Integrated Design/Construction/Operations Analysis for Fast-track Urban Freeway Reconstruction

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ABSTRACT

The California Department of Transportation is rehabilitating or reconstructing deteriorated urban freeways using long-life (30+ years) strategies. These pavements were constructed between 1955 and 1970 with design lives of 20 years. This paper summarizes pre-construction analysis of the fast-track pavement reconstruction on Interstate-15 (I-15) at Devore which used two one-roadbed continuous (about 210 hours) closures with round-the-clock (24/7) operations. The integrated analysis concluded that the one-roadbed continuous closures are the most economical scenario when compared to traditional nighttime or weekend closures from the perspective of schedule, delay, and costs. The pre-construction was validated with as-built construction and traffic performances monitored during construction. The construction management plan – including contingency, incentives, and CPM schedule – was developed utilizing the Construction Analysis for Pavement Rehabilitation Strategies (*CA4PRS*) computer model. The results of this planning study are useful for transportation agencies in developing highway rehabilitation strategies that balance the maximization of construction productivity with a minimization of traffic delay.

LIST OF KEYWORDS

Highway construction, Concrete pavement, Fast-track rehabilitation, Constructability analysis, Case study

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INTRODUCTION

Pavement Deterioration and Rehabilitation

The 256,000 kilometers of the National Highway System represent four percent of the 6 million km of road in the United States (Bureau of the Census 1994). However this vital infrastructure system carries 75 percent of all truck traffic and connects 95 percent of the businesses and 90 percent of the households in the United States (FHWA 1996). Most of the pavements in this system were originally built between 1950 and 1980 with 20 year design lives, which have now been exceeded. For this reason, the focus of highway construction has shifted from building new transportation facilities to "4-R" projects: restoration, resurfacing, rehabilitation, and reconstruction (Herbsman and Glagola1998).

When an advanced state of pavement structural damage has been reached, routine maintenance and standard rehabilitation strategies provide diminishing returns in terms of cost–effectiveness for the owner agency, and result in increasing road user costs because of the increasing frequency of lane closures for maintenance and rehabilitation. Thus new strategies must be found to restore long-term functional reliability of the highway pavement. As an additional complication, in 1999-2001 about 30 percent of the pavements requiring 4-R type construction highway projects were in urban areas, where construction causes serious problems with traffic service for the communities that use the freeways (WisDOT 2002).

A pioneer when it comes to highway construction, the State of California is now faced with widespread deterioration of its highway infrastructure. The California highway system includes over 78,000 lane-km, with most built between 1955 and 1975 with the typical 20 year design life. A large number of the pavements in this system have been exposed to heavier traffic volumes and loads than they were originally designed to handle, and are continuing to be made to function 10 to 30 years after their intended life. Increasing road user costs associated with the aging of the highway network include safety, ride quality, traffic delay and vehicle operating costs. As traffic volumes continue to soar in California, reconstruction during daytime commute hours becomes ever more unpopular.

In 1998, the California Department of Transportation (Caltrans) launched the Long-Life Pavement Rehabilitation Strategy (LLPRS) program to rebuild approximately 2,800 lane-kilometers (lane-km) of badly damaged pavements over 10 years (Caltrans 2003). The criteria for LLPRS candidates were poor structural condition and ride quality and a minimum of 150,000 Average Daily Traffic (ADT) or 15,000 truck ADT. The main goals of the LLPRS program are to provide new pavement with at least 30 years of design life and requiring minimal maintenance. Most of the candidate projects are interstate freeways in urban corridors in the Los Angeles and San Francisco Bay areas and currently have Portland cement concrete (PCC) pavements.

Innovative Closure Strategies

Traditionally, urban freeway rehabilitation projects in California have used 7-hour or 10-hour nighttime closures because daytime closures cause unacceptable traffic delays during weekday peak travel periods. The disadvantages of nighttime closures include difficulty in controlling construction quality control, which often has detrimental effects on pavement life and surface smoothness, and the severely restricted set of pavement rehabilitation strategies that can be completed and opened to traffic in 7 to 10 hours. These disadvantages make the goal of long-life pavement and minimal maintenance nearly impossible to achieve. Nighttime closures also pose increased safety risks for road users and construction crews. They often result in longer total closure times, higher construction and traffic handling costs, and greater traffic delay to road users (Lee et al. 2000).

In recognition of these problems with nighttime closures, Caltrans has initiated the use on LLPRS projects of innovative pavement rehabilitation strategies (pavement designs and materials) and accelerated construction with 24 hour per day operations during multiple 55-hour weekends or 72-hour weekdays or continuous closures. (In continuous closures, lanes are closed and not reopened until construction is completed.)

The concept of the 55-hour extended weekend closure was validated in 2000 on the first concrete LLPRS demonstration project on Interstate 10 in Pomona (Lee et al. 2002a), and on the first asphalt LLPRS demonstration project on Interstate 710 in Long Beach, completed in 2003 (Lee et al. 2005a). The time savings of fast-track highway reconstruction with extended longer closures are offset to some degree by the risk of significant traffic disruption if the project's schedule slips. Nevertheless, the study on the I-10 Pomona project showed that construction under the 55-hour weekend closure was on average about 40 percent more productive than traditional nighttime closures.

