Constructability and Productivity Analysis for Long Life Pavement Rehabilitation Strategies (LLPRS)

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Pavement Research Center + Construction Engineering & Management
University of California, Berkeley
Background of Constructability Research
Motivation: CA Highway Situation

- **Needs Massive Rehabilitation**
  - Total 80,000 l-km Highway System
  - Built 50s-70s with 20 years Design Life
  - Service 30-40 years: Adverse Effects
  - 7,000 l-km Needs Immediate Care
  - Other States: Partnership (CA, WA, TX & MN)

- **LLPRS: Caltrans’ Rehabilitation Strategies**
  - SHOPP($10B): Rehab. 3,000 l-km (1998-2007)
  - Long Life Pavement Rehabilitation Strategies
    - Provide 30-40 years of Service Life
    - 6 lane-km Rehab./55-hour Weekend Closure
UCB LLPRS Constructability Research

- **Stage 1: Concrete Constructability Analysis**
  - Caltrans (CAL/APT)

- **Stage 2: Concrete Case Study**
  - I-10 Project with IPRF/FHWA

- **Stage 3: Asphalt Constructability Analysis**
  - Caltrans (P-PRC)

- **Stage 4: Asphalt Case Study**
  - I-710 Project with NAPA

- **Stage 5: Analysis Simulation Software**
  - 4 States Fund (CA/WA/MN/TX)
Constructability Information Process

Joint Research

DOT (CALTRANS)

UCB Pavement Research Center

UCB Construction Engineering Management

Contractors Association (ACPA & NAPA)

Field Sections

LLPRS
Construction Windows Lane Closure Tactics

Design Criteria
Material Design
Material Test

Technical Analysis
Economic Analysis
Developing Innovations

Provision of Information
Verification of Information

Site Observations
Case Studies

Field Sections

Joint Research
Typical Failures of Rigid Pavement

(a) Typical Faulting Distress

(b) Typical Transverse Fatigue and Corner Cracks

(c) Typical Longitudinal Cracks

(from PRC of UCB)
Example of Typical Failures (I-10)
Two Types of Pavement Rehabilitation

- **Concrete Rehabilitation**
  - Shoulder
  - Non-Truck Lanes
  - Truck Lanes
  - Shoulder
  - Replace Broken Slabs
  - Remove Existing PCC & Base
  - PCC Reconstruction

- **Asphalt Rehabilitation**
  - Shoulder
  - Non-Truck Lanes
  - Truck Lanes
  - Shoulder
  - Crack and Seat Slabs
  - Place Overlay (CSOL)
  - Remove Existing PCC & Base
  - Place Full Depth A/C
Research Approach & Objectives

- Define Typical Rehabilitation Strategies
- Model Detailed Rehabilitation Process
  - Hierarchical Analysis Structure
- Prototype Analysis Software
  - Estimate Production Capability
- Parametric Study
  - Constraints & Innovation for Improvement
- Case Studies
  - Validation / Calibration of Analysis Model
- Professional Analysis Simulation Software
Two Analysis Modules

- **Deterministic Analysis**
  - Constants Parameters
  - Most Likely Number as Input
  - Estimate Average Production Capability

- **Stochastic Analysis**
  - Random Variable Analysis
  - “Mote Carlo Simulation” Technique
  - Crystal Ball / Excel / VBA Interface
  - PDF (Probability Distribution Function)
  - Predicted Production Capability
    - Lower Boundary, Mean, Upper Boundary
# Basic Condition of the Project:

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>Unit</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective</td>
<td>6.0</td>
<td>lane-km</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mobilization</td>
<td>3.5</td>
<td>hours</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construction Window</td>
<td>55.0</td>
<td>hours</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demobilization</td>
<td>4.0</td>
<td>hours</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Batch Plant**: 220 cu yd/hour 1 no
- **Dump Truck**: 18 per hour 10 ton
- **End Dump Truck**: 10 per hour 7 cu yd
- **Paver Speed**: 10 ft/min 1 no
- **E-D-Truck (CTB)**: 0 per hour 0 cu yd

