extends from the south end of the Golden Gate Bridge Toll Plaza to Broderick Street on the east, including Richardson Avenue, Gorgas Avenue, and Marina Boulevard, from PM 6.8 to PM 7.1 and from PM 8.0 to PM 9.8. On the easterly side of the project, access to Doyle Drive is provided via two approaches. The first approach begins at the intersection of Marina Boulevard and Lyon Street and the other at the intersection of Richardson Avenue and Lyon Street. On the westerly side, the project access is provided through Veterans Boulevard (Presidio Park, State Route 1 (SR 1)) to Doyle Drive (Caltrans 2010c).

The Doyle Drive lane configuration consists of 13 lanes at the toll plaza and narrows down to nine lanes in the vicinity of the last San Francisco exit. Then, it reduces to seven lanes by a series of lane drops and merging lanes and eventually to five through-lanes in the vicinity of the SR 1/Presidio interchange off- and on-ramps. Then, it continues east with a six-lane configuration, which includes an auxiliary lane introduced as part of the SR 1/ US 101 southbound on-ramp. Finally, it widens and splits to five lanes towards Marina Boulevard and three lanes towards Richardson Avenue at the end of the freeway segment (Caltrans 2010c).

During the Doyle Drive construction project, five existing capacity lanes were maintained through the different contracts and construction stages. All contract work was completed in compliance with the traffic charts. A single three-day Full Weekend Closure (FWC) was required for Doyle Drive partial demolition and shifting traffic to a new detour in order to allow for the removal and construction of the new viaduct. The entire project consisted of eight different contracts, beginning with Contract 1, which included Environmental and Right-of-Way acquisition, and ending with Contract 8, which included final grading and landscaping (Caltrans 2010c).

Several TMP strategies were utilized in this project to mitigate traffic demands, including Public Information, Motorist Information System, Incident Management System, Construction Strategy, Demand Management, and Alternate Routes. Total TMP cost estimated for this project was $10,485,000 (Caltrans 2010c).

US 101 TULLY PROJECT

The project limits of the US 101 Tully Project ranged from Willow Road interchange (PM 0.9) to the Marsh Road interchange (PM 3.6) in the cities of Menlo Park and East Palo Alto in San Mateo County. In addition to the auxiliary lanes, other major components of the project included replacing a pedestrian over-crossing (POC) to provide sufficient clearances for the proposed auxiliary lanes, widening of the Hetch Hetchy Aqueduct Bridge, realignment of existing off-ramps, widening of on-ramps and AC overlaying within the existing sound walls, rapid strength concrete (RSC) slab replacements at some locations, and modification of the existing ramp metering system (Caltrans 2010d).

The goal of the project was to reduce traffic congestion resulting from merge-and-diverge operations, weaving operations, and to improve the overall freeway system performance between the project limits. The project also improved safety and provided enhanced pedestrian access over the freeway (Caltrans 2010d).

The number of working days for this project, based on the construction calendar and schedule, was 268 Working Days. The TMP recommendation for number of working days based on CA4PRS analysis was 180 Working Days (Caltrans 2010d).

Several TMP strategies were utilized in this project to mitigate traffic demands, including: Public Information, Motorist Information System, Incident Management System, Construction Strategy, Demand Management, and Alternate Routes. The estimated TMP cost of this project was $1,117,300 (Caltrans 2010d).

SR 37 SONOMA CREEK BRIDGE PROJECT

The Richard Janson Bridge on State Route 37 (SR 37) spanning Sonoma Creek was rehabilitated using polyester concrete overlay, as well as replacing joint seals and approach slabs. The existing deck was ground down three inches and resurfaced with fast-setting hydraulic cement concrete (FSHCC). The construction for this project was scheduled for nighttime closures during the weekends. SR 37 was closed according to its Lane Closure Charts (Caltrans 2009b).

The SR 37 bridge rehabilitation projects were scheduled to take place concurrently, and a cooperation clause was included in both projects to facilitate construction. Also, cooperation with stakeholders was considered to avoid impacts on special events venues, including the Sears Point Infineon Raceway, Six Flags, and others. Both projects were scheduled for extended-weekend night closure. Three extended-weekend night closures were sufficient to complete the bridge rehabilitation as well as the dig-out project. Contractors needed to coordinate with each other to facilitate the schedule and concurrent completion of both projects. A weeknight construction window between hours 0000 and 0400 was available for the asphalt concrete rehabilitation construction project separate from the three extended weekend-night closures. SR 37 was closed for the bridge rehabilitation over the extended weekend with some detours (Caltrans 2009b).

The TMP strategies were of a general nature and mitigated the level of congestion. The strategy can be grouped into four broad categories: Public Information, Motorist Information System, Incident Management System, and Construction Strategies. Total TMP cost estimated for this project was $171,440 (Caltrans 2009b).

SR 9 SANTA CLARA PROJECT

This project involved erosion control work on slopes uphill from the State Route 9 (SR 9) northbound (NB) roadway at four locations as shown on the plans (see Figure 1). The project required erosion control work (Type B netting and Hydroseed) on SR 9 NB at Locations 1 (PM 1.62 NB), 2 (PM 1.65 NB), 3 (PM 5.13 NB), and 4 (PM 5.25 NB). Also, the work consisted of installing and utilizing a temporary signal system at PM 1.62 and PM 1.65. Around Locations 1 and 2, temporary railing was installed beginning at Station Number (STA) 94+81 and ending at STA 98+61. At Locations 1 and 2, the erosion control work was conducted on the uphill slope of the NB lane side, utilizing a temporary signal system to control one-way traffic on the southbound lane. At Locations 3 and 4, the erosion control work was conducted on the NB lane side, utilizing flaggers to monitor one-way traffic control. No detours or contingency routes were identified as alternatives to one-way traffic control (Caltrans 2010e).

Location 1 (PM 1.62 NB) performed erosion control work of Type B netting and Hydroseed. Location 2 (PM 1.65 NB) performed erosion control work of Type B netting and Hydroseed. SR 9 NB was closed according to the specified limits as shown on the plans. There was one-way traffic control on the SB lane, utilizing a temporary signal system to control traffic around the construction area. Along the median (east-side stripe) of SR 9, from limits STA 94+81 to STA 98+61, Temporary Crash Cushions (T511) and Temporary Railing was installed (Caltrans 2010e).