The Pomona and Long Beach projects formed the baseline for the pre-construction analysis of the reconstruction of Interstate 15 at Devore, the subject of this paper. The Devore project differs from the previous two projects because it employed an integrated and simultaneous consideration of schedule, traffic handling, and cost during development and implementation of the project management plan through the planning, design, and construction phases. Traditional project development and implementation for highway projects typically looks at cost, schedule and traffic handling sequentially, which often results in decisions being made in each stage that have unintended negative effects on other elements of the project plan.

Integration Approach to LLPRS Projects

Taking more lanes away from traffic facilitates fast construction by providing more space for removal of huge volumes of demolished pavement, delivery of new paving materials, and operation of large numbers of heavy equipment during urban freeway rehabilitation. Traditional design of long-life pavements focuses on thicker layers and high quality materials that often require considerable time to construct. Faster construction requires thinner pavement structures and materials that quickly develop strength to be able to handle construction and road user traffic.

To meet the conflicting design life and constructability goals for LLPRS projects requires innovative pavement designs that provide long-life with thinner structural sections, as well as materials that shorten construction and curing time, without sacrificing quality and performance (Roesler et al. 1999). Construction planning must focus on speeding the construction process by incorporating such concepts as contingency management, incentives/disincentives (I/D), and cost (A) plus schedule (B) bidding (Arditi et al. 1997), and by balancing the traffic needs of road users on one side of the lane closure barrier and construction equipment on the other. The integration of pavement design and materials, construction, and traffic analyses provides the basis for an efficient project management plan that minimizes life cycle costs within project constraints.

Research Objectives and Scope

A joint research team from the University of California Pavement Research Center (Berkeley and Davis) conducted integrated analyses of design, construction, and operations in the planning and design stages of the Devore project to help Caltrans refine methods for fast-track pavement reconstruction. The main objective of this pre-construction study was to develop the most efficient construction management plan possible by building on and adding to the practices and lessons learned from the Pomona and Long Beach projects.

In the first step of the analysis, four construction window closure alternatives (i.e., 55-hour weekend, 72-hour weekday, 10-hour nighttime, and one-roadbed continuous closures) were evaluated and compared. The objective was to select the most economical construction closure scenario from the perspective of production schedule, traffic delay (total delay and maximum time spent in a queue), and total costs (the sum of construction and road user costs). Based on the integrated analysis and feedback from public hearings, Caltrans decided to use one-roadbed continuous closures, closing the entire roadbed in one direction of travel and placing traffic traveling in both directions on the other roadbed with a movable barrier separating them. Construction was planned to occur 24 hours per day and 7 days per week during each closure.

Then, a more detailed constructability analysis of the selected scenario was performed to refine the construction management plan, especially focusing on the contractor's (1) logistical resource constraints, (2) incentives/ disincentives requirement, and (3) contingency provisions. Results of that analysis were used to develop the project special provisions.

Finally, the pre-construction estimates were compared with the contractor's production performance and traffic delay data collected during monitoring of the reconstruction. A summary of the monitoring data is presented in this paper for comparison with the project plan. Detailed results of construction and traffic monitoring will be presented in another paper as a post-construction study.

These studies will help Caltrans and other transportation agencies develop better management techniques for fast-track rehabilitation of highways with high traffic volumes.

CA4PRS Computer Model

The innovative analysis approach for the Devore project was made possible by the use of a sophisticated production estimation model called Construction Analysis for Pavement Rehabilitation Strategies (*CA4PRS*). This model was developed by the University of California Pavement Research Center. The software was coded with support from the State Pavement Technology Consortium (California, Florida, Minnesota, Texas, and Washington), a Federal Highway Administration pooled fund program.

The *CA4PRS* model estimates the maximum amount of highway pavement rehabilitation or reconstruction (lane-km and centerline-km) that can be completed during various types of closures (Lee and Ibbs 2005) by taking account of project constraints such as scheduling interfaces, pavement materials and design, contractor logistics and resources, and traffic operations. A powerful feature of *CA4PRS* is that it can be integrated with macro- and microscopic traffic simulation models to quantify road user costs during construction. When used with traffic models, the *CA4PRS* software can help determine which pavement structures and rehabilitation strategies maximize on-schedule construction production without creating intolerable traffic delays. This information is vital to balancing the three competing goals of long-life pavement, faster construction, and minimum traffic delay.

The *CA4PRS* model was designed in consultation with the sponsoring state departments of transportation currently engaged in validation and implementation of the software. *CA4PRS* is a planning tool designed to be used during the planning, design, and construction stages. It was validated by the Pomona project, and was used on the Long Beach projects to evaluate construction plans.

I-15 DEVORE RECONSTRUCTION PROJECT

Project Overview

Caltrans District 8 planned to rebuild a 4.5 km section of Interstate 15 (Fig. 1), with construction to be completed in October 2004. Caltrans split the project into two segments for construction staging to facilitate traffic detours using median crossovers. Segment 1, built in 1975, is 2 km long with four lanes in each direction. Segment 2, built in 1969, is 2.5 km long with three lanes in each direction.

The passenger car lanes (inner one or two lanes) in each direction were still in good condition in both segments. The two truck lanes were to be rebuilt or repaired to correct extensive cracking, rough ride, and patches. In the inner truck lane approximately 15 percent of the total linear length was selected to receive individual slab replacements for the badly cracked slabs. The entire outer truck lanes in each direction were planned to have removal of the lane and reconstruction with new pavement. (see Fig. 2).

