Economic Implications of Selection of Long-Life versus Conventional Caltrans Rehabilitation Strategies for High-Volume Highways

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EXECUTIVE SUMMARY

This report presents the results of a two-part study that compared the lifecycle costs of two long-life pavement (LLP) rehabilitation options and several conventional rehabilitation strategies for existing asphalt and concrete pavements, considering both agency costs and road user cost associated with traffic delay caused by construction. In the first part of the research, data from a 1996 study was reanalyzed using a more appropriate method of calculating traffic demand whilst using other assumptions of the earlier study. Then, a factorial sensitivity study was performed comparing lifecycle costs of hypothetical long-life strategies and conventional rehabilitation strategies, but with more variables than were included in the 1996 study and more appropriate data sourced from recent projects. The RealCost software package, developed by the Federal Highway Administration, was used for all analyses.

The results of the analyses showed that for the current data and assumptions (pavement lives, construction productivity, hourly traffic patterns) used in the study together with better traffic delay analysis, the LLP options have greater total costs than conventional rehabilitation alternatives assuming 24-hour-per-day closures for LLP options and 8-hour nighttime closures for conventional alternatives. However, the sensitivity analyses showed that as traffic demand is reduced by implementation of Traffic Management Plans (TMP) and use of weekend closures, the traffic delay costs associated with LLP options are significantly reduced. The sensitivity analyses also showed that if non-pavement costs are reduced for the LLP options (they were not considered for the conventional rehabilitation alternatives), LLP options become competitive for projects with large numbers of lanes.

Because of a lack of good pavement performance data, and limited cost data for long-life projects (two projects), the results of the sensitivity analyses presented in this report should be considered in terms of their general trends, and should absolutely not be used to compare

different conventional rehabilitation strategies or alternative long life strategies for individual projects without using better and site-specific data. The alternatives considered in this study are all hypothetical cases. The study was limited to rehabilitation strategies only and is not applicable to new construction or widening.

The sensitivity analyses made clear the need to perform lifecycle cost analysis for each project using project-specific data for both agency costs and road user costs. Despite the findings of this study, LLP is still considered to be a feasible rehabilitation option. It is thus strongly recommended that LCCA be performed on a case-by-case basis when determining whether to use long-life or conventional strategies as significantly different results could be obtained when project specific data and actual overhead and administration costs are used. An example is provided in the report in which lifecycle cost analyses showed LLP to be more cost-effective than conventional rehabilitation alternatives because the existing pavement condition made some conventional rehabilitation alternatives infeasible, which would have resulted in shorter lives than those assumed in this study. Local conditions resulted in a traffic management plan with significantly greater reduction in traffic demand that that assumed in this study.

The results of LCCA are dependent on the following variables which are different for each project:

- Traffic demand patterns, including hourly demand, weekday and weekend demand, directional peaks and discretionary versus job-related travel
- Alternative routes and modes
- Lane and shoulder configurations and highway geometry in each direction
- Feasibility and expected life of each rehabilitation strategy, which depend on truck traffic and existing pavement condition in each lane

- Expected construction durations

Sensitivity analyses should be carried out to identify specific issues that influence the agency and road user costs and which could be managed better to reduce the costs on alternative strategies. There is consensus in the industry that quality LCCA in the design phase of rehabilitation projects can result in more appropriate strategies, considerable total savings (agency and road user) and better cash flow management.

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1.0 INTRODUCTION

The California Department of Transportation (Caltrans) has a number of options available for rehabilitating high traffic volume highways. The choice of an appropriate option depends on many factors including the existing pavement type and condition, funding, and traffic characteristics, among others. Caltrans policy, detailed in the Highway Design Manual (*1*), has been to seek greatest efficiency in the use of available funding in terms of pavement lifecycle cost and road user delay cost associated with maintaining pavement serviceability.

In 1996, an internal Caltrans study was undertaken to compare the lifecycle costs of rehabilitating an existing Portland cement concrete pavement using a standard 10-year asphalt concrete overlay strategy with those of using a 35-year Portland cement concrete, so-called "long-life" rehabilitation strategy. The study entailed a basic spreadsheet computation that compared the net present values of pavements with different lifecycle maintenance and rehabilitation costs under different traffic volume assumptions. Data were obtained from five projects with annual average daily traffic (AADT) volumes varying between 50,000 and 220,000 vehicles per day and 10 to 20 percent heavy vehicles. The study found that for AADT above about 150,000 and/or truck traffic higher than about 15,000 units per day, user costs were dominant in strategy selection and that long-life pavement (LLP) designs typically had lower lifecycle costs than conventional designs.

The 1996 study was undertaken with limited data and basic lifecycle cost analysis (LCCA) principles. More data has since become available, and in late 2004 Caltrans requested that a more detailed study be undertaken by the Pavement Research Center (PPRC) to determine whether the 150,000 AADT/15,000 trucks figures were still appropriate. This report summarizes the study, part of which was originally written up as a dissertation for a Master's thesis at the University of California, Davis (*2*). The study consists of a reanalysis of the 1996 study using new information, a factorial sensitivity study comparing lifecycle costs of long-life strategies and conventional rehabilitation strategies with more variables than were included in the 1996 study, and more appropriate data from recent projects.

1.1 Basic Elements of Lifecycle Cost Analysis

The basic elements of lifecycle cost analysis (LCCA) pertinent to this study include:

- Costs
- Analysis period
- Discount rate
- Salvage value
- Sensitivity and uncertainty

Each of these is briefly introduced in the following sections. Additional information on LCCA can be found in the literature (*3, 4*).

1.1.1 Costs

Numerous factors, each with a cost, are associated with pavements over their lifecycle. For LCCA, two distinct categories can be distinguished, namely agency-related costs and added costs. Agency costs are those directly represented by the budget or out-of-pocket costs paid by the road owner and include the following:

- Initial construction costs
- Future costs (maintenance, rehabilitation, renovation, and reconstruction)
- Salvage return or residual value at the end of the design period
- Engineering and administration
- Costs of borrowing

For this study, at least some historical construction cost data was available for initial construction costs and resulting rehabilitation and major maintenance for each strategy considered. Routine minor maintenance, costs of engineering, and Caltrans overhead were not considered because of lack of readily available state-wide data. Borrowing costs were also not considered.

The added cost component comprises two main elements:

- User costs (e.g., vehicle operating, time, and accidents costs)
- External costs (e.g., environmental and social costs)

Of these added costs, only the road user delay costs associated with Caltrans pavement maintenance, rehabilitation, and reconstruction activities were considered, following Caltrans policy in the Highway Design Manual (*1*).

1.1.2 Analysis Period

The analysis period is a fundamental component of the lifecycle cost analysis process and is essentially a policy decision dependent on the agency, circumstances, and infrastructure involved. It should be long enough to include the maintenance and rehabilitation and/or reconstruction activities that are a consequence of the initial strategy selected, but the period should not fall outside what can be reliably predicted into the future from historical records. Furthermore, any costs anticipated far into the future that are discounted back to present worth will become negligible in terms of the other costs earlier on in the lifecycle.

Analysis periods for highway rehabilitation typically do not exceed 20 years. A general rule is that the analysis period should be approximately 1.5 times the design life of the strategy selected. However, periods of 35 years need to be considered for long life pavement designs, but the implications of discounting and projecting traffic volumes over the longer period must be assessed. A 35 year analysis period was used for this study.

In the California Highway Design Manual (*1*), the recommended analysis periods vary depending on the pavement service life and range from 20 to 50 years for 10- and 40-year pavement service lives, respectively.

1.1.3 Discount Rate

The discount rate takes into account the time value of money and is essentially the difference between inflation and the interest rate. The selection of an appropriate discount rate is critical since it can result in the preference of a particular alternative if one discount rate is chosen over another. Two extreme cases therefore exist:

- **The discount rate is too low.** Future costs, especially when there are many, dominate over the initial cost when the discount rate is low.
- **The discount rate is too high.** Initial costs dominate, and the future costs are discounted to insignificant present worth costs when the discount rate is high.

Most agencies specify discount rates for lifecycle cost analysis as a matter of policy. Caltrans has typically used a 4 percent discount rate in the LCCA calculator included in the Highway Design Manual. Four percent was used for the analyses in this study.

1.1.4 Salvage Value

When fixed analysis periods are used in LCCA, the serviceable life of some alternatives might stretch beyond that period. The salvage value refers to the economic value remaining in the pavement after the analysis period. The FHWA characterizes the salvage value as the cost of the last rehabilitation activity multiplied by the ratio of years until the end of the analysis period to the years until the next activity beyond the analysis period, essentially a straight line depreciation of the pavement asset (*3*). Furthermore, any pavement will have some intrinsic value at the end of its lifecycle—whether that is the recycling value of the construction materials or the value of the engineered base below the surface of the pavement. Salvage values are typically small in comparison with the other costs associated with the lifecycle of a pavement. For this study, salvage values followed straight line depreciation to the end of their design life.

1.1.5 Sensitivity and Uncertainty

Sensitivity analyses are usually included in LCCA to understand and address the variability within input assumptions, projections, and estimates, which are typically averages based on imperfect historical pavement performance, rehabilitation, lifecycle and road user data. When analyzing the results of a lifecycle cost analysis, the accuracy of the estimation of each cost component will vary from good to poor, depending on the quality of the historical data and its applicability to the activities considered in the lifecycle cost analysis. The procedure treats all costs as if they are equally important (*5*). Specific comments are made in this report on the potential variability of the assumptions made for the analyses, and some sensitivity analyses were performed with regard to traffic assumptions.

1.2 The LCCA Process

LCCA typically entails seven steps:

1. Identification of alternatives
2. Mapping of lifecycles for each alternative
3. Estimation of lifecycle costs
4. Defining constants

5. Discounting future costs
6. Summing all present values
7. Comparing alternatives

1.3 RealCost LCCA Software

The RealCost LCCA software (*6*) was used for all of the calculations presented in this report. RealCost was developed by the FHWA as a tool for pavement designers to incorporate lifecycle costs into pavement investment decisions. It automates LCCA methodology as it applies to pavements incorporating agency and user costs associated with construction and rehabilitation. The user must input agency costs and service lives for individual construction or maintenance and rehabilitation (M&R) activities. Default values for other agency costs as well as road user costs are provided. Each of the defaults was checked against Caltrans policy before use in this study. As with any economic tool, LCCA provides critical information to the overall decision-making process, but not the answer itself. RealCost performs calculations for LCCA, but the validity of the results is dependent on the validity of the information used as input to the program.