Location 3 (PM 5.13 NB) performed erosion control work of Type B netting and Hydroseed. Location 4 (PM 5.25 NB) performed erosion control work of Type B netting and Hydroseed. SR 9 NB and SB traffic was one-way traffic controlled utilizing flaggers. Flaggers needed to be mindful and cautious of not only the traveling motorists, but also public walking and bicycling in the area (Caltrans 2010e).

Under one-way reversing traffic control operations, public traffic could be stopped in one direction for periods not to exceed five minutes. After each stoppage, all accumulated traffic for that direction had to pass through the work zone before another stoppage was made. The maximum length of a single stationary lane closure was 0.5 miles. Not more than two separate stationary lane closures were allowed in each direction of travel at one time. Concurrent stationary lane closures could be placed no closer than one mile apart (Caltrans 2010e).

Caltrans controlled and monitored access to the construction work to minimize the impact to the public. All construction activities were completed outside of the nesting season (mid-May to mid-October) for the Marbled Murrelet as shown on the plans: Location 1 (PM 1.62), Location 2 (PM 1.65), and Location 4 (PM 5.25). The temporary signal system at Locations 1 and 2 and flaggers handling one-way traffic control at Locations 3 and 4 were in operation for the life of the project (Caltrans 2010e).

For this project, the TMP strategies for mitigating construction-related traffic delays were identified and described. The TMP strategies were designed to mitigate the overall level of congestion. The strategies identified in this plan can be grouped into six broad transportation management strategies: Public Information, Motorist Information System, Incident Management System, Construction Strategies, Demand Management, and Alternate Routes. The estimated TMP cost of this project was $150,800 (Caltrans 2010e).

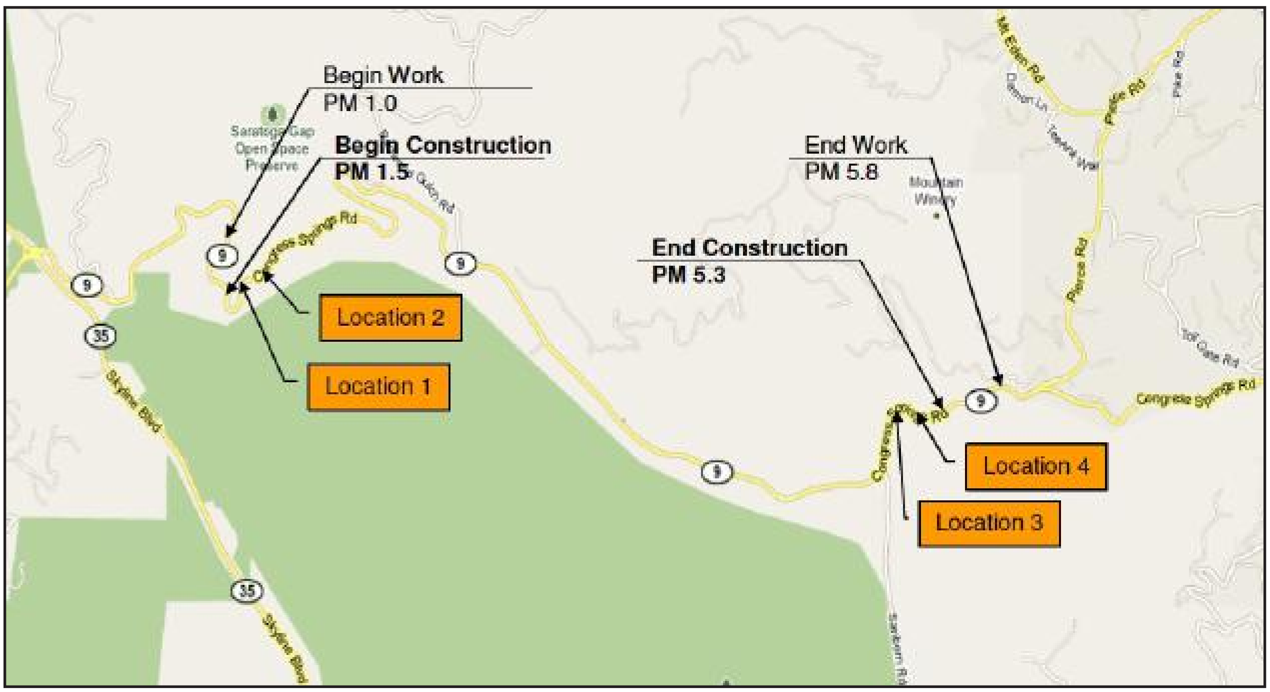

Figure 1. Construction Locations of the SR 9 Santa Clara Project
Source: Caltrans 2010e.

SR 17 SANTA CRUZ PROJECT

For this project, the major scope of work consisted of constructing various drainage systems and resurfacing the existing pavement in order to reduce wet pavement related accidents during wet weather conditions (Caltrans 2010f).

The project proposed to improve the drainage systems within the project limits from PM 0.0 to PM 2.8. All damaged and nonfunctional drainage systems were repaired, relocated or reconstructed, depending on need. The entire pavement in both southbound and northbound lanes was ground and resurfaced. Median concrete barriers and the outside MBGR were upgraded (Caltrans 2010f).

The median barrier was removed in order to install median drainage improvements. Pavement rehabilitation consisted of cold plane of existing pavement and placing of new open grade friction course (OGFC) over Hot Mix Asphalt Type A (HMA(A)). The drainage system improvements included: lining some existing cross culverts, installing new slotted corrugated pipe in the median, installing new cross culverts, installing new drainage inlets, removing and replacing new down drains, constructing rock slope protection (RSP), and lining or replacing drainage risers (Caltrans 2010f).

The SR 17 Santa Cruz project TMP included Public Information, Motorist Information, Incident Management, and Construction Strategies. Total TMP cost estimated was $1,242,000 (Caltrans 2010f).

I-15 ONTARIO PROJECT

The Interstate 15 (I-15) Ontario Project (Caltrans EA 08-47221) was a 4.7 mile pavement rehabilitation project on I-15 beginning near the city of Ontario in Riverside County at the I-15/SR 60 separation structure (PM 51.4) and continuing across the San Bernardino/Riverside County line to Seventh Street (PM 3.8), just north of the I-10/I-15 interchange. The I-15 Ontario corridor carries about 200,000 ADT, with about six percent being heavy trucks during peak-hours (Caltrans 2007).

The project (about $82 million) rehabilitated concrete pavement sections of the No. 3 and No. 4 lanes in both directions, interchange ramps and freeway-to-freeway connectors, and asphalt concrete shoulders. Other major project features included widening of the inside shoulder, widening of the median roadway and structure crossings to accommodate traffic detours during construction, and pavement grinding of all lanes (Caltrans 2007).