The Devore corridor carries approximately 110,000 ADT, with about 10 percent heavy trucks. In contrast to typical urban freeways in California, which typically have low traffic on weekends and high traffic during rush-hour weekday peak periods, the Devore corridor has both very high weekday commuter-peaks and high leisure traffic volume on weekends. The two highest peak traffic volumes are northbound on Friday afternoon and southbound on Sunday afternoon, when leisure travelers in the Los Angeles area are going to and from Las Vegas.

Construction Work-zone Closure

The existing and replacement structures for the outer truck lanes are shown in Fig. 3. The Old Section is a typical 1970s Caltrans design, using undowelled plain jointed concrete slabs. The New Section uses concrete mixes with high early strengths, and includes placement of asphalt concrete (AC) base between the slabs and remaining old aggregate base.

The construction staging required the northbound freeway to be closed for reconstruction first, switching traffic to the other side (southbound) through the median crossovers at the ends of Segment 1 and 2. As illustrated on Fig. 2, construction occurred on the two truck lanes while the two inside lanes were used for access by construction trucks and other equipment.

The two directions of traffic shared the southbound lanes, separated by a Moveable Concrete Barrier (MCB), a system referred to as “counter flow traffic”. Ramps in the work zone were closed to traffic other than construction equipment.

The outside shoulder was used as a traffic lane in Segment 2 to get two lanes for each direction of traffic. The same process was repeated for the reconstruction of the other direction (southbound).

Most Economical Closure Scenario

The benefits to traffic of using a 55-hour weekend closures instead of weekday nighttime closures, which are obvious for most Southern California freeways, were not as clear for the Devore project because of its unique traffic patterns. Four construction closure scenarios were compared from the perspective of construction schedule, traffic inconvenience, and agency costs:

- 72-hour weekday [Tuesday-Thursday],
- 55-hour weekend [Friday-Sunday],
- one-roadbed continuous [about 9 days], and
- 10-hour nighttime closures.

The *CA4PRS* model was used to estimate the total number and duration of closures for each closure scenario. Traffic analysis was then performed for each closure scenario to calculate total traffic delay and maximum delay (queue length) per closure, using a demand-capacity spreadsheet model based on the Highway Capacity Manual (HCM 2000) with the hourly distributions of freeway traffic data particular to each closure.

Cost projections in most states and on many projects in California typically include only agency costs (construction and traffic handling). Caltrans recognized that, at least for LLPRS projects, the cost of additional traffic delay caused by highway construction to road users is as important as agency cost. There are other road user costs (RUC) associated with highway construction projects, however, only construction related traffic delay costs were considered because of the difficulties of calculating other costs, and traffic delay costs are generally the largest.

The total cost, calculated as the sum of the agency cost and road user cost, was used to select the most economical closure scenario. Using a combined total cost for selection and giving agency and road user costs equal weighting is unusual in selecting highway construction alternatives. The road user cost was calculated using typical values used in Caltrans studies for commercial ($24/hour) and private ($9/hour) vehicles. Table 1 shows the result of the comprehensive comparison from the perspectives of schedule, traffic delay, and total cost used to select the most economical closure scenario (Lee at al. 2005b).

The one-roadbed continuous closure scenario was selected as the best candidate strategy in terms of agency, road user, and total costs. The analysis shows that the one-roadbed continuous closure scenario is about 26 percent more economical from the total cost ($20 million versus $27 million) perspective when compared with the 55-hour weekend closures. The one-roadbed continuous closure scenario requires 81 percent less total closure time, 29 percent less road user cost due to traffic delay, and 28 percent less agency cost for construction and traffic control compared to traditional 10-hour nighttime closures.

CONSTRUCTABILITY COMPARISON

More detailed constructability and productivity analyses were performed using the *CA4PRS* model after selection of the most economical reconstruction closure scenario. The constructability analysis compared the following alternatives for the new pavement from the production and scheduling point of view:

- Concrete mix design (cement strength gain time)
- Pavement base type (asphalt concrete base versus lean concrete base)
- Outer truck lane width (widened truck lane versus tied concrete shoulder)

The underlying assumption in the constructability analysis, based on earlier studies and laboratory and field tests for LLPRS projects, was that using these three comparison criteria in all alternatives would provide similar pavement performance and life expectancy (Roesler et al. 1999). The scheduling analysis with *CA4PRS* answered the question of how quickly the whole project could be completed for each permutation of the three variables by estimating the maximum production (distance) per closure and the total number of closures to complete the entire project.

Based on the constructability analysis results, Caltrans decided to use Type III concrete mixes, (2) asphalt concrete base, and (3) a widened truck lane. Details of the constructability analysis are summarized in the following section.

Concrete Mix Design

Two concrete mix designs were compared for the slabs: rapid strength concrete (Type III PCC) which allows opening to traffic within 12 hours of placement and fast-setting hydraulic cement concrete (FSHCC) which allows traffic opening within 4 hours. The 8 hour time advantage of FSHCC is offset by higher concrete slump and material stickiness, the need for more delivery trucks and a smaller paving machine, the restriction to single-lane paving at one time, and the typically rougher finished surface which frequently requires diamond grinding after curing. In addition, FSHCC is about twice as expensive as Type III PCC in California. The *CA4PRS* model indicated that the two materials result in approximately the same overall project completion time.

Pavement Base Type

Two types of base material were considered for the project: asphalt concrete base (ACB) and lean concrete base (LCB). The *CA4PRS* model estimated that significantly more time would be needed if LCB was used instead of ACB because the LCB requires a 12-hour curing time before PCC slab paving. LCB also requires placement of a bond-breaker to minimize friction between the base and slab that increases the risk of early-age cracking, which would slow production. The ACB scenario also permits parallel production of the base and slabs, with each operation utilizing its own resources, while the LCB needs to use the PCC plant and paver.

