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Innovative Tools and Techniques to Accelerate Pavement Construction Workshop: Workshop Materials

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Perform Feasibility Study on Use of Innovative Tools and Techniques to Accelerate Pavement Construction

Innovative Tools and Techniques to Accelerate Pavement Construction Workshop

April 2021

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Workshop Agenda

Time (Estimated)	Topic
9:00 a.m.–10:00 a.m. (with a break included)	Pavement Evaluation Procedures 1. The description and criteria for selecting candidate projects. 2. The description of the available tools and analysis software for pavement testing. The basics of establishing a testing plan.
10:00 a.m.–10:30 a.m.	Traffic Control 1. The timing strategies. 2. The analysis basics. 3. The software description.
10:30 a.m.–10:45 a.m.	Break
10:30 a.m.–12:00 p.m.	Cost and Time Savings 1. Case Study—SH 6: A Discussion of Savings Provided by Using These Techniques and Tools

Pavement Evaluation Procedures

Candidate Project Criteria

The Texas Department of Transportation's (TxDOT's) accelerated construction guidelines [1] describe aspects of good candidate projects including the following:

- High-traffic volume generally in urban areas.
- Major road, freeway ramp, or intersection closures.
- Major bridge closures.
- Lengthy construction detour routes.
- Access impediments to schools, emergency services, or major traffic generators.
- Access barriers to adjacent businesses.

All projects should evaluate existing pavement. The pavement is the most expensive part of any project except exclusive bridge projects. The pavement performance, including construction and final condition is critical to a good perception from the traveling public. Good stewards of taxpayers' dollars consider saving time and money not just in the immediate time frame but over the life cycle of the project. The goal is a cost- and time-effective design that accelerates construction without accelerating repairs.

The pavement project's evaluation should consider the following project details:

- The existing pavement condition of:
  - All travel lanes.
  - Shoulders and other paved surfaces that may be used for future travel lanes.
- The alignment changes.
- The widening criteria and limitations.
- The detours and traffic-handling sections.

TxDOT Form 2440, page 15 of 21, has a section on evaluating accelerated construction (Figure 1).

Form 2440 (Rev. 5/18)
Page 15 of 21

Accelerated Construction Procedures

A. Are accelerated contracting procedures required?

(The following types of projects will require the use of accelerated construction contract provisions. Check all that apply to this project.)

- ☐ Interstate or freeway project with lane closures during one or more phases of construction
- ☐ Bride closure (either as the entire project or a portion of a larger project)
- ☐ Road closure
- ☐ Added Capacity projects
- ☐ Non-freeway with ADT > 10,000 and land closures during one or more phases of construction
- ☐ Provides access to a nearby school, emergency services (hospital, fire, etc.), or major traffic generator
- ☐ Project affects access to adjacent businesses
- ☐ Other (Projects that are time critical such as traffic signal work at high accident locations)

  Explain:
- ☐ None of the above (Acceleration provisions are not required)

  Type of work:

B. Is an exception request to DES needed? ☐ Yes ☐ No

(Note: If the project meets any of the above criteria and accelerated contract provisions are not utilized, Design Division approval will be required. Request for approval to not utilize accelerated contract provisions should be submitted in advance of PS&E submission for letting.)

Request submitted: Approval received:

C. What type of accelerated contract procedure will be used?

(Check the accelerated contract provision(s) to be used on this project.)

- ☐ Calendar Day Definition for Working Day
- ☐ Incentive Using Contract Administrative Cost
- ☐ Increased Liquidated Damages
- ☐ Milestones with Incentives/Disincentives
- ☐ Substantial Completion Incentives/Disincentives
- ☐ Lane Rental Disincentive
- ☐ A+B Provisions

D. What technique will be used to calculate road user costs?

- ☐ FREQ, CORSIM or HCS models
- ☐ PASSER models
- ☐ Manual techniques
- ☐ Other:

E. Who will perform road user costs calculations?

- ☐ consultant
- ☐ interagency agreement
- ☐ district

Figure 1. TxDOT Form 2440.

Tools and Analysis

Introduction

The research project's focus is accelerating construction through selecting efficient pavement designs and construction methods. Accelerated construction will often maximize existing material reuse through rehabilitation and recycling methods. For an aging roadway, the agency must decide whether to maintain, rehabilitate, or reconstruct the project. An existing pavement evaluation can provide critical information for determining the appropriate plan.

This section discusses tools for the rapid and intelligent collection of pavement condition data, layer properties, and right-of-way cross sections. The discussion offers general guidance for using different pavement evaluation systems. One-page summaries for each system describe the underlying technology, data collection and analysis methods, benefits, and limitations.

While these tools alone do not dramatically accelerate the construction process, they may identify if a faster design option that could maximize existing material reuse is viable.