**Working Method**: 8" PCC, Curing: 4 hrs, Concurrent: T1
Predicted Production (Deterministic)

**Basic Condition:**
- 8" PCC, Curing: 4 hrs, Concurrent: T1, Mobil: 3.5 hrs, DeMo: 4.0 hrs

**Within Construction Window:** 55.0 hours

- Production: 2.8 lane-km
- Constraint Resource: End Dump Truck

**To Meet Objective:** 6.0 lane-km

- The Construction Window needed: 99 hours

**To Meet Objective:** 6.0 lane-km, within Construction Window: 55.0 hours

**The Needed Resources:**
- Batch Plant: 148 cuyd/hr
- End Dump Truck: 21 no/hr
- Dump Truck: 27 no/hr
- Paver Speed: 8 ft/min
Predicted Production (Stochastic)

Certainty is 68.00% from 1,266 to 1,581 lane-meters

Mean = 1,401

Worst Scenario

Best Scenario

Most Likely

Mean = 1,401

Certainty is 68.00% from 1,266 to 1,581 lane-meters
Concrete Analysis Model
Concrete Analysis Structure

- **Paving Material**
  - 203 mm Slab
    - **Curing Time**
      - 4 hour: FSHCC
      - 8 or 12 hour: PCC
    - **Concurrent**
      - Single-Lane
      - Double-Lane
    - **Sequential**
      - Single
      - Double

- **254 or 305 mm Slab**
  - **Curing**
    - 4 hour
    - 8 or 12 hour
  - **C**
    - **S**
    - **D**
    - **S**
    - **D**
Typical Concrete Profiles

Caltrans Objective:
6 ln-km per 55 hrs
Concurrent Working Method

(a) Concurrent / Single(T1)

(b) Concurrent / Single(T2)

(c) Concurrent / Double(T1+T2) (Counter-Flow Traffic)

(d) Linear Scheduling

Schedule (hours)

Progress (lanes-km)

- Mob.
- Demol
- Paving
- Curing
- C.W.
Sequential Working Method

(a) Sequential / Single(T1)

(b) Sequential / Single(T2)

(c) Sequential / Double(T1+T2)

(d) Linear Scheduling
Typical CPM (Sequential Method)
<table>
<thead>
<tr>
<th>Resources</th>
<th>Unit</th>
<th>Capacity</th>
<th>Concurrent</th>
<th>Sequential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batch Plant</td>
<td>M³ / hour</td>
<td>1</td>
<td>150-250</td>
<td>150-250</td>
</tr>
<tr>
<td>Dump Truck (Demo)</td>
<td>per hour</td>
<td>25 Ton</td>
<td>8-12</td>
<td>8-12</td>
</tr>
<tr>
<td>End Dump Truck (PCC)</td>
<td>per hour</td>
<td>6-9 M³</td>
<td>8-12</td>
<td>8-12</td>
</tr>
<tr>
<td>Paver Speed</td>
<td>M / min.</td>
<td>1</td>
<td>3-5</td>
<td>3-5</td>
</tr>
<tr>
<td>End Dump Truck (CTB)</td>
<td>per hour</td>
<td>9 M³</td>
<td>5-8</td>
<td>5-8</td>
</tr>
</tbody>
</table>

- **Total Number of Trucks to be Mobilized**

  Trucks per hour x Shift No. x Turn-around time
Results of Concrete Analysis
### Example of Single lane Production

[unit: Lane-km]

<table>
<thead>
<tr>
<th>Slab Thick.</th>
<th>203mm Concrete</th>
<th>254mm Concrete</th>
<th>305mm Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curing Time</td>
<td>Concurrent</td>
<td>Sequential</td>
<td>Concurrent</td>
</tr>
<tr>
<td>4 hour</td>
<td>3.8</td>
<td>2.4</td>
<td>1.9</td>
</tr>
<tr>
<td>8 hour</td>
<td>3.4</td>
<td>2.2</td>
<td>1.7</td>
</tr>
<tr>
<td>12 hour</td>
<td>3.0</td>
<td>2.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Constraint</td>
<td>Paver Speed</td>
<td>Paver Speed</td>
<td>Dump Truck</td>
</tr>
<tr>
<td>(Demo:Pave)</td>
<td>N/A</td>
<td>1 : 1.31</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Example of Concrete Analysis Results