Pavement Structure Design

Two options were considered for the width of the outside truck lane: normal width 3.7 m slabs tied to new concrete shoulder; or a widened truck lane (4.3 m). The schedule analysis showed that the tied concrete shoulder option would slow construction, and require additional closures.

Slab Demolition Methods

Two types of demolition methods for old PCC pavement are commonly used in California: "non-impact demolition," in which each slab is cut into three or four large pieces which are lifted out by an excavator; and "impact demolition," in which the slabs are broken into small pieces by a breaker (rubblizer or stomper) and scooped out by the excavator. Non-impact demolition used on the Pomona project (Lee et al. 2002a) was 58 percent slower than impact demolition on the Long Beach project (Lee et al. 2005a). However, the non-impact demolition method was selected for the Devore project because it was determined that the noise made by the slab rubblizer during the night could disturb residents and wildlife habitat in environmentally sensitive areas near the site.

RECONSTRUCTION PROCESS AND PRODUCTIVITY

The expected reconstruction process and construction staging plan for the Devore project, based on the previous LLPRS projects, was outlined and distributed to the contractors in the pre-bid meeting as a guideline and reference.

Reconstruction Process

The Devore reconstruction project involved three main operations: closure mobilization, pavement reconstruction during main closure, and closure demobilization. The expected detailed activities are as follows:

I. Closure Mobilization Operation

1) Set up construction work zone signs
2) Set up MCB on the traffic roadbed
3) Remove lane marking and temporary re-striping of the traffic road bed
4) Partial closure of the traffic roadbed

II. Main Reconstruction Operation

5) Full closure of construction roadbed and switching of traffic to the traffic roadbed
6) Saw-cut old PCC slabs
7) Cold plane (milling) old outside AC shoulder
8) Demolition of old PCC slabs and excavation of CTB and part of aggregate base (AB)
9) Grade and compact AB
10) Production and delivery of hot mix asphalt
11) Pave new AC base (76 mm thick × 2 lifts)
12) Compaction and cooling of AC base
13) Production and delivery of concrete
14) New PCC slab paving
15) Finishing and spreading the curing compound
16) PCC slab curing
17) Saw-cut new PCC slab joints
18) AC overlay of outside shoulder
19) Clean-up of the newly constructed pavement

III. Closure Demobilization Operation

20) Mark lanes (striping) on the new pavement
21) Open the construction roadbed to traffic
22) Partial closure of the traffic roadbed
23) Remove MCB on the traffic road bed
24) Remove temporary lane marking and re-striping on traffic roadbed
25) Open both directions of the freeway

Construction Staging Plan

Primary pavement reconstruction activities during the one-roadbed continuous closure included the following:

- Demolition of the existing old pavement structure
- Paving AC base
- Paving PCC slab

- Cold plane and AC overlay of the outside shoulder.

These four activities were expected to progress concurrently, although equipment could not work at the same location. Based on the linear scheduling technique, one activity followed the other while maintaining a distance and time buffer to avoid interference between the activities. A rehabilitation technique known as the “concurrent double-lane paving method” with a slip form paver was used for this project since two passenger lanes are available for construction access to rebuild two truck lanes at once (Lee and Ibbs 2005). This allows demolition, ACB paving, and PCC paving to proceed simultaneously.

As the *CA4PRS* production analysis estimated, each segment during the one-roadbed closure was subdivided into equal sections approximately 500 m long for construction convenience. ACB paving was to begin following demolition once the demolition operation progressed far enough (about 500 m) that equipment interferences are minimized and ACB operations would not catch up with the demolition activities. Similarly, PCC paving began and followed ACB paving once ACB paving progressed sufficiently.

Productivity Estimate with *CA4PRS*

The *CA4PRS* software was used for the pre-construction productivity analysis. The hourly production rate and resource constraints used in the *CA4PRS* analysis were confirmed by Caltrans construction engineers and paving contractors (Western States Chapter of the American Concrete Pavement Association) through a series of constructability meetings prior to construction.

Fig. 4 shows an example output screen from the stochastic *CA4PRS* analysis, which calculates the likelihood of maximum production capability per one-roadbed continuous closure. The *CA4PRS* model estimated that about 200 hours of operations with lead-lag time relationship between main activities were needed to finish 5.1 lane-km (including the random slab replacement) of each roadbed closure (one complete direction finished in each closure), with a total closure time of 210 hours when mobilization and demobilization were included. A baseline CPM schedule was developed using the *CA4PRS* production analysis.

The following sections summarize the *CA4PRS* productivity analysis.

PCC Demolition Productivity

Two demolition teams were assumed in the *CA4PRS* analysis based on the previous LLPRS projects. Each demolition team was assumed to use an excavator (backhoe) for loading and ten 22-ton capacity end dump trucks for hauling operations. Previous case studies showed that ten end dump trucks per hour per team is generally the maximum possible productivity for non-impact demolition because at least five minutes of cycle time was required to load each haul truck (Lee et al. 2002a).

The *CA4PRS* analysis model utilizing the linear scheduling technique identified balancing resource requirements for the other two major operations (demolition and PCC paving) based on number of haul trucks as the critical resource constraint. The balanced productivity, i.e., hourly progress of the demolition calculated from the analysis with the given hauling volumes, scheduling, and resource constraints, is 100 m per hour on average.

