Integration of Design, Construction and Traffic for Urban Freeway Rehabilitation

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University of California
Davis and Berkeley

Are Pavements Important?

- **Investment in highway pavements**
  - about $400 billion for US
- **Annual cost of maintenance and rehabilitation**
  - Caltrans contracted M&R ~ $ 190 to 850 million per year
  - CA local government/private ~ $ 1,200 million per year

Outline

- Introduction to Partnered Pavement Research Center (PPRC) research
- The “Dilemma”
- How to get long life
- How to build it quickly
- How to minimize delay
- Picking the best alternative
- Summary

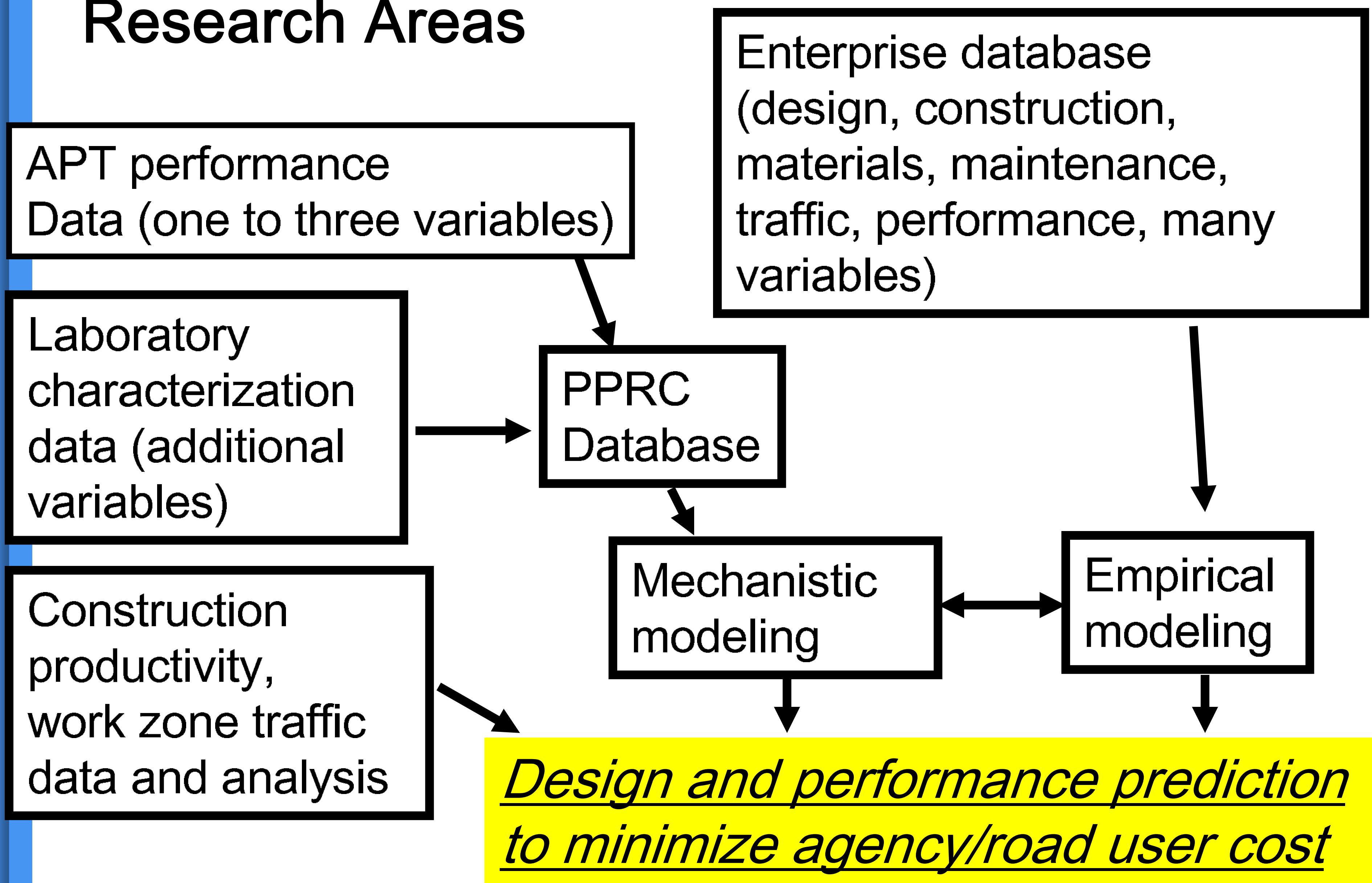
Partnered Pavement Research Center (PPRC)

- Contracted research between Division of Research and Innovation and University of California at Davis and Berkeley
- In operation since 1994
- Subcontract to industry and other universities for various research expertise and operations as needed

Mission and Scope

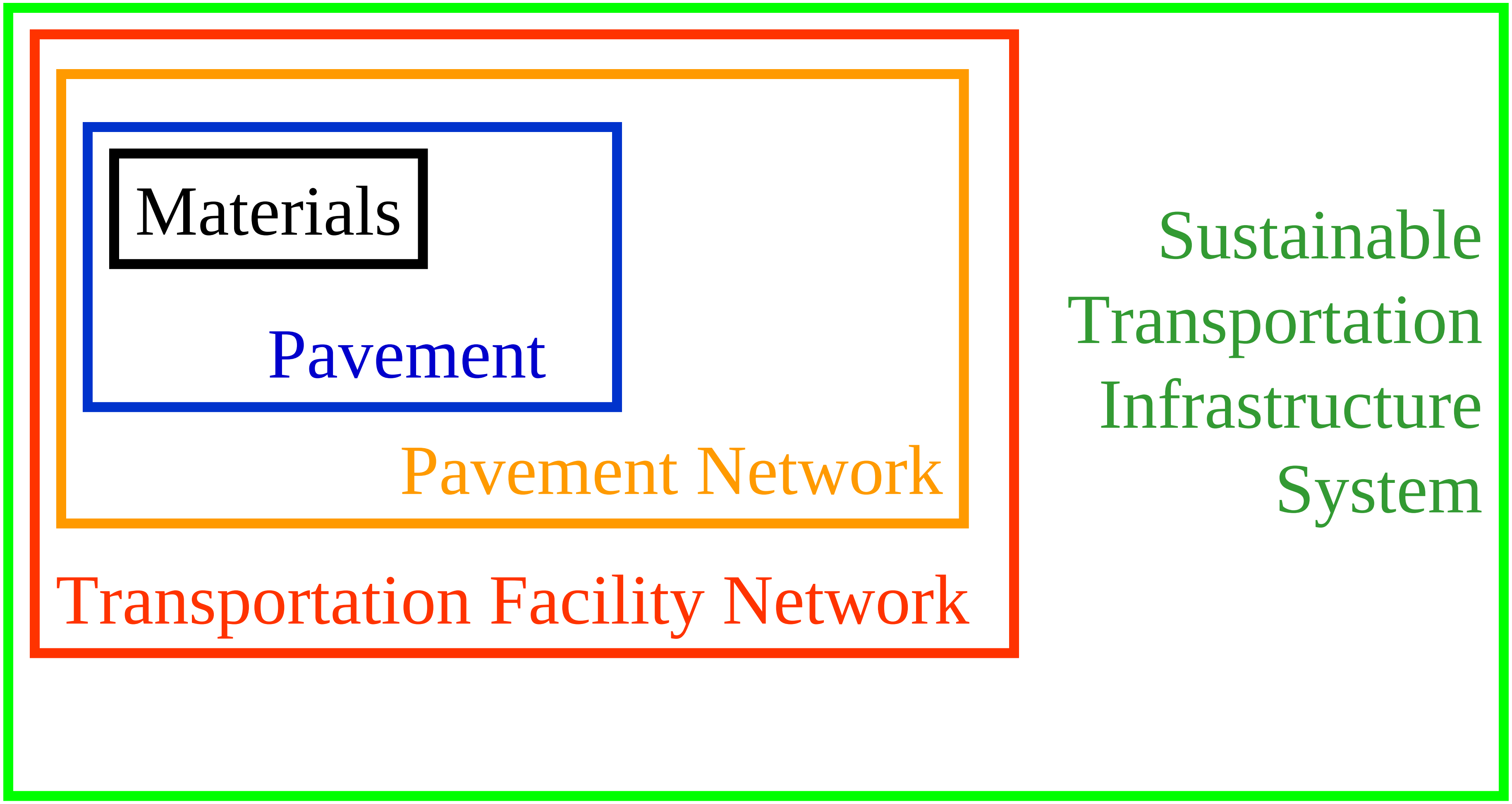
- Mission: provide best available data, analysis and tools to Caltrans to support good decision-making and more efficient operations
- Technical Advisory Panel: Pavement Standards Team (PST)
  - Also work with Traffic operations
- Strategic Plan
  - Current strategic plan on web site at www.its.berkeley.edu/pavementresearch

PPRC Research Areas



Pavement System Boundaries

Continued expansion of the system boundaries in which pavement research problems are defined



The Challenge

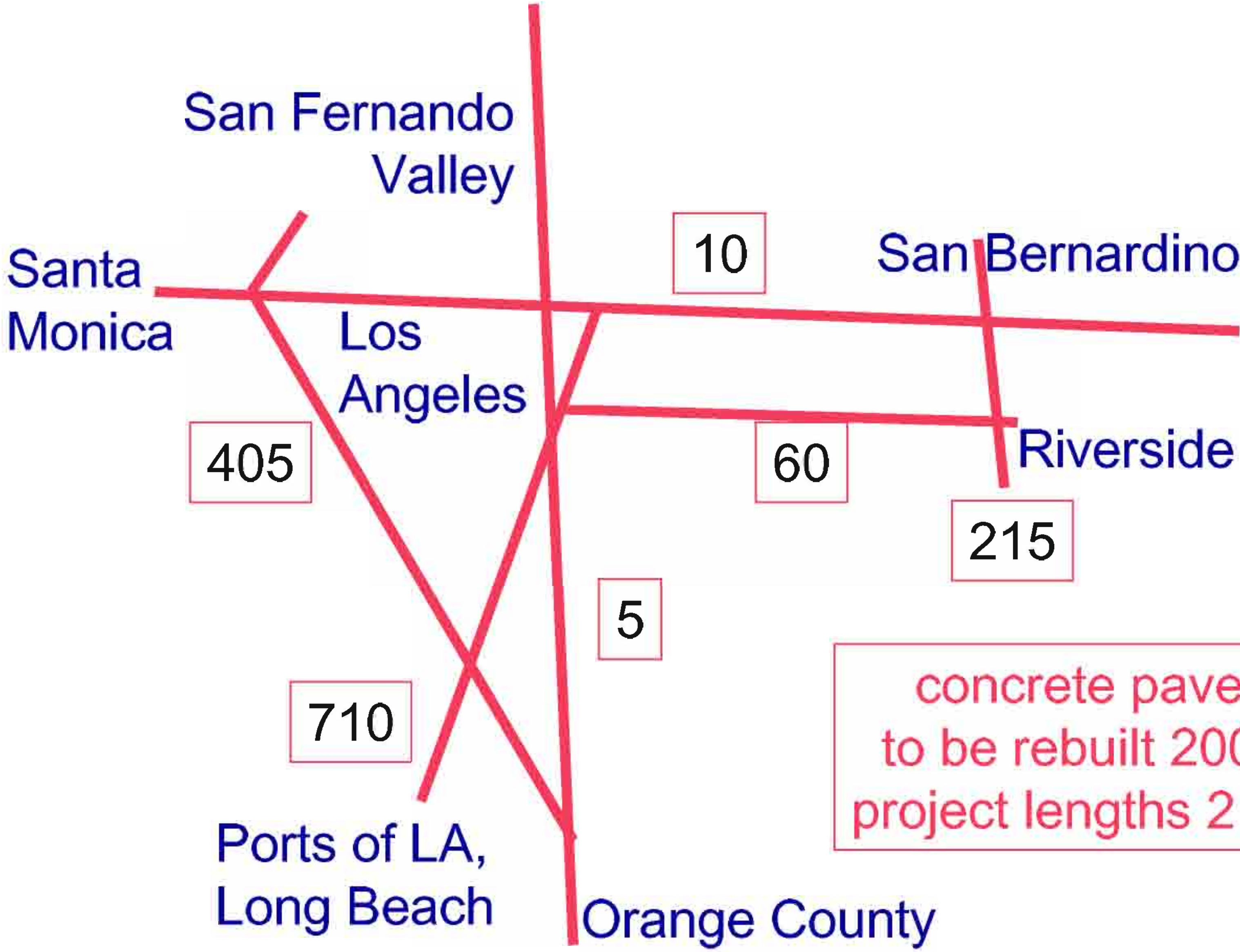
California Highway System

- Total 80,000 lane-km Highway System
- 90% of urban freeway pavements built 1955 – 1970
- Result: Increased Costs, Safety, Traffic Delay, VOC

Long Life Pavement Rehabilitation Strategies

- About 2,500 lane-km candidates for LLPRS
- LLPRS Objectives:
  - 30-40 years design life with minimum maintenance
  - Minimum traffic delay during construction
  - Must be able to afford them

Los Angeles Basin Freeway Network



concrete pavements
to be rebuilt 2000-2015
project lengths 2 to 50 km

I-15 Devore

Maintenance and rehabilitation are less effective when underlying structure reaches advanced deterioration

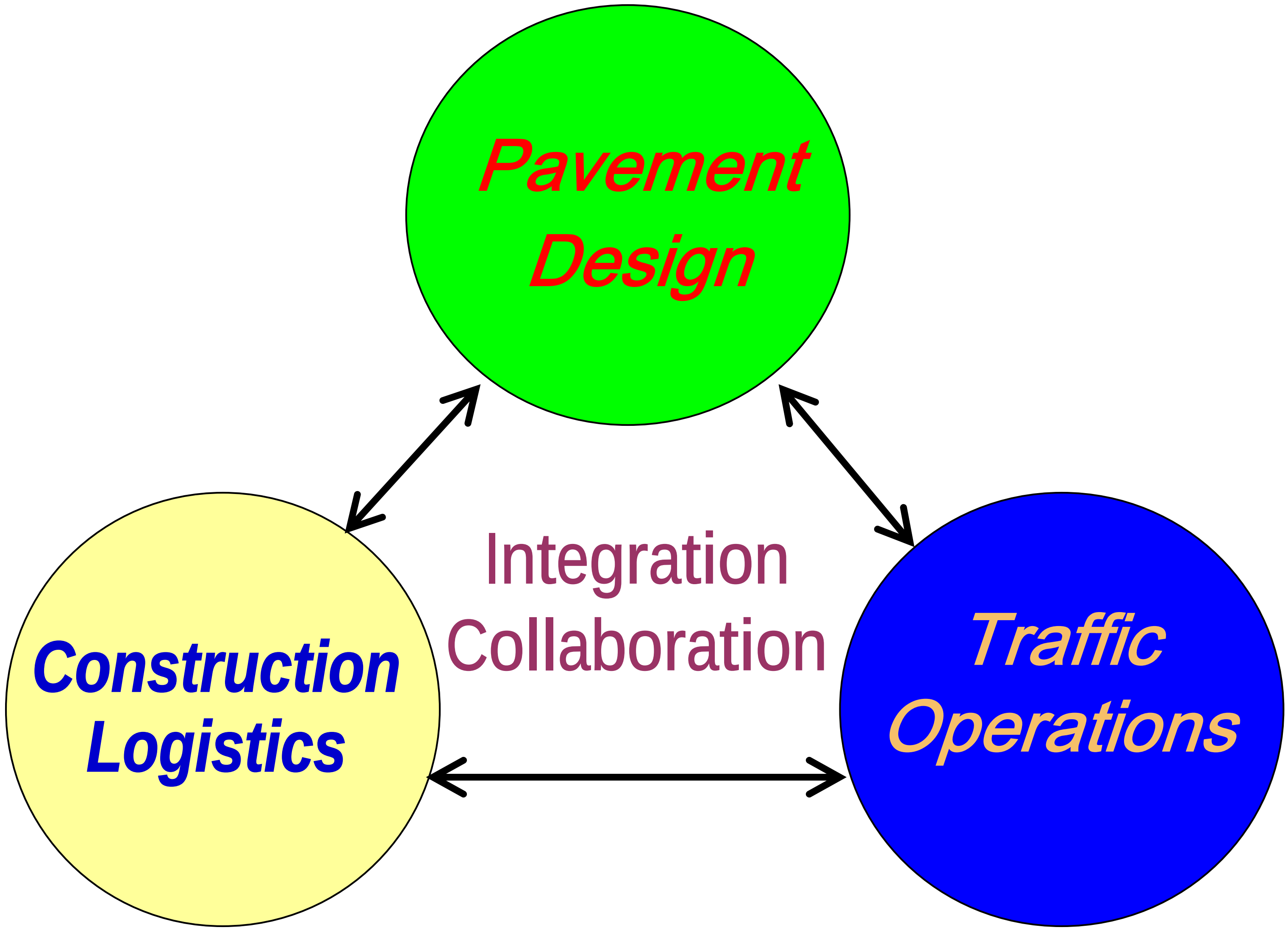
I-10 Pomona

30 to 50 year old pavements require maintenance and rehabilitation at shorter and shorter intervals