Progress vs. Curingtime

- 8"
- 10"
- 12"
- Objective
<table>
<thead>
<tr>
<th>Options</th>
<th>Comparison</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Profile</td>
<td>203 =&gt; 254</td>
<td>40%</td>
</tr>
<tr>
<td></td>
<td>203 =&gt; 305</td>
<td>47%</td>
</tr>
<tr>
<td></td>
<td>254 =&gt; 305</td>
<td>12%</td>
</tr>
<tr>
<td>Curing Time</td>
<td>4 hr =&gt; 8 hr</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>8 hr =&gt; 12 hr</td>
<td>11%</td>
</tr>
<tr>
<td></td>
<td>4 hr =&gt; 12 hr</td>
<td>19%</td>
</tr>
<tr>
<td>Work Method</td>
<td>203 mm</td>
<td>29%</td>
</tr>
<tr>
<td>(Concur. =&gt; Sequen.)</td>
<td>254 or 305mm</td>
<td>21%</td>
</tr>
<tr>
<td>Paving lane</td>
<td>203 mm</td>
<td>17%</td>
</tr>
<tr>
<td>(Double =&gt; Single)</td>
<td>254 or 305mm</td>
<td>7%</td>
</tr>
<tr>
<td>EDT Capacity</td>
<td>22 =&gt; 15 ton</td>
<td>15%</td>
</tr>
<tr>
<td>Cycle Time</td>
<td>3 =&gt; 4 min</td>
<td>24%</td>
</tr>
</tbody>
</table>
Comparison of Construction Windows

<table>
<thead>
<tr>
<th>Slab Thickness</th>
<th>203 mm</th>
<th>254 mm</th>
<th>305 mm</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cont. (3 shift)</td>
<td>1.4</td>
<td>2.1</td>
<td>2.4</td>
<td>Weeks</td>
</tr>
<tr>
<td>Cont. (1 Shift)</td>
<td>4.0</td>
<td>5.9</td>
<td>6.6</td>
<td>Weeks</td>
</tr>
<tr>
<td>Weekend</td>
<td>6.2</td>
<td>10.1</td>
<td>11.4</td>
<td>No. of Weekend</td>
</tr>
</tbody>
</table>
Preliminary Findings for Concrete

- **Caltrans’ Objectives for LLPRS**
  - Maximum Target = 3.5 Truck lane-km / 55 HR
  - Most likely = 2.0 - 3.0 lane-km

- **Parametric Study (Critical Parameters)**
  - Concrete Curing Time is Not the Most Critical Parameter
  - Design Profile has the Biggest Impact
  - Delivery Trucks Constrain Production

- **Unclear Benefits of FSHCC (vs. PCC)**
  - Needs Production vs Cost Analysis
Summary of Concrete Case Study (I-10)
Case Study: Concrete on I-10
Asphalt (AC) on I-710
I-10 Project: Work Scope

- 20 lane-km (3 l-km Weekend + Nighttime)
- Rebuild Two Truck lanes (No.3 & 4)
- 8” Slab Replacement with FSHCC (4 hr curing)
- Concurrent Work / Single Lane
I-10 Project: Traffic Conditions

Traffic before Rehabilitation

Traffic during Rehabilitation
I-10 Project: Slab Demolition (non-impact)

Non-Impact Demolition
Drilling Holes for Tie-bars

Installation of Dowel Bars and Tie Bars
I-10 Project: Screed for FSHCC Paving
I-10 Project: Washing / Chipping (FSHCC)

Washing Mixer Truck

Chipping FSHCC Build-up

Washing Mixer Truck
I-10 Project: Breakdown of M-T Cycle-time

Breakdown of a Mixer cycle-time (70 min.)