Traffic delay costs in RealCost are calculated using demand-capacity models and queue formation and dissipation algorithms similar to those in the Transportation Research Board Highway Capacity Manual. Default hourly distributions for weekday traffic in RealCost were used for this study. These algorithms have been validated by measurements made by the PPRC during the rehabilitation of I-710 at Long Beach (*7*) and I-15 at Devore (*8*). A typical hourly distribution was used for weekend traffic delay analysis. There is a great deal of variation in hourly traffic distribution patterns for both weekdays and weekends across high traffic volume highways in California. The traffic distributions used for this analysis are reasonable for representing typical distributions across the state; however, they are not necessarily the same as the actual traffic distribution for any individual project.

2.0 RE-ANALYSIS OF THE 1996 DATA

2.1 The 1996 Study

In 1996, Caltrans undertook a study to compare the economic benefits of conventional asphalt concrete (AC) overlay rehabilitation to longer life Portland cement concrete (PCC) overlays (*9*). The study used basic LCCA principles in an Excel spreadsheet and was based on the principle that the justification of using a long life pavement (LLP) strategy would be driven by the implicit or real user cost savings that resulted from avoiding user delays and coincident vehicle costs.

2.1.1 Input

Data were obtained from existing projects at the time, the 1995 Caltrans Highway Congestion Management Plan (HICOMP) and interviews with Caltrans staff.

The following assumptions were made for input:

- Treatments: thick PCC overlay versus multiple AC Overlays
- Analysis period: 35 years (salvage value included in analysis)
- Congestion period: assumed to increase by 50 percent during construction
- User costs: $7.20/hour/vehicle, $25.00/hour/truck
- Initial lane mile costs per mile:
  - AC overlay $250,000
  - PCC Long-Life $600,000
- Lane mile costs per mile for additional M&R:

- AC Overlay: thin blanket, year 10, $15,000;

  routine maintenance, year 18, $12,000;

  AC overlay, year 21, $250,000;

  routine maintenance, year 28, $15,000;

  thin blanket, year 32, $25,000

- PCC Long-Life: joint seal, year 8, $12,000;

  CAPM, year 20, $85,000;

  CAPM, year 28, $85,000

- Site Locations as examples for each AADT:
  - 220,000/10% trucks: LA 5 (San Bernardino Fwy to Ventura Fwy)
  - 200,000/10% trucks: LA 710 (Long Beach to I-5)
  - 150,000/10% trucks: Sacramento 99 (Florin Rd to Rte 50)
  - 100,000/12% trucks: San Bernardino 10 (Rte 38 to Yucaipa Blvd)
  - 50,000/20% trucks: San Joaquin 5 (Hammer Ln to Pocket Rd)

- Traffic delay was estimated separately for each individual project, and calculated using a simple formula based only on change of traffic speed (miles per hour) through the work zone, as follows:

AADT	AC overlay	PCC Long-Life
220,000	45 to 25	45 to 25
200,000	45 to 25	45 to 25
150,000	50 to 30	60 to 35
100,000	55 to 35	55 to 35
50,000	60 to 60	60 to 35

- Traffic delay through the work zone for AC overlay was calculated directly from the assumed speed changes, and applied to assumed congested hours per day. The number of congested hours per day was assumed to be the same for both PCC long-life and AC overlay construction, meaning that differences in traffic delay between 55-hour weekend closures for PCC long-life and weeknight closures for AC overlays were not considered. It was assumed that there would be no queuing, only two lanes would be affected by the traffic speed change, and the change of speed in the work zone had an influence on vehicle operating costs (*9*).

- Traffic delays were only assumed for the initial construction, and for AC overlays, with all other M&R activities having no delay cost. Traffic delay costs per day were multiplied by the assumed number of construction work days for each project and strategy as follows:

AADT	**AC overlay**	**PCC Long-Life**
220,000	40	100
200,000	45	100
150,000	45	100
100,000	75	100
50,000	75	100

2.1.2 Results

The study found that for AADT above about 150,000 and/or truck traffic higher than about 15,000 vehicles per day, user costs were dominant in strategy selection and long-life pavement designs typically had lower lifecycle costs than conventional designs. For traffic volumes below 150,000 AADT, conventional AC overlay strategies had lower lifecycle costs.

2.2 Re-analysis with RealCost

2.2.1 Input Data

The 1996 study was re-analyzed using RealCost. The data used in the 1996 study was used as input and RealCost defaults were used for those aspects not included in the original study, except as described below.

Traffic delay in construction work zone closures was calculated using the HCM-based simple model in RealCost. The use of 24-hour-per-day weekday closures was assumed for both the AC overlay and PCC long-life strategies to provide a common baseline. Vehicle operating costs were not considered.

Input data is summarized in Table 1. The agency costs for the two alternatives are very similar and consequently have little influence on the total cost in contrast to the user cost.

Table 1 Input Data for Re-analysis with RealCost, Analysis Options

Parameter	Values used	Comment
Discount rate (%)	4	
Annual average daily traffic ('000s)	50, 100, 150, 200, 220	
Truck traffic (%) for AADTs above	10, 10, 10, 12, 20	
Annual traffic growth (%)	2.625	
Free flow capacity (v/hr/lane)	2,000	
Work zone capacity (v/hr/lane)	1,000	
Free flow speed (mph)	60	
Work zone speed (mph)	35	
Queue dissipation capacity (v/hr/ln)	1,500 and 2,000	
User time value - car ($/hr)	7.20	RealCost default
User time - single unit truck ($/hr)	25.00	RealCost default
User time - combination truck ($/hr)	25.00	RealCost default

2.2.2 Results

The results of the re-analysis of the 1996 study data are presented in Table 2. The long life Portland cement concrete strategy is clearly the lower cost option for all five of the traffic scenarios when compared with the multiple asphalt concrete overlay strategy. This contradicts the findings of the 1996 study discussed in the previous section, because of the difference in the traffic delay calculations, and the assumption of 24-hour-per-day weekday closures for both alternatives. The results confirm that user costs have increasing influence on total user costs as AADT increases.

Table 2 Cost (× $1000) Comparison of Asphalt Concrete Overlay and Long Life PCC Strategies from Rerun of 1996 Study

AADT	AC Overlay			PCC Long-Life		
	Agency	User	Total	Agency	User	Total
50	6,225	64,210	70,436	10,987	41,934	52,921
100	6,225	195,470	201,696	10,987	79,179	90,165
150	6,225	269,523	275,748	10,987	98,014	109,001
200	6,225	347,863	354,088	10,987	174,611	185,597
220	6,225	614,531	620,757	10,987	237,261	248,248

Because both the 1996 study and the simple recalculation of the 1996 study do not consider many variables, notably differences in traffic delay cost and comparisons with rehabilitation alternatives in addition to AC overlay and PCC Long-Life, a larger factorial sensitivity analysis was undertaken (Section 3 of this report).

3.0 FACTORIAL SENSITIVITY ANALYSIS

A RealCost LCCA was carried out on various scenarios to supplement the 1996 analysis. Data from recently completed projects were used. Certain RealCost defaults were used if accurate California specific data could not be obtained. It should be noted that although actual costs were used where possible, the study remained largely hypothetical because of lack of project specific data. There is a low probability that a real project would have exactly similar combinations of variables as those used for these calculations. Due to the exponential increase in the number of RealCost analyses each time a variable is added, the study was also limited to those variables selected. Project specific studies will therefore provide a more realistic output than that obtained from this study, although this study provides an indication of trends in lifecycle cost between long-life and conventional rehabilitation alternatives with respect to the variables included in the analysis, assuming that the input data used is realistic.

3.1 Experiment Design

The study was based on a partial factorial design. Components of this design included:

- Three traffic scenarios (100,000, 150,000, and 250,000 AADT)
- Two centerline lengths (4 and 12 miles)
- Three different lane configurations (6, 8, and 10: total number of lanes in both directions)
- Two different long life pavement rehabilitation strategies (AC and PCC)
- Up to three conventional rehabilitation strategies for each underlying pavement type (flexible or rigid).

Within each conventional rehabilitation strategy, an assumed lifecycle of activities was evaluated. Each activity within that strategy had its own assumed serviceable life. It was also assumed that rehabilitation strategies were carried out on a timely basis and that interventions took place before the condition of the pavement deteriorated to poor or very poor condition. Two types of closure were considered: 8-hour night time for conventional rehabilitation strategies and 24-hour continuous for long-life strategies.

This resulted in an initial factorial of 180 cells, which was reduced to a partial factorial design of 140 cells by excluding the following unrealistic combinations:

- The 10 lane option for the 100,000 AADT scenario
- The 6 lane option for the 250,000 AADT scenario

For each run, the agency, user, and total costs (in present worth) were calculated for both alternatives. Variations to check the sensitivity of the analysis to certain inputs were also considered. These are discussed in more detail in Section 3.4.

3.2 Input Data—Baseline Study

The input data used in this study is summarized in Tables 3–7. Cost data for conventional rehabilitation activities were obtained from construction and maintenance records averaged over five years, published by Caltrans (*10*). There was a great deal of variability in the cost per lane-mile of many activities during this period. Construction durations for each conventional rehabilitation activity were estimated by experienced Caltrans Construction Division staff as there is currently no database of construction durations available for Caltrans projects. The construction durations for the LLP strategies were based on data from the recent LLP

Table 3 Input Data for RealCost LCCA, Analysis Options

Parameter	Values used	Comment
Analysis period	35	See discussion in Section 1
Start year of Analysis Period	2005	-
Discount rate (%)	4	Rate recommended in Highway Design Manual
Truck traffic (%)	10	-
Annual traffic growth (%)	2	-
Free flow capacity (v/hr/lane)*	2,000	-
Free flow speed (mph)*	65	-
Queue dissipation capacity (v/hr/lane)*	1,750	-
User time value - car ($/hr)	7.20	RealCost default
User time - single unit truck ($/hr)	25.00	RealCost default
User time - combination truck ($/hr)	25.00	RealCost default

*Capacity, speed, and queue dissipation for this study were based on the assumption of a morning peak in one direction and an afternoon peak in the opposite direction. It should be noted that on many highways in California, morning and afternoon peaks occur in both directions. Traffic delay costs for LLP projects used weekday traffic patterns, not weekend patterns