The Dilemma

- Want Long Life and Fast Construction and Minimum Traffic Delay
- Pavement design strategies:
  - Thicker and higher quality provide longer life
- Construction windows/traffic delays:
  - shorter windows less efficient
  - some strategies impossible in 7-10 hour windows
  - which best for traffic delay, safety and cost?
    55 hour weekend, 72 hour weekday, continuous
- Requires Pavement Engineering + Construction Engineering + Traffic Engineering

Integrated Planning, Design and Construction



Research Approach

- Pavement Engineering
  - Thinner structural sections to meet design life
  - Use of faster materials
  - Combined optimization of design (long life) and construction (speed and cost)
- Construction Engineering
  - Modeling of construction process
  - Analysis of construction windows and scenarios
  - Combined optimization of construction (speed and cost) and traffic (delay)

Research Approach

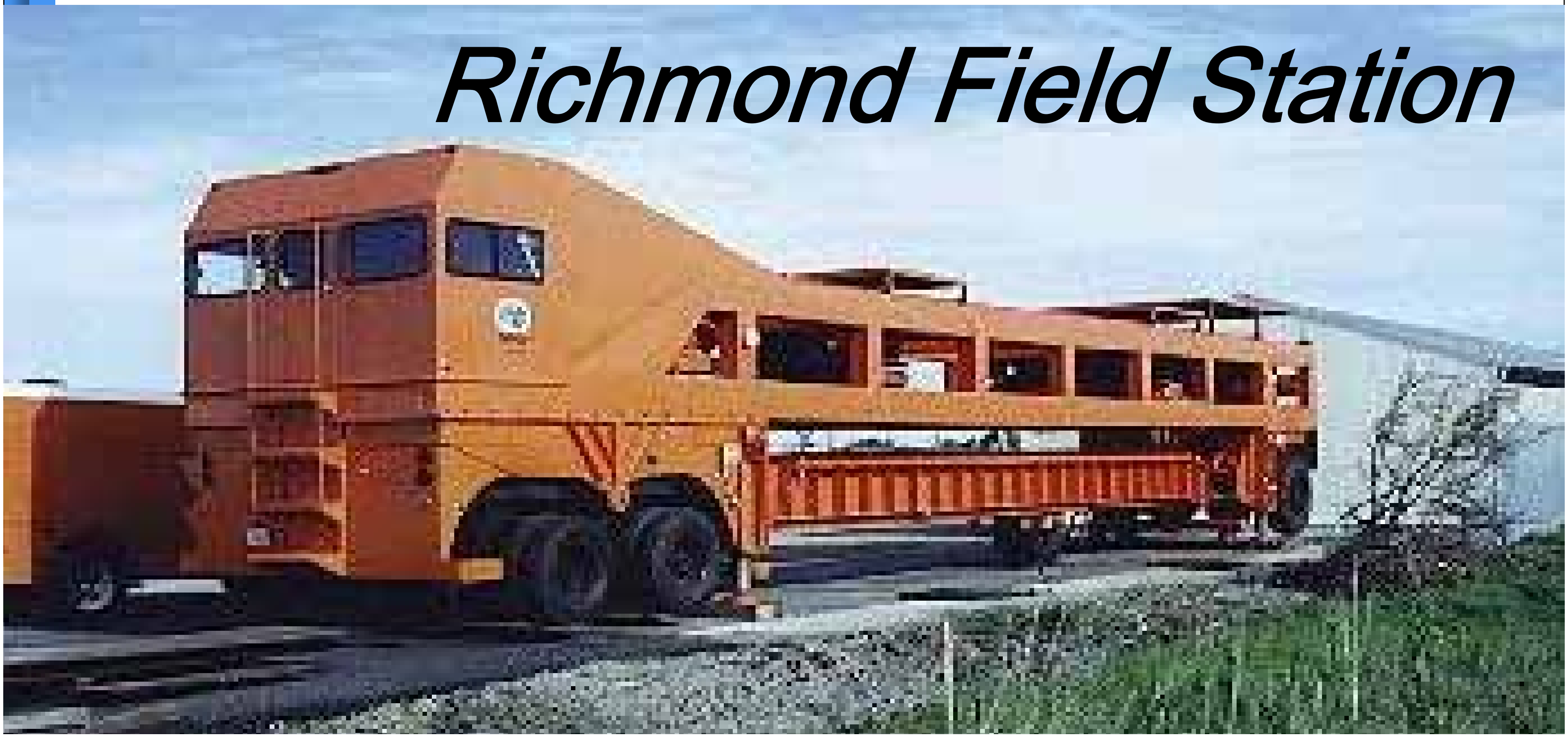
- Traffic Engineering
  - Modeling of construction impact on urban networks, estimation of delay
  - Analysis of construction windows and scenarios, traffic management strategies
- Integration
  - Final analysis within project constraints
  - Minimization of Life Cycle Cost

How to get long life

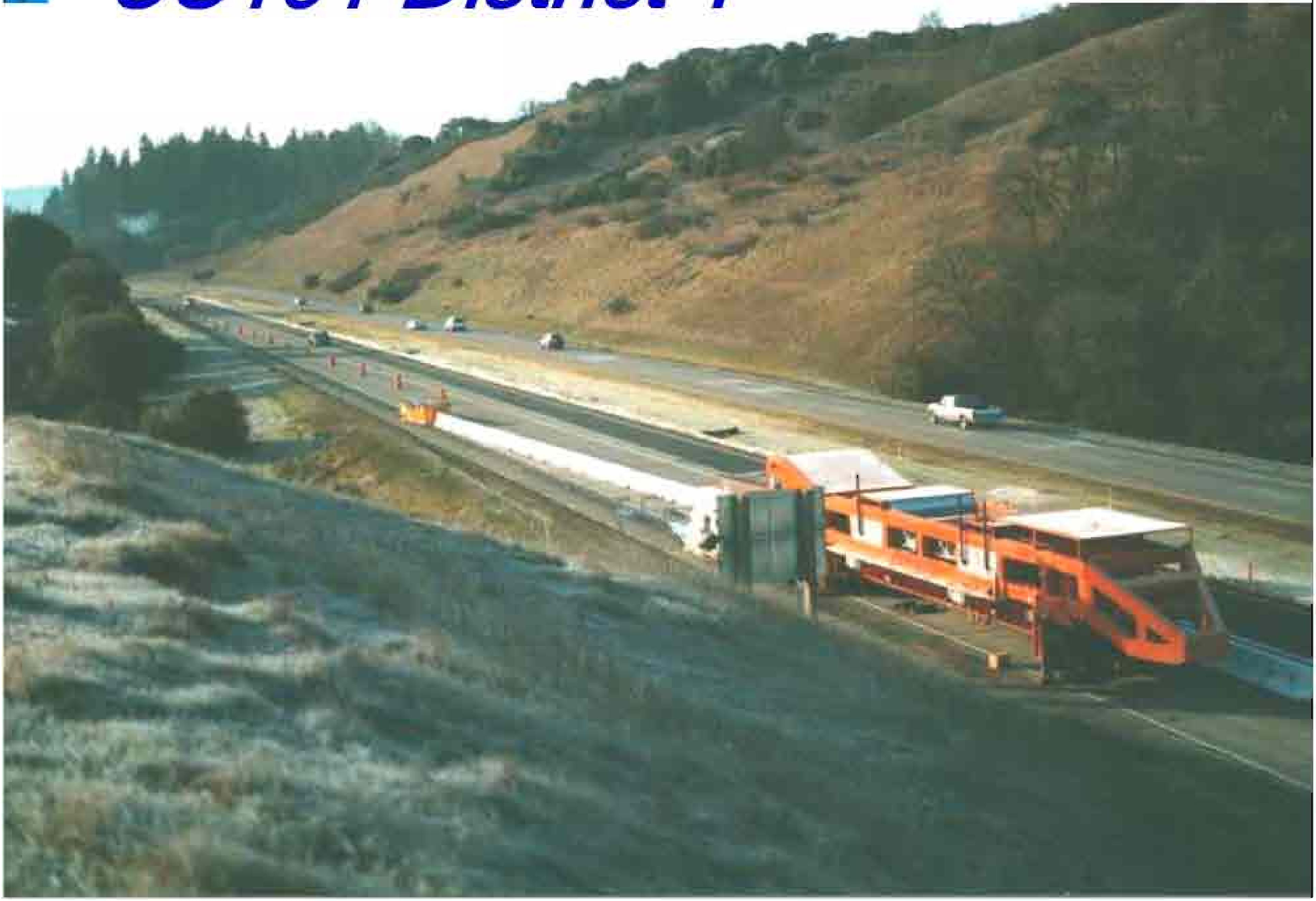
- Use Mechanistic-Empirical Design
  - Incorporate benefits of new materials and structural designs/features in design
  - Current Caltrans design methods cannot
- Caltrans is moving towards use of mechanistic-empirical methods

Accelerated Pavement Testing with the Heavy Vehicle Simulators (HVS)

Provides Quick Validation of Mechanistic Designs



US101 District 1



SR14 District 7

SR89 District 3


SR89 District 3

Current Long-Life Rehab Strategies

Existing Structure

200-225 mm PCC

100 mm CTB

150 mm ASB

75-100 mm PBA-6a,
5 % air-voids

150-200 mm AR-8000
AC, 5 % air-voids

50-75 mm Rich Bottom
AC, 2 % air-voids

Crack and Seat PCC,
Place Thick AC Overlay

Remove PCC, Replace
with 200-300 mm
Doweled
PCC

LLPRS-Rigid

- Fail by:
  - Transverse cracking
  - Longitudinal and corner cracking
  - Faulting
  - Early-age cracking
- Mechanistic analysis shows how to obtain longer life for each distress

Transverse Cracks

Transverse Cracking

Longer life comes from:

- shorter joint spacing
- thicker slab
- stronger flexural strength of concrete
- load transfer at edge (wide lane or tied joint)
- aggregate source (thermal expansion)

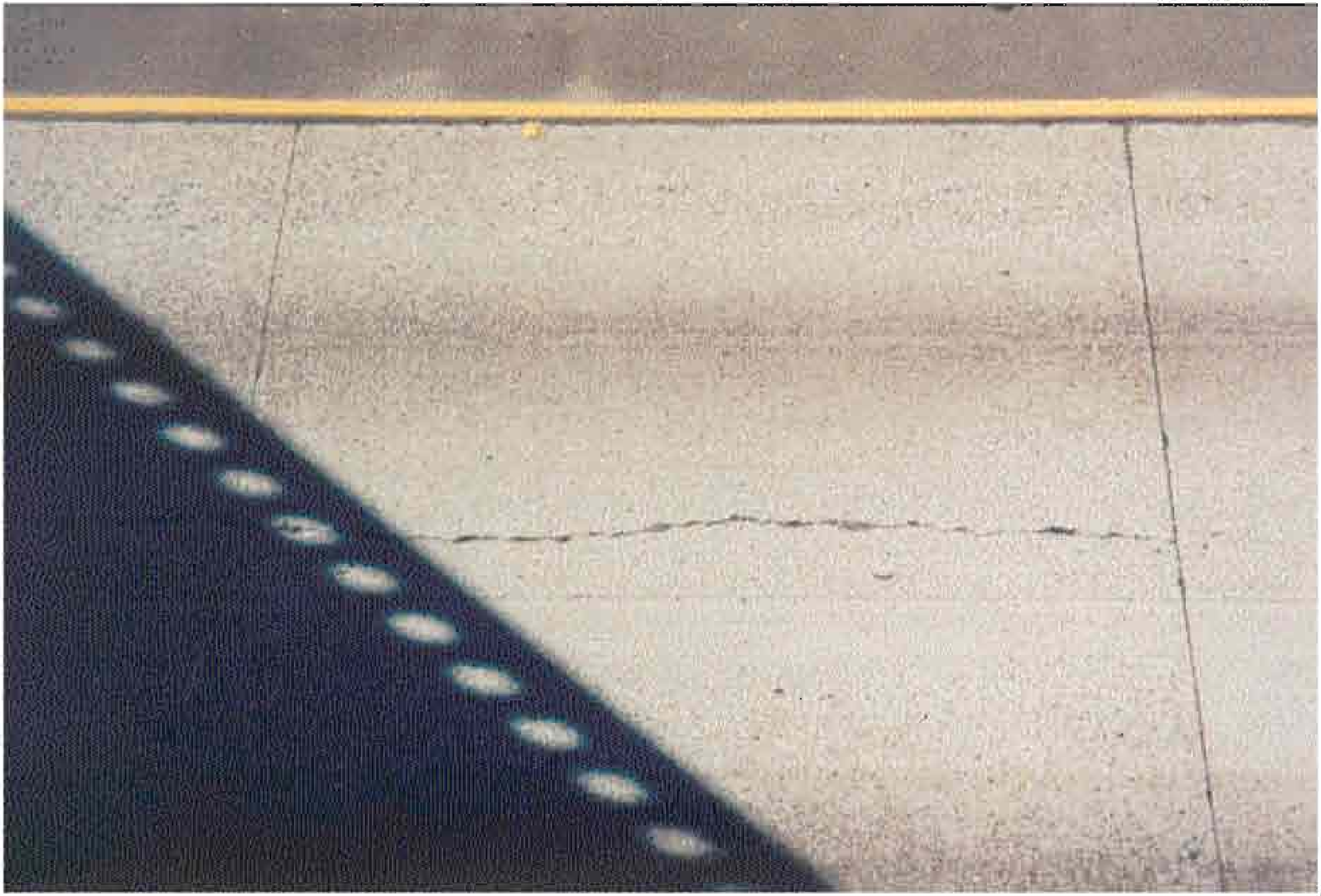
Corner Cracks

Corner Cracking

Longer life comes from:

- thicker slab
- stronger flexural strength of concrete
- load transfer at joint and edge (dowels, wide lane or tied shoulder)
- aggregate source (thermal expansion)

Longitudinal Crack



Longitudinal Cracking

Longer life comes from:

- thicker slab
- stronger flexural strength of concrete
- aggregate source (thermal expansion)

Faulting

Photo from L. Khazanovich

Faulting

Longer life comes from:

- Dowels, dowels, dowels
- Non-erodible bases

Smoothness controlled by:

- Initial construction smoothness
- Faulting

Long-Life Asphalt Concrete General Approach

- Drive distresses to the surface
- Keep the mix simple to produce and the design simple to construct
- Integrate
  - mix design
  - structural design
  - constructability

Crack, Seat and Overlay

Sacrificial layer – safety, noise 25-50 mm

Top layer – rutting, cracking 75-100 mm

Middle layer – cracking, rutting Varying thickness

fabric

Bottom layer - cracking 30 mm

Existing grade

Cracked and Seated PCC

Base layers

subgrade

Full-Depth Asphalt Concrete

Existing grade

Sacrificial layer – safety, noise	25-50 mm
Top layer – rutting, cracking	75-100 mm
Middle layer – cracking, rutting	Varying thickness
Bottom layer - cracking	50-75 mm
granular base (recycled PCC)	0 or 150 mm
subgrade	

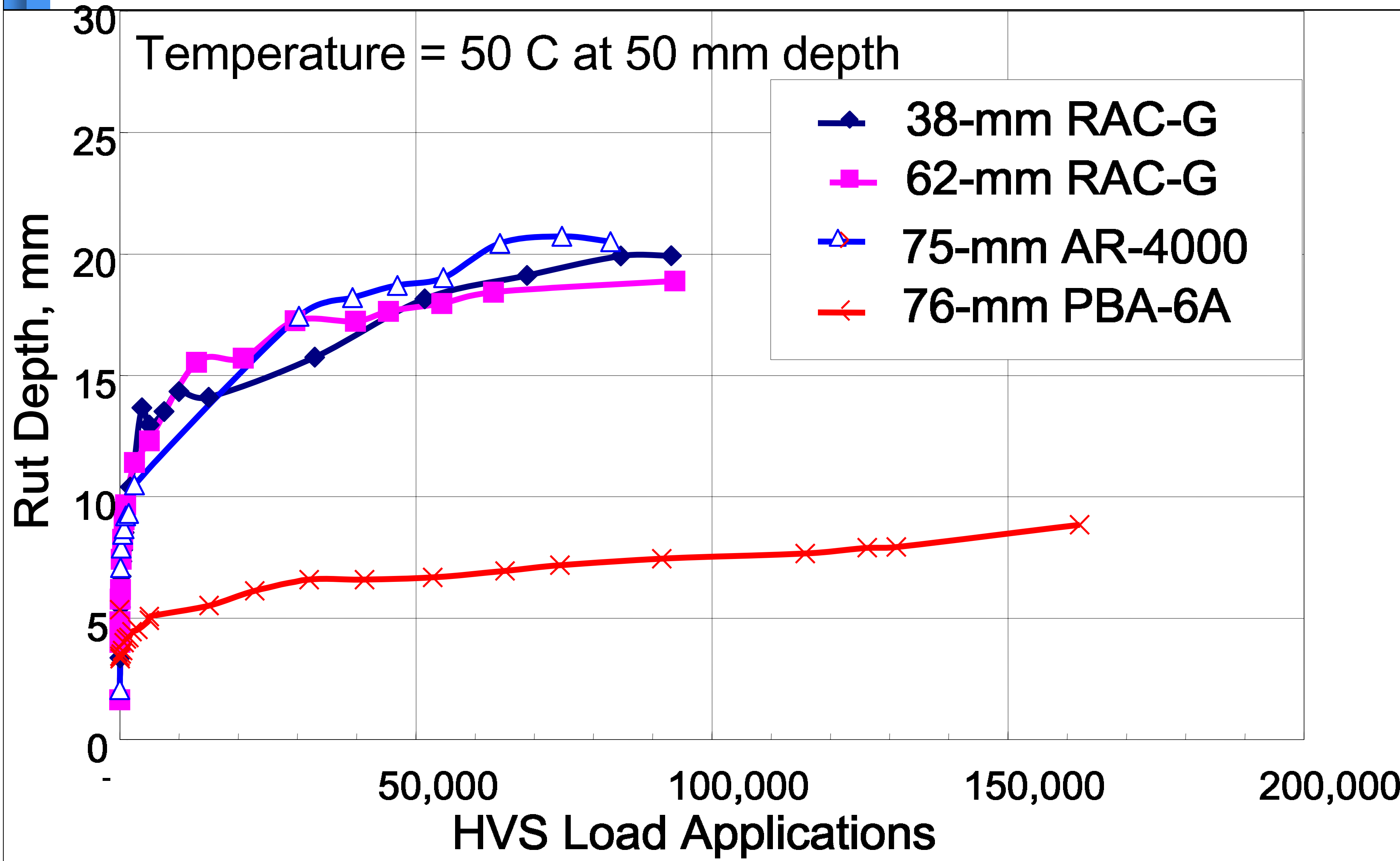
Design Effects on Construction Productivity