The I-15 Ontario rehabilitation project utilized the following four pavement types, mainly depending on the rehabilitation location, as a matter of traffic control for lane closures and construction access:

- PCC rehabilitation: about 25 lane-miles, including RSC rehabilitation
- Rapid Strength Concrete (RSC) rehabilitation
- Precast (Super Slab) rehabilitation: about 1.8 lane-miles
- Fast-Setting Hydraulic Cement Concrete (FSHCC) rehabilitation: approximately 6 lane-miles
- Total TMP cost estimated for this project was $1,764,600 (Caltrans 2007).

SUMMARY OF CASE STUDIES

A total of eight Caltrans construction projects were investigated and summarized for the TMP case studies in this report. Each project consists of one major work type and several minor work types. The project length of each ranged from 0.3 to 12.8 miles with an average of 4.7 miles. The engineers' estimated cost of each case study project ranged from $0.5 million to $136 million. The estimated TMP cost for each project ranged from $0.2 million to $10.5 million dollars. The project costs and total TMP estimates are summarized in Table 5. It also shows the breakdown of TMP estimate cost components for each case study project.

Table 5. Project Construction Costs and TMP Costs

Project Title	Project EA or Code	Post Mile	Total Construction Cost ($)	TMP Cost Estimates ($)							
				Total	Public Info.	Traveler Info.	Incident Mgmt.	Constr. Strgy.	Demand Mgmt.	Alternate Route	Other Strgy.
I-80 Dixon	3A300K	38.35-47.22	N/A	1.6M	120K	89K	1,408K	10K	0	0	0
I-680 Alameda	447001	0.0-12.8	70.0M	0.5M	19K	260K	159K	32K	0	0	0
US 101 Doyle	163701	8.0-9.8 (US 101), 6.8-7.1 (SR 1)	N/A	10.5M	1,310K	1,500K	3,919K	255K	2,550K	445K	500K
US 101 Tully	235631	0.9-3.6	136.0M	1.5M	116K	32K	556K	5K	250K	158K	0
SR 37 Sonoma	0E5104	SON 4.1-6.245, SOL 0.0-R7.4	N/A	0.2M	10K	86K	73K	0	0	2K	0
SR 9 Santa Clara	4000001014	1.5-5.3	N/A	0.2M	5K	27K	19K	100K	0	0	0
SR 17 Santa Cruz	400000741	0.0-2.8	N/A	1.2M	50K	112K	1,030K	0	0	50K	0
I-15 Ontario	08-47221	51.4	82.0M	1.764K	200K	35K	1,500K	30K	0	0	0

IV. TMP COST ESTIMATE MODELING PROCEDURE

The proposed TMP strategy selection and cost estimate (STELCE) model consists of two major steps: 1) selection of TMP strategies and 2) cost estimation for the selected TMP strategies. The TMP strategy selection process was performed using both the Performance Attribute Matrix (PAM) method (Lee et al. 2011) and a TMP cost estimation method interacting with the results of traffic delay analysis and construction analysis in CA4PRS.

The PAM method is a systematic assessment for determining the attributes' relative weights in meeting the project's need and purpose. It is used to determine the relative importance of each of the performance attributes for the project by converting the qualitative components to quantitative scores, based on reflecting the general consensus in value analysis. In this research, instead of using performance attributes, the major attributes affecting TMP were selected and scaled in score to determine Intensity Level of the construction projects (Caltrans 2010g).

Figure 2 illustrates the TMP cost estimate modeling procedure using PAM with CA4PRS outcomes.

TMP STRATEGY SELECTION METHOD

This research proposes adoption of a PAM method to select appropriate TMP strategies for the project-specific traffic and construction conditions. The major attributes affecting TMP selection are: 1) project size, 2) project scope, 3) construction type, 4) construction schedule, and 5) traffic user delay cost.

In general, some base TMP strategies are applied regardless of the major attributes described above. However, the costs of the base TMP strategies depend on the project-specific conditions, such as project scope and construction schedules. The following TMP strategies are classified as base TMP by the authors:

- Public Information (Category A): Brochures and Mailers (A1), Media Releases (A2), Paid Advertising (A3), Public Meeting (A8), Local Cable TV and News (A2), Internet (A7), and E-mail (A9),

- Traveler (Motorist) Information (Category B): Existing Electronic Message Signs (B2), Portable Changeable Message Signs (B3), Temporary Motorist Information Signs (B4), and California Highway Information Network (B7), and

- Incident Management (Category C): California Highway Patrol (C2) and Freeway Service Patrol (C6).