- Waiting for pouring: 15 minutes
- Concrete pouring: 5 minutes
- Washing: 5 minutes
- Move to batch plant: 15 minutes
- Measure weight: 5 minutes
- Waiting for charge: 5 minutes
- Concrete charge: 10 minutes
- Record slip: 5 minutes
- Move to site: 5 minutes
## I-10 Project: Nighttimes vs Weekend

<table>
<thead>
<tr>
<th></th>
<th>Nighttime Closure</th>
<th>Weekend Closure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main Work (hours)</strong></td>
<td>2 hour</td>
<td>5 hours</td>
</tr>
<tr>
<td><strong>Auxiliary Work (hours)</strong></td>
<td>5 hours</td>
<td>5 hours</td>
</tr>
<tr>
<td><strong>Slab No. Replaced</strong></td>
<td>15</td>
<td>50</td>
</tr>
<tr>
<td><strong>Productivity (slabs / hour)</strong></td>
<td>7.5</td>
<td>10</td>
</tr>
<tr>
<td><strong>Major Resources</strong></td>
<td>7 D-T 4 M-T</td>
<td>7 D-T 8 M-T</td>
</tr>
<tr>
<td></td>
<td>21 D-T 12 M-T</td>
<td></td>
</tr>
</tbody>
</table>
I-10 Project: Prediction from the UCB Model

Forecast: FSHCC-4hr

1,500 Trials

12 Outliers

Certainty is 85.00% from 2.4 to 3.4

Estimate = 2.4 ~ 3.4 lane-km / 55 hours
Mean = 2.9 lane-km / 55 hours
I-10 Project: Overall Rehabilitation Progress

Actual Performance = 2.8 lane-km / 55 hours
Concrete Case Study: I-10 Project
I-10 Project: Traffic Flow Comparison

Mean = 2,000 Cars / hour
Speed = 50 ~ 80 mph
AC (Asphalt) Analysis Model
Change of Design Profile (CSOL: Crack Seat and Overlay)

Existing Pavement

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thick.</th>
<th>Cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCC</td>
<td>203mm (8&quot;)</td>
<td></td>
</tr>
<tr>
<td>CTB</td>
<td>102mm (4&quot;)</td>
<td></td>
</tr>
<tr>
<td>AB</td>
<td>305mm (12&quot;)</td>
<td></td>
</tr>
<tr>
<td>SG</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Layer Profile "A"

Total thick. = 230 mm (9")

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thick.</th>
<th>Cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final Lift</td>
<td>25 mm</td>
<td>0.5 hour</td>
</tr>
<tr>
<td>3rd Lift</td>
<td>75 mm</td>
<td>4 hour</td>
</tr>
<tr>
<td>2nd Lift</td>
<td>75 mm</td>
<td>4 hour</td>
</tr>
<tr>
<td>1st Lift</td>
<td>55 mm</td>
<td>2 hour</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thick.</th>
<th>Cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCC</td>
<td>203mm (8&quot;)</td>
<td></td>
</tr>
<tr>
<td>CTB</td>
<td>102mm (4&quot;)</td>
<td></td>
</tr>
<tr>
<td>AB</td>
<td>305mm (12&quot;)</td>
<td></td>
</tr>
<tr>
<td>SG</td>
<td>25 mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>75 mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>75 mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>55 mm</td>
<td></td>
</tr>
</tbody>
</table>

Layer Profile "B"

Total thick. = 200 mm (8")

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thick.</th>
<th>Cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final Lift</td>
<td>50 mm</td>
<td>2 hour</td>
</tr>
<tr>
<td>3rd Lift</td>
<td>50 mm</td>
<td>2 hour</td>
</tr>
<tr>
<td>2nd Lift</td>
<td>75 mm</td>
<td>4 hour</td>
</tr>
<tr>
<td>1st Lift</td>
<td>25 mm</td>
<td>0.5 hour</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thick.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCC</td>
<td>203mm (8&quot;)</td>
</tr>
<tr>
<td>CTB</td>
<td>102mm (4&quot;)</td>
</tr>
<tr>
<td>AB</td>
<td>305mm (12&quot;)</td>
</tr>
<tr>
<td>SG</td>
<td>25 mm</td>
</tr>
</tbody>
</table>

OR

Retained Fabric AC(CSOL)
Work Plan (CSOL)

1. Full Closure + Full Completion

2. Half Closure + Full Completion

3. Half Closure + Partial Completion

(a) Plan View (1'\text{st} \text{ stage})

(b) Sequence of Paving
# Change of Design Profile (Full Depth AC Replacement)