AC Base Paving Productivity

The *CA4PRS* analysis indicated that the resources needed for the ACB paving and paving of new AC shoulders to balance with the demolition and paving operation are six 24-ton bottom dump semi tractor trailers per hour on average. The AC batch plant needs to produce 150 tons per hour to keep up with paving operations. AC cooling time was calculated to check any time delays in starting PCC slab paving using the “MultiCool” cooling analysis program integrated into *CA4PRS* (Timm et al. 2001). The productivity analysis indicated that each 500 m section of ACB can be paved in approximately five hours, which itself is not expected to be a production constraint.

PCC Paving Productivity

The *CA4PRS* analysis estimated that twenty 6.5 m^3 (15 ton) dump trucks are needed each hour on average for concrete delivery to achieve the overall maximum production for the PCC slab paving operation. This means each delivery truck has about a three-minute cycle time for concrete charging in the batch plant and also for discharging time on site. This cycle time was validated in the previous case studies and confirmed by the industry group in the constructability meetings as the minimum practically achievable, using a batch plant producing at least 120 m^3 per hour.

The slip form paver must pave at least 1.7 m per minute to match production. The paver speed was confirmed to not be a constraint, even with the two-lane concurrent paving, which is typical of projects evaluated to date.

In summary, the balanced progress of the PCC slab paving operation with given resource constraints was estimated to be 100 m per hour on average by the *CA4PRS* analysis.

CONTINGENCY PLAN

The criticality of achieving accelerated construction on the Devore project required specific contingency strategies to minimize the number and magnitude of unforeseen problems and hidden risks. Critical items for this contingency plan were determined based on the previous LLPRS case studies. Some key requirements contractually imposed on the contractor in the project special provisions are summarized below.

Poor Subgrade Replacement

As-built plans for the existing pavement structure on the construction corridor show 200 mm PCC over 100 mm CTB over AB. However, this pavement was constructed in the 1960s and 1970s, and accurate as-built construction records were not available. At some locations poor subgrade might be encountered during demolition and excavation as was observed on the Long Beach project (Lee et al. 2005a). Therefore, contingency planning required pre-planned solutions to potential problems identified during the contingency planning. Additional geotechnical site investigations were performed prior to construction, including coring in the mainline and shoulder and trench investigation in the shoulder to evaluate site conditions.

These activities might delay the schedule and add to the cost. To compensate for any delay, the contractor was allowed to use FSHCC for some sections.

Appropriate Gap between Operations

To minimize equipment interruptions, a minimum gap was required between the locations where major reconstruction operation activities (demolition, AC base paving, and PCC paving) are proceeding concurrently. As noted previously, it was recommended that each segment be divided into four equal sections (about 500 m) and that these activities occur in different sections concurrently. At the same time, the gap between demolition and AC base paving or PCC slab paving also was limited to a certain distance that in the event of an unforeseeable breakdown of a paving operation the demolished pavement could be repaved before the end of the closure. The contingency plan included the use of temporary paving material for that section.

Use of Two Concrete Mixes

The use of FSHCC mix on the final slabs of each closure within 12 hours of traffic opening is referred to as the "stitch", which can save paving hours. The project special provisions allowed the contractor to use different types of cement concrete materials. FSHCC was allowed on the stitch, either to achieve more production at the end of the closure, to make up for any unforeseen delay, or as a temporary paving material in case of an emergency. The contractor was required to arrange an appropriate set of resources, such as delivery trucks and paving machines to handle these two different mix designs.

Standby Paving Materials for Emergencies

Caltrans decided to retain the contractual authority to open the freeway prior to the end of closure due to emergencies, for example due to severe weather, fires, vehicle accidents, or construction-related problems that would compromise the quality of the finished product. Under such circumstances, the contractor was required to use FSHCC, hot mix asphalt, or cold mix AC as temporary paving materials to be eventually replaced with specified materials.

Incentives/Disincentives Contract

Traditional Caltrans practice for rapid highway rehabilitation projects has been to rely on ad hoc estimates in developing incentives/disincentives to promote the production objective, often without quantitative calculations. The Devore project incorporated the unique approach of using the additional cost associated with road user traffic delay to develop the incentives/disincentives requirement. The assessment of incentives/disincentives was based on the CA4PRS production schedule and traffic simulation analyses (Lee et al. 2005b).

Due to a high demand of traffic volume during closures and the public desire for early completion of the reconstruction, Caltrans decided to apply two types of incentives/disincentives provisions to encourage the contractor to complete the closure earlier or on time. The primary provision paid incentives to minimize the duration of each roadbed closure. The secondary provision paid incentives to minimize the total closure days of the entire main reconstruction.

The projected road user cost using the demand-capacity spreadsheet based on the HCM model was used as the baseline of the incentives/disincentives calculation for the one-roadbed closures. However, only one third of the road user cost was factored into the incentives / disincentives calculation, a commonly used practice in other states. The incentives were limited by the realities of the budget limitations of the State, and a value of $600,000 was used for the incentive cap.

The contractor would be eligible for a closure incentive bonus of $300,000 if one-roadbed continuous closure is completed in equal or less than two units of time segment (111 hours per unit), or be subject to a closure disincentive penalty without a limit if the closure takes longer than three units of time segment (one extra was given for realistic flexibility). In addition to this closure incentives requirement, the contractor would be eligible to receive a daily incentive bonus of $75,000 if the entire major reconstruction was completed in fewer than 19 days (total 456 hours), or be subject to a daily disincentive penalty (without a limit) if the reconstruction took longer.