- Analyzed using CA4PRS software
- Construction productivity linearly proportional to pavement thickness
- Less thickness to meet design life reduces:
  - Construction time
  - Traffic delay
  - Initial cost

I-710 Reduction of Full-Depth Pavement Thickness for 30 year life

Original design	Mechanistic design
535 mm thick asphalt concrete 8 % air-voids, AR 4000 mix design throughout	75 mm PBA-6a 125 mm, 5 % air-voids, AR-8000 75 mm, Rich Bottom
Recompacted Subgrade	Recompacted Subgrade

HVS Rut Test Results



How to build it quickly

- Thinner pavement
  - And faster materials
- Take more lanes away from traffic to use for construction traffic
- Model construction to optimize productivity using CA4PRS software

CA4PRS Software

(Construction Analysis for
Pavement Rehabilitation Strategies)

Integrating Design, Construction, and Traffic for Rapid Highway Rehabilitation Projects

Capability of CA4PRS Software

- Evaluates “what-if” scenarios
- Finds maximum distance of rehabilitation within a closure:
  - Number of closures
  - Project duration
- Utilizes Critical Path Method and linear-scheduling techniques

Where in a Project Can CA4PRS be Used?

Project Planning to balance competing objectives

- Long-life Pavement Design
- Fast-track Construction
- Minimum Traffic Delay

Pre-Construction Decision support tool

- Evaluate "What-if" rehabilitation scenarios
- Integrate traffic/construction/design constraints

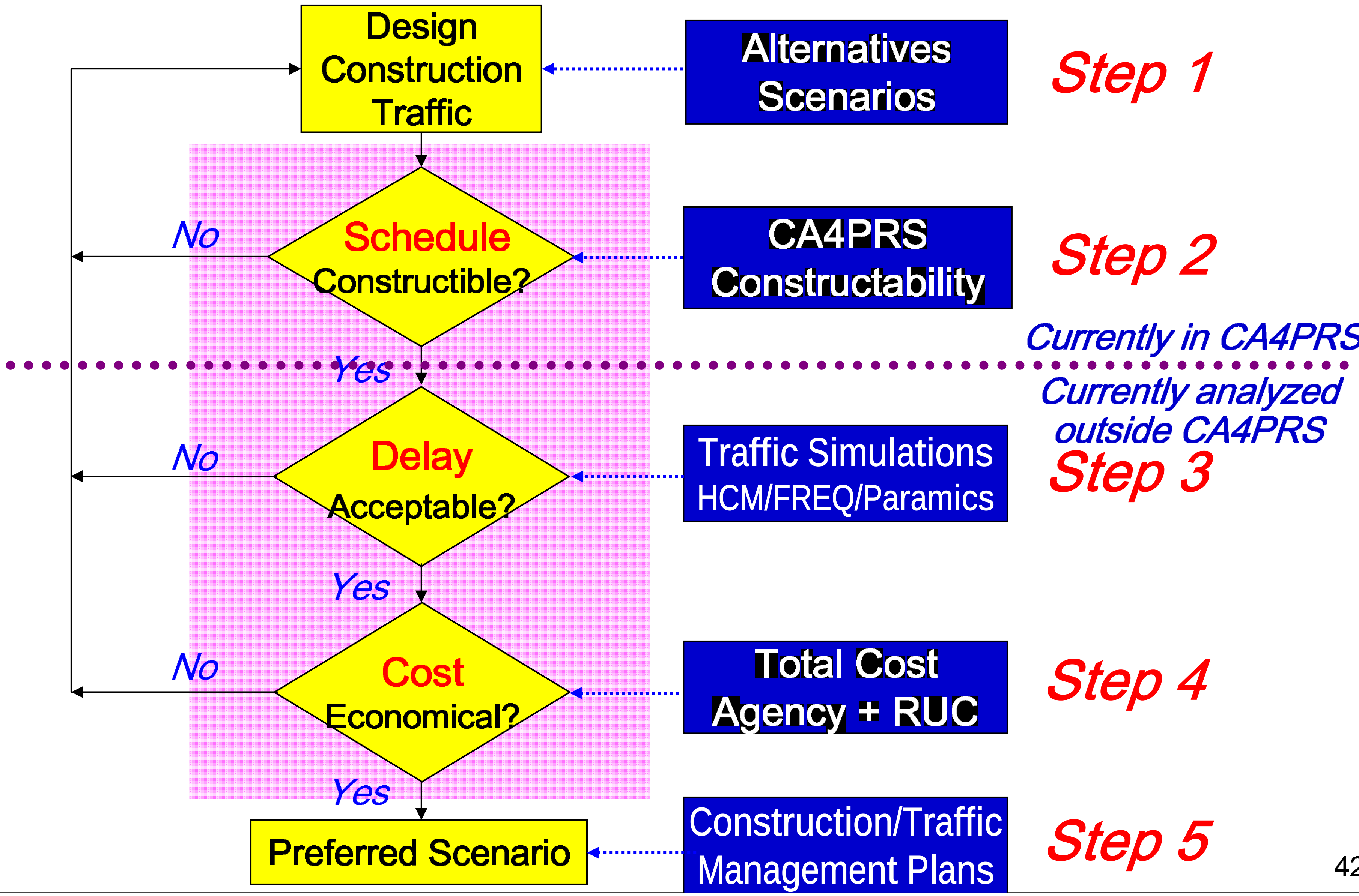
Develop construction baseline

- Schedule baseline
- "A+B" and Incentives contract

Evaluate Contractor's Plan

- Review construction-staging and constructability

Selection Process for the Most Economic Rehabilitation Scenario



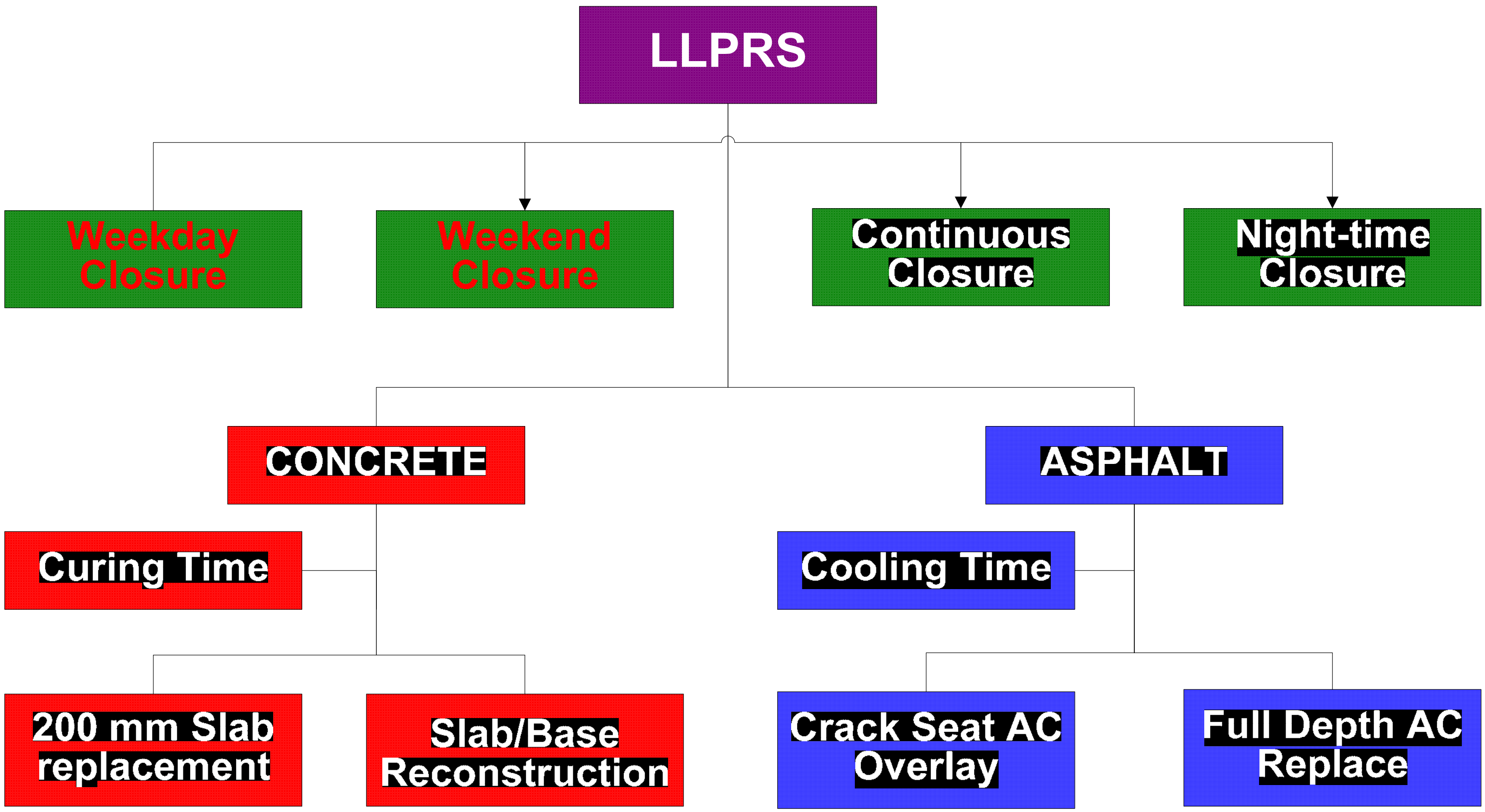
Step 1: *CA4PRS* V1.0 Main Inputs
Create Alternative Scenarios

- Pavement Design
  - Rehabilitation strategy alternatives
  - Design (cross-section) alternatives
  - Materials alternatives
- Traffic Control & Operations
  - Construction widows (Closure timing)
  - Lane closure alternatives
- Construction Logistics and Constraints
  - Activity lead-lag time relationships
  - Construction resources logistics
  - Weather (AC Cooling time, PCC curing time)

Step 2: *CA4PRS* Constructability Schedule Analysis Outputs

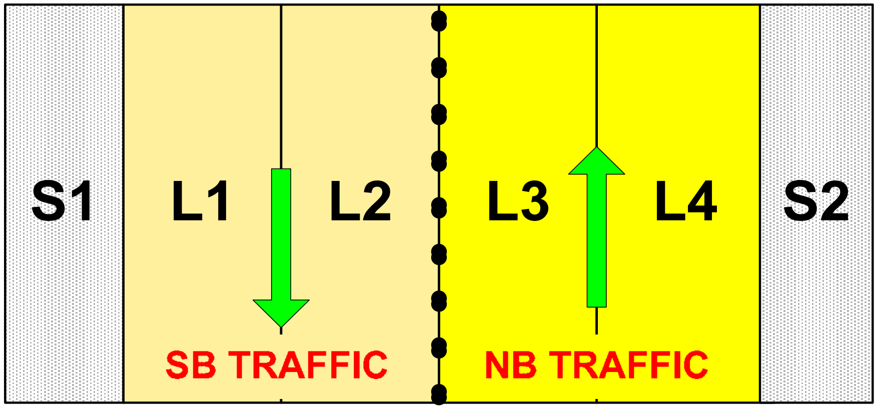
- *CA4PRS* Outputs
  - Maximum rehabilitation production (lane-km)
  - Total number of construction closures
  - Total closure durations
  - Parameters sensitivity
- Constructability Analysis
  - Compares mix, base type, etc
  - Evaluate construction schedule benefits
- Future addition to *CA4PRS* for Traffic and Cost analysis
  - To be discussed later
  - Currently use HCM-based spreadsheet

Outline *of CA4PRS* Analysis Model

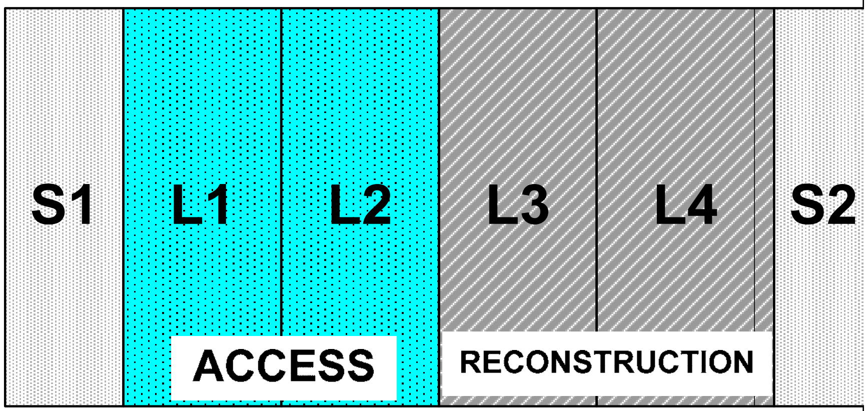


Full Closure (Counter-flow Traffic)

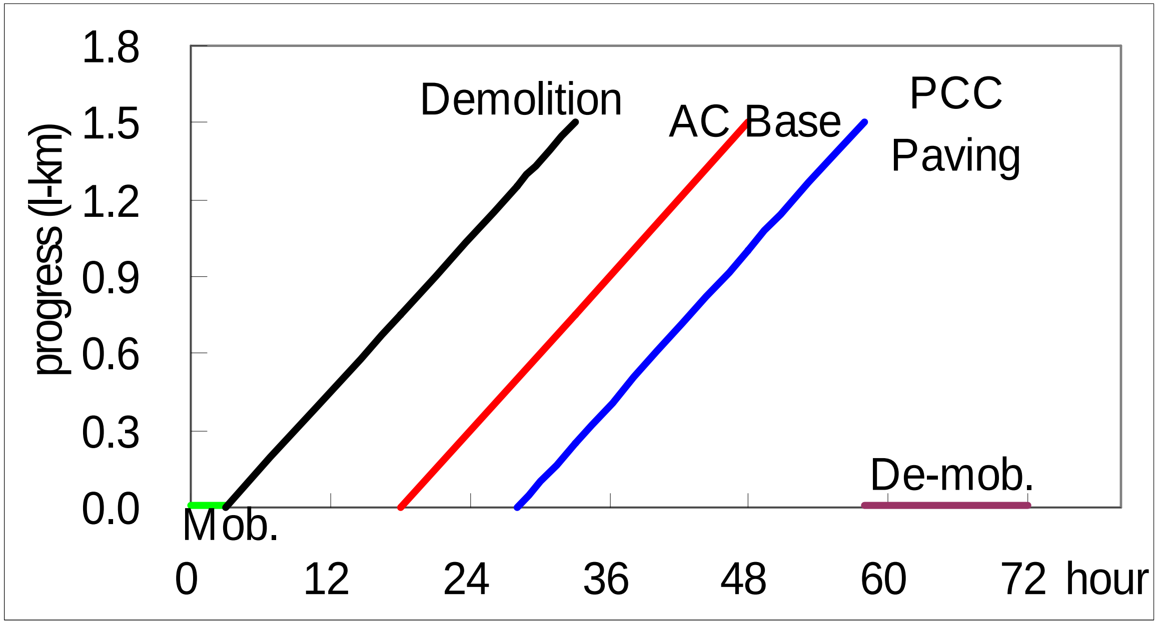
PCC Concurrent Double-lane Rehabilitation