## Existing Pavement

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thick.</th>
<th>Cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCC</td>
<td>203mm (8&quot;)</td>
<td></td>
</tr>
<tr>
<td>CTB</td>
<td>102mm (4&quot;)</td>
<td></td>
</tr>
<tr>
<td>AB</td>
<td>305mm (12&quot;)</td>
<td></td>
</tr>
<tr>
<td>SG</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Layer Profile "A"

<table>
<thead>
<tr>
<th>Lift</th>
<th>Layer</th>
<th>Thick.</th>
<th>Cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>AB</td>
<td>76mm</td>
<td>1 hour</td>
</tr>
<tr>
<td>2nd</td>
<td>AB</td>
<td>76mm</td>
<td>2 hour</td>
</tr>
<tr>
<td>3rd</td>
<td>AB</td>
<td>76mm</td>
<td>6.5 hour</td>
</tr>
<tr>
<td>4th</td>
<td>AB</td>
<td>76mm</td>
<td>1.5 hour</td>
</tr>
<tr>
<td>Final</td>
<td>AB</td>
<td>279mm (11&quot;)</td>
<td>0.5 hour</td>
</tr>
</tbody>
</table>

*Total thick.=330mm (13")*

## Layer Profile "B"

<table>
<thead>
<tr>
<th>Lift</th>
<th>Layer</th>
<th>Thick.</th>
<th>Cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>AB</td>
<td>76mm</td>
<td>1 hour</td>
</tr>
<tr>
<td>2nd</td>
<td>AB</td>
<td>76mm</td>
<td>1.5 hour</td>
</tr>
<tr>
<td>3rd</td>
<td>AB</td>
<td>76mm</td>
<td>6 hour</td>
</tr>
<tr>
<td>4th</td>
<td>AB</td>
<td>76mm</td>
<td>4 hour</td>
</tr>
<tr>
<td>Final</td>
<td>AB</td>
<td>203mm (8&quot;)</td>
<td>1 hour</td>
</tr>
</tbody>
</table>

*Total thick.=406 mm (16")*

## OR

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thick.</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB</td>
<td></td>
</tr>
<tr>
<td>SG</td>
<td></td>
</tr>
</tbody>
</table>

## Layers Changed
- Removed: PCC
- Retained: CTB, AB, SG
- AC
Work Plan (Full Depth AC)

(a) Single-lane (T1: 1'st weekend)

(b) Single-lane (T2: 2'nd weekend)

(c) Double-lane (T1+T2)

(d) Linear Scheduling
## Resource Constraint for AC Analysis

<table>
<thead>
<tr>
<th>Resources</th>
<th>Unit</th>
<th>Capacity</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AC Mixing Plant</strong></td>
<td>$M^3$/ hour</td>
<td>1</td>
<td>Each</td>
</tr>
<tr>
<td><strong>Dump Truck (Demo/Full Depth)</strong></td>
<td>per hour</td>
<td>25</td>
<td>Ton</td>
</tr>
<tr>
<td><strong>Semi-bottom Truck (AC)</strong></td>
<td>per hour</td>
<td>25</td>
<td>Ton</td>
</tr>
<tr>
<td><strong>Paver Speed</strong></td>
<td>Km/hour</td>
<td>1</td>
<td>Each</td>
</tr>
</tbody>
</table>

### Details:
- **AC Mixing Plant**
  - Unit: $M^3$/ hour
  - Capacity: 1
  - Number: 150 (100-200)
- **Dump Truck (Demo/Full Depth)**
  - Unit: per hour
  - Capacity: 25
  - Number: 10 (8-12)
- **Semi-bottom Truck (AC)**
  - Unit: per hour
  - Capacity: 25
  - Number: 12 (9-20)
- **Paver Speed**
  - Unit: Km/hour
  - Capacity: 1
  - Number: 6.0 (4.5 – 7.5)
CalCool
AC Cooling Time Analysis Software
AC Cooling-time Analysis: CalCool

- **Cooling-time Impact to Production**
  - Waiting Time (Next Layer Paving or Traffic Switch)

- **Parameters Considered**
  - Design
  - Sub-base
  - Environment
  - Delivery & Stop Temperature

![Graph showing Average Pavement Temperature over time with optimal compaction time and temperatures indicated.](image)
CalCool: Tabular and Graphic Output