VALIDATION OF THE PRE-CONSTRUCTION ANALYSIS

Successful Project Completion

Initially, Caltrans moved ahead assuming the use of 72-hour weekday closures due to major concern about traffic delay on weekends for Las Vegas bound leisure traffic. However, Caltrans met with strong opposition to the 72-hour weekday closures from weekday commuters, which surfaced at public hearings. Weekday commuters felt that their time delay was of greater value than that of leisure traffic. Although the contract was awarded based on the 72-hour weekday closures, Caltrans adjusted the reconstruction plan to one-roadbed continuous closures just one month before the first extended closure was set to begin. The one-roadbed continuous closure was expected to result in longer queues, but balanced traffic delay to both weekday commuters and weekend leisure traffic, and shortened the total project duration.

Eventfully, the reconstruction project was successfully completed with two one-roadbed continuous closures with round-the-clock-operation in October 2004 (Fig. 5). The northbound reconstruction was completed in 216 hours. The southbound reconstruction was finished in 210 hours several weeks later.

Validation of the Pre-construction Analysis

Construction and traffic monitoring studies by the research team during reconstruction confirmed that the overall performance of the reconstruction was consistent with the outlined schemes in this pre-construction analysis with respect to construction process and progress. The *CA4PRS* model under estimated production by about 5 percent, which is reasonable for a planning tool. The number of hauling and delivery trucks per hour turned around for the major reconstruction operations were similar to the assumed resource inputs in the *CA4PRS* model.

The overall impact of reconstruction closures on traffic was “acceptable” according to a traffic measurement study and web-surveys during and after the construction. In fact, the maximum peak hour delay (although very infrequent) was measured at about 75 minutes on weekends (northbound) and about 45 minutes on weekdays (southbound). It turned out that about 20 percent reduction in actual traffic demand during the one-roadbed continuous closures (10 percent greater than the reduction initially expected) resulted in less inconvenience to motorists than had been anticipated. The reduction was attributed to Caltrans’ pro-active public outreach and traffic control efforts. What could have been potentially grievous public relations resulted in mostly complimentary feedback for Caltrans for keeping traffic moving during the closures.

Technical reports are currently being in preparation to summarize state-of-the-practice technology and innovation applied in this fast-track highway reconstruction project. Some examples of the state of the practice products implemented on this project included:

- Automated work zone information systems that provided travelers through the construction work zone with near real-time travel time and detour routes information displayed on the permanent and changeable message signs, and
- Extensive public outreach efforts including a project website (with about 400,000 visits in October) on the Internet that featured a live traffic

roadmap (displayed with CCTV) and construction sequences and public updates (Caltrans 2004).

CONCLUSIONS

The conclusions of the pre-construction analysis for the Devore project, since validated by the actual construction, are summarized as follows:

- The integrated analysis concluded that the one-roadbed continuous closure scenario is the best candidate strategy in terms of agency, road user, and total costs. For example compared to traditional 10-hour nighttime closures, the one-roadbed continuous closure scenario requires 81 percent less total closure time, 29 percent less road user cost due to traffic delay, and 28 percent less agency costs for construction and traffic control.
- A detailed constructability and productivity analysis was implemented using the *CA4PRS* model to develop a construction management plan for the project. Furthermore, a typical reconstruction process was defined, the CPM schedule was developed, and major input resource requirements were outlined.
- A contingency plan, which was necessary due to the project's tight schedule and production goals, was developed to minimize the impact of unforeseen problems. A baseline for the incentives/disincentives was developed with an innovative approach based *CA4PRS* analysis of expected construction duration, and traffic delay analysis and traffic delay cost estimation.
- The *CA4PRS* model has been shown to be an invaluable schedule analysis tool and is recommended for use on future high-volume urban freeway reconstruction projects. The production estimation with *CA4PRS* was accurate enough (production was about 5 percent underestimated) as a planning tool, compared with the contractor's as-built production performance of the one-roadbed continuous closures.
- Constructability technical experts have been involved from the initial planning stage to identify project constraints and to mitigate obstacles for this rapid reconstruction. The agency has continued the partnership and communication with the paving industry to maximize constructability benefits.
- The advantages of using this method of accelerated construction were: shortest period of disruption for the traveling public; greater life expectancy for the new pavement than could have been obtained using nighttime closures; improved safety for motorist and workers; and significantly reduced construction costs (about $6 million).
- California now has a unique opportunity to validate and further calibrate the processes, tools, and expertise used in this integrated pre-construction analysis. Thus, post-construction reports are being prepared to gather "lessons learned" based on the construction/traffic monitoring study from this project for future LLPRS projects.