Table 4 Input Data for RealCost LCCA, Rehabilitation and Maintenance Activities

Option	Existing Pavement	Description
OG-ACOL	AC	Open graded asphalt concrete (AC) overlay, for noise and spray reduction, mostly in urban areas
ACOL flex	AC	AC overlay and inner membranes on existing flexible pavement
PCC overlay	AC	PCC overlay on rigid or flexible pavement
LLP-1 AC	AC, PCC	AC pavement intended to last at least 35 years between rehabilitation treatments
LLP-2 PCC	AC, PCC	PCC pavement intended to last at least 35 years between rehabilitation treatments
ACOL rigid	PCC	AC overlay and inner membranes on existing rigid pavement
PCC grind	PCC	Removing irregularities in the surface to improve ride quality
PCC slab (5%)	PCC	PCC slab replacement - 5% of all slabs replaced
PCC slab (10%)	PCC	PCC slab replacement - 10% of all slabs replaced

Table 5 Input Data for RealCost LCCA, Activity Costs and Construction Durations

Option	Parameters		
	Workdays 8-hr nighttime closure 4 lane-miles	Workdays 24-hr closure across 72-hour weekdays 4 lane-miles	Agency cost/lane mile ($)
OG-ACOL	1.0	-	32,970
ACOL flex[1]	2.5	-	233,770
PCC overlay[2]	22.0	-	918,460
LLP-1 AC	-	5,0[4]	1,280,000
LLP-2 PCC*	-	9.0[5]	1,600,000
ACOL rigid[3]	4.5	-	348,490
PCC grind	12.0		150,460
PCC slab (5%)	7.5	-	71,632
PCC slab (10%)	15.0	-	143,264

[1] ACOL flex construction productivity assumes 3-in. overlay
[2] ACOL rigid assumes crack and seat, leveling course, fabric interlayer and 3-in. overlay
[3] PCC overlay assumes continuous 10-in. rapid strength concrete with no grade adjustment
[4] LLP Option 2 only rehabilitates two truck lanes per direction
[5] LLP Options require a continuous 24-hour closure for initial construction. Thereafter maintenance is on 8-hour nighttime closures.

Table 6 Input Data for RealCost LCCA, Assumed Sequence of Activities for Each Rehabilitation Strategy

Option	Lifecycle															
AC Overlay Flex	Year	0			10.5			21			31.5			42		
	Strategy	ACOL flex			ACOL flex			ACOL flex			ACOL flex					
	Life*	10.5	8	13	10.5	8	13	10.5	8	13	10.5	8	13			
AC Overlay Rigid	Year	0			9			18			27			36		
	Strategy	ACOL rigid + PCC slab 5%			ACOL flex			ACOL flex			ACOL flex					
	Life*	9	7	11	9	7	11	9	7	11	9	7	11			
PCC - grind	Year	0			10.5			21			30			39.5		
	Strategy	PCC Grind all			PCC Grind 2 truck lanes			PCC slab 5% + ACOL rigid			ACOL flex					
	Life*	10.5	8	13	10.5	8	13	9	7	11	9	7	11			
PCC - overlay	Year	0			22.5			30.5			44					
	Strategy	PCC overlay			PCC slab 5%			PCC slab 5%								
	Life*	22.5	18	22	8	8	8	8	8	8						
LLP - 1	Year	0			8			16			24			32		
	Strategy	LLP - 1			OGAC			OGAC			OGAC			ACOL flex		
	Life*	10	8	13	10	8	13	10	8	13	10	8	13	10	8	13
LLP - 2	Year	0			32.5			39								
	Strategy	LLP – 2 for truck lanes			PCC slab 5% + PCC grind											
	Life*	32.5	30	35	8	8	8									

* Life: Average | minimum | maximum; Average lives used for analysis included in this report

Table 7 Results of LCCA (Project Cost), Lowest Cost Alternative for AC Pavements

Scenario				AC Lowest Cost Alternative ($'000)				LLP-1 ($'000)			LLP-2 ($'000)		
#	Traffic	Centerline Miles	Lanes	Strategy	Agency	User	Total	Agency	User	Total	Agency	User	Total
1	100	4	6	ACOL Flex	12,980	625	13,605	32,633	61,694	94,327	26,275	77,424	103,699
2			8	ACOL Flex	17,308	104	17,412	43,511	910	44,421	36,602	7,330	43,932
3		12	6	ACOL Flex	38,940	1,876	40,816	97,900	185,082	282,982	78,826	232,272	311,098
4			8	ACOL Flex	51,921	313	52,234	130,534	24,324	154,858	79,501	21,991	101,492
5	150	4	6	ACOL Flex	12,980	26,037	39,017	32,633	75,913	108,546	26,275	110,935	137,210
6			8	ACOL Flex	17,308	2,904	20,212	43,511	12,835	56,346	36,602	118,166	154,768
7			10	ACOL Flex	21,634	196	21,830	54,389	15,219	69,608	26,725	11,033	37,758
8		12	6	ACOL Flex	38,940	78,110	117,050	97,900	227,739	325,639	78,826	332,804	411,630
9			8	ACOL Flex	51,921	8,711	60,632	130,534	337,897	468,431	79,501	354,499	434,000
10			10	ACOL Flex	64,900	588	65,488	163,167	45,658	208,825	80,176	33,099	113,275
11	250	4	8	ACOL Flex	17,308	48,684	65,992	43,511	102,511	146,022	36,602	140,883	177,485
12			10	ACOL Flex	21,634	22,100	43,734	54,389	189,785	244,174	26,725	168,764	195,489
13		12	8	ACOL Flex	51,921	146,052	197,973	130,534	426,032	556,566	79,501	422,650	502,151
14			10	ACOL Flex	64,900	66,300	131,200	163,167	569,356	732,523	80,176	506,291	586,467

reconstruction projects on I-710 and I-15, on which intensive construction productivity data was collected by the PRC.

The conventional strategy called Concrete Pavement Restoration (CPR) in Reference (*10*) was not included in the analysis because the lack of detail as to which activities are included for different projects made it too difficult to estimate the lives.

The costs associated with long life pavement projects were based on construction data obtained from Caltrans from the recent I-80 and I-710 reconstruction projects and include cost multipliers considering pavement and non-pavement items obtained from a study by the Partnered Pavement Research Center to assess costs of recent long life pavement projects (*11, 12*). Therefore, the comparative costs between the two LLP strategies are based on one project only for AC and PCC pavements, each with its own special conditions and thus these values and the relative costs of the two types of LLP strategy should absolutely not be assumed to be representative of other projects. They should only be used to obtain a general trend of LLP strategies versus conventional strategies. Also, cost multipliers for non-pavement items that may be included in conventional rehabilitation strategies were not included in the analyses because of lack of data.

Discussions with Caltrans Maintenance Division staff indicated that conventional rehabilitation costs from the 2003 State of the Pavement Report (*10*) and the LLP costs contain similar scope (include all costs paid to the contractor for the work and no Caltrans internal overhead and engineering costs). Maintenance staff also indicated that where several conventional rehabilitation types are performed within a given project, the costs of all of the rehabilitation types in that project are summed together and categorized in the State of the Pavement report according to the type with the greatest cost. The summed cost is then divided by the total project lane-miles to find the cost per lane-mile. This approach is used for expediency because of the large amount of time necessary to separate out individual items within a contract. This practice may explain some of the variability from year to year of different rehabilitation treatments as reported in the State of the Pavement Report.

Eight-hour weeknight closures were assumed for conventional rehabilitation strategies, and 72-hour continuous weekday closures were assumed for LLP strategies. Traffic closure sequences were assumed for the LLP alternatives based on experience to date. These may vary significantly from project to project, based on site-specific traffic demand and the availability of shoulders for traffic use.

A major shortcoming of the analyses included in this study is the need to assume the lives of various conventional rehabilitation activities (Table 7) even on average for the entire state, due to lack of availability of performance data. The lives (duration of serviceable use) of AC overlays on flexible and rigid pavements were estimated based on average values from 1978 to 1992 (*13*). The lives of other conventional activities were estimated based on anecdotal observation. The effects of different traffic volumes could not be considered in estimating average lives of conventional activities because of the lack of data.

The effects of existing pavement condition also could not be considered in the analysis because it would lead to a significant number of variables in the analysis, with many combinations that are not realistic. These assumptions again emphasize that only general trends can be obtained from factorial analyses such as those presented in this report, and that lifecycle cost analysis to select the most cost-effective rehabilitation strategy should be done for each project using the specific information for that project.

3.3 Results

The lowest project cost alternative of each option detailed in Table 5 for the rehabilitation of AC and PCC pavements are summarized in Table 8 and Table 9 respectively for each traffic volume. The costs of both LLP options are also provided in each table for comparative purposes. All costs are recalculated for AC and PCC pavements as lane mile costs in Tables 9 and 10, respectively. The results of the lowest cost alternative for each pavement type from each table are illustrated in Figures 1–4.

Care should be taken in interpreting the results, given that the scenarios are hypothetical highways and not project specific. Although input data were based on actual project costs and experience, specific details with regard to engineering design have not been accommodated.

3.3.1 Asphalt Concrete Pavements

The results of the LCCA on the 14 closure scenarios indicate that:

- The asphalt overlay flexible pavement rehabilitation strategy with periodic asphalt concrete overlays was the lowest total cost alternative for all fourteen scenarios.
- The next lowest alternatives were in all instances significantly more costly than the lowest alternative and will not be discussed further. This confirms the need to undertake quality LCCA for each project undertaken.
- The cost of the lowest long-life pavement option was at least double the cost of the cheapest alternative.
- For the LLP-1 option, agency costs were 2.5 times higher than the cost of the cheapest alternative, while for the LLP-2 option, agency costs varied between 1.2 and 2.1 times higher. The difference in agency costs between the cheapest alternative and the LLP-2 option reduced with increasing traffic and number of lanes.