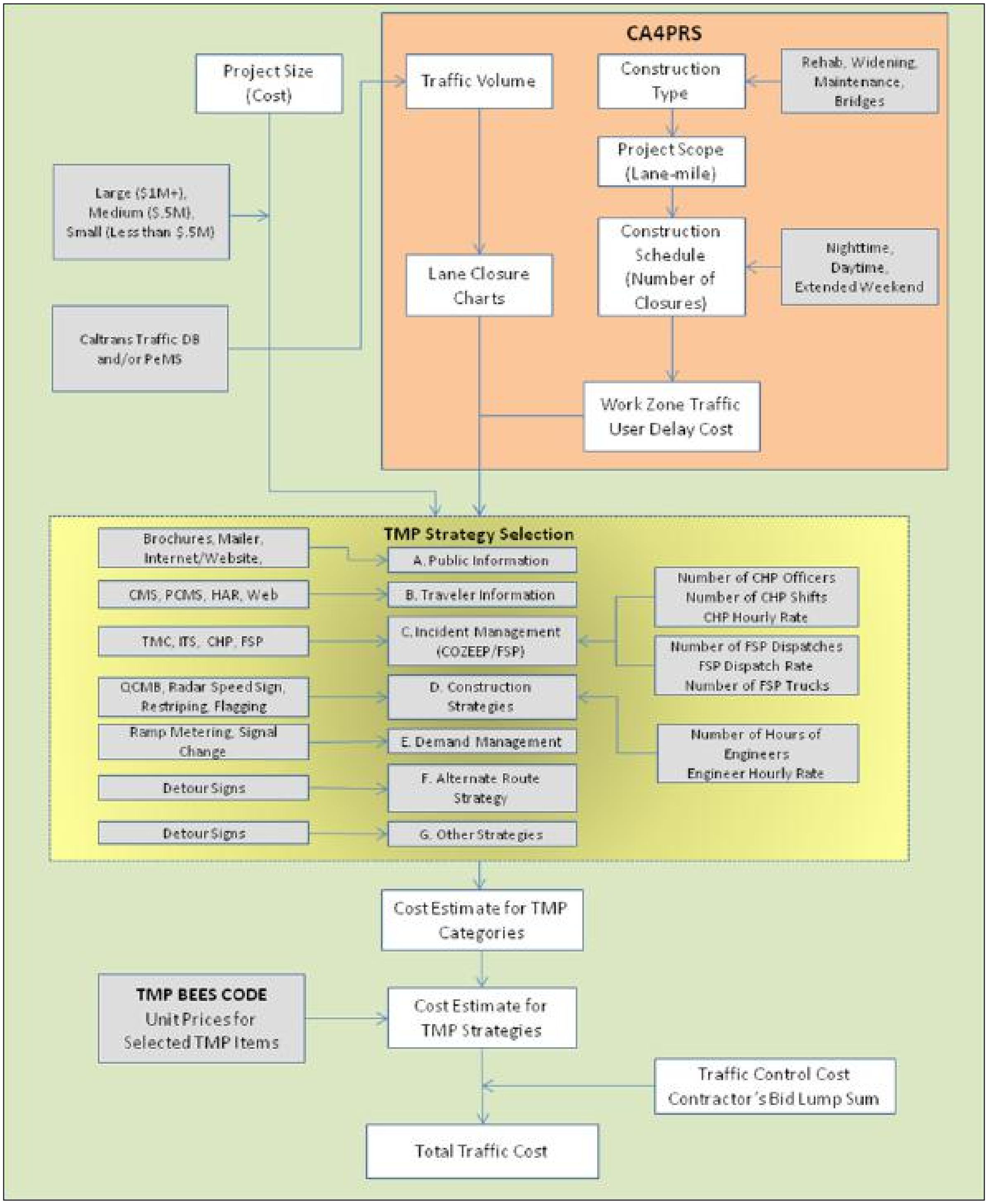

Figure 2. TMP Cost Estimate Modeling Procedure

Source: Authors' flowchart.

Project size and project scope are identified during the construction planning stage, and the construction type is determined by pavement design engineers. The construction schedule is estimated by CA4PRS based on the given project scope and construction type. User traffic delay costs can be estimated by CA4PRS or some other traffic delay analysis tools, based on the estimated construction schedule, lane closure charts, and hourly traffic volumes. The hourly traffic volumes are available through the Caltrans real-time traffic performance measurement system (PeMS).

Scores are assigned to the major attributes affecting TMP strategy selection based on the comprehensive perceptive discernment from the case studies using a proratable system of fits method. Project Size, Construction Type, and Construction Schedule are assigned points from zero to ten, based on their intensity. For Project Scope, one mile is equivalent to one point, and one minute equals one point in User Traffic Delay. Three project size classifications are identified, from small (less than $0.5 million total project cost) to large (over $1.0 million total project cost), with corresponding scores from one point to eight points. For Construction Type, nighttime closure receives one point, and daytime and extended-weekend closures receive seven points. The points increase proportional to the number of total construction closures for Construction Schedule. For example, when the number of total construction closures is less than 50, one point is used. The points increase as the number of closures increase. Table 6 shows the attribute ranges and scores.

Based on the comprehensive perceptive discernment from the case studies, ranges of the attribute scores are categorized into five Intensity Levels as shown in Table 7. The relationship of level of TMP and intensity of attributes is shown in Table 8.

Table 6. Scores for Attribute's Range

Attributes	Range	Scores
Project Size	Small ($0-0.5M)	1 point
	Medium ($0.5-1.0M)	5 points
	Large (over $1.0M)	8 points
Project Scope (Lane-Miles)	1 mile equals 1 point	
Construction Type	Nighttime	1 point
	Daytime	7 points
	Extended Weekend	7 points
Construction Schedule (Number of Closures)	0-50	1 point
	51-100	3 points
	101-150	5 points
	Over 151	7 points
Full Closure	No	0 points
	Yes	10 points
User Traffic Delay (Minutes)	1 minute equals 1 point	

Table 7. Intensity Level for Range of Attribute Score

	Intensity Level of Attribute				
	1	2	3	4	5
Range of Attribute Score	0-10	11-15	16-20	21-30	Over 30

Table 8. Relationship of TMP Classification and Intensity Level of Attribute

TMP Classification	Types of Conditions	Intensity Level of Attributes
Blanket TMP	No expected delays. Work done at off-peak hours. Low volume roads. Moving lane closures.	1 (Base TMP)
Minor TMP (majority of projects)	Minimal impacts caused by work. Lane closure charts required. Some mitigation measures required.	2-3
Major TMP	Significant impacts caused by work. Multiple traffic management strategies required Multiple contracts involved.	4-5

Once the intensity of the attributes is determined, the selection of the TMP strategies is performed according to Table 9. TMP strategy categories include an optional category, Category G (Other Strategies). However, this category is not considered by the proposed model in this study. The proper strategies for each TMP category are recommended for each Intensity Level. For example, an Intensity Level 1 project requires a Blanket TMP, as traffic volumes through the work zone corridor are low and the lane closures cause no delays. Although no traffic delays are expected, minimum transportation management must still be planned and its minimum TMP cost should be estimated according to the Caltrans TMP guidelines.

Intensity Level 1 indicates the base TMP mitigations necessary regardless of project attribute score. Subcategories are described earlier in this report (refer to Appendix A for the definition of each, and for the category coding used in Table 9).

Higher intensity levels also include all the TMP strategies of lower intensity levels.

Table 9. TMP Strategy Selection by Intensity of Attributes

		TMP Strategy Categories						
		A	B	C	D	E	F	G
	Title	Public Information	Motorist Information	Incident	Construction Strategies	Demand Management	Alternate Routes	Other Strategies
Subcategory (Defined in Appendix A)	1	1	2	2	2	4	3	
	2	1	1	1	3	4	4	
	3	1	1	1	3	4	4	
	4	2	1	3	4	4	4	
	5	2	3	4	3	4	3	
	6	4	2	1	4	3	3	
	7	1	1	2	4	4	3	
	8	1	3		5	5		
	9	1			4	5		
	10	3			2	4		
	11	3			4	5		
	12	4			4			
	13				2			
	14				2			
	15				3			
	16				3			
	17				4			
	18				3			
	19				2			
	20				4			
	21				4			

Table 10 lists the strategy categories used at each level of intensity. Note that subsets of categories A, B, and C are applied at Intensity Level 1, and that Category D strategies are only applied at Intensity Level 2 or higher. As the TMP intensity increases, all strategies from the lower intensity level are recommended, along with additional strategies and categories of strategies. All the TMP strategies in practice are recommended at Intensity Level 5, which involves the most serious traffic conditions and construction environment.