Traffic Roadbed

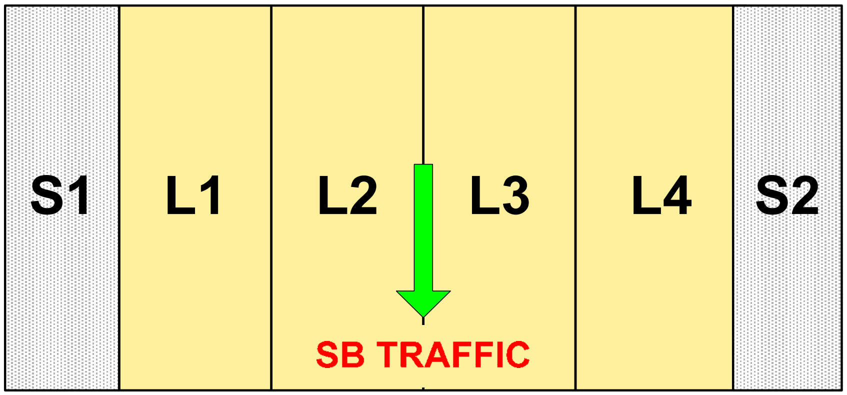


Construction Roadbed

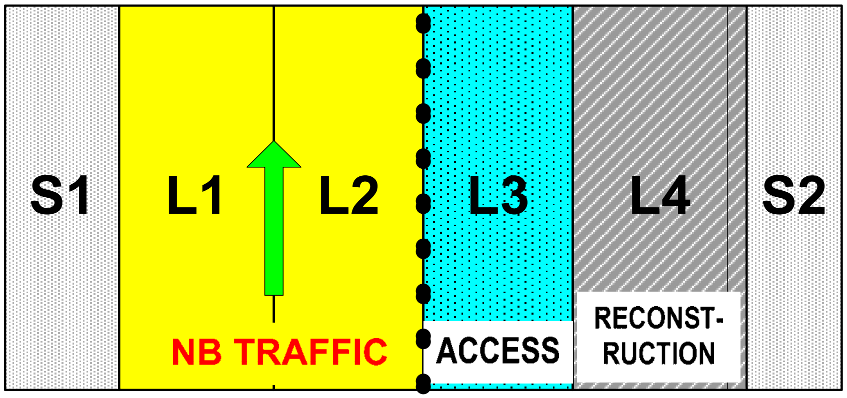


Half or Partial Closure

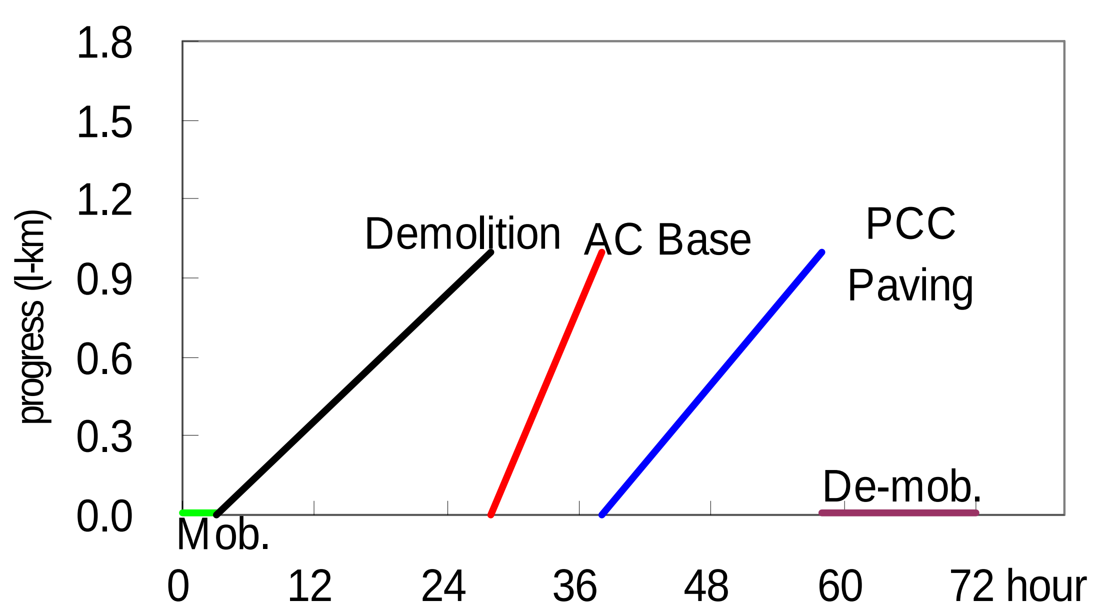
PCC Sequential Single-lane Rehabilitation