Table 8 Results of LCCA (Project Lane-Mile Cost), Lowest Cost Alternative for AC Pavements

Scenario				AC Lowest Cost Alternative ($'000)				LLP-1 ($'000)			LLP-2 ($'000)		
#	Traffic	Centerline Miles	Lanes	Strategy	Agency	User	Total	Agency	User	Total	Agency	User	Total
1	100	4	6	ACOL Flex	541	26	567	1,360	2,571	3,930	1,095	3,226	4,321
2			8	ACOL Flex	541	3	544	1,360	28	1,388	1,144	229	1,373
3		12	6	ACOL Flex	541	26	567	1,360	2,571	3,930	1,095	3,226	4,321
4			8	ACOL Flex	541	3	544	1,360	253	1,613	828	229	1,057
5	150	4	6	ACOL Flex	541	1085	1,626	1,360	3,163	4,523	1,095	4,622	5,717
6			8	ACOL Flex	541	91	632	1,360	401	1,761	1,144	3,693	4,837
7			10	ACOL Flex	541	5	546	1,360	380	1,740	668	276	944
8		12	6	ACOL Flex	541	1085	1,626	1,360	3,163	4,523	1,095	4,622	5,717
9			8	ACOL Flex	541	91	632	1,360	3,520	4,879	828	3,693	4,521
10			10	ACOL Flex	541	5	546	1,360	380	1,740	668	276	944
11	250	4	8	ACOL Flex	541	1521	2,062	1,360	3,203	4,563	1,144	4,403	5,546
12			10	ACOL Flex	541	553	1,093	1,360	4,745	6,104	668	4,219	4,887
13		12	8	ACOL Flex	541	1521	2,062	1,360	4,438	5,798	828	4,403	5,231
14			10	ACOL Flex	541	553	1,093	1,360	4,745	6,104	668	4,219	4,887

Table 9 Results of LCCA (Project Cost), Lowest Cost Alternative for PCC Pavements

Scenario				AC Lowest Cost Alternative ($'000)				LLP-1 ($'000)			LLP-2 ($'000)		
#	Traffic	Centerline Miles	Lanes	Strategy	Agency	User	Total	Agency	User	Total	Agency	User	Total
1	100	4	6	PCC grind	11,814	1,620	13,434	32,633	61,694	94,327	26,275	77,424	103,699
2			8	PCC grind	15,211	397	15,608	43,511	910	44,421	36,602	7,330	43,932
3		12	6	PCC overlay	35,443	4,860	40,303	97,900	185,082	282,982	78,826	232,272	311,098
4			8	PCC grind	45,631	1,192	46,823	130,534	24,324	154,858	79,501	21,991	101,492
5	150	4	6	PCC overlay	22,753	53,188	75,941	32,633	75,913	108,546	26,275	110,935	137,210
6			8	PCC grind	15,211	4,267	19,478	43,511	12,835	56,346	36,602	118,166	154,768
7			10	PCC grind	18,606	718	19,324	54,389	15,219	69,608	26,725	11,033	37,758
8		12	6	ACOL rigid	68,259	159,564	227,823	97,900	227,739	325,639	78,826	332,804	411,630
9			8	PCC grind	45,631	12,802	58,433	130,534	337,897	468,431	79,501	354,499	434,000
10			10	PCC grind	55,819	2,153	57,972	163,167	45,658	208,825	80,176	33,099	113,275
11	250	4	8	PCC overlay	30,847	79,224	110,071	43,511	102,511	146,022	36,602	140,883	177,485
12			10	ACOL rigid	37,922	42,440	80,362	54,389	189,785	244,174	26,725	168,764	195,489
13		12	8	PCC overlay	92,541	237,672	330,213	130,534	426,032	556,566	79,501	422,650	502,151
14			10	ACOL rigid	113,766	127,319	241,085	163,167	569,356	732,523	80,176	506,291	586,467

Table 10 Results of LCCA (Project Lane-Mile Cost), Lowest Cost Alternative for PCC Pavements

Scenario				PCC Lowest Cost Alternative ($'000)				LLP-1 ($'000)			LLP-2 ($'000)		
#	Traffic	Centerline Miles	Lanes	Strategy	Agency	User	Total	Agency	User	Total	Agency	User	Total
1	100	4	6	PCC grind	492	68	560	1,360	2,571	3,930	1,095	3,226	4,321
2			8	PCC grind	475	12	488	1,360	28	1,388	1,144	229	1,373
3		12	6	PCC overlay	492	68	560	1,360	2,571	3,930	1,095	3,226	4,321
4			8	PCC grind	475	12	488	1,360	253	1,613	828	229	1,057
5	150	4	6	PCC overlay	948	2,216	3,164	1,360	3,163	4,523	1,095	4,622	5,717
6			8	PCC grind	475	133	609	1,360	401	1,761	1,144	3,693	4,837
7			10	PCC grind	465	18	483	1,360	380	1,740	668	276	944
8		12	6	ACOL rigid	948	2,216	3,164	1,360	3,163	4,523	1,095	4,622	5,717
9			8	PCC grind	475	133	609	1,360	3,520	4,879	828	3,693	4,521
10			10	PCC grind	465	18	483	1,360	380	1,740	668	276	944
11	250	4	8	PCC overlay	964	2,476	3,440	1,360	3,203	4,563	1,144	4,403	5,546
12			10	ACOL rigid	948	1,061	2,009	1,360	4,745	6,104	668	4,219	4,887
13		12	8	PCC overlay	964	2,476	3,440	1,360	4,438	5,798	828	4,403	5,231
14			10	ACOL rigid	948	1,061	2,009	1,360	4,745	6,104	668	4,219	4,887

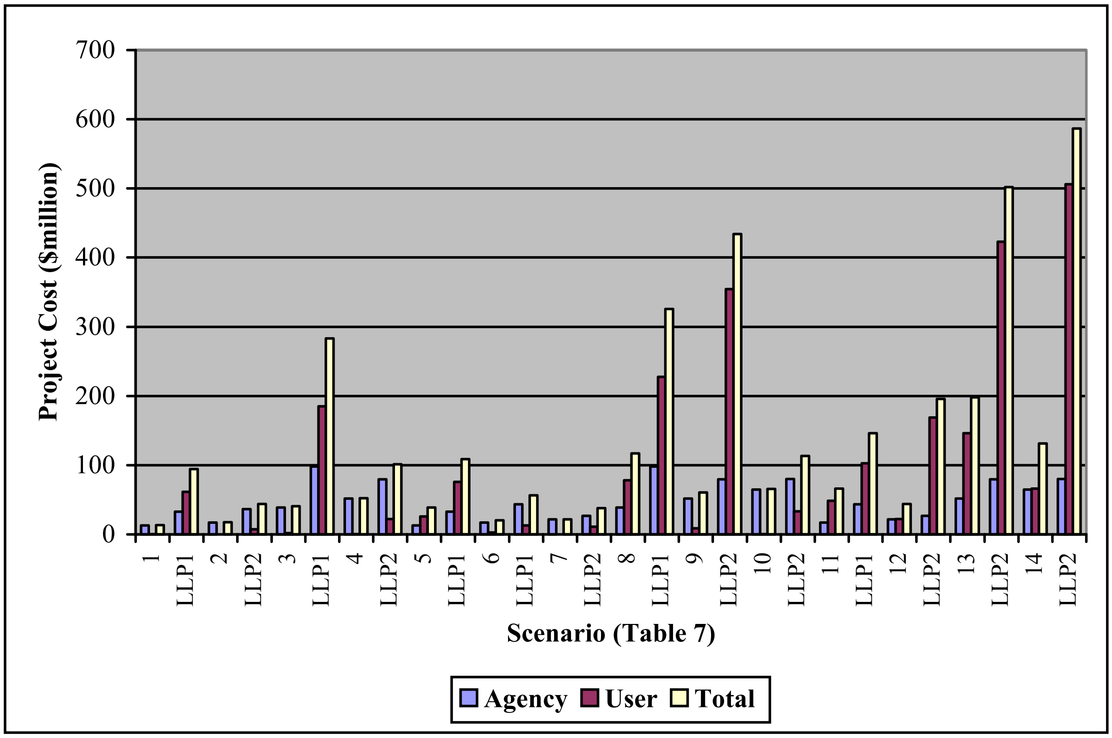

Figure 1. Lowest cost alternatives compared to lowest cost LLP for AC pavements, project cost.

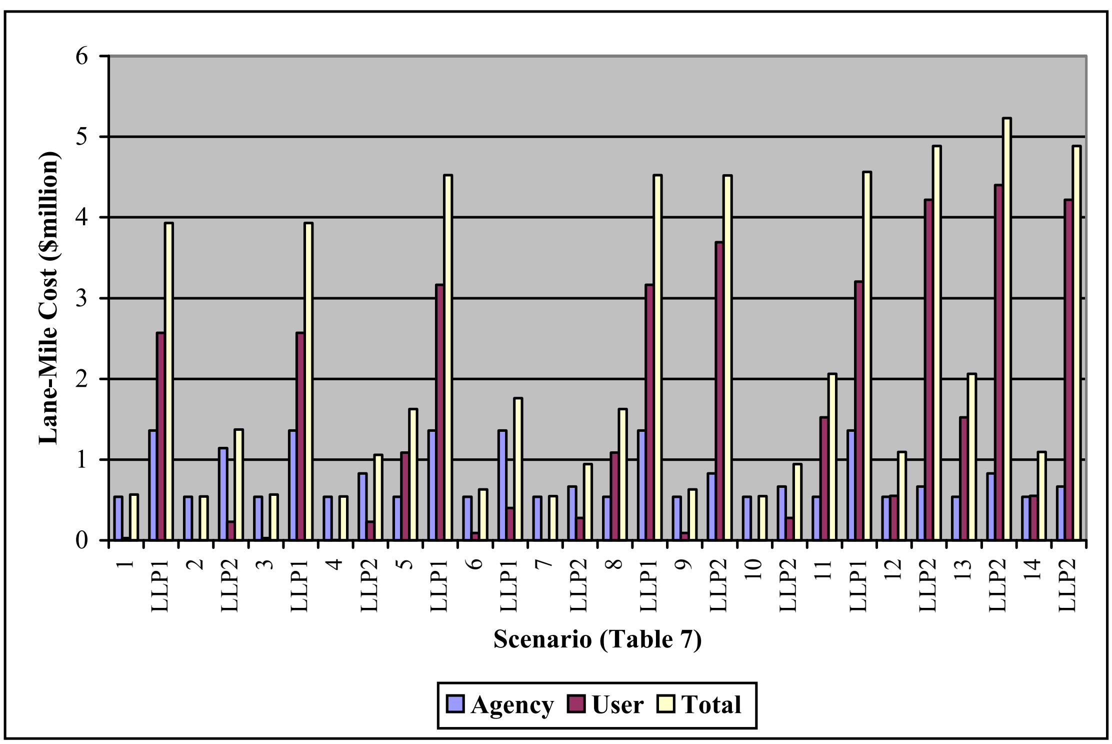

Figure 2. Lowest cost alternatives compared to lowest cost LLP for AC pavements, lane-mile cost.