TMP COST ESTIMATE METHOD

The second step of the model methodology was to develop a model to directly estimate costs for the TMP categories and assign cost amounts to each TMP strategy in the TMP categories, based on unit price information and the contract bid database. This research proposes scientific and engineering analysis to estimate costs for the TMP categories selected by the PAM approach introduced in the previous section. The TMP cost estimate method utilizes Intensity Level determined by traffic construction conditions given by the CA4PRS analysis in the first step. The cost estimate equation for each TMP category was developed from the case studies' cost data using their trends. This provided a best-fit to the data.

Table 10. TMP Strategy Selection by TMP Intensity

TMP Intensity			TMP Strategy Categories (Defined in Appendix A)
	1	A	A1, A2, A3, A7, A8, A9
		B	B2, B3, B4, B7
		C	C2, C3, C6
		D	
		E	
		F	
	2	A	A1, A2, A3, A4, A5, A7, A8, A9
		B	B1, B2, B3, B4, B6, B7
		C	C1, C2, C3, C6, C7
		D	D1, D10, D13, D14, D19
		E	
		F	
	3	A	A1, A2, A3, A4, A5, A7, A8, A9, A10, A11
		B	B1, B2, B3, B4, B5, B6, B7, B8
		C	C1, C2, C3, C4, C6, C7
		D	D1, D2, D3, D5, D10, D13, D14, D15, D16, D18, D19
		E	E7
		F	F1, F5, F6, F7
	4	A	A1, A2, A3, A4, A5, A6, A7, A8, A9, A10, A11, A12
		B	B1, B2, B3, B4, B5, B6, B7, B8
		C	C1, C2, C3, C4, C5, C6, C7
		D	D1, D2, D3, D4, D5, D6, D7, D9, D10, D11, D12, D13, D14, D15, D16, D17, D18, D19, D20, D21
		E	E1, E2, E3, D4, E5, E6, E7, E10
		F	F1, F2, F3, F4, F5, F6, F7
	5	A	A1, A2, A3, A4, A5, A6, A7, A8, A9, A10, A11, A12
		B	B1, B2, B3, B4, B5, B6, B7, B8
		C	C1, C2, C3, C4, C5, C6, C7
		D	D1, D2, D3, D4, D5, D6, D7, D8, D9, D10, D11, D12, D13, D14, D15, D16, D17, D18, D19, D20, D21
		E	E1, E2, E3, D4, E5, E6, E7, E8, E9, E10, E11
		F	F1, F2, F3, F4, F5, F6, F7

Source: Derived by the authors. Strategy definitions located in Appendix A.

According to the Caltrans TMP Guidelines (Caltrans 2009a), TMP costs can range from a small percentage of project cost to more than 20 percent, and is often not dependent on the size of the project contract amount. The ranges of TMP cost estimates for each Intensity Level are shown in Table 11. The transportation management for Intensity Level 1 includes the base TMP strategies as described in the previous section and its TMP costs are less than $200,000. This research recommends that the transportation management for Intensity Level 5 include the most extensive TMP strategies to mitigate traffic delay and increase safety. The TMP cost for Intensity Level 5 is predicted to be over $1,500,000, based on the Caltrans current TMP trends and the case studies.

Table 11. TMP Cost Range for Intensity Level

Intensity Level	TMP Cost (Lump Sum)
1	Up to $200,000
2	$200,001 - $500,000
3	$500,001 - $1,000,000
4	$1,000,001 - $1,500,000
5	$1,500,001 or greater

In order to estimate the cost of a TMP category, constant values for each TMP category were established as the baseline TMP cost amounts (constants named a, b, c, d, e, and f). The constant values determine the cost to execute the TMP strategies selected in each category (refer to Table 12). The cost of the TMP category is then estimated by a function of the constant value and Intensity Level (denoted as IL in the calculations). The total TMP cost is calculated by the summation of each TMP category cost. Each equation is driven by the proportional allotment of each category in the total TMP cost, using a proratable system of fits method. The costs of the TMP categories estimated by the equations are shown in Table 12. The pattern of cost change of each TMP category by Intensity Level is illustrated in Figure 3. The trends shown in the figure mostly appear linear but at different slopes.

Table 12. Cost Equation for TMP Category by Intensity Level

Intensity Level	Cost for TMP Category ($)						Total TMP ($)
	A	B	C	D	E	F	
Cost Eqn.	a*IL	b*IL	c*IL*log((IL+1)*5)	d*(IL-1)	e*(IL)/3	f*(IL)/3	
1	15,000	30,000	100,000	N/A	N/A	N/A	145,000
2	30,000	60,000	235,200	100,000	N/A	N/A	425,200
3	45,000	90,000	390,300	200,000	150,000	150,000	1,025,300
4	60,000	120,000	559,200	300,000	200,000	200,000	1,439,200
5	75,000	120,000	738,600	400,000	250,000	250,000	1,863,600

Notes: a = 15,000, b = 30,000, c = 100,000, d = 100,000, e = 150,000, f = 150,000, and IL = Intensity Level.