<table>
<thead>
<tr>
<th>Lift#</th>
<th>Thickness mm</th>
<th>Time, min</th>
<th>Temp[C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>50.8</td>
<td>55</td>
<td>182</td>
</tr>
<tr>
<td>3</td>
<td>50.8</td>
<td>53</td>
<td>127</td>
</tr>
<tr>
<td>2</td>
<td>76.2</td>
<td>64</td>
<td>74</td>
</tr>
<tr>
<td>1</td>
<td>25.4</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

Existing Layer

- Download from the PRC or 4 States WEB
- http://www.its.berkeley.edu/pavementresearch/CalCool/CalCool.exe
CalCool Validation (Multi-lift AC)

Lompoc H-Street AC Construction
Point 11, 2 Lifts over Rich bottom

Date: October 8, 1999
Time: 8:50, 11:22 AM
Avg Air Temp: 23, 32 °C
Avg Wind: 5.0, 0 kph
Existing Surface: AC, AC
Existing Surface Temp: 23, 58°C
Cloud Cover: Clear and dry, clear and dry
Mix Specification: DGAC
Lift Thickness: 80, 80 mm
Result of AC (Asphalt) Analysis
AC Analysis: CSOL (Deterministic)

CSOL Production Graph
(4 lanes: lane-meter)

Cycle time of Semi Bottom Truck (min.)

Production (lane-meter)

- full-close
- full-complete profile "B"
- full-close full-complete profile "A"
- half-close full-complete profile "B"
- half-close part-complete profile "B"
AC Analysis: CSOL (Stochastic)

CSOL Stochastic Analysis
(4 lanes: lane-meter)

- Lower bound
- Mean
- Deterministic
- Upper bound

Analysis Option (Closure / Completion / Profile)

- full-close full-complete profile "B"
- full-close full-complete profile "A"
- half-close full-complete profile "B"
- half-close full-complete profile "A"
- half-close partl-complete profile "B"

Forecast: Distance (CSOL/Half/Profile "A")

- Certainty is 68.00% from 1,266 to 1,581 lane-meters

Frequency Chart

1,000 Trials
10 Outliers

Certainty is 68.00% from 1,266 to 1,581 lane-meters
### AC Analysis: CSOL Comparison

<table>
<thead>
<tr>
<th>Closure Option</th>
<th>Full Closure</th>
<th>Half Closure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Completion Option</td>
<td>Full Completion</td>
<td>Full Completion</td>
</tr>
<tr>
<td>Profile Option</td>
<td>Profile “A”</td>
<td>Profile “B”</td>
</tr>
<tr>
<td>Average Production</td>
<td>4,808</td>
<td>5,534</td>
</tr>
<tr>
<td>Comparison</td>
<td>87 %</td>
<td>100%</td>
</tr>
<tr>
<td>Waiting (hours)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Cooling waiting Traffic switch</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
AC Analysis: Full Depth (Stochastic)

Full-Depth Stochastic Analysis

Analysis Option (Paving Lane / Layer Profile)
### Construction Windows (Asphalt)

<table>
<thead>
<tr>
<th>Design</th>
<th>CSOL</th>
<th>Full-Depth AC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer Profile</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thickness</td>
<td>Profile“A”</td>
<td>Profile”A”</td>
</tr>
<tr>
<td></td>
<td>230mm(9”)</td>
<td>330mm(13”)</td>
</tr>
<tr>
<td>Weekend</td>
<td>4.2</td>
<td>4.8</td>
</tr>
<tr>
<td>Cont. (16H)</td>
<td>1.8</td>
<td>2.1</td>
</tr>
<tr>
<td>Cont. (24H)</td>
<td>1.2</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>Profile”B”</td>
<td>Profile”B”</td>
</tr>
<tr>
<td></td>
<td>200mm(8”)</td>
<td>406mm(16”)</td>
</tr>
<tr>
<td></td>
<td>3.7</td>
<td>5.9</td>
</tr>
<tr>
<td></td>
<td>1.6</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>1.1</td>
<td>1.8</td>
</tr>
</tbody>
</table>

![Construction Windows Comparison](chart.png)

- **Weekend**: 4.2, 3.7, 4.8, 5.9
- **Cont. (16H)**: 1.8, 1.6, 2.1, 2.6
- **Cont. (24H)**: 1.2, 1.1, 1.4, 1.8
Sensitivity of AC Analysis