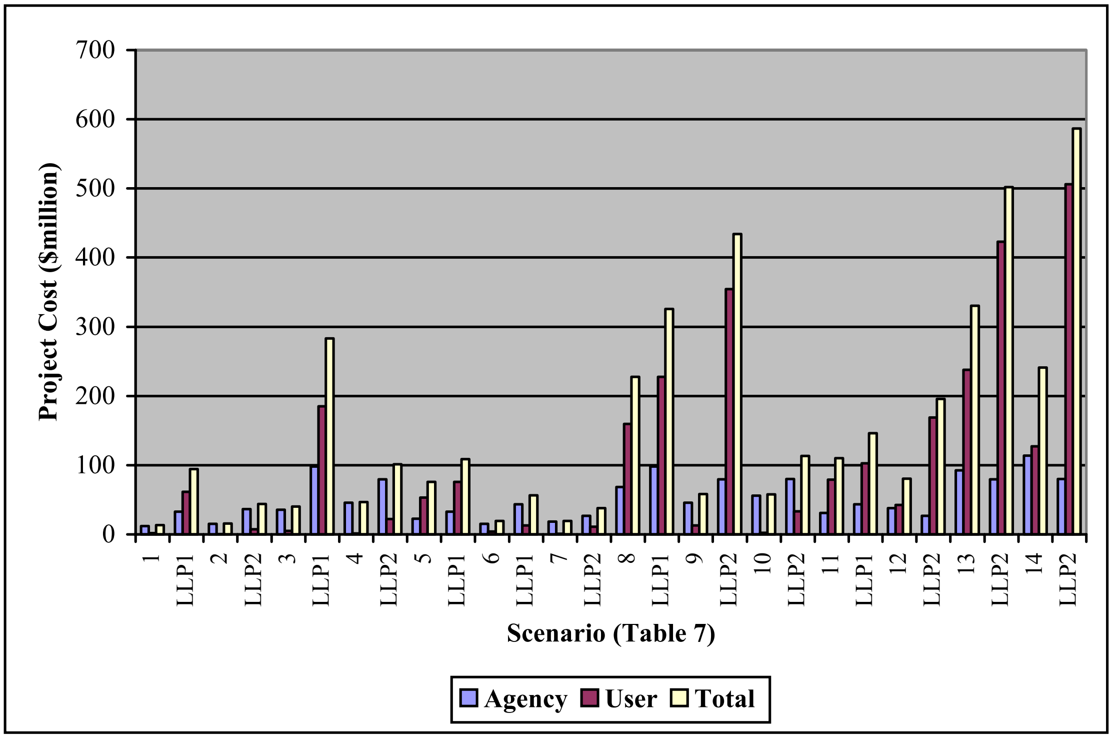

Figure 3. Lowest cost alternatives compared to lowest cost LLP for PCC pavements, project cost.

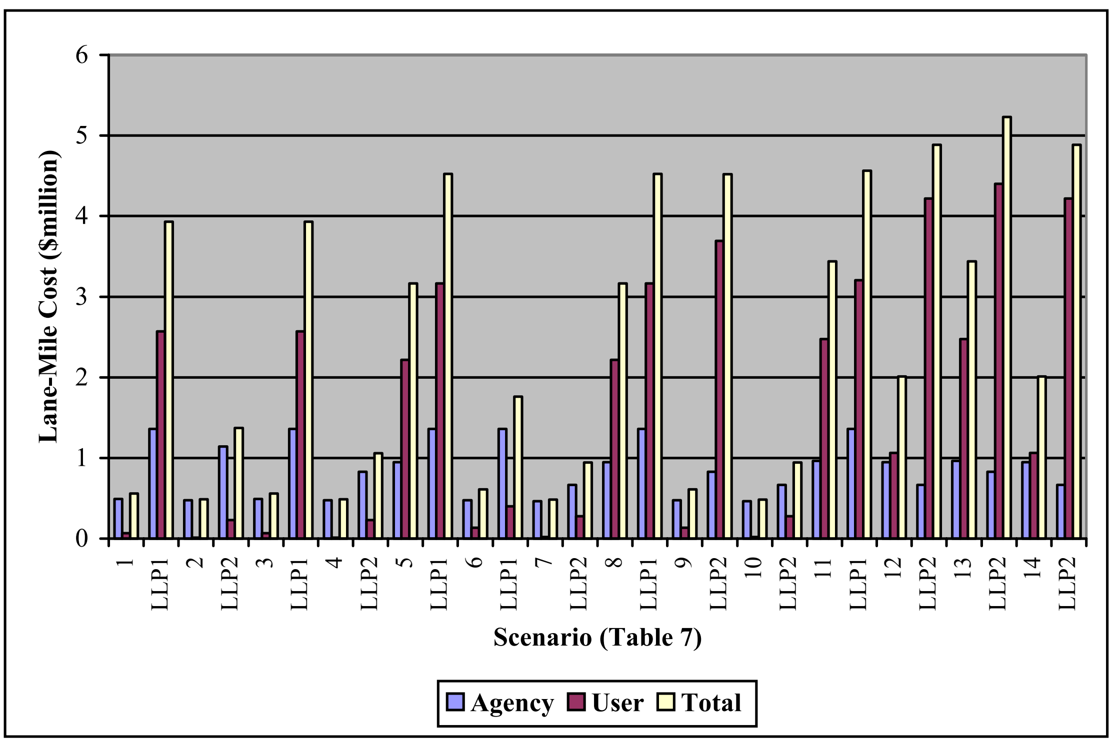

Figure 4. Lowest cost alternatives compared to lowest cost LLP for PCC pavements, lane-mile cost.

- Road user costs varied between 3 and 100 and between 3 and 124 times the costs of those of the cheapest alternative for the LLP-1 and LLP-2 options respectively.
- The difference between the LLP-1 option and the cheapest alternative remained constant, while the difference between the LLP-2 option and the cheapest alternative reduced with increasing traffic, project distance and number of lanes, with agency costs having the biggest influence. The reason for this is that as the total number of lanes increases, the cost of LLP-1 to rehabilitate all lanes increases proportionally, while the cost of the LLP-2, which only rehabilitates the outer two truck lanes, remains fairly constant.
- The results do not compare with the 1996 study results in that both LLP options are still significantly more costly than the cheapest conventional rehabilitation alternative, regardless of traffic. This was attributed to the use of more realistic data and more thorough analysis using the RealCost LCCA software. The biggest influence attributed to the higher costs of the LLP options appears to be related to 24-hour continuous closures, compared to the 8-hour night time closures used for the conventional rehabilitation strategies. No traffic reduction through Traffic Management Plans was considered in this baseline study.

3.3.2 Portland Cement Concrete Pavements

The results of the LCCA on the 14 PCC pavement scenarios indicate that:

- The PCC grind strategy was the lowest cost alternative in 7 of the 14 scenarios. The PCC overlay was lowest in 4 of the scenarios, typically in projects with fewer lanes. The AC overlay for rigid pavements was the lowest alternative in the remaining three scenarios, two of which were those projects with highest traffic and highest number of lanes.

- The agency cost of the LLP-2 option was cheaper than the agency cost of the lowest total cost alternative for three of 14 scenarios, all of which had the highest traffic level.
- The next lowest alternatives were in all instances significantly more costly than the lowest alternative and will not be discussed further.
- The cost of the cheapest LLP option was in most instances at least double the cost of the cheapest alternative for the 100,000 and 150,000 traffic scenarios. For the 250,000 AADT traffic scenario, the difference reduced to 1.3 times more costly.
- For the LLP-1 option, agency costs were between 1.4 and 2.9 times higher than the cheapest alternative, while the LLP-2 option varied between being 1.4 times cheaper than the selected alternative (higher traffic/higher lane numbers) to 2.4 times more expensive than the cheaper alternative.
- Road user costs varied between 1.3 and 37.8 times higher than the user costs of the cheapest alternative, while for the LLP-2 alternative, the costs were between 1.8 and 47.4 times higher. The difference between the LLP options and the cheapest alternative were generally less for higher traffic/higher lane numbers than for lower traffic/lower lane numbers.
- The results do not compare with the 1996 study results for the same reasons cited in Section 3.3.1. <u>No traffic reduction through Traffic Management Plans was considered in this baseline study.</u>

3.4 Other Considerations

The initial analysis discussed above revealed that the long-life pavement options were in most instances significantly more expensive than a conventional rehabilitation strategy with both agency and users costs affecting the result. However, it should again be noted that the analyses are largely hypothetical and that the use of project specific data will probably provide significantly different results. In order to assess the sensitivity of the process to various factors, a number of refinements were made to the input data and the files re-run with RealCost. These changes and the results are discussed below. While these are still hypothetical cases, they identify trends in change of costs with changes in input variables.

3.4.1 Traffic Refinements

Given that user costs tend to dominate the output in most of the scenarios, two additional analyses were carried out to monitor the impact of different lane closure strategies on the two LLP options. The first entailed a scenario that assumes 25 percent less AADT during weekends and a single widely spread peak hour in the early afternoon (approximately 1:00 PM to 4:00 PM). The second accommodates the implementation of a Traffic Management Plan that assumes a 15 per1cent reduction in AADT during weekday closures, but maintains the normal double AM/PM peak traffic pattern. A comparison of these two alternatives with the originals is summarized as lane mile cost in Table 11 and Figures 5 (LLP-1) and 6 (LLP-2).