General Guidance for Non-destructive Pavement Evaluation Tools

Available pavement evaluation tools measure a pavement's functional and structural properties. Structural properties include pavement and subgrade stiffness, pavement layer thickness, pavement layer condition, and load transfer. Functional properties include roughness, rut depth, geometry, skid resistance, and noise. These properties together provide information that is useful in a pavement design and evaluation process. This section lists specific non-destructive tools to address many of these properties and focuses on tools that specifically promote accelerated construction design.

Structural Properties

Pavement Stiffness

Two vehicle-mounted non-destructive devices used for measuring pavement stiffness are:

- The falling weight deflectometer (FWD).
  - The MODULUS software analyzes the data. This data analysis results in an estimate of the pavement structure's remaining life as well as the elasticity values' layer modulus to input into FPS-21, which is the pavement design software.
- The total pavement acceptance device (TPAD).
  - The TPADana software analyzes the data. This software integrates a high-definition video (HDV) image, global positioning system (GPS) location, and ground-penetrating radar (GPR) data to assist with the analysis. The analysis helps with identifying the locations of poor subgrade support and load transfer.

Pavement Layer Thickness and Deterioration

GPR identifies the pavement layer thickness and potential deterioration areas. Pavement forensic studies successfully use GPR as a tool to:

- Estimate the pavement layer thickness.
- Identify the base's defects.
- Identify the hot mix's defects (stripping, segregation, or joint density).
- Locate deterioration in asphalt-covered bridge decks.

- Locate the water-filled voids under concrete pavements.
- Define the limits of defects.

Load Transfer (Jointed Concrete Pavement)

FWD and TPAD, as previously discussed, can identify poor load transfer in jointed concrete pavements.

Functional Properties

Roughness

An inertial profiler measures longitudinal and transverse roughness statistics at highway speeds. The real-time measurements are quantified into two indexes: the serviceability index (SI) and the international roughness index (IRI). The SI is an input in the FPS-21 software. Construction projects use the IRI to measure a new construction's ride quality. The indexes also identify the locations of localized roughness, bumps, and dips.

Geometry

The mobile light detection and ranging (LiDAR) system measures the roadway geometry. The data generated are useful for many geometric calculations. Some of the typical uses are rut mapping and cross-slope estimation. Geometric calculations can also measure the side road geometry to provide information for drainage or other design needs.

Subgrade Properties

The U.S. Department of Agriculture's (USDA's) web soil survey (USDA-WSS) includes the subgrade physical and engineering properties. Field testing at specific locations with moisture content concerns can use electrical resistivity tomography (ERT).

Pavement Testing and Technical Support

TxDOT's Pavement Analysis and Design Branch in the Maintenance Division is the contact for equipment testing or loan requests and technical support.

Appendix A includes one-page equipment technical summaries developed for the following NDT systems:

- GPR systems (overview).
  - Air-coupled GPR with a 1-GHz antenna.
  - Step-frequency GPR with a 3D radar system.
  - Ground-coupled GPR with an antenna frequency range of 200 MHz to 2.5 GHz.
  - GPR with a rolling density meter.
- LIDAR.
- FWD.
- TPAD.
- Inertial profiler.
- ERT.
- USDA-WSS.
- Dynamic cone penetrometer (DCP).
- HDV.

The technical summaries are laid out in the following format:

- General Description.
- Measured Properties.
- Data Analysis.
- Benefits for Accelerated Construction.
- Limitations and Availability.

Testing Plan

Overview

Develop an engineered testing plan for all projects with pavement work.

Review of Existing Data

Review all existing data before determining new data requirements. As-built plans, specifications, and estimate (PS&E), the project management information system (PMIS) data, the soil reports, and the pavement design reports are the most common information sources. USDA-WSS is a good information source concerning soil properties. Google Earth is a good resource for historical pavement images. These images can help to plan GPR collection strategies. For example, visual distresses that are in unusual locations can indicate that the data collection may need to use a slalom pattern to cross a joint between the lane and shoulder.

Testing Plan Steps

Develop a phased testing plan. This plan will be dynamic and change as information is gathered and analyzed.

Phase 1, Background and Non-Destructive Testing

Phase 1: Background and Non-destructive (NDT) Testing

1) Gather and review background information including typical section and maintenance history data.
2) Perform a GPR with an HDV survey of the pavement. Determine locations and the survey's limits. The locations should include the portion of the typical section to be tested, such as the lanes, shoulders, medians, and non-standard collection (slalom across longitudinal joints, etc.).
3) Use information from Step 1 and 2 to determine an NDT plan.
    a) Determine locations and the survey's limits for each testing method. The locations should include the portion of the typical section to be tested, such as the lanes, shoulders, medians, and non-standard collection (slalom across longitudinal joints, etc.).
    b) Consider one or a combination of the following systems:
        i) FWD.
        ii) TPAD.
        iii) LIDAR.
        iv) Inertial profiler.