• **Sensitivity (AC vs. Concrete)**
  - AC Paving more Complex than Concrete
  - Sensitivity Study is Difficult

• **Most Critical Parameters**
  - Pavement Thickness (Proportional)
  - Asphalt Delivery Trucks
  - Demo. Hauling Trucks (Full Depth only)
  - Lane Closure Tactics (Cooling Time)
  - Mixing Plant, Paver
Preliminary Finding for AC Analysis

- **Production Objectives**: 6 km per weekend
  - **CSOL**
    - Achieve 40% of target (2.5 lane-km Truck-lanes)
    - Faster, pave all lanes (30% for shoulders)
  - **Full depth AC**
    - Achieve 30% of Target (2.0 lane-km Truck-lanes)
    - Slower, but fewer lanes (Truck Lanes only)

- **Lane Closure Tactics**
  - **CSOL**: Full- Closure is 20% More Productive
  - **Full Depth**: Single-lane is 10% More Productive
Asphalt Concrete Case Study I-710 Project
I-710 Project (Stage Construction)

Construction is Scheduled in 2001
I-710 Project Stage Construction (I)

STAGE 3: Overlay & Replacement Willow Through PCH S/B
STAGE 3 - Use Moveable Barriers. Reconstruct S/B Pavement at PCH and Willow OC and overlay portion closed to traffic. Lower profile at PCH and Willow to provide Standard Vertical Clearance.

STAGE 4: Overlay & Replacement Rte 405 Through Wardlow S/B
STAGE 4 - Use Moveable Barriers. Reconstruct S/B Pavement at Route 405 and Wardlow OC and overlay portion closed to traffic. Lower profile at Wardlow OC and Rte 405 to provide Standard Vertical Clearance.
I-710 Project Stage Construction (II)

STAGE 5: Overlay & Replacement Wardlow Through Rte 405 N/B

STAGE 5 - Use Moveable Barriers. Reconstruct N/B Pavement at Route 405 and Wardlow OC and overlay portion closed to traffic.
Lower profile at Wardlow OC to provide Standard Vertical Clearance.

STAGE 6: Overlay & Replacement PCH Through Willow N/B

STAGE 6 - Use Moveable Barriers. Reconstruct N/B Pavement at PCH and Willow OC and roadway closed to traffic.
I-710 Project: UCB Model Prediction

710 (CSOL Stochastic Analysis)

- Production (meter)
- Lower bound
- Mean
- Deterministic
- Upper bound

710 (Full-depth Stochastic Analysis)

- Production (meter)
- Lower bound
- Mean
- Deterministic
- Upper bound
### I-710 Project: UCB Prediction vs. Plan

<table>
<thead>
<tr>
<th>Option</th>
<th>Unit</th>
<th>UCB Model</th>
<th>Stage 3,6</th>
<th>Stage 4,5</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSOL</td>
<td>Centerline-km</td>
<td>1.55</td>
<td>1.60</td>
<td>1.10</td>
</tr>
<tr>
<td></td>
<td>Lane-km</td>
<td>4.83</td>
<td>4.80</td>
<td>3.30</td>
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<tr>
<td>Full Depth</td>
<td>Centerline-km</td>
<td>0.50</td>
<td>0.80</td>
<td>0.65</td>
</tr>
<tr>
<td></td>
<td>Lane-km</td>
<td>1.50</td>
<td>2.40</td>
<td>2.00</td>
</tr>
</tbody>
</table>
Further Steps
(Current and Future)
Current Focus and Further Steps

- **Constructability Analysis Software**
  - 4 State Fund: CA, WA, MN, and TX DOTs
  - Knowledge-based Analysis Simulation Software
  - MS Access + Visual Basic
  - Deterministic & Stochastic Analysis Modules

- **More Case Studies (Validation)**
  - Validation & Calibration of UCB Model
  - Concrete Model: PCC vs. FSHCC
  - AC Model with I-710

- **Life Cycle Cost Analysis**
  - Direct Construction & Indirect User Delay Costs
  - Durability, Maintenance Cost, and Policy Aspects
Questions and Answers

If Need More Information …

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