The results indicate that the user costs in both LLP options are sensitive to refinements. In this analysis, user costs in both the weekend allowance and the traffic management plan refinements were lower than the original with the weekend allowance showing the largest reduction in costs. The difference generally increased with increasing traffic and number of

Table 11 Comparison of Normal, Weekend, and Weekday Traffic Management Plan (Lane-Mile Cost)

Scenario					Original 72-hour Weekdays ($'000)			55-hour Weekend Traffic ($'000)			72-hour Weekdays with 15% AADT Reduction (TMP) ($'000)		
#	Traffic	Centerline Miles	Lanes	Strategy	Agency	User	Total	Agency	User	Total	Agency	User	Total
1	100	4	6	LLP-1	1,360	2,571	3,930	1,360	2,482	3,842	1,360	2,557	3,917
				LLP-2	1,095	3,226	4,321	1,095	2,979	4,047	1,095	3,072	4,167
2			8	LLP-1	1,360	28	1,388	1,360	19	1,378	1,360	21	1,381
				LLP-2	1,144	229	1,373	1,144	28	1,172	1,144	75	1,219
3		12	6	LLP-1	1,360	2,571	3,930	1,360	2,482	3,842	1,360	2,557	3,917
				LLP-2	1,095	3,226	4,321	1,095	2,979	4,074	1,095	3,072	4,167
4			8	LLP-1	1,360	253	1,613	1,360	30	1,390	1,360	82	1,442
				LLP-2	828	229	1,057	828	28	,856	828	75	903
5	150	4	6	LLP-1	1,360	3,163	4,523	1,360	2,783	4,142	1,360	2,846	4,205
				LLP-2	1,095	4,622	5,717	1,095	4,605	5,700	1,095	4,622	5,717
6			8	LLP-1	1,360	4,013	1,761	1,360	45	1,405	1,360	124	1,483
				LLP-2	1,144	3,693	4,837	1,144	1,442	2,586	1,144	1,927	3,070
7			10	LLP-1	1,360	380	1,740	1,360	45	1,405	1,360	123	1,483
				LLP-2	668	276	944	668	34	702	668	90	758
8	150	12	6	LLP-1	1,360	3,163	4,523	1,360	2,783	4,142	1,360	2,846	4,205
				LLP-2	1,095	4,622	5,717	1,095	4,605	5,700	1,095	4,622	5,717
9			8	LLP-1	1,360	3,520	4,879	1,360	1,601	2,961	1,360	2,123	3,483
				LLP-2	828	3,693	4,521	828	1,442	2,271	828	1,927	2,755
10			10	LLP-1	1,360	380	1,740	1,360	45	1,405	1,360	123	1,483
				LLP-2	668	276	944	668	34	702	668	90	758
11	250	4	8	LLP-1	1,360	3,203	4,563	1,360	2,172	3,532	1,360	2,815	4,174
				LLP-2	1,144	4,403	5,546	1,144	4,416	5,560	1,144	4,403	5,546
12			10	LLP-1	1,360	4,745	6,104	1,360	2,955	4,315	1,360	3,882	5,242
				LLP-2	668	4,219	4,887	668	2,664	3,332	668	3,737	4,405
13		12	8	LLP-1	1,360	4,438	5,789	1,360	3,897	5,257	1,360	4,111	5,471
				LLP-2	828	4,403	5,231	828	4,416	5,244	828	4,403	5,231
14			10	LLP-1	1,360	4,745	6,104	1,360	2,955	4,315	1,360	3,882	5,242
				LLP-2	668	4,219	4,887	668	2,664	3,332	668	3,737	4,405

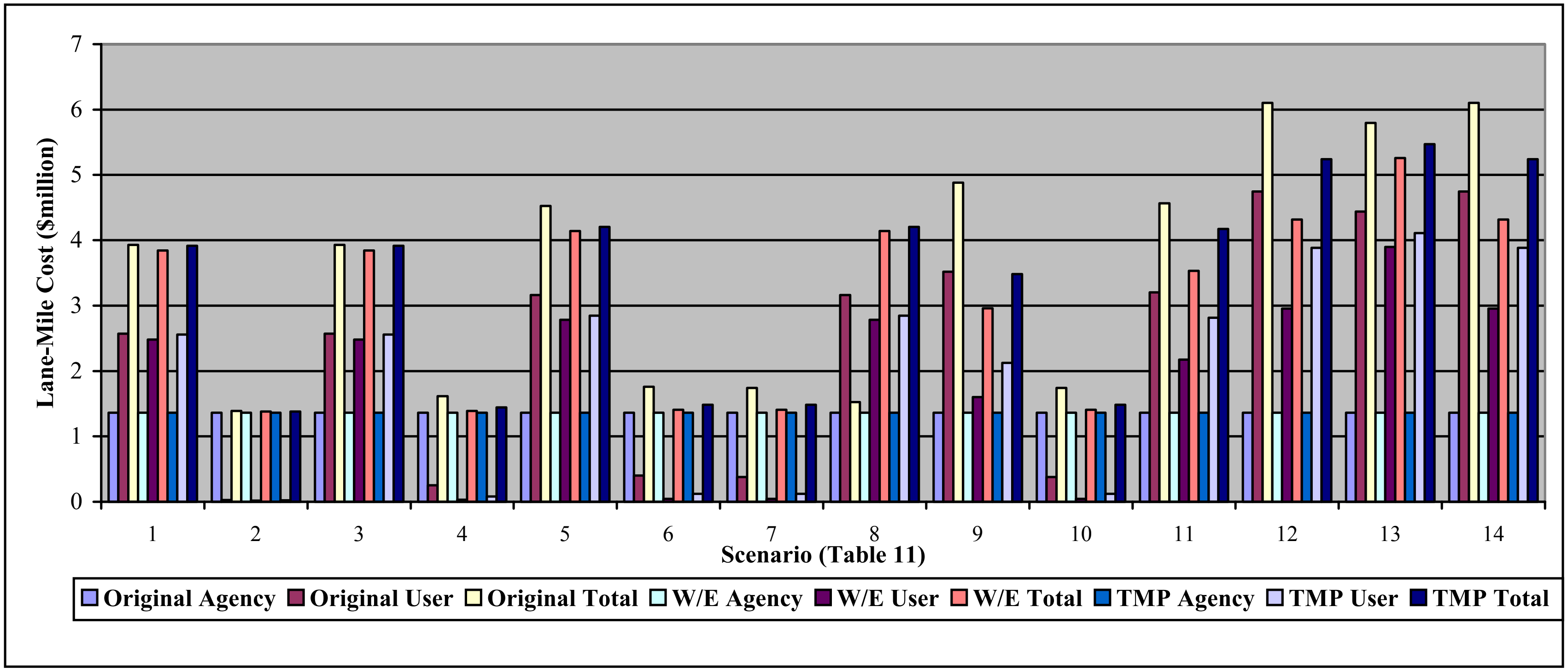

Figure 5. Comparison of traffic refinements for LLP-1, lane-mile cost.

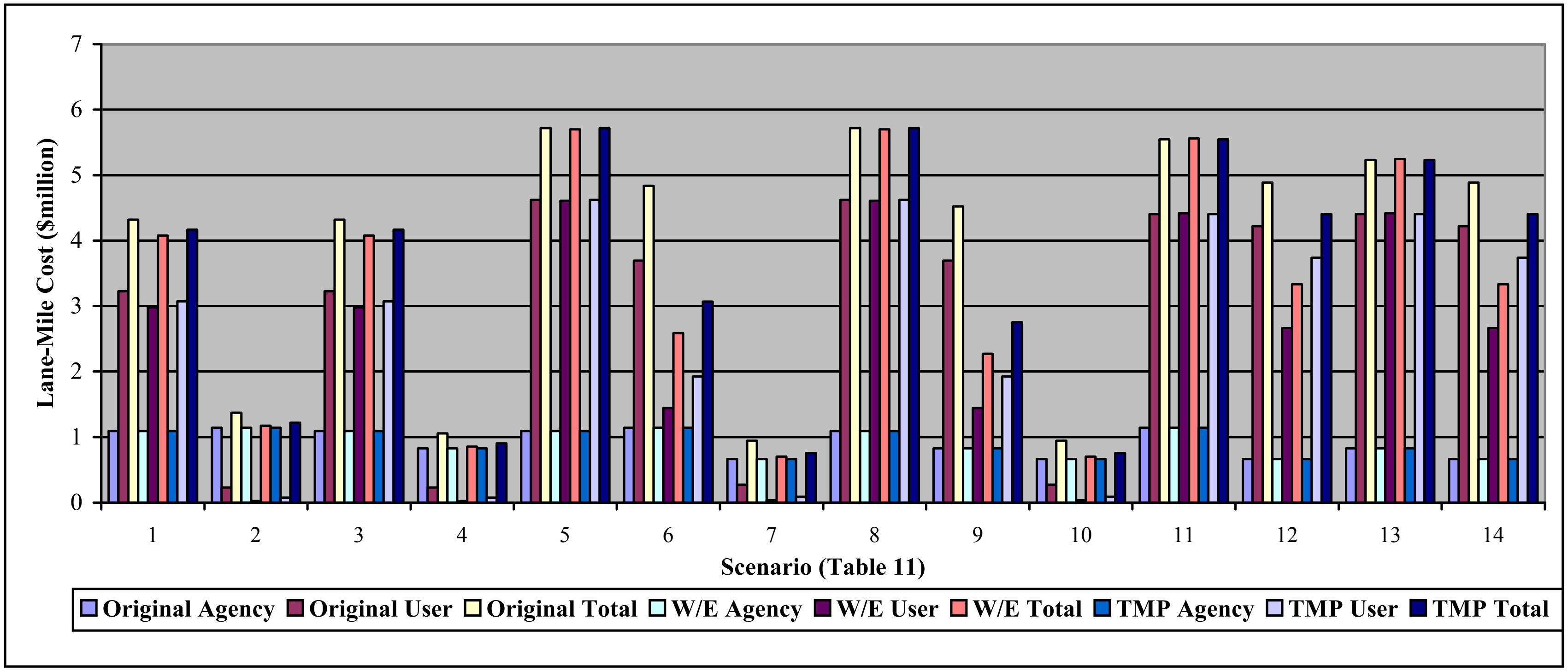

Figure 6. Comparison of traffic refinements for LLP-2, lane-mile cost.

lanes. However, the user costs on both LLP options after refinement were still significantly higher than the cheapest alternative discussed in the previous section using the very conservative reductions in traffic included in this analysis.

The assumption of the weekend traffic pattern was conservative, and since much of weekend traffic is discretionary for many project locations, a much greater traffic reduction may occur during weekend closures. This was illustrated by the experience on the reconstruction of the I-710 freeway at Long Beach where a well-developed traffic management plan and the ability to use shoulders as traffic lanes resulted in almost no traffic delay during the 55-hour weekend closures (*7*). A sophisticated traffic management plan used for the reconstruction of the I-15 freeway at Devore resulted in an approximate 40 percent reduction in weekday traffic during the peak periods and thus reducing the traffic delay significantly more than was captured with the 15 percent reduction assumed in this analysis (*8*). However, the results in these two cases cannot be assumed to be applicable to all project sites in the state, again pointing to the need for site-specific lifecycle cost analysis for each project.

3.4.2 Non-pavement Related Multipliers

In the original analysis discussed in Section 3.3, non-pavement related multipliers were included in the costs of the LLP options, but not in the costs of the conventional rehabilitation options. In this refinement, the multiplier was subtracted from the cost of the LLP options in order to assess its impact. The results of the comparison with the original analysis are listed in Table 12 and illustrated in Figures 7 (LLP-1) and 8 (LLP-2).