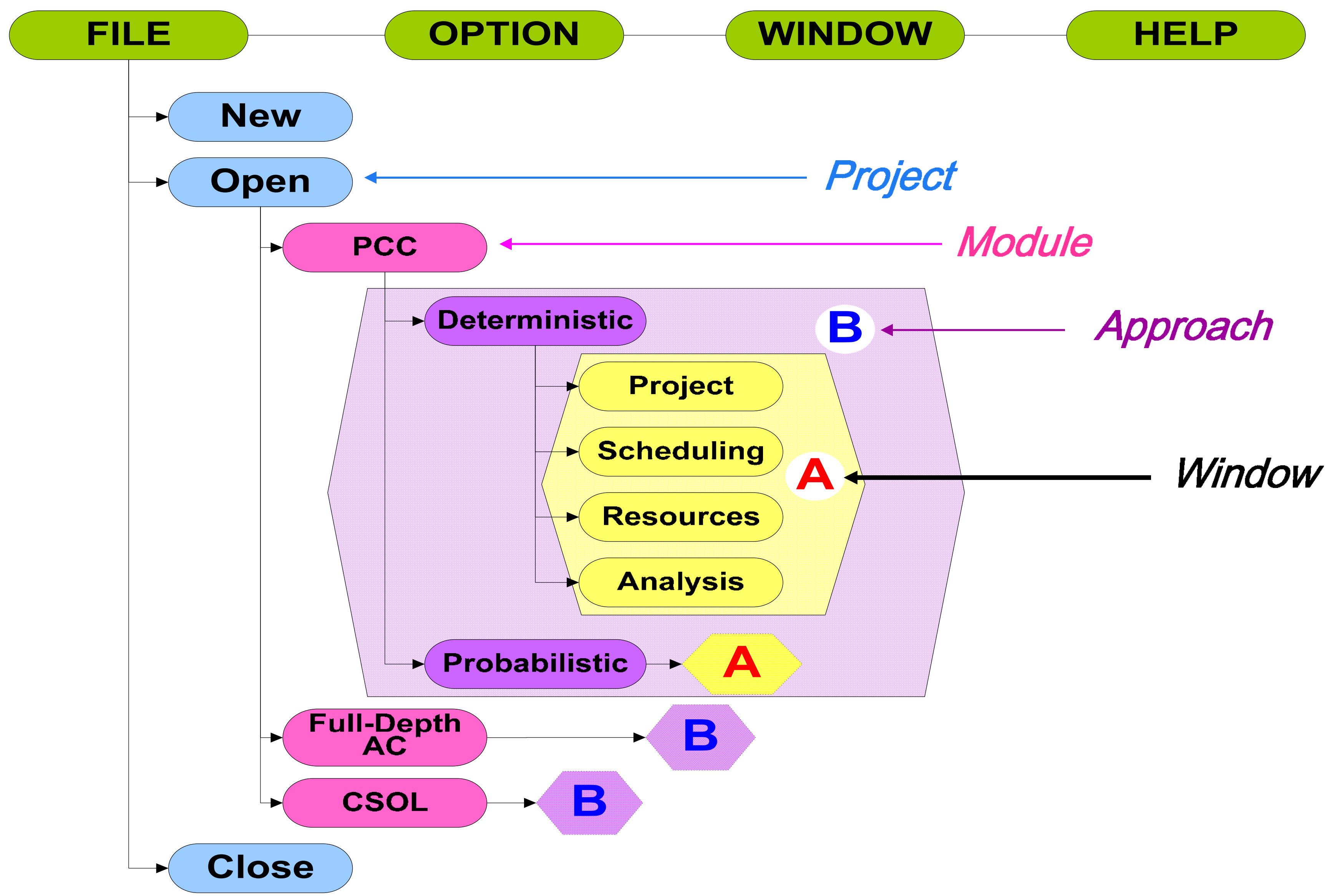
Traffic Roadbed



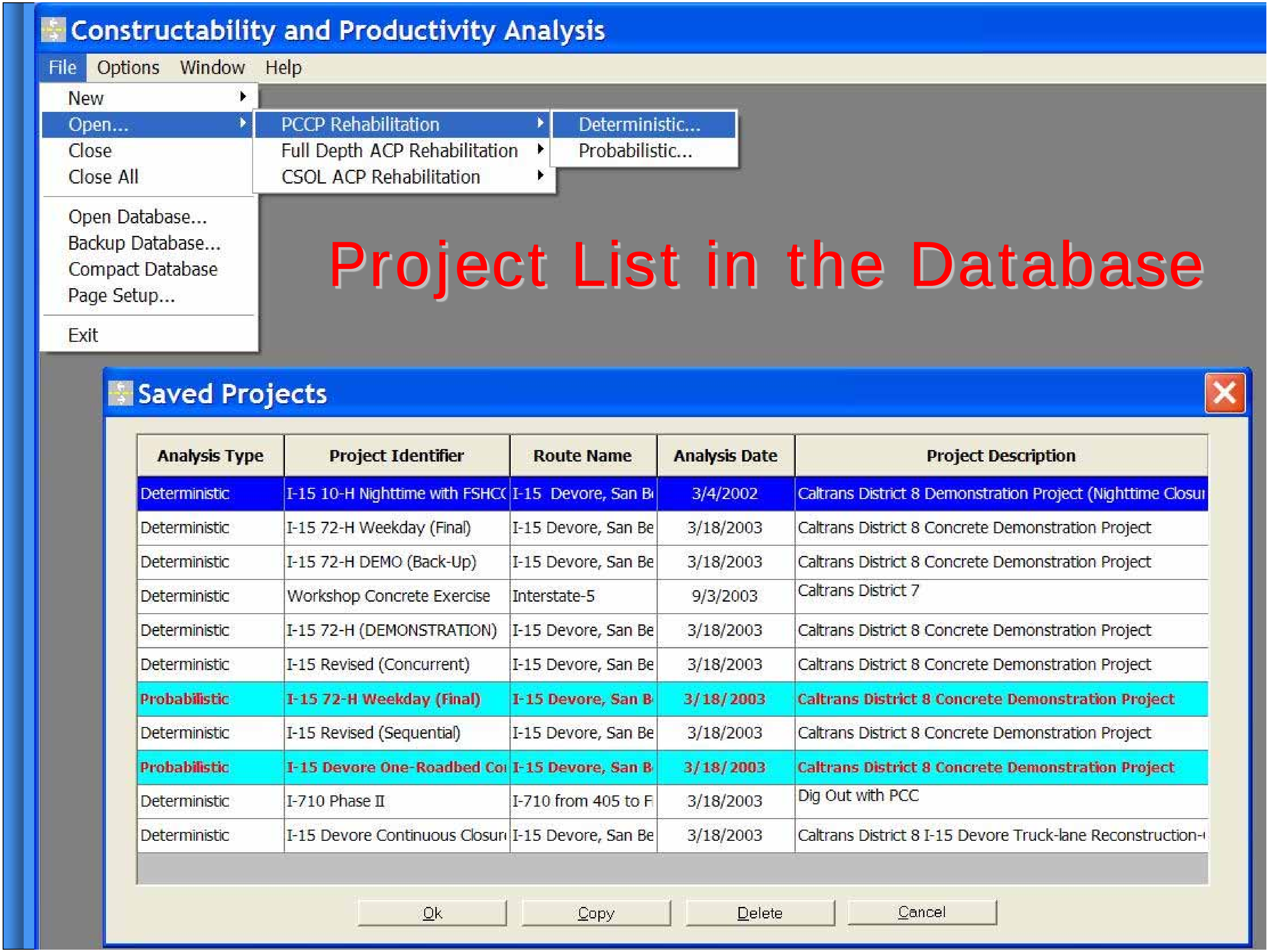
Construction Roadbed



CA4PRS Software Menu Tree

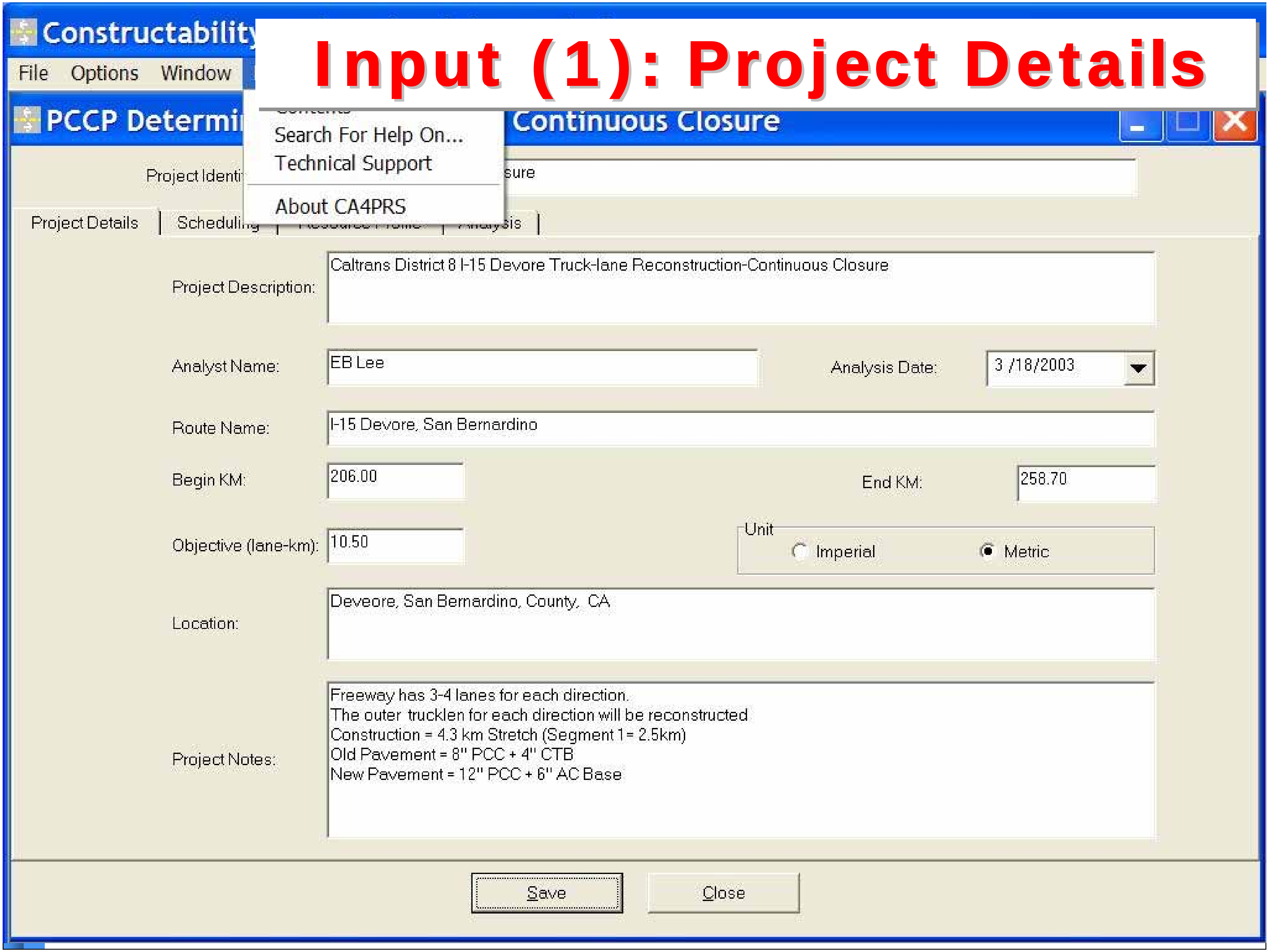


Project List in the Database

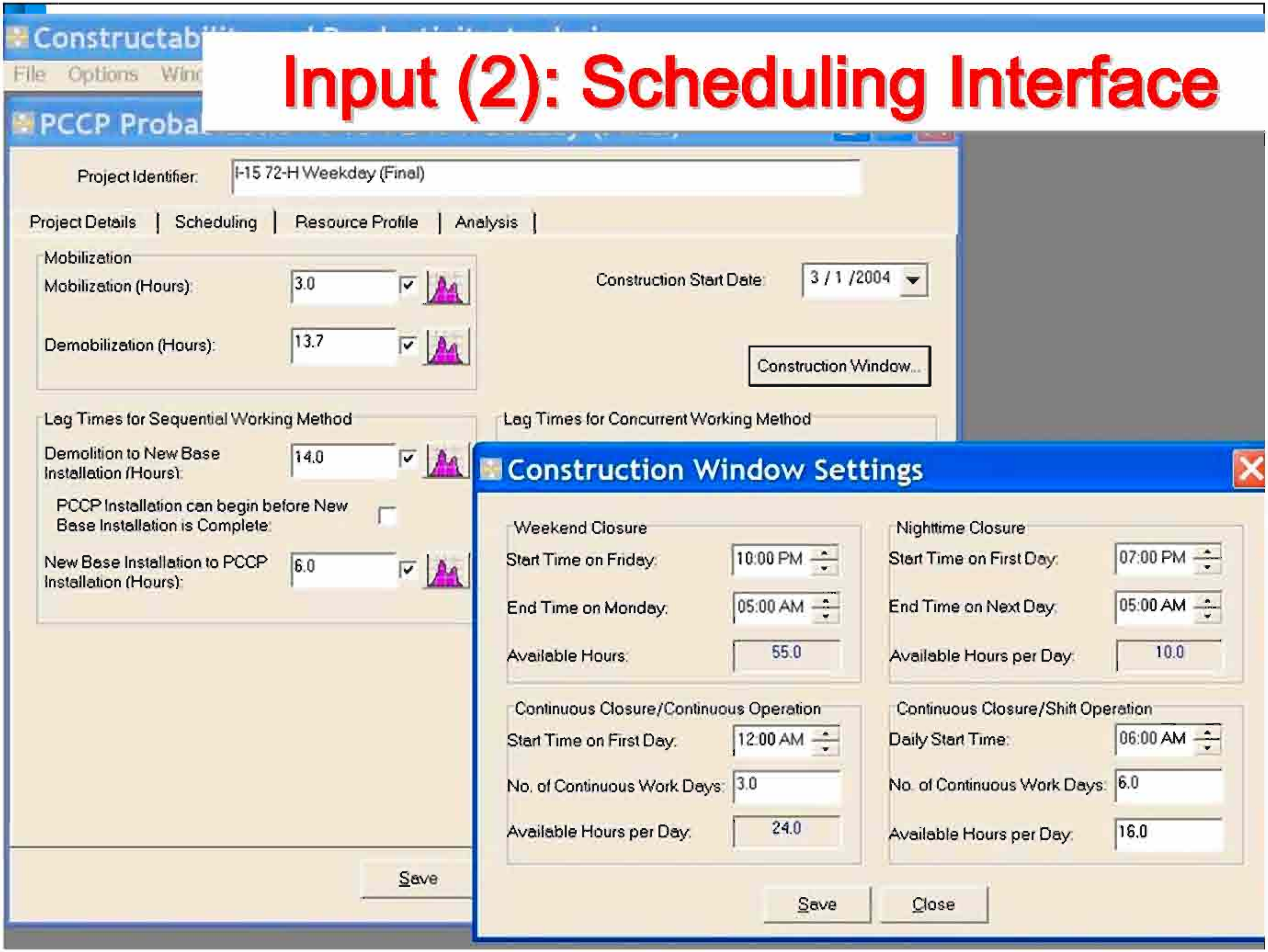


Analysis Type	Project Identifier	Route Name	Analysis Date	Project Description
Deterministic	I-15 10-H Nighttime with FSHC(	I-15 Devore, San B	3/4/2002	Caltrans District 8 Demonstration Project (Nighttime Closu
Deterministic	I-15 72-H Weekday (Final)	I-15 Devore, San Be	3/18/2003	Caltrans District 8 Concrete Demonstration Project
Deterministic	I-15 72-H DEMO (Back-Up)	I-15 Devore, San Be	3/18/2003	Caltrans District 8 Concrete Demonstration Project
Deterministic	Workshop Concrete Exercise	Interstate-5	9/3/2003	Caltrans District 7
Deterministic	I-15 72-H (DEMONSTRATION)	I-15 Devore, San Be	3/18/2003	Caltrans District 8 Concrete Demonstration Project
Deterministic	I-15 Revised (Concurrent)	I-15 Devore, San Be	3/18/2003	Caltrans District 8 Concrete Demonstration Project
Probabilistic	**I-15 72-H Weekday (Final)**	**I-15 Devore, San B**	**3/18/2003**	**Caltrans District 8 Concrete Demonstration Project**
Deterministic	I-15 Revised (Sequential)	I-15 Devore, San Be	3/18/2003	Caltrans District 8 Concrete Demonstration Project
Probabilistic	**I-15 Devore One-Roadbed Co**	**I-15 Devore, San B**	**3/18/2003**	**Caltrans District 8 Concrete Demonstration Project**
Deterministic	I-710 Phase II	I-710 from 405 to F	3/18/2003	Dig Out with PCC
Deterministic	I-15 Devore Continuous Closur	I-15 Devore, San Be	3/18/2003	Caltrans District 8 I-15 Devore Truck-lane Reconstruction-

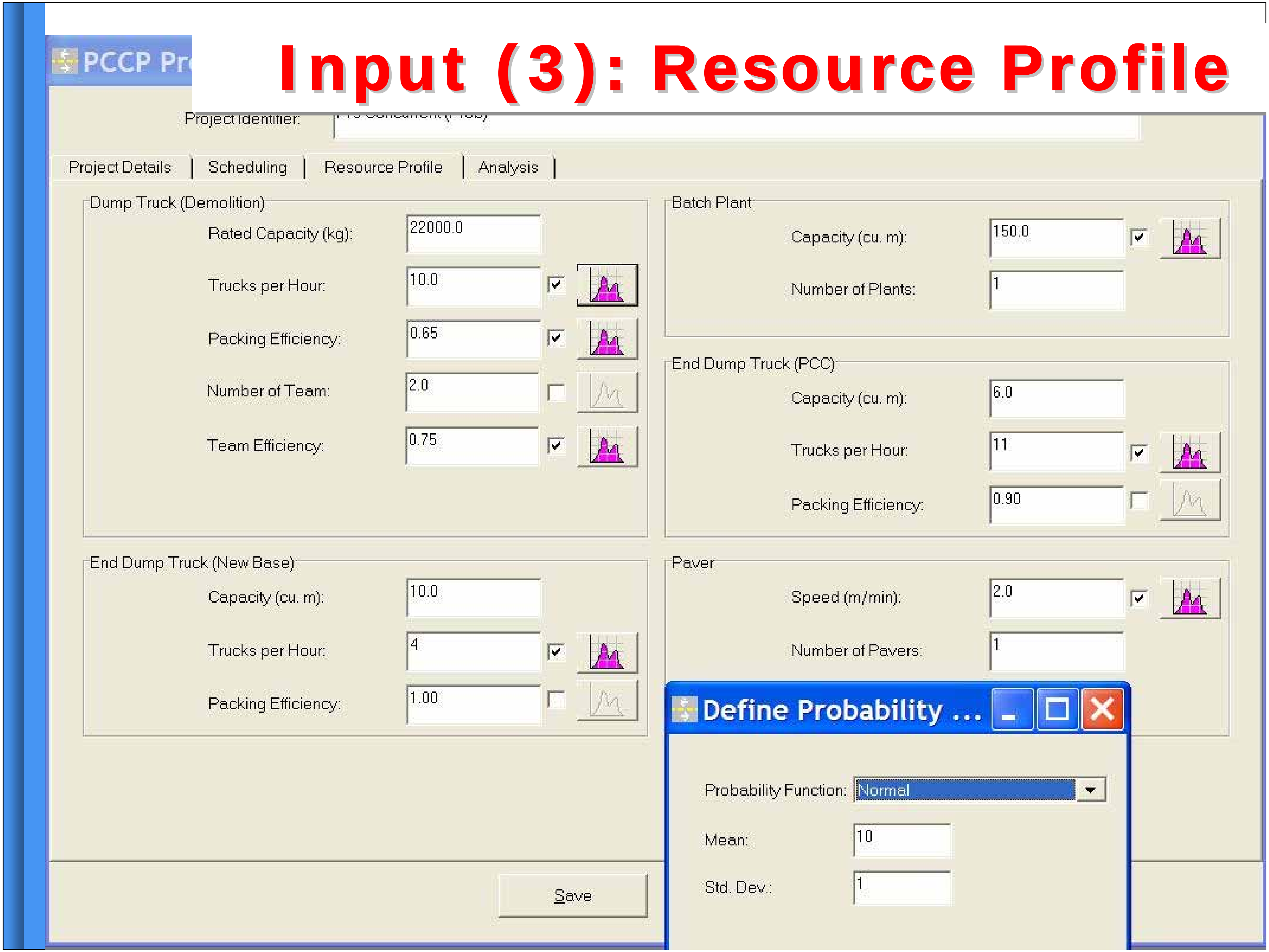
Input (1): Project Details



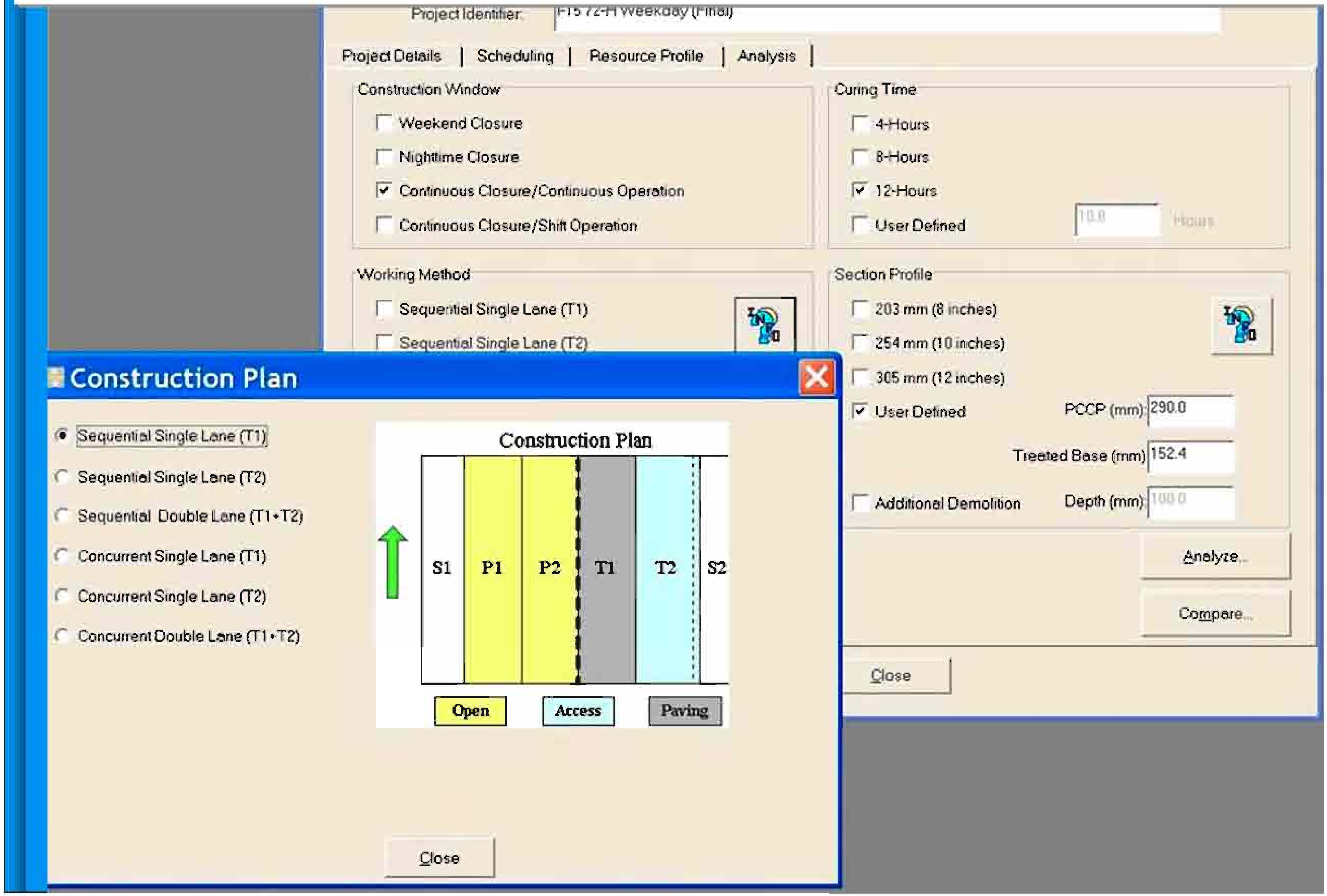
Input (2): Scheduling Interface



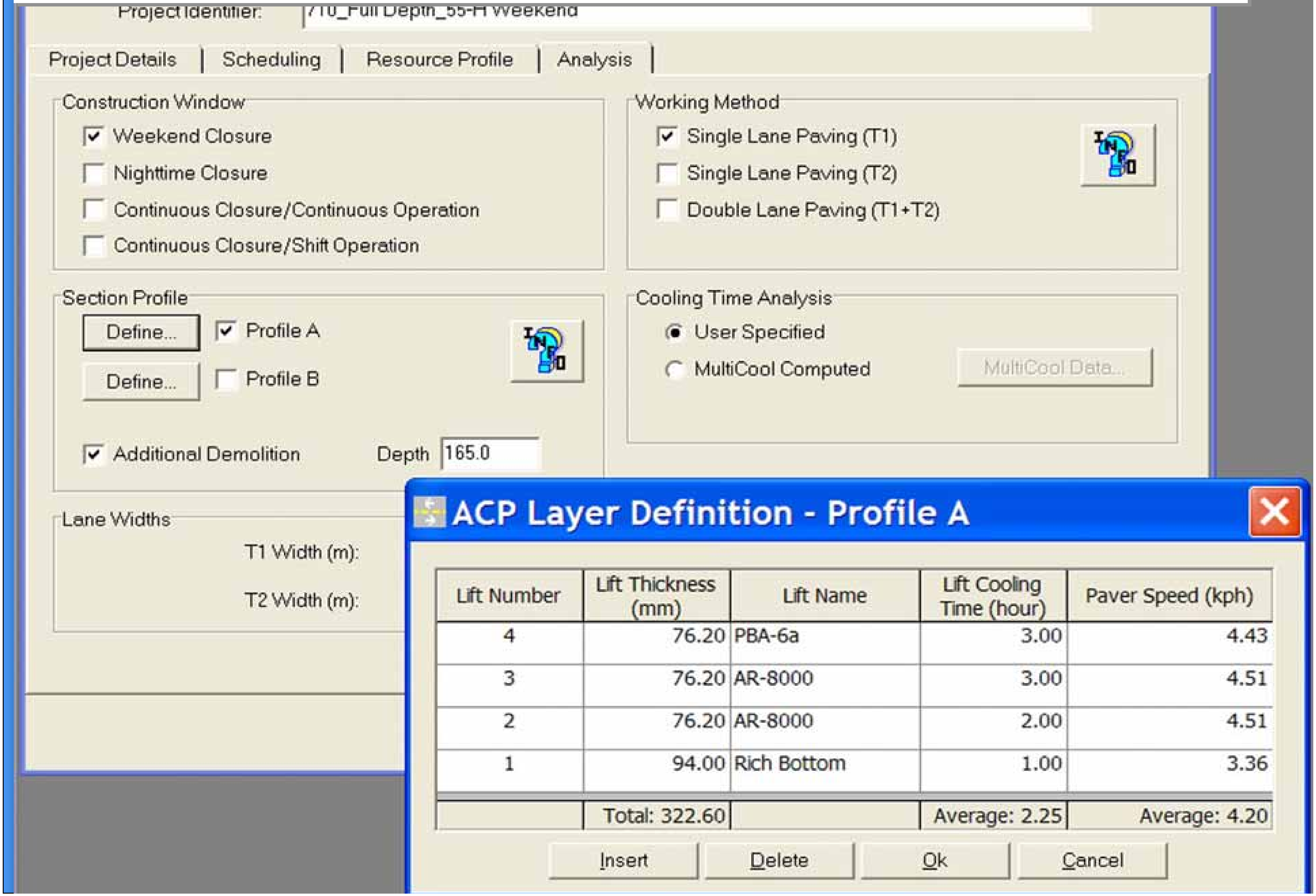
Input (3): Resource Profile



Input (4) - Concrete: Design & Traffic



Input (4) – Asphalt: Design & Traffic



Lift Number	Lift Thickness (mm)	Lift Name	Lift Cooling Time (hour)	Paver Speed (kph)
4	76.20	PBA-6a	3.00	4.43
3	76.20	AR-8000	3.00	4.51
2	76.20	AR-8000	2.00	4.51
1	94.00	Rich Bottom	1.00	3.36
	Total: 322.60		Average: 2.25	Average: 4.20

Deterministic Outputs

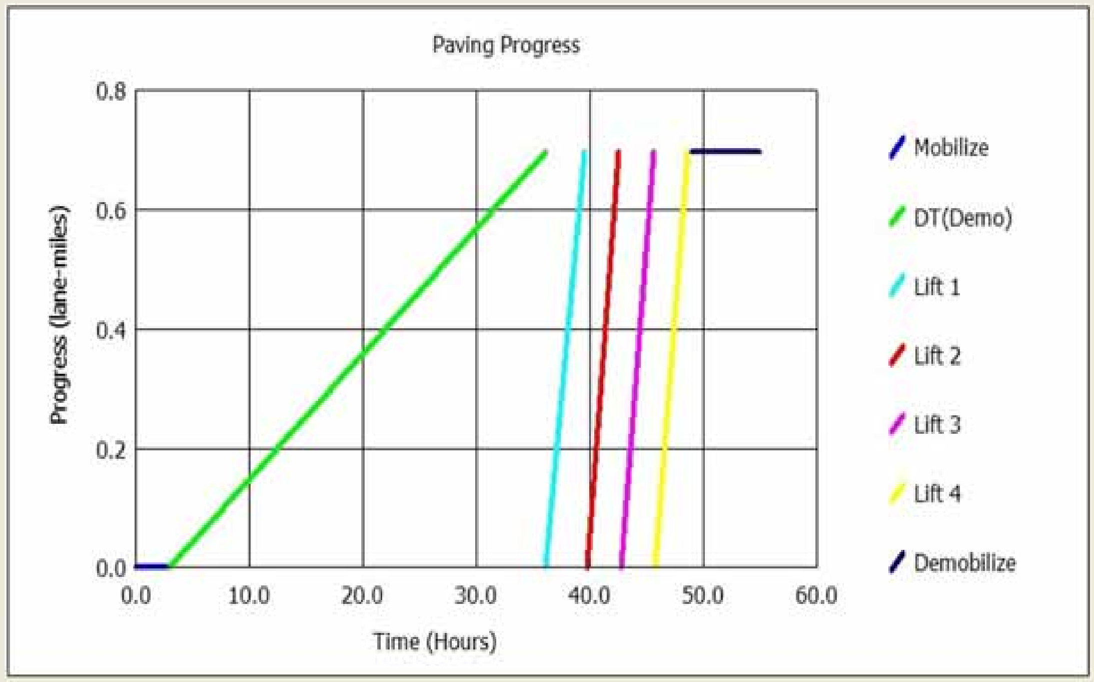
Production Details | Production Chart | Gantt Chart