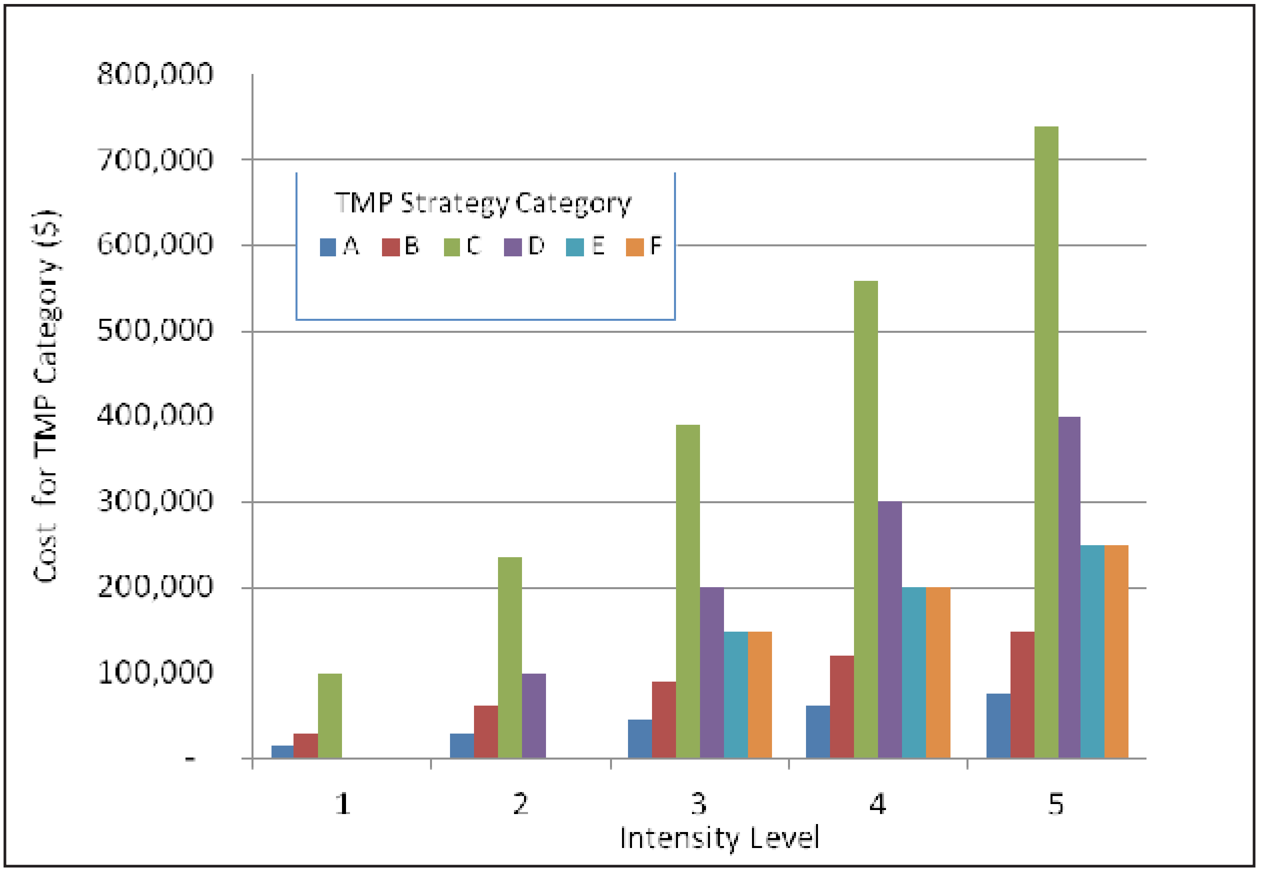

Figure 3. Cost per TMP Category by Intensity Level

Source: Authors' calculations using the TMP cost estimate model.

The total TMP cost is calculated using the base cost constant values (a, b, c, d, e, and f) and Intensity Level in the equation below:

$$\text{TMP Cost} = a * IL + b * IL + c * IL * \log((IL+1) * 5) + d * (IL - 1) + e * (IL)/3 + f * (IL)/3$$

Once the cost of each TMP category is estimated by the TMP cost estimate procedure described above, the cost of each strategy selected in each category is allocated by the items' quantities and unit prices. The unit prices of the elements for the selected TMP strategies are available in the Caltrans contract bid database website (http://www.dot.ca.gov/hq/cpsd/BEES/home.html) using the Basic Engineering Estimating System (BEES) codes shown in Table 13 (Caltrans 2012).

The cost of each strategy with known information (cost of the TMP category and cost of TMP elements in that category) is determined by using "what-if" analysis. The what-if analysis allows users to experiment with several different sets of values in one or more formulas to explore all the various results (Herodotou and Babu 2011).

For example, the TMP strategy cost of PCMS (Strategy B3) for the Motorist Information (Category B) is determined by the quantity and the PCMS unit price, since the quantity of PCMS is determined considering the trade-offs of the cost of PCMS and the costs for other strategies in that category. Because traffic and construction conditions, such as construction type, construction scope, and user traffic delay, were already considered in the TMP selection process, balancing costs of the TMP strategies in one category creates equilibrium among the strategies in the same category. This approach provides engineers efficiency and flexibility in deciding the cost of each strategy in the same category.

Furthermore, the optional strategies in the Category G (Other Strategies) can be selected with justification by the engineers. The optional strategies include Application of New Technology and Innovative Products items. However, these are not included within this model.

Table 13. The TMP Elements for Highway Projects

BEES CODE	ITEM	BEES CODE	ITEM
66003	State Furnished Materials	66578	Portable Changeable Message Signs (PCMS)
66004	Miscellaneous State Furnished Materials	66825	Temporary Striping
66005	Concurrent Work	66872	Service Contract
66006	Miscellaneous Concurrent Work	120100	Traffic Control System
66008	Incentive Payment	128602	Traffic Control System (One Way)
66009	Utility Expense	129150	Temporary Traffic Screen
66010	Work by Others	860793	Telephone Service (Location 1)
66060	Additional Traffic Control	860811	Detector Loop
66061	CHP Enhanced Enforcement	860925	Traffic Monitoring Station (Count)
66062	COZEEP Contract	860927	Traffic Monitoring Station (Incident)
66063	Traffic Management Plan Public Information	860930	Traffic Monitoring Station
66064	Specter Radar Unit	861088	Modify Ramp Metering System
66070	Maintain Traffic	66096	Traffic Management, Public Transit Support
66072	Maintain Detour	66097	Traffic Management Plans, Rideshare Promotion
66074	Traffic Control	66063	Traffic Management Plans - Public Information
66076	Temporary Traffic Control	869070	Power and Telephone Service
66077	Install Traffic Control Devices	994920	Bicycle Parking Rack
66095	Freeway Service Patrol (FSP)	995000	Bus Shelter

Source: Caltrans Basic Engineering Estimating System (Caltrans 2012).

V. MODEL VALIDATION

In this chapter, the researchers demonstrate an application of the proposed methodology for selecting TMP strategies and estimating TMP costs in this research. Among the eight case study projects, the I-15 Ontario rehabilitation project was used to test the TMP STELCE model's performance in order to validate the proposed method as a systematic model to estimate TMP costs.