Table 12 Comparison of Normal and Normal without Multiplier Factor (Lane-Mile Cost)

Scenario					Original ($'000)			Minus Multiplier Factor ($'000)		
#	Traffic	Centerline Miles	Lanes	Strategy	Agency	User	Total	Agency	User	Total
1	100	4	6	LLP-1 LLP-2	1,360 1,095	2,571 3,226	3,930 4,321	873 689	2,571 3,226	3,444 3,915
2			8	LLP-1 LLP-2	1,360 1,144	28 229	1,388 1,373	873 840	28 229	902 1,069
3		12	6	LLP-1 LLP-2	1,360 1,095	2,571 3,226	3,930 4,321	873 589	2,571 3,226	3,444 3,915
4			8	LLP-1 LLP-2	1,360 828	253 229	1,613 1,057	873 524	253 229	1,127 753
5	150	4	6	LLP-1 LLP-2	1,360 1,095	3,163 4,622	4,523 5,717	873 689	3,163 4,622	4,036 5,312
6			8	LLP-1 LLP-2	1,360 1,144	4,013 3,693	1,761 4,837	873 840	401 3,693	1,274 4,533
7			10	LLP-1 LLP-2	1,360 668	380 276	1,740 944	873 425	380 276	1,254 701
8		12	6	LLP-1 LLP-2	1,360 1,095	3,163 4,622	4,523 5,717	873 689	3,163 4,622	4,036 5,312
9			8	LLP-1 LLP-2	1,360 828	3,520 3,693	4,879 4,521	873 524	3,520 3,693	4,393 4,217
10			10	LLP-1 LLP-2	1,360 668	380 276	1,740 944	873 425	380 276	1,254 701
11	250	4	8	LLP-1 LLP-2	1,360 1,144	3,203 4,403	4,563 5,546	873 840	3,203 4,403	4,077 5,242
12			10	LLP-1 LLP-2	1,360 668	4,745 4,219	6,104 4,887	873 425	4,745 4,219	5,618 4,644
13		12	8	LLP-1 LLP-2	1,360 828	4,438 4,403	5,789 5,231	873 524	4,438 4,403	5,311 4,927
14			10	LLP-1 LLP-2	1,360 668	4,745 4,219	6,104 4,887	873 425	4,745 4,219	5,618 4,644

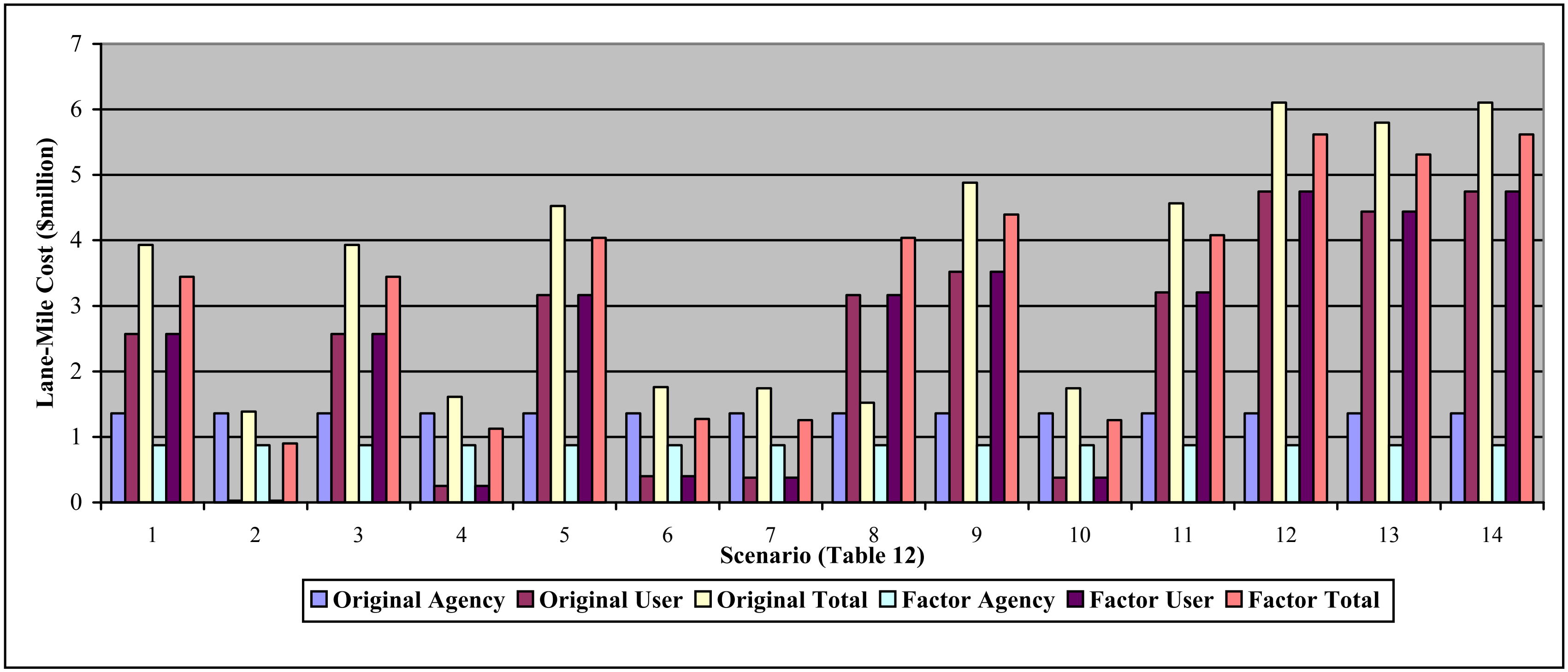

Figure 7. Comparison of multiplier effect for LLP-1, lane-mile cost.

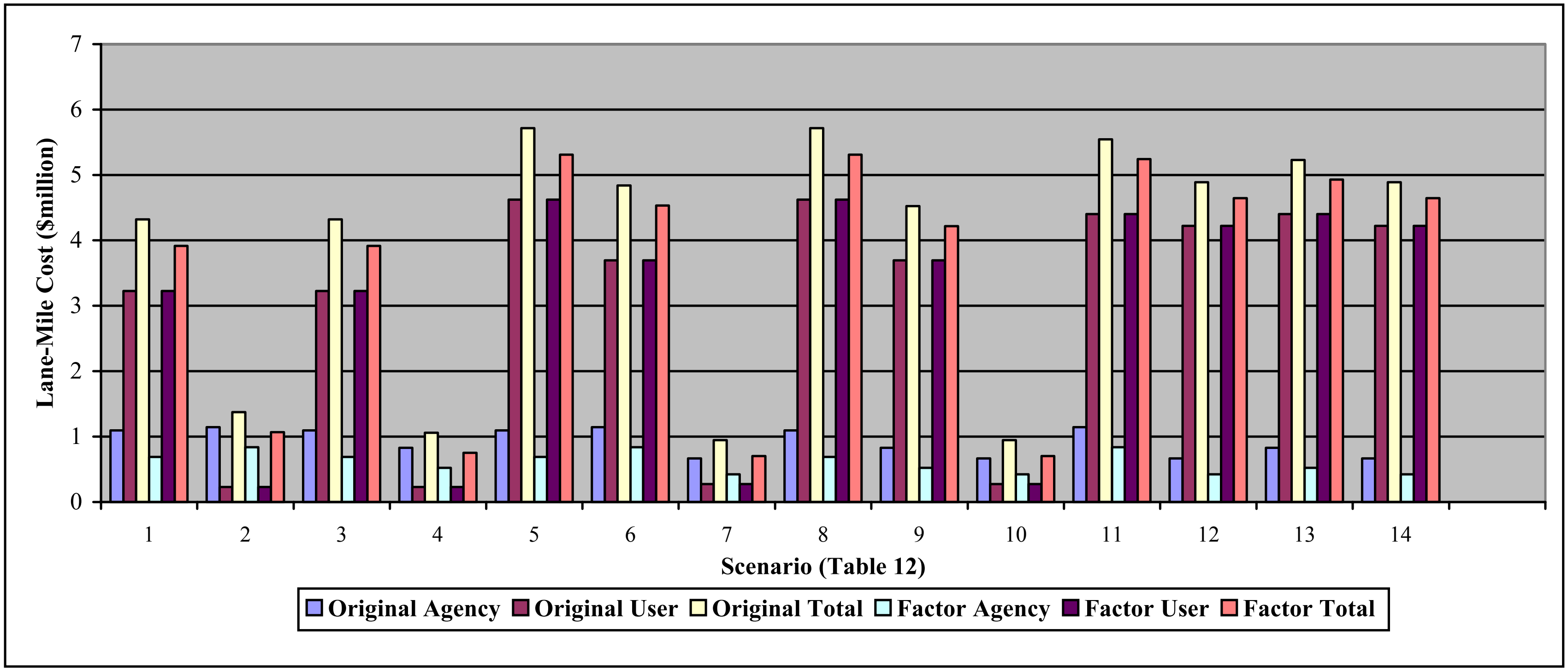

Figure 8. Comparison of multiplier effect for LLP-2, lane-mile cost.

The results indicate a significant reduction in agency and hence total cost compared to the original input. User costs are not affected for obvious reasons. Despite the reduction in agency cost after taking the multiplier into consideration, the LLP options are still more costly with respect to total cost when compared to the lowest cost alternative discussed in Section 3.3. However, when only agency costs are compared, as shown in Table 13, the agency costs of one or both of the LLP options without the multiplier are less than or similar to those of the conventional rehabilitation strategy for 12 centerline miles and 8 and 10 lanes. These results

Table 13 Comparison of Agency Costs, LLP without Multiplier Factor and Lowest Cost Alternative Strategies (Lane-Mile Cost)

Scenario				Agency Cost without Multiplier ($'000)					
#	Traffic	Centerline Miles	Lanes	LLP Strategy	Cost without Multiplier	PCC Pavement Strategy	Cost	AC Pavement Strategy	Cost
1	100	4	6	LLP-1 LLP-2	873 689	PCC Grind	492	AC Overlay Flex	541
2			8	LLP-1 LLP-2	873 840	PCC Grind	475	AC Overlay Flex	541
3		12	6	LLP-1 LLP-2	873 589	PCC Overlay	492	AC Overlay Flex	541
4			8	LLP-1 LLP-2	873 524	PCC Grind	475	AC Overlay Flex	541
5	150	4	6	LLP-1 LLP-2	873 689	PCC Overlay	948	AC Overlay Flex	541
6			8	LLP-1 LLP-2	873 840	PCC Grind	475	AC Overlay Flex	541
7			10	LLP-1 LLP-2	873 425	PCC Grind	465	AC Overlay Flex	541
8		12	6	LLP-1 LLP-2	873 689	AC Overlay Rigid	948	AC Overlay Flex	541
9			8	LLP-1 LLP-2	873 524	PCC Grind	475	AC Overlay Flex	541
10			10	LLP-1 LLP-2	873 425	PCC Grind	465	AC Overlay Flex	541
11	250	4	8	LLP-1 LLP-2	873 840	PCC Overlay	964	AC Overlay Flex	541
12			10	LLP-1 LLP-2	873 425	AC Overlay Rigid	948	AC Overlay Flex	541
13		12	8	LLP-1 LLP-2	873 524	PCC overlay	964	AC Overlay Flex	541
14			10	LLP-1 LLP-2	873 425	ACOL rigid	948	AC Overlay Flex	541

indicate that, for large projects, LLP options need to be seriously considered as a means of reducing pavement lifecycle costs.