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Table 1. Schedule, Delay, and Cost Comparison for Closure Scenarios

Closure Scenario (1)	Schedule Comparison		Traffic Comparison[a]		Cost Comparison	
	Closure Number (2)	Closure Hours (3)	Road User Cost ($M) (4)	Peak Delay (Minute) (5)	Agency Cost[b] ($M) (6)	Total Cost[c] ($M) (7)
1-Roadbed Continuous	2	400	5	80	15	20
72-Hour Weekday	8	512	5	50	16	21
55-Hour Weekend	10	550	10	80	17	27
10-Hour Nighttime	220	2,200	7	30	21	28

[a] with assumption of 20 percent traffic demand reduction

[b] Engineer's re-estimate based on the unsuccessful first round of bid

[c] Total cost = Road user cost + Agency cost (per row)

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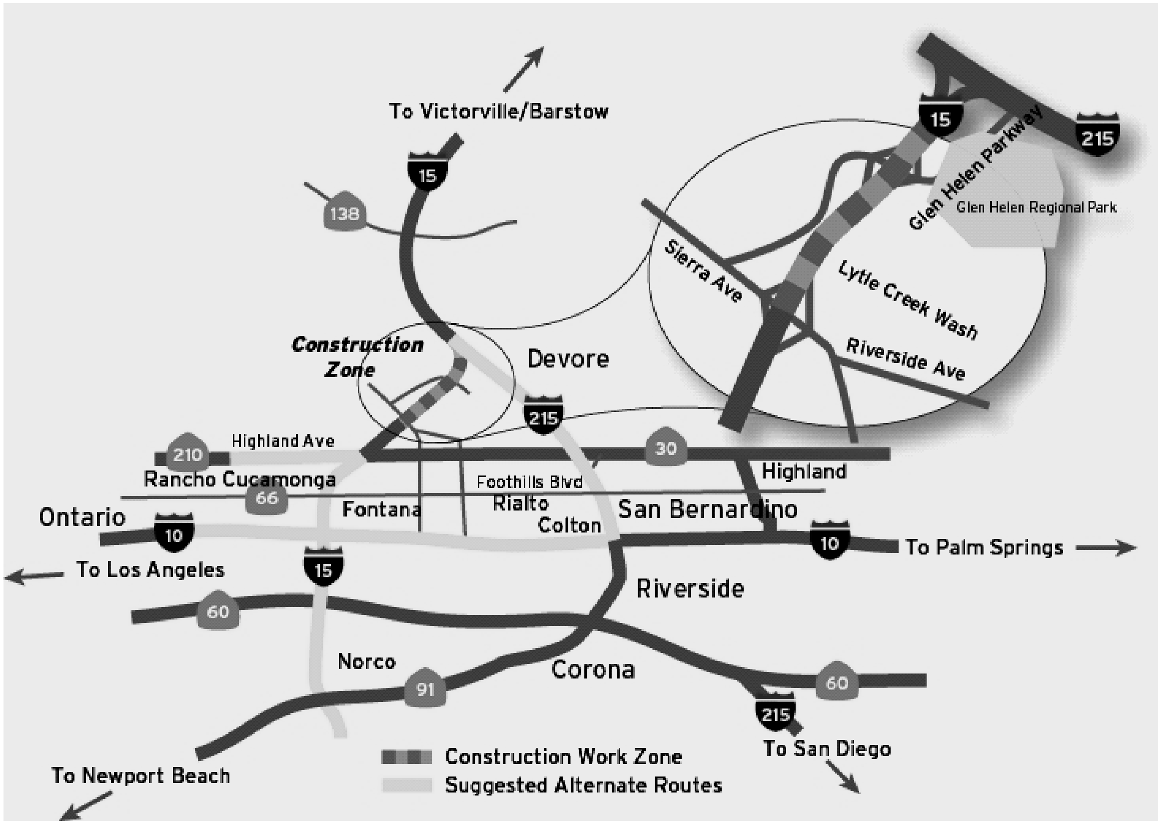