Construction Window:	Continuous Closure/Continuous
Working Method:	Concurrent Double Lane (T1+T2)
Section Profile:	PCCP: 290.0 mm, New Base: 152.4
Curing Time:	12-Hours
Objective (lane-km):	17.00
Maximum Possible (lane-km):	2.56
Maximum Possible (c/l-km):	**1.28**
Construction Windows Needed	6.64
Demolition Quantity (cu. m):	4485.0
New Base Quantity (cu. m):	1545.0
Concrete Quantity (cu. m):	2940.0
Constraint Resource:	
Demolition to Paving:	N/A
Demolition Hours:	35.0
Paving Hours:	35.0

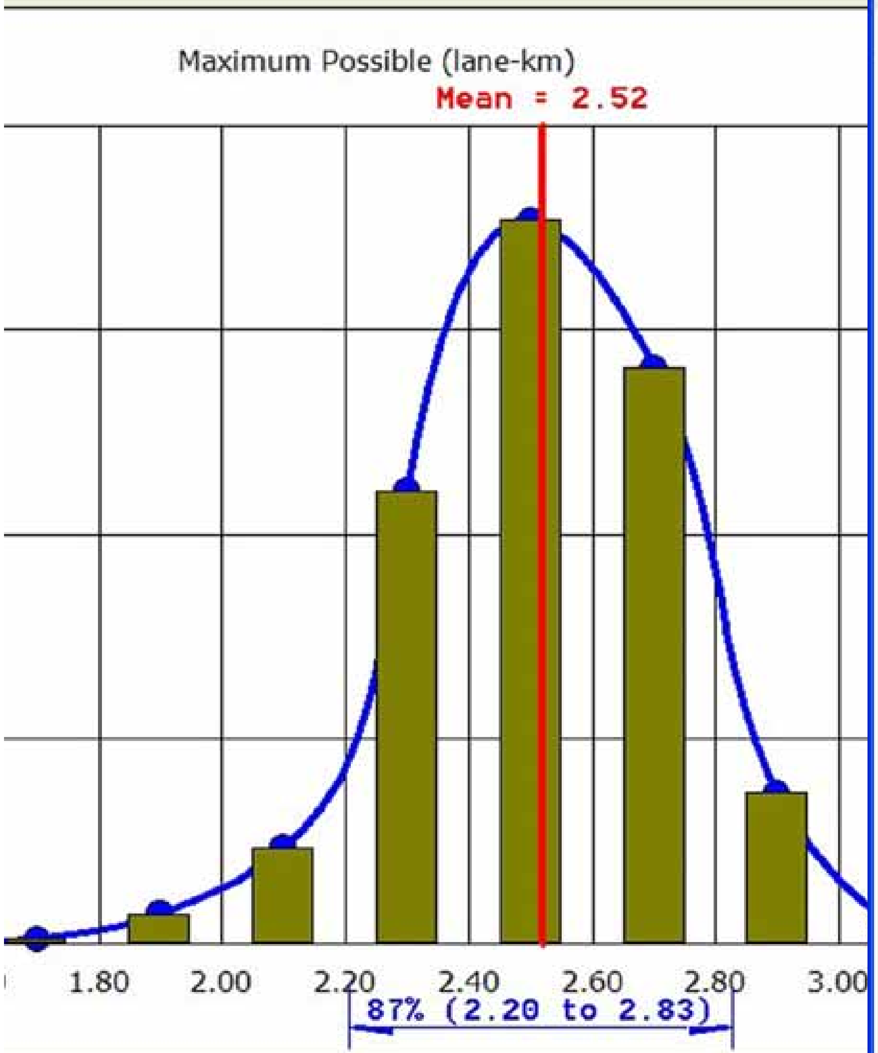
Resource	Allocated	Utilized
Dump Truck (per hour)	10.0	8.4
End Dump Truck (New Base)	8.0	6.3
Batch Plant (cu-m/hour)	150.0	84.0
End Dump Truck (PCC) (per	14.0	14.0
Paver Speed (m/min)	2.0	0.6

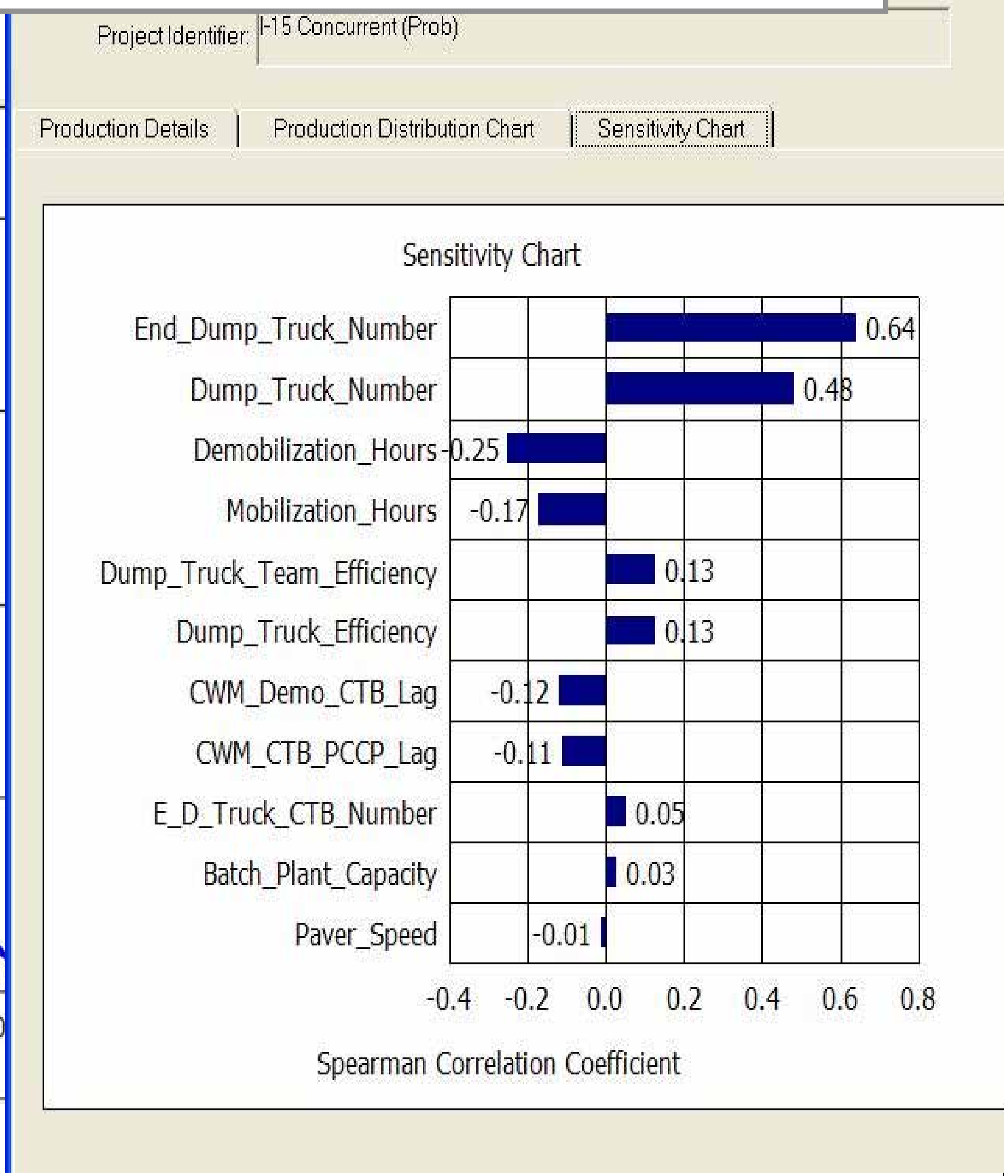
Project Identifier: 710_Full Depth_55-H Weekend

Production Details | Production Chart | Gantt Chart



Probabilistic Outputs





Alternatives Comparison - I-15 72-H (DEMONSTRATION)

Construction Window	Section Profile	Curing Time	Working Method	Maximum Possible (lane-km)	Constraint Resource	Construction Windows	Total Working Hours
Weekend Closure (55 Hours/Weekend)	203 mm (8 inches)	4-Hours	Concurrent Double Lane (T1+T2)	4.84	EDT(New Base),	3.51	193.0
		12-Hours		4.12	EDT(New Base),	4.13	227.1
	305 mm (12 inches)	4-Hours		2.06	DT(Demo)	8.26	454.1
		12-Hours		1.65	DT(Demo)	10.32	567.6
Nighttime Closure (15 Hours/Day)	203 mm (8 inches)	4-Hours		0.00	N/A	N/A	N/A
		12-Hours		0.00	N/A	N/A	N/A
	305 mm (12 inches)	4-Hours		0.00	N/A	N/A	N/A
		12-Hours		0.00	N/A	N/A	N/A
Continuous Closure/Continuous Operation (72 Hours/Closure)	203 mm (8 inches)	4-Hours		6.90	EDT(New Base)	2.46	177.3
		12-Hours		6.18	EDT(New Base),	2.75	198.2
	305 mm (12 inches)	4-Hours		3.23	DT(Demo)	5.27	379.4
		12-Hours		2.81	DT(Demo)	6.04	435.0

Production Comparison Analysis

Color Coding Legend

- Green: Objective can be accomplished in one Construction Window
- Cyan: Objective requires more than one Construction Window
- Red: Not a feasible Construction Window

Output Report

Report - I-15 72-H (DEMONSTRATION)

File

1/3

Constructability and Productivity Analysis for LLPRS

Project Details

Project Identifier: I-15 72-H (DEMONSTRATION)
Project Description: Caltrans District 8 Concrete Demonstration Project
Location: Deveore, San Bernardino, County, CA
Project Notes: Freeway has 3-4 lanes for each direction.2 trucklens for each direction will be reconstructedConstruction = 4.3 km Stretch (Segment 1= 2.5 km, Segment 2=1.8km)Total 17 lane-km = 4.3 (2.5 + 1.8) x 2 lanes x 2 directionsOld Pavement = 8" PCC + 4" CTBNew Pavement = 12" PCC + 6" AC Base

Analyst Name: EB Lee
Route Name: I-15 Devore, San Bernardino
Width of Outside Truck Lane (m): 3.6576
Construction Start Date: 3/1/2004
Mobilization (Hours): 4

Analysis Date: 3/18/2003
Objective (lane-km): 17.00
Width of Inside Truck Lane (m): 3.6576

Demobilization (Hours): 6

Resource Profile

Resource Description	Capacity Characteristics
Dump Truck (Demolition)	Rated Capacity: 22000 kg Trucks per Hour: 10 Efficiency: 0.65 Number of Team: 2 Team Efficiency: 0.90
End Dump Truck (New Base)	Rated Capacity: 7 cu. m Trucks per Hour: 8 Efficiency: 1.00
Batch Plant	Capacity: 150 cu. m/hour Number of Plants: 1
End Dump Truck (PCC)	Rated Capacity: 6 cu. m Trucks per Hour: 15 Efficiency: 1.00
Paver	Speed: 2 m/min Number of Pavers: 1

Analysis Options and Results

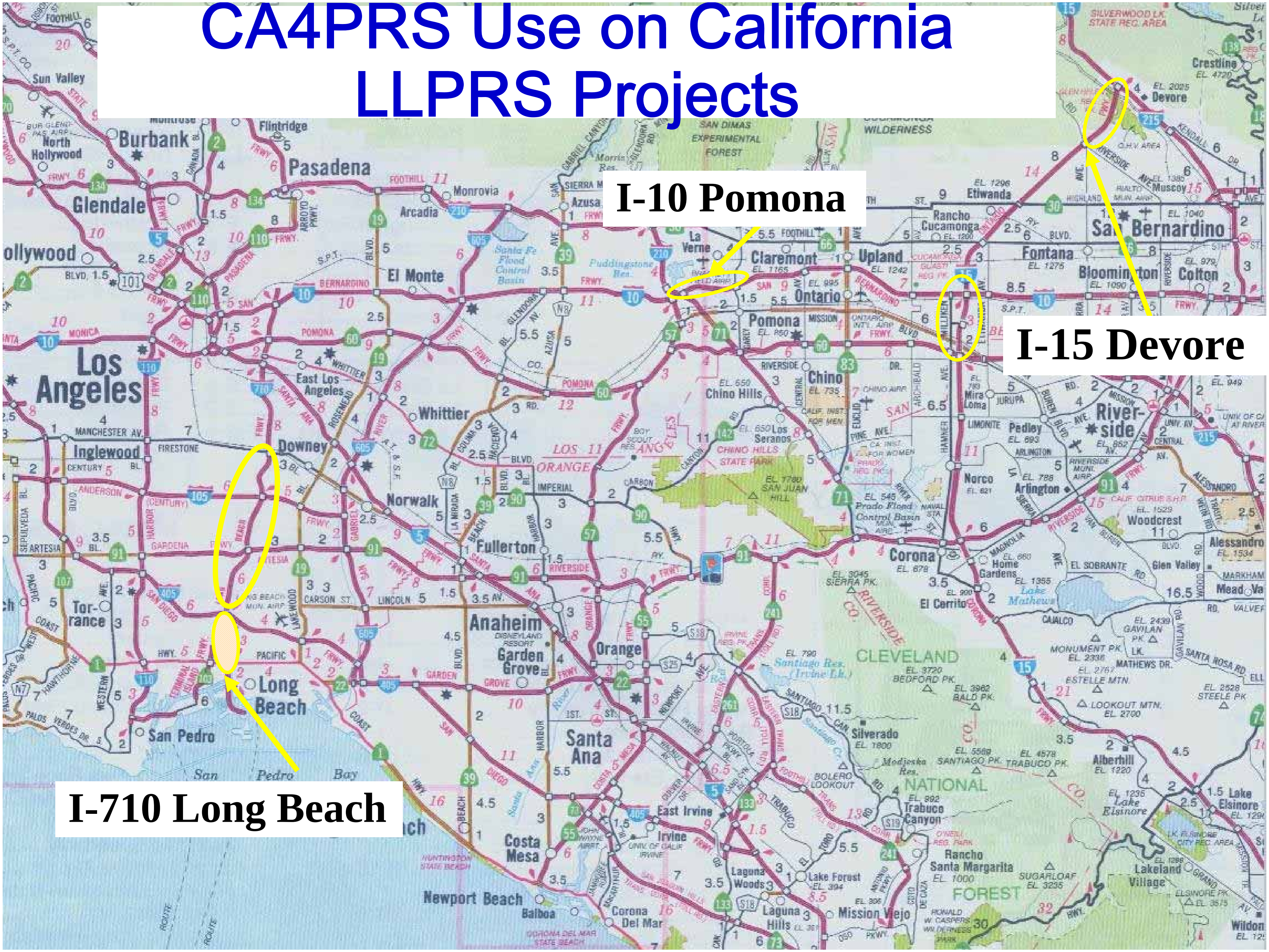
Construction Window:	Continuous Closure/Continuous Operation (72 Hours/Closure)

CA4PRS Application

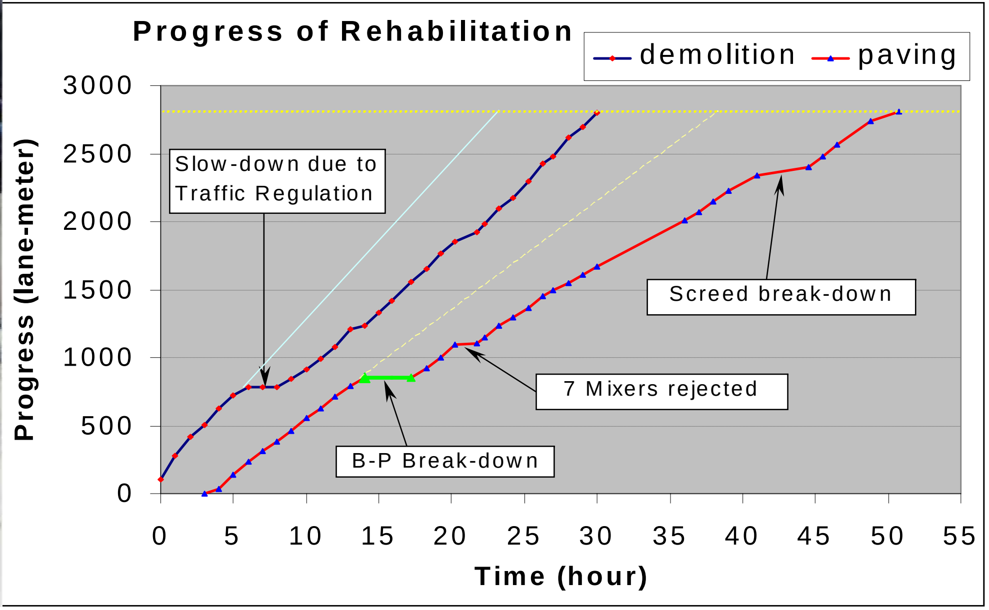
Software was developed with FHWA pooled-fund (SPTC): CA, MN, TX, WA