3.5 Project-Specific Sensitivity Analysis

Apart from the refinements discussed in the previous section, additional sensitivity analyses were not attempted given that the scenarios are not project specific and numerous assumptions were made in terms of data input. To continue with additional sensitivity analyses leads to the creation of very detailed, yet completely hypothetical projects. They should, however, be undertaken when project specific studies are carried out.

The trends shown in the sensitivity analyses presented in this report indicate that considerations in project-specific sensitivity analyses should include:

- The condition of the existing pavement and its effect on the performance and cost of a conventional rehabilitation. For example, badly cracked PCC slabs are not suitable for PCC grinding, and will significantly shorten the life of AC overlays. For AC pavements, thicker AC overlays will be required for high truck traffic conditions and existing pavements in very poor condition. The construction productivity and therefore the traffic delay and project cost will depend on the project-specific overlay design.
- The extent to which traffic can be reduced and delay minimized during construction through implementation of a Traffic Management Plan. This will depend on factors such as:
    - how much traffic demand is discretionary
    - the presence of alternative routes and modes
    - the ability to use shoulders as traffic lanes or construction access lanes

- the ability to widen the pavement to carry traffic during construction
- impacts of continuous closures on local business and residents

- The statement of work proposed for the project, and costs of non-pavement items included in the project, which will control the pavement to non-pavement cost multiplier. Multipliers should be considered for both LLP options and conventional rehabilitation strategies. The multipliers include the costs of traffic handling for both types of projects.
- The importance of the route and of minimizing future maintenance and rehabilitation activities on the route.

For some projects, LLP options will be shown by lifecycle cost analysis to be more cost-effective when project-specific conditions are considered. For example, on the I-15 Devore project the existing slabs were so badly cracked and displaced in the outer truck lane that grinding was not an option, and that an AC overlay would have had a short life. Cost calculations for the agency cost for the project showed that long-life rigid rehabilitation was more cost-effective.

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 with the hourly distributions of freeway traffic data particular to each closure, very similar to the approach used in RealCost.

The total cost, calculated as the sum of the agency cost and cost of traffic delay caused by construction, was used to select the most economical closure scenario. Table 14 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 (*8*). The one-roadbed continuous closure scenario was selected as the best candidate strategy in terms of agency, road user, and total costs.

The PCC long-life option with the 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 to replace the concrete slabs in the outside truck lane. The traffic costs are based on the assumption of a 20 percent reduction in traffic demand, which was made possible in part by the local network configuration and nature of the traffic demand for this project location.

Table 14 Schedule, Delay, and Cost Comparison for Closure Scenarios for I-15 Devore Rehabilitation

	Schedule Comparison		**Traffic Comparison[a]**		**Cost Comparison**	
Closure Scenario	**Closure Number**	**Closure Hours**	**Traffic Delay Cost ($1000)**	**Peak Delay (Minute)**	**Agency Cost[b] ($1000)**	**Total Cost[c] ($1000)**
1-Roadbed Continuous	2	400	5,000	80	15,000	20,000
72-Hour Weekday	8	512	5,000	50	16,000	21,000
55-Hour Weekend	10	550	10,000	80	17,000	27,000
10-Hour Nighttime	220	2,200	7,000	30	21,000	28,000

[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 = Traffic delay cost + Agency cost (per row)

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

This brief study into the economic implications of rehabilitation strategies on high traffic roads in California has emphasized the need for detailed lifecycle cost analysis for all projects using project-specific information, based on the significant variation in total costs of the various scenarios considered. The need for improved pavement performance data and construction duration data has also been identified.

In a 1996 study, it was concluded that traffic delay costs dominate lifecycle costs and that a PCC long-life option was more cost-effective than repeated AC overlays at AADT levels above 150,000 when considering total cost (agency cost and traffic delay cost). Traffic delay in that study was based on assumed change of speed through the work zone and not traffic delay analysis. Differences in traffic delay between 55-hour weekend closures for PCC long-life and weeknight closures for AC overlays were also not considered in the study.

The 1996 data was reanalyzed using most of the same assumptions but using the simple traffic delay calculations in RealCost, a software package developed by the Federal Highway Administration. 24-hour-per-day closures for both PCC long-life and AC overlays, similar to those used in the 1996 study, were used in this re-analysis. The long life Portland cement concrete strategy was found to be clearly the lowest cost option for all five of the traffic scenarios analyzed (AADT of 100,000 to 220,000) when compared with the multiple asphalt concrete overlay strategy. This contradicts the findings of the original study, and is attributed to the difference in the traffic delay calculations and the assumption of 24-hour-per-day weekday closures for both alternatives. The results confirmed that user costs have increasing influence on total user costs as AADT increases.

A new sensitivity study was then performed. This used a factorial experiment design that considered both AC and PCC long-life strategies, more conventional rehabilitation strategies instead of just conventional AC overlays, a new set of assumptions of the performance of different alternatives and cost data from recently completed projects. “Typical” construction productivities for the conventional rehabilitation measures were obtained from construction experts, while productivities from two recent LLP projects were used for the long-life alternatives. Certain RealCost defaults were used, particularly the assumed hourly traffic pattern, which is “typical,” but does not represent the large variety of traffic patterns found in California. It should be noted that although actual costs were used where possible, the study remained largely hypothetical because of lack of project specific data. There is a low probability that a real project would have exactly similar combinations of variables as those used for these calculations, which were based on a variety of lane configurations and AADTs combined with 4- and 12-mile centerline lengths.

In the baseline factorial sensitivity study, the long-life cost data included combined pavement and non-pavement costs for recent long-life projects, and assumed 8-hour nighttime closures for the conventional rehabilitation alternatives and 24-hour-per-day closures for the long-life alternatives. The results contradicted the earlier findings, instead indicating that conventional asphalt concrete overlays were the most cost-effective rehabilitation option for existing asphalt pavements regardless of the traffic volume, while grinding, PCC overlays or AC overlays were found to be the most cost-effective options for PCC pavements depending on circumstances. The long-life pavement options were in all instances considerably more expensive that the conventional strategy, with road user costs having a significant impact in all scenarios. This discrepancy in findings between the earlier and current studies is attributed to the use of more realistic data, more appropriate traffic analysis with the RealCost software package and the significant impacts that 24-hour continuous closures and higher up-front agency costs have on the total cost of the long-life alternatives.

Two additional analyses were carried out to assess the impact of different lane closure strategies on the two LLP options. While these are still hypothetical cases, they identified trends that result in change of costs with changes in input variables. The first entailed a scenario that assumed 25 percent less AADT during weekends and a single widely spread peak hour in the early afternoon (approximately 1:00 PM to 4:00 PM). The second assumed the implementation of a Traffic Management Plan that assumes a 15 percent reduction in AADT during weekday closures, but maintains the normal double AM/PM peak traffic pattern. A comparison of these two alternatives with the originals still showed that the conventional rehabilitation alternatives had lower total costs than the long-life alternatives, although the results were somewhat closer, particularly as the number of lanes and the AADT increased.

A third additional analysis was performed in which the original traffic closure assumptions were maintained, but the non-pavement item multiplier was removed from the long-life costs. This permitted a comparison with just pavement costs for both the conventional and long-life alternatives. The results indicated a significant reduction in agency and hence total cost. Despite the reduction in agency cost (but using baseline traffic delay assumptions) after taking the multiplier into consideration, the LLP options are still more costly with respect to total cost when compared to the lowest cost conventional rehabilitation alternative. However, when only agency costs were compared, the agency costs of one or both of the LLP options without the multiplier are less than or similar to those of the conventional rehabilitation strategy for 12 centerline miles and 8 and 10 lanes.

All of the analyses presented in this report used hypothetical data that in many instances could have had a significant influence on the findings and hence the results should be interpreted with caution, and should not be taken to be applicable to all projects. This is emphasized in the findings that the results were sensitive to both traffic management refinements and the inclusion of multiplier factors. The results indicated that long-life projects can become more cost-effective where traffic delay costs for 24-hour-per-day closures can be reduced through traffic management plans, and where non-pavement multipliers can be minimized.

It is expected that project specific studies using actual data and fewer assumptions may provide significantly different results. An example was presented where the existing pavement was in such poor condition that some conventional rehabilitation treatments were not feasible and others would have had shorter lives than that assumed in this study. In addition, a reduction in traffic demand was achieved by means of a Traffic Management Plan (TMP) that was greater than that assumed in this study.

The study was limited to rehabilitation strategies only and is not applicable to new construction or widening.

4.2 Recommendations

There is consensus in the industry that quality LCCA in the design phase of rehabilitation projects can result in more appropriate strategies, considerable total savings (agency and road user) and better cash flow management. It is therefore recommended that LCCA is adopted as a standard procedure on all projects and that realistic and accurate data are used.

The findings of this study contradict findings from a 1996 study that found that long-life strategies will generally have lower total cost for higher traffic facilities with more lanes. However, LLP is still considered to be a feasible rehabilitation option and it is strongly recommended that LCCA be performed on a case-by-case basis when determining whether to use long-life or conventional strategies as significantly different results could be obtained when realistic project specific data are used.

The results of LCCA for each project will be dependent on the following variables which are different for each project:

- Traffic demand patterns, including hourly, weekday, and weekend demand; directional peaks; and discretionary versus job-related travel
- Alternative routes and modes
- Lane and shoulder configurations and highway geometry in each direction
- Feasibility and expected life of each rehabilitation strategy, which depend on truck traffic and existing pavement condition in each lane
- Expected construction durations

Sensitivity analyses should be carried out to identify specific issues that influence the agency and road user costs and which could be managed better to reduce the costs on alternative strategies. Better comparisons of strategies will be obtained if overhead and administration costs are included in the analyses. However, it is important to ensure that correct costs are used in each alternative considered to ensure that realistic and accurate comparisons are made.

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