The project cost of the I-15 Ontario rehabilitation project was $82 million, with the project scope of 2.5 centerline miles, including four lanes in each direction. The I-15 Ontario corridor carries about 200,000 ADT, with six percent of heavy truck traffic. The nominal maximum traffic delay during construction was estimated to be as much as 363 minutes (about six hours), and the number of days the traveling public was impacted during construction (i.e., the total lane closure duration) was estimated at 260 days. This number includes only those days on which either temporary reduction in the number of travel lanes were required or weekend full-connector closures were in place.

Table 14 summarizes the results from applying the proposed TMP cost estimate model on the I-15 Ontario project. For instance, the score associated with the project size is 8 points, and the project scope score is 4.1 points. The score for the construction type is 7 points and the score for the construction schedule is 7 points. The full closure score is 0 points because this project did not use full closure. Due to high traffic volumes, traffic delay contributes the highest score (363 points) to the total. The total attribute score is 389 and the corresponding Intensity Level is 5, which is the highest impact level.

Table 14. Attribute Scores for the I-15 Ontario Rehabilitation Project

Attributes	Range	Scores
Project Size	Large (over $1.0M)	8 points
Project Scope (Miles)	4.1 miles	4.1 points
Construction Type	Extended Weekend	7 points
Construction Schedule (Number of Closures)	Over 151	7 points
Full Closure	No	0 points
User Traffic Delay (Minutes)	363 minutes	363 points
Total Attribute Score	**389 points**	
Attribute Intensity	**5**	

Following the TMP cost estimating procedure proposed in the previous chapter, the estimated total TMP cost for the I-15 Ontario rehabilitation project in the model is estimated at $1,863,600 versus $1,764,600 in the Caltrans TMP report. The costs for each TMP category between the model and the Caltrans project TMP report are compared in Table 15.

The cost estimate in the Caltrans TMP report does not include the cost for Demand Management and Alternate Route strategies, although the cost estimate in the model includes them. This implies that the TMP strategy selection and the cost estimating procedure require flexibility to address project-specific conditions, such as alternate route availability. When no alternate route is available near the work zone corridor of an Intensity Level 5 project, the TMP estimated cost for the Category F (Alternate Route) must be allocated to more appropriate categories, instead of ignoring the estimated cost for the non-applicable category.

The proposed overall cost estimate calculated by the TMP STELCE model, compared with the cost estimate in the Caltrans I-15 Ontario TMP report, shows a good match. For example, the cost difference between the estimate in the proposed model and the planned estimate in the project TMP report is about $100,000 (approximately 5 percent of the total TMP cost), which is considered to be within an acceptable range for this type of estimating.

Table 15. Estimate Cost Comparison Between the Model and the Caltrans TMP Report

I-15 Ontario Rehabilitation Project	Cost Estimated in the Caltrans TMP Report (dollars)	Cost Estimated in the Model (dollars)	Difference (Report-Model)
Category A Public Info.	200,000	75,000	125,000
Category B Motorist Info.	35,000	150,000	-115,000
Category C Incident Mgmt.	1,499,600	738,600	761,000
Category D Const. Strat.	30,000	400,000	-370,000
Category E Demand Mgmt.	0	250,000	-250,000
Category F Alt. Routes	0	250,000	-250,000
Total TMP Cost	**1,764,600**	**1,863,600**	**-99,000**

VI. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

This study investigated Transportation Management Plan (TMP) procedures for highway rehabilitation and maintenance projects in California through literature reviews and eight case studies of recent projects. Based on these investigations, it was found that engineers rely more on their experience and subjective judgment than on the use of a systematic procedure to select TMP categories and strategies for given project-specific information. Although the Caltrans Transportation Management Plan Guideline (2009) introduces the recent TMP strategies and technologies, it does not provide a detailed step-by-step procedure that engineers can follow for TMP strategy selection and cost estimating.

In this research, the TMP STELCE model, a detailed step-by-step TMP strategy selection and cost estimate model, was developed considering various situations, including diversity of traffic conditions, and construction schedules and resources. The TMP selection model takes into account the CA4PRS analysis results as an input value to determine Intensity Level using the PAM method.

It is well known that the use of CA4PRS is especially beneficial for transportation agencies, when it is implemented during the planning and design stages of highway project development, in order to balance schedule (construction production), inconvenience (traffic delay), and affordability (agency budget). The CA4PRS provides the major parameters to the TMP STELCE model. The resulting TMP cost estimates are then used as input into the CA4PRS so that it can be included in the agency's cost estimate.

The TMP STELCE model classifies the project into one of five Intensity Levels, depending on the score earned through quantitative valuation for the project attributes (project size, project scope, construction schedule, closure type, and traffic delay). The TMP strategies in the TMP categories are determined by the resulting Intensity Level. The costs for TMP strategies, which are selected in the category's corresponding Intensity Level, are estimated by a function of Intensity Level and the base cost dollar amounts (constants a, b, c, d, e, and f). The cost of each strategy with known information (cost of the TMP category and cost of TMP elements in that category) is determined by using "what-if" analysis. The model-calculated total TMP costs range from \$15,000 (Intensity Level 1) to \$1,863,600 (Intensity Level 5) by Intensity Level.

The TMP STELCE model was verified using the I-15 Ontario rehabilitation case study. Comparing the results between the costs estimated by the model and those estimated by the Caltrans TMP report shows an acceptable difference (5 percent).

As to the limitations of the model, the proposed TMP STELCE model was developed based on the Caltrans TMP practices and strategies. Therefore, other state departments of transportation might require some adjustments and modifications, reflecting their TMP processes, for their adoption of this model.

RECOMMENDATIONS

Based on the TMP case studies, it is recommended that the TMP Guidelines be revised to include a more specific and systematic step-by-step process to estimate accurate TMP costs, which is the minimal effort: adding the process, or using the resulting process. The items comprising each TMP strategy need to be specified and their cost standards need to be provided by project size. For example, the cost for establishing a Traffic Management Center (TMC) varies by the project size and construction scope. This means the TMC requires different numbers of items based on different project sizes and construction scopes. The TMP Guidelines should consider all of this and provide a logical procedure to estimate accurate costs for each TMP strategy. Different project engineers should be able to calculate similar amounts of TMP costs for the same project when they follow the TMP Guidelines.

The proposed model is just a prototype process; a framework based on a limited number of TMP case study projects. As a next step, accuracy and reliability of the model can be improved by incorporating more TMP reference projects (i.e., by implementing more case studies). Prototyping the TMP STELCE model in Excel, using macro and Visual Basic functionalities, would improve calculation reliability. Further, coding the model as a standalone Windows application with a user-friendly interface would greatly improve usability by professionals, making the model marketable.