1999: I-10 Pomona (CA), FSHCC
2002: I-710 Long Beach (CA), AC
I-5 Seattle (WA), PCC
2003: I-15 Devore (CA), 12-hour PCC
2004: I-710 Phase 2 (CA), AC vs PCC
I-494 St. Paul (MN), AC
2005: I-15 Ontario (CA), PCC

CA4PRS Use on California LLPRS Projects



I-10 Pomona Project CA4PRS Verification

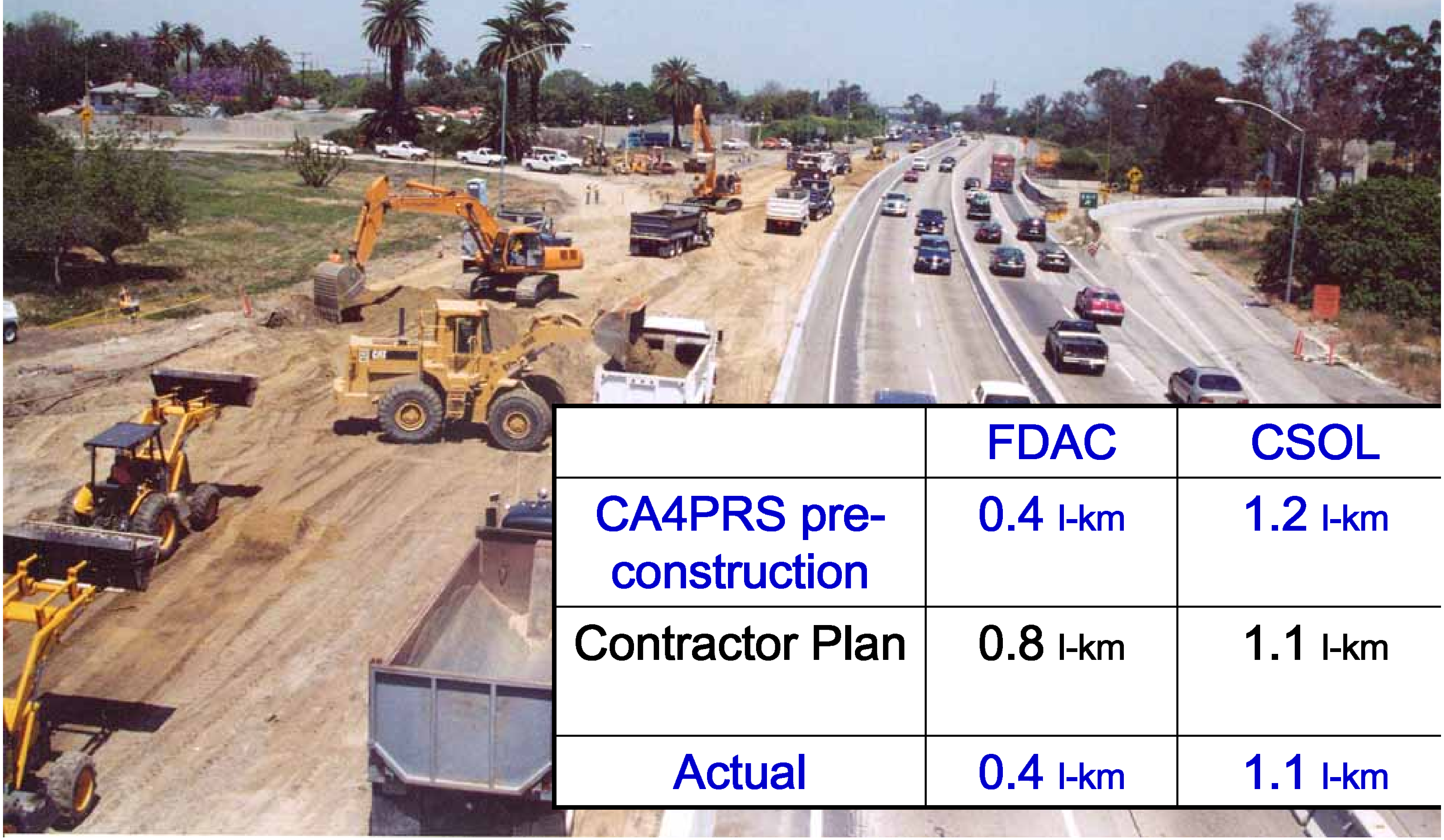


55-hour Weekend Production

- Contractor's Plan = 3.5 lane-km
- CA4PRS Estimate = 2.9 lane-km (2.4-3.4)
- Actual Performance = 2.8 lane-km

I-710 Long Beach project

Contractor revised “Staging-Plan” based on CA4PRS Recommendation



	FDAC	CSOL
CA4PRS pre-construction	0.4 l-km	1.2 l-km
Contractor Plan	0.8 l-km	1.1 l-km
Actual	0.4 l-km	1.1 l-km

Application of CA4PRS on I-15 Devore Project

2002 – Project Planning

- Compared night-time, 55-hr, 72-hr and continuous closures, lane closure approval
- Used to develop construction staging-plan for two truck lanes reconstruction

2003 – Design Development

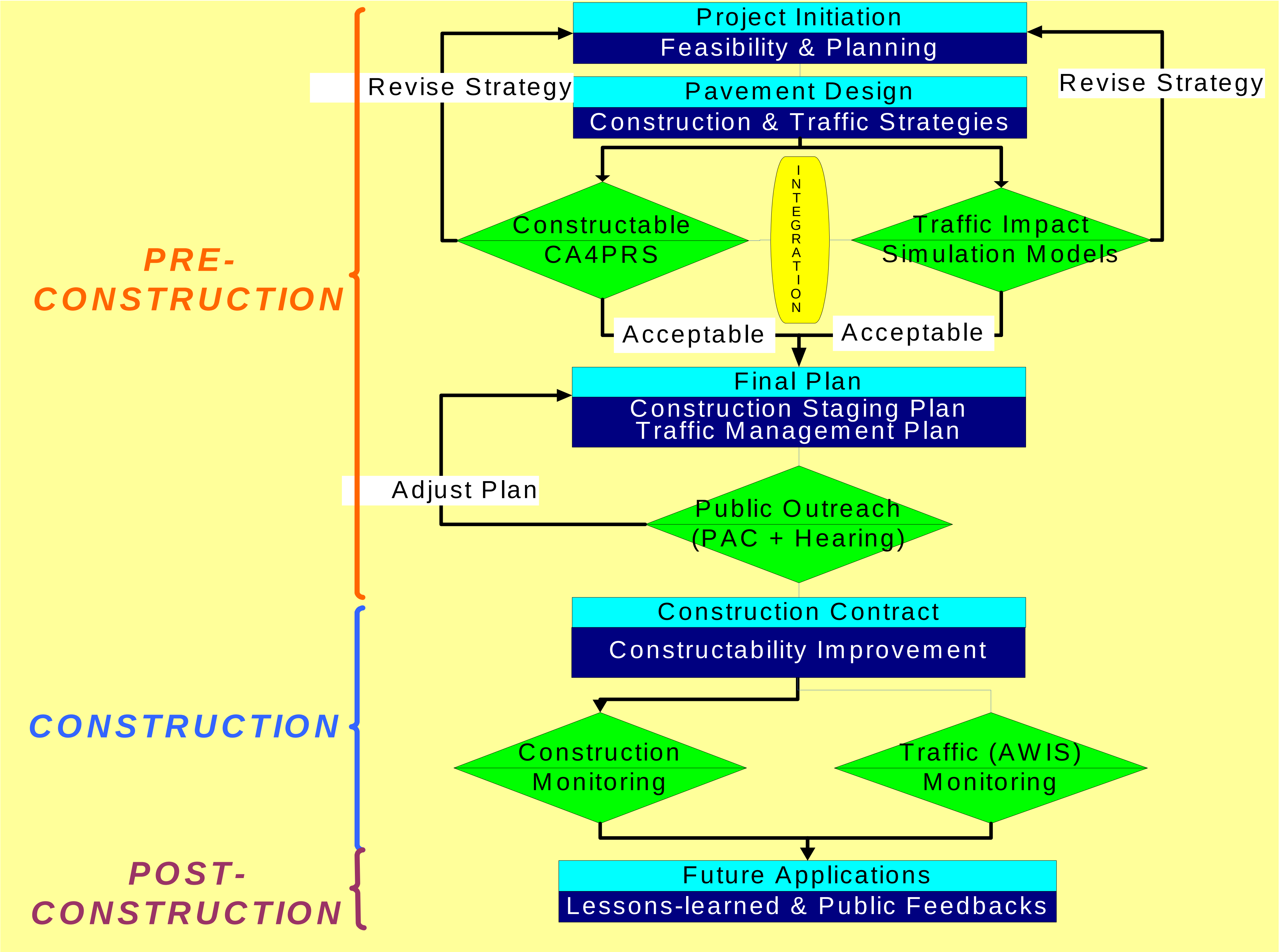
- Supported initial construction and traffic plans
- Detailed constructability and Incentives

2003 – Revise Plan due to high bid

- Reduce scope of reconstruction
- Evaluate full-closure vs partial closure

2004 – Revise Scheme for public response

- Support decision to use continuous closure



Project Initiation
Feasibility & Planning
Revise Strategy
Pavement Design
Construction & Traffic Strategies
Revise Strategy
Constructable
CA4PRS
INTEGRATION
Traffic Impact
Simulation Models
PRE-
CONSTRUCTION
Acceptable
Acceptable
Final Plan
Construction Staging Plan
Traffic Management Plan
Adjust Plan
Public Outreach
(PAC + Hearing)
Construction Contract
Constructability Improvement
CONSTRUCTION
Construction
Monitoring
Traffic (AWIS)
Monitoring
POST-
CONSTRUCTION
Future Applications
Lessons-learned & Public Feedbacks

I-15 Devore: Old vs. New Pavement Cross-section

CONCRETE	205mm (8")
CTB	102mm (4")
AB	305mm (12")
SG	

Old Section

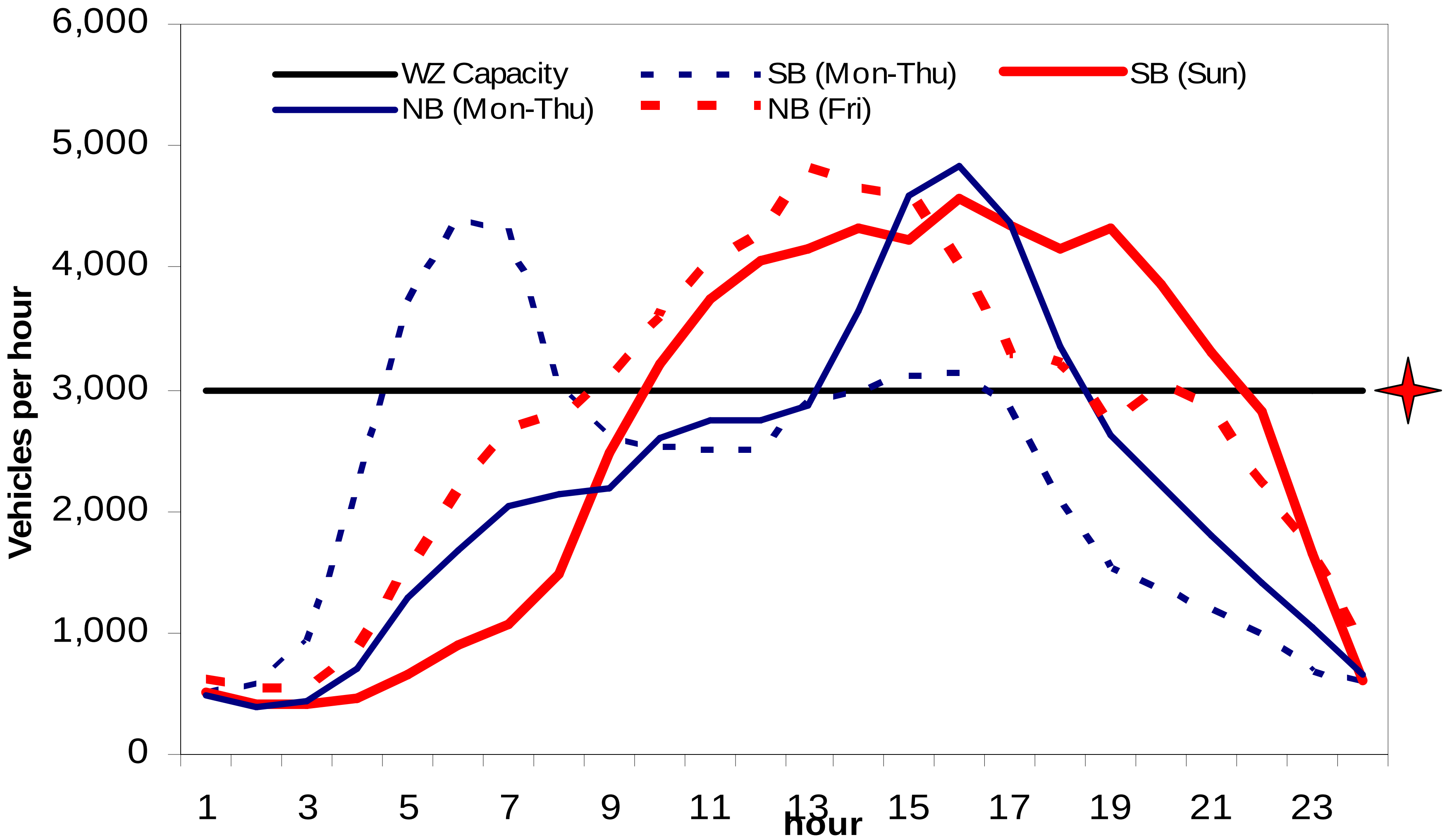
Removed | Retained

12-H Type III CONCRETE	290mm (11.5")
AC Base	152mm (6")
AB	152mm (6")
SG	

New Section

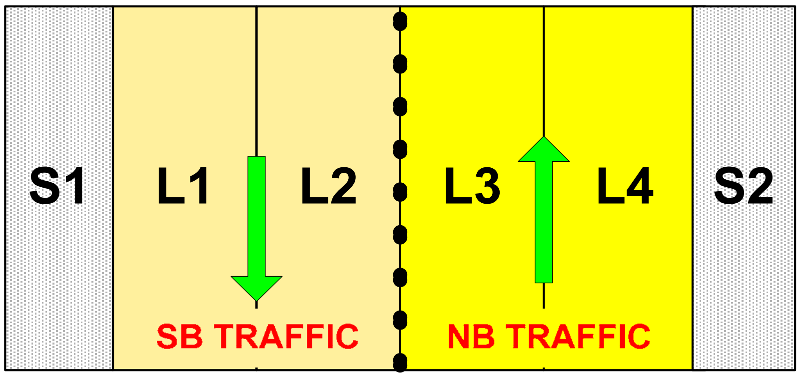
New PCC | New Base

I-15 Devore: Daily Traffic Patterns

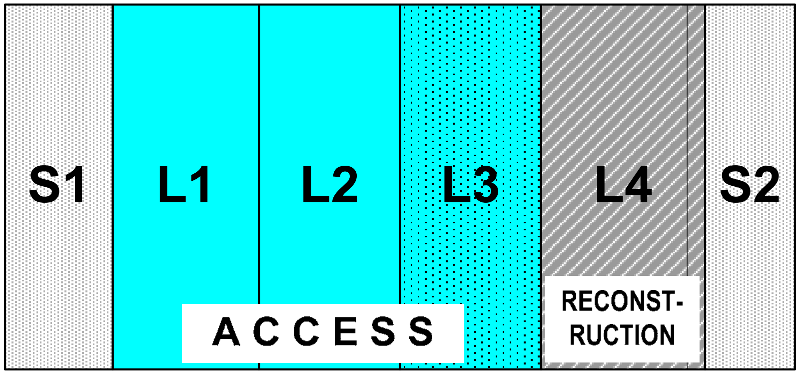


Lane Closure: Full-closure with Counter-flow Traffic

Segment 1 (4-lane) Section

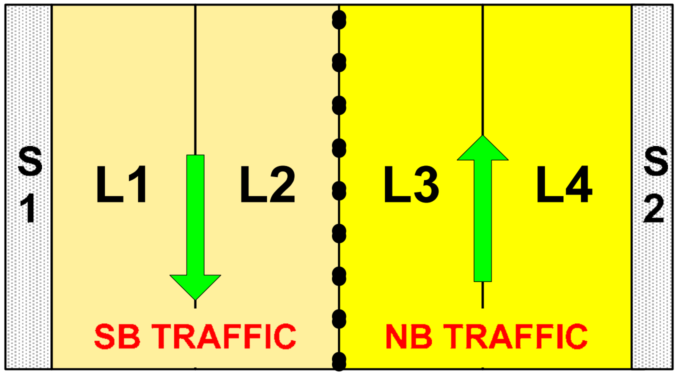


Traffic Roadbed

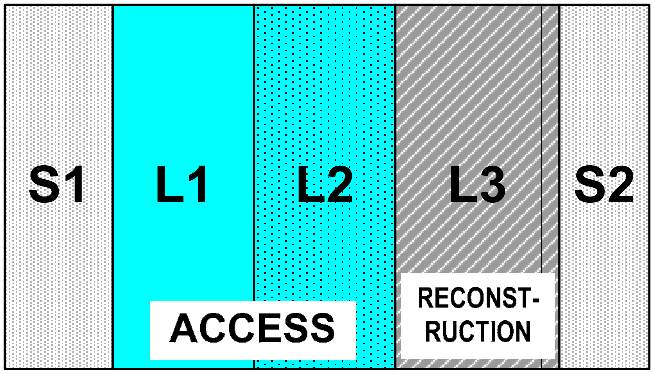


Construction Roadbed

Segment 2 (3-lane Section)