Fig. 1. The site location of the I-15 Devore reconstruction project

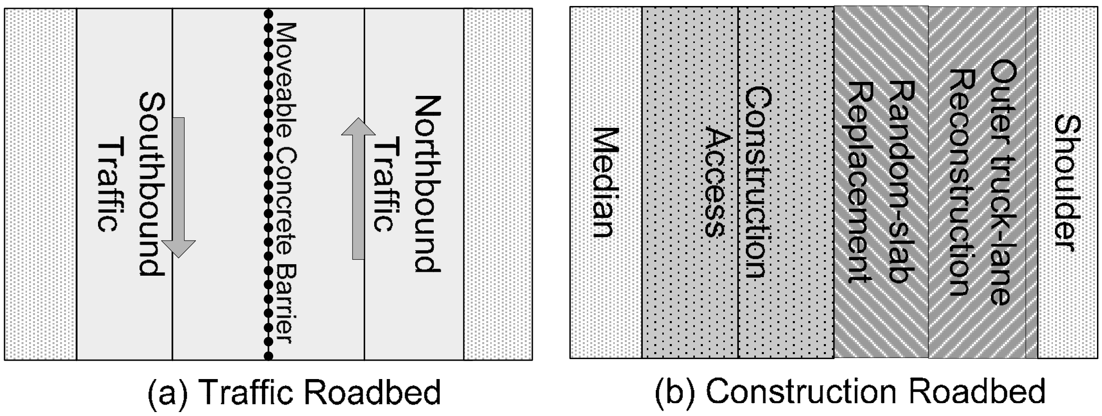

Fig. 2. Plan view of the construction and traffic roadbeds in Segment 1

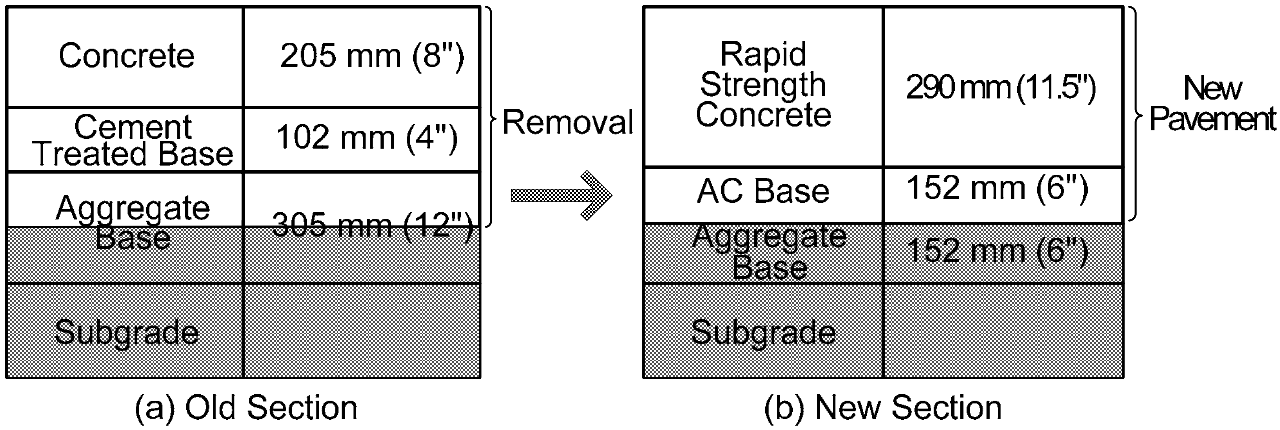

Fig. 3. The change of concrete pavement cross-section

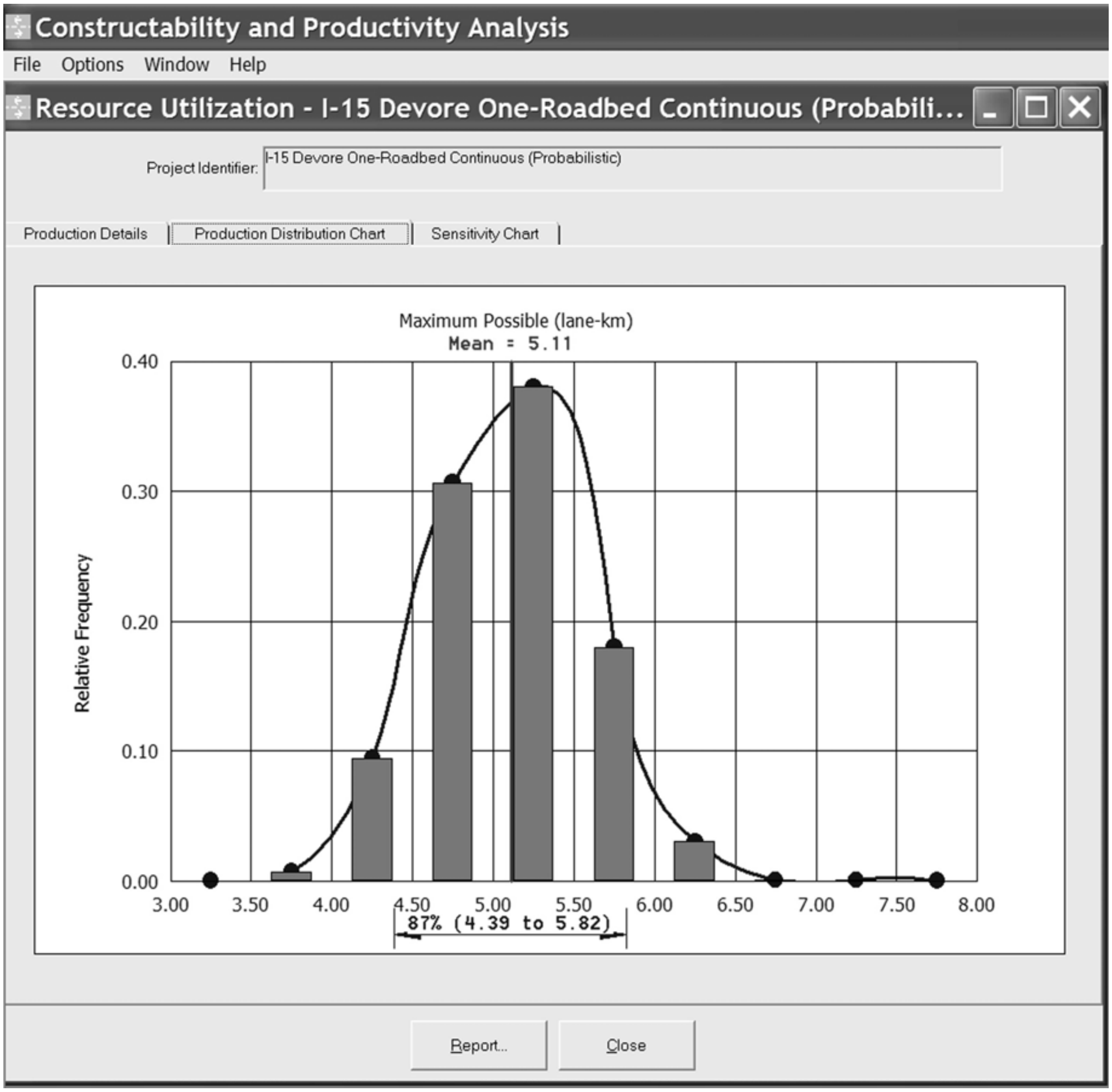

Fig. 4. The output screen of the *CA4PRS* stocastic production analysis

Fig. 5. Construction and traffic operations during I-15 Devore reconstruction