Currently, the TMP STELCE model separately imports and uses traffic and construction information from CA4PRS to select TMP strategies and to estimate costs for the TMP strategies selected. The costs estimated in the TMP STELCE model are then used as input to CA4PRS and are added to the construction cost in the CA4PRS agency's project cost analysis. In order to expedite the cost estimating process and enhance accuracy of cost calculations, it is recommended that the TMP STELCE model be embedded into the CA4PRS cost module as a sub-module for TMP cost, similar to the user traffic delay cost estimate. With its own graphical user interface, this TMP STELCE module within CA4PRS would enable engineers to estimate realistic agency costs, including reasonable TMP costs (along with the road user costs already embedded in CA4PRS).

APPENDIX A: TMP STRATEGIES AND THEIR ELEMENTS

Table 16. TMP Strategies and Their Elements

Category	Title	Subcategory	Subtitle
A	Public Information	A1	Brochures and Mailers
		A2	Press Releases/Media Alerts
		A3	Paid Advertisements
		A4	Public Information Center
		A5	Telephone Hotline
		A6	Planned Lane Closure Web Site
		A7	Project Web Site
		A8	Public Meetings/Hearings
		A9	Community Task Force
		A10	Communication with Selected Stakeholders
		A11	Information Kiosk
		A12	Freight Travel Information
B	Motorist Information	B1	Traffic Radio Announcements
		B2	Fixed Changeable Message Signs (FCMS)
		B3	Portable Changeable Message Signs (PCMS)
		B4	Temporary Motorist Information Signs
		B5	Dynamic Speed Message Signs
		B6	Highway Advisory Radio (HAR)
		B7	Caltrans Highway Information Network (CHIN or 511)
		B8	Wizard CB Alert Systems
C	Incident Management	C1	Transportation Management Center (TMC)
		C2	Traffic Management Team (TMT)
		C3	Intelligent Transportation System (ITS)
		C4	Surveillance Equipment
		C5	Helicopter for Aerial Surveillance
		C6	Tow (Freeway Service Patrol)
		C7	Dedicated (Paid) Law Enforcement

Category	Title	Subcategory	Subtitle
D	Construction	D1	Lane Requirement Chart
		D2	Construction Staging
		D3	Traffic Handling Plans
		D4	Full Facility Closures
		D5	Lane Modifications: - Reduced Lane Widths to Maintain Number of Lanes (Construction) - Lane Closures to Provide Worker Safety - Reduced Shoulder Width to Maintain Number of Lanes - Shoulder Closures to Provide Worker Safety - Lane Shift to Shoulder or Median to Maintain Number of Lanes
		D6	One-Way Reversing Operation
		D7	Two-Way Traffic on One Side of Divided Facility
		D8	Reversible Lanes
		D9	Ramp Closure/Relocation
		D10	Night Work
		D11	Extended Weekend Work
		D12	Pedestrian/Bicycle Access Improvements
		D13	Maintain Business Access
		D14	A+B Bidding
		D15	Incentive/Disincentive Clauses
		D16	Innovative Construction Techniques (for example, precast members, rapid cure materials)
		D17	Railroad Crossing Controls
		D18	Coordination with Adjacent Construction Site(s)
		D19	Speed Limit Reduction
		D20	Traffic or “Gawk” Screens
		D21	Bus Priority Access
E	Demand Management	E1	Telecommuting
		E2	Truck/Heavy Vehicle Restrictions
		E3	Parking Supply Management
		E4	Variable Work Hours
		E5	Ramp Metering
		E6	Ramp Closures
		E7	Transit Service Improvements
		E8	Transit Incentives
		E9	Shuttle Services
		E10	Ridesharing/Carpooling Incentives
		E11	Park-and-Ride Promotion

Category	Title	Subcategory	Subtitle
F	Alternate Routes (Detour)	F1	Off-Site Detours/Use of Alternate Routes
		F2	Signal Timing/Coordination Improvements
		F3	Temporary Traffic Signals
		F4	Street/Intersection Improvements
		F5	Bus Turnouts
		F6	Turn Restrictions
		F7	Parking Restrictions

ABBREVIATIONS AND ACRONYMS

4R	Restoration, Resurfacing, Rehabilitation, and Reconstruction
AC	Asphalt Concrete
ADT	Average Daily Traffic
AHMCT	Advanced Highway Maintenance and Construction Technology
BEES	Basic Engineering Estimating System
CA4PRS	Construction Analysis for Pavement Rehabilitation Strategies
Caltrans	California Department of Transportation
CCTV	Closed-Circuit Television
CHIN	Caltrans Highway Information Network (511)
CHP	California Highway Patrol
COZEEP	Construction Zone Enhanced Enforcement Program
CSAC	Crack-Seat Asphalt Concrete
PCMS	Fixed Changeable Message Sign
FHWA	Federal Highway Administration
FSP	Freeway Service Patrol
FSHCC	Fast-Setting Hydraulic Cement Concrete
FWC	Full Weekend Closure
HAR	Highway Advisory Radio
HMA(A)	Hot Mix Asphalt Type A
I-15	Interstate 15
I-10	Interstate 10
IL	Intensity Level
K-rail	Jersey Barrier
MAZEEP	Maintenance Zone Enhanced Enforcement Program
MBGR	Metal Barrier Guard Railing
MOT	Maintenance of Traffic
NB	Northbound
OGFC	Open Grade Friction Course
PAM	Performance Attribute Matrix
PCC	Portland Cement Concrete
PCMS	Portable Changeable Message Sign
PeMS	Freeway Performance Measurement System
PID	Project Initiation Document
PIO	Public Information Officer
PM	Post Mile
POC	Pedestrian Overcrossing
PS&E	Plans, Specifications and Estimates
RSC	Rapid Setting Concrete
RSC	Rapid Strength Setting Concrete

RSP	Rock Slope Protection
SR 1	California State Route 1
SR 9	California State Route 9
SR 17	California State Route 17
SR 37	California State Route 37
SR 60	California State Route 60
STA	Station Number
STELCE	Strategy Selection and Cost Estimate
TMC	Transportation Management Center
TMP	Transportation Management Plan
TO	Transportation Operations
T511	Temporary Crash Cushions
TTC	Temporary Traffic Control
Type B	Erosion Control Netting
US 101	U.S. Route (Highway) 101
USDOT	United States Department of Transportation
WZ	Work Zone

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