Traffic Roadbed



Construction Roadbed

I-15 Devore: Construction Scenarios Evaluated

- Basic: Construction Windows
  - 72-Hour Weekday Closures
  - 55-Hour Weekend Closures
  - 1 Roadbed Continuous Closures
  - 10-Hour Night-time Closures
- Constructability Reviews
  - Variation of 72-Hour Weekday Closures
  - Mix Design: <u>12-Hour Type III</u> vs. FSHCC
  - Base Type: Lean-concrete vs. <u>AC Base</u>
  - <u>Widened truck-lane</u> vs. Tied-concrete shoulder

I-15 Devore: Schedule Comparison
CA4PRS Analysis Results

	Construction Scenario	Total Closures	Total Closure Hours	%
(2)	72-Hour Weekday	***8***	***512***	***100%***
(3)	55-Hour Weekend	***10***	***550***	***110%***
(1)	1 Roadbed Continuous	***2***	***400***	***78%***
(4)	10-Hour Night-time	***220***	***2,200***	***430%***

Provided Schedule-baseline for Traffic and Cost analyses

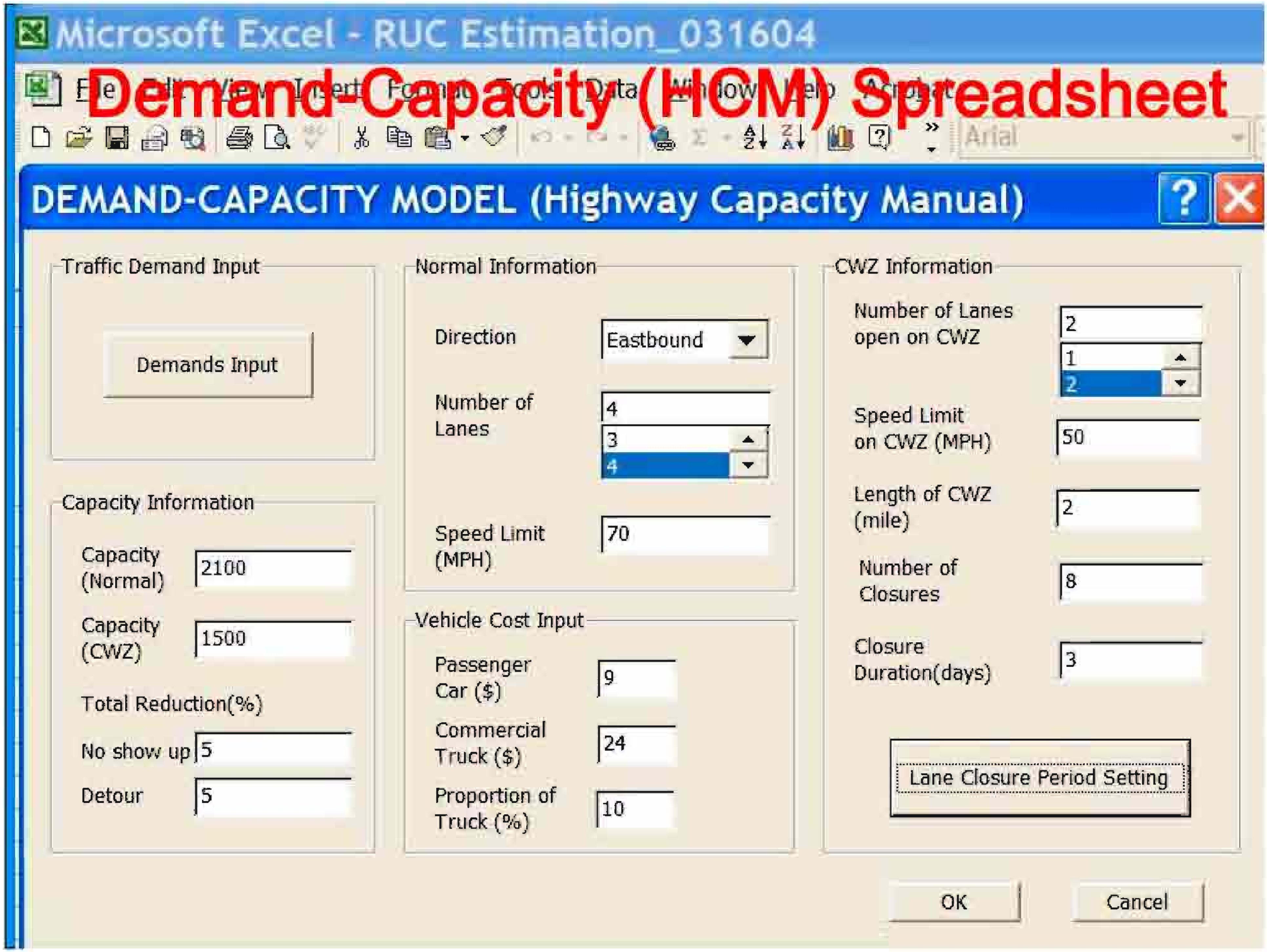
How to minimize delay

- Traffic Management Plan
  - Reduce demand through Construction Work Zone
  - Traveler information
- Design traffic separators to minimize chaos
- Maximize work zone traffic lane capacity
- Fast construction

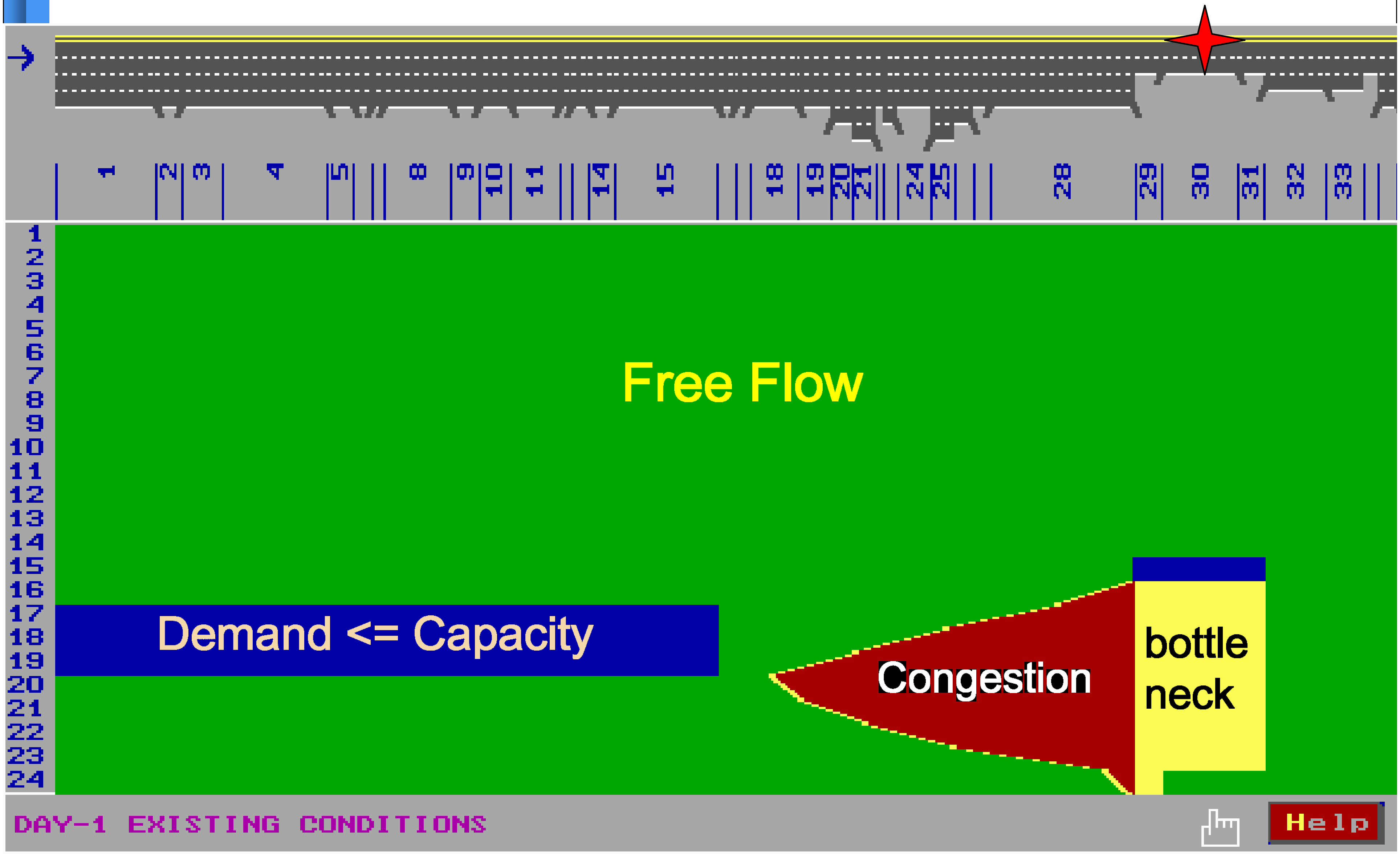
I-15 Devore: Traffic Analysis Models Integrated with CA4PRS

- Step 1: Demand-Capacity Model (HCM)
  - Road user cost: Compare all scenarios
  - Select the most economical scenario: Total cost
  - Sensitivity for TMP (Demand reduction, CWZ capacity)
- Step 2: Macro Traffic Simulation (FREQ)
  - Focus on the Selected Construction Scenario
  - Baseline for Incentives/disincentives and A+B contract
  - Develop lane closure charts
- Step 3: Microscopic Simulation (PARAMICS)
  - Blocking Freeway Connector: I-210 to I-15 NB
  - Truck restriction during peak hours through CWZ
  - Relocate the junction split location

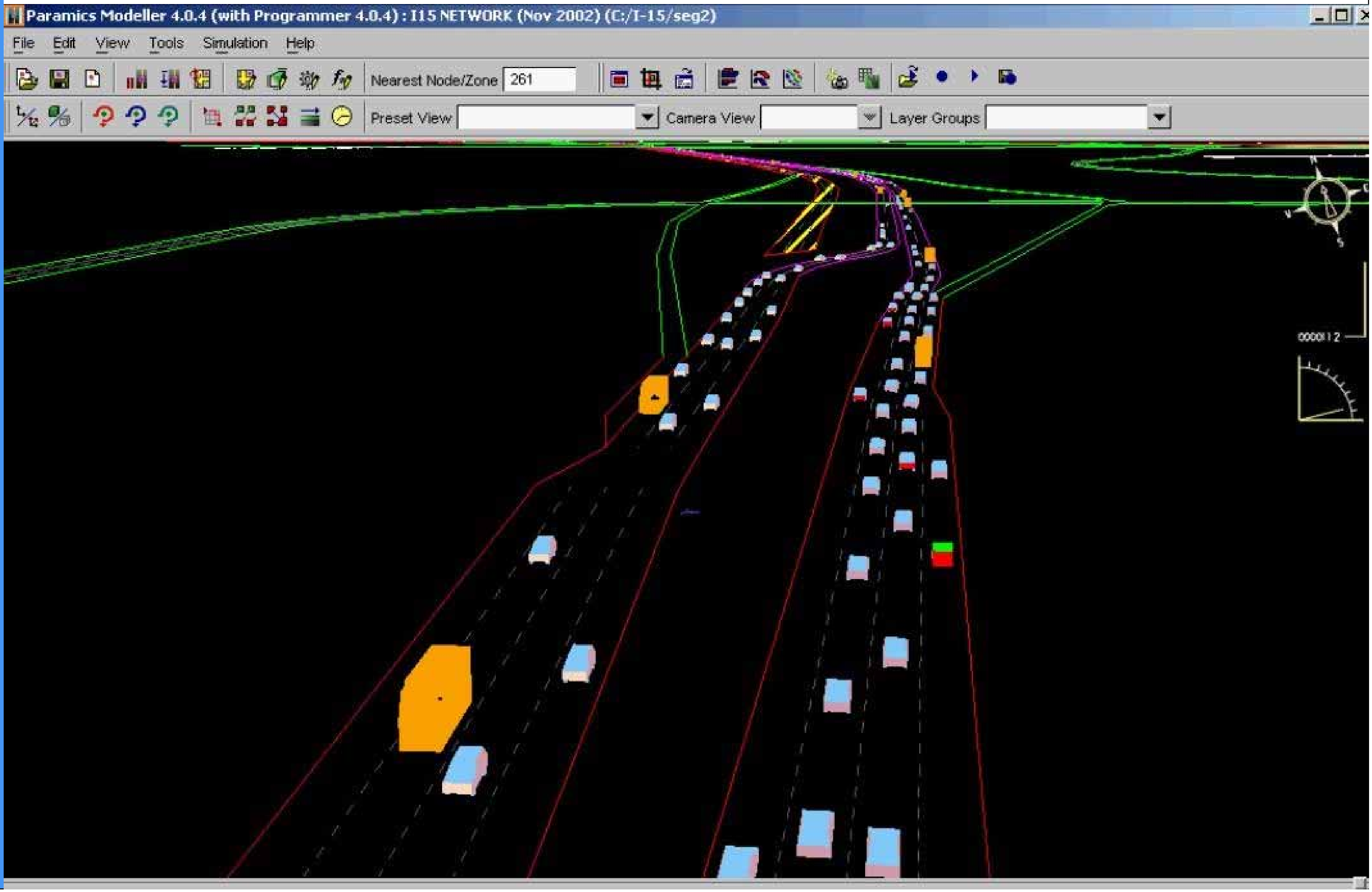
Demand-Capacity (HCM) Spreadsheet



FREQ Macro-simulation
Segment 1 Northbound Closure (NB traffic)



Paramics: Microscopic Simulation Model



CA4PRS on DRI Website

Construction Analysis for Pavement Rehabilitation Strategies (CA4PRS) - Microsoft Internet Explorer

Address: http://www.dot.ca.gov/research/roadway/ca4prs/ca4prs.htm

Division of Research and Innovation

CA4PRS

Construction Analysis for Pavement Rehabilitation Strategies (CA4PRS)

Developed as a LLPRS planning tool, CA4PRS (Construction Analysis for Pavement Rehabilitation Strategies) estimates the amount of highway pavement that can be rehabilitated under various project constraints. The software provides a construction schedule baseline for the integrated analysis of pavement design, construction logistics, and traffic operations. It was designed to help agencies and paving contractors develop construction schedules that minimize traffic delay and agency costs. Application to several urban freeway rehabilitation projects with heavy traffic volume in California, including I-10 Pomona (District 7), I-710 Long Beach (District 7), and I-15 Devore (District 8) reconstruction projects, has demonstrated the tool's value.

CA4PRS considers **what-if** scenarios for major parameters and alternatives, such as the followings:

- ***Rehabilitation strategy:*** Portland Cement Concrete (PCC) reconstruction, crack-seat PCC and asphalt concrete overlay (CSOL), or full-depth asphalt concrete replacement (FDAC).
- ***Construction window:*** nighttime closures, weekend closure,

Picking the best alternative

Use life cycle cost analysis for specific project conditions

I-15 Devore Selected the Most Economical Scenario: Schedule, Traffic Delay, Total Costs

Construction Scenario	*Schedule Comparison*		Cost Comparison ($M)			Max. Peak Delay (Min)
	Total Closures	Closure Hours	User Delay	Agency Cost	Total Cost	
1 Roadbed Continuous	*2*	*400*	*5.0*	*15.0*	*20.0*	80
72-Hour Weekday Continuous	*8*	*512*	*5.0*	*16.0*	*21.0*	50
55-Hour Weekend Continuous	*10*	*550*	*10.0*	*17.0*	*27.0*	80
10-Hour Night-time Closures	*220*	*2,200*	*7.0*	*21.0*	*28.0*	30

Public responses changed 72-hour closures scheme to one-roadbed continuous scenario

Summary

- Areas of PPRC research to support Caltrans rehabilitation of the network
  - Pavement design and materials
  - Construction
  - Construction work zone traffic
  - Life cycle cost analysis
- Bottom line:
  - There is no benefit from research unless it is successfully implemented