Phase 2: Field Sampling and Testing

1) Use Phase 1 information to determine a field sampling and testing plan for pavement and soils.
    a) Different locations and numbers of samples may occur for soil versus pavement based on the material types and variability.

b) In general, sampling locations should be in an accessible area. When determining the locations, always avoid overhead power lines and underground utilities. If possible, avoid steep slopes and standing or flowing water. Deviations within a 50-ft radius of the designated locations are not usually excessive, but make note of adjustments on the logs, including enough information to describe the adjustment and the reason for the adjustment.
    i) Request that the district review the sampling and testing plan, including traffic control, and in some cases assist with organizing and providing traffic control.
c) Follow Tex-100-E: Surveying and Sampling Soils for Highways and Tex-141-E: Manual Procedure for Description Identification of Soils for field sampling and logging information.

2) Include the following in-place testing as appropriate for the survey objective:
    a) Ground-coupled GPR with an antenna frequency range of 200 MHz to 2.5 GHz.
    b) ERT.
    c) DCP.

Phase 2a: Soil Sampling

1) Determine the number of locations, depth, and quantity of material required for soil exploration. Consider the following when developing the field plan:
    a) The testing location: Designate enough locations to establish the typical condition for the subgrade and identify potential problem areas. Consider the following when determining locations:
        i) The complexity of geological conditions.
            (1) Review existing data such as USDA-WSS.
            (2) Analyze TxDOT as-built project soil reports.
        ii) The testing conducted in Phase 1.
    b) The depth of testing (refer to the appropriate test procedure) based on the evaluation criteria:
        i) Tex-124-E: Determining Potential Vertical Rise samples a minimum of 15-ft-deep soil column measured from the top of the proposed untreated natural subgrade elevation unless the TxDOT district-specific standard operating procedure revises the soil column's depth. When the standard operating procedure revises the soil column's depth, use the district-specific requirement.
        ii) Pavement design information: Sample a minimum of 2-ft-deep soil column measured from the top of the proposed subgrade. Review potential laboratory testing needed and obtain enough material to perform tests.
    c) The log samples.

Phase 2b: Pavement Sampling

1) Determine the number of locations, depth, and quantity of material required for soil exploration. Consider the following when developing the field plan:
    a) Review potential pavement design strategies or a combination of strategies.
        i) Refer to TxDOT's *Treatment Guidelines for Soils and Base in Pavement Structures* found at http://ftp.dot.state.tx.us/pub/txdot/mtd/treatment-guidelines.pdf.
    b) Designate enough testing locations to establish the typical pavement condition and significant pavement changes and identify potential problem areas. Consider testing locations needed for the various design strategies.
        i) Review the proposed geometric design and number of proposed roadbeds.

(1) Review the typical sections.
(2) Review the proposed vertical and horizontal alignments.

ii) Understand the complexity of the existing pavement structure.
(1) Review existing data including as-built PS&E, PMIS data, design and construction records, and pavement design reports.
(2) Analyze NDT such as GPR, FWD, TPAD, LIDAR, ERT, and inertial profiler.
(a) Variability of:
(i) The layer thickness.
(ii) The material changes by layer and along the project.
(iii) The condition of existing materials (presence and extent of defects).

c) Obtain samples of each layer of material within the pavement structure to the top of the subgrade, including treated subgrade at each testing location.
d) Log each pavement layer by recording the layer thickness and visual condition. Photograph the materials.
e) Include spot-specific testing such as DCP.

2) In general, obtain the quantity of material shown in Table 1.

Phase 3: Laboratory Testing

1) Develop material logs—Use information from Phase 2 and perform laboratory testing to describe the engineering properties of the subgrade and pavement.
2) Design testing—Perform testing required for the proposed pavement design strategies.

Documentation

Document the testing plan, including the following:

- Resources and references used to develop the testing plan.
- Testing locations.
- Testing types.
- Testing dates.
- Name of person(s) who performed the test.
- Quantity of material sampled.
- Material logs.
- Testing data.
- Testing results (data analysis).
- Recommendations.

Table 1. Material Sampling Quantities.

Sample Container	Description	Approx. Weight of Material in Container		Comments
Bag	Plastic sample bag	15 lb		Typically a 10.5" x 18" plastic sample bag.
Bucket	5-gal plastic bucket	45 lb		14" by 25" canvas sample sack may be used.
Test Method	**Title**	**Sample Container**	**Quantity**	**Comments**
Tex-103-E	Moisture Content	Bag	1	Seal the bag to prevent loss of moisture.
Tex-104-E	Liquid Limits	Bag	1	Tex-104-E (or Tex-107-E), Tex-105-E, and Tex-106-E are performed as one test. One bag is enough for all methods; a bag for each method is not necessary.
Tex-105-E	Plastic Limit			
Tex-106-E	Plasticity Index			
Tex-107-E	Bar Linear Shrinkage			
Tex-110-E	Particle Size Analysis	Bucket	1	
Tex-113-E	Moisture–Density Relationship for Base	Bucket	3	
Tex-114-E	Moisture–Density Relationship for Subgrade, Embank, Soils, and Backfill	Bucket	3	If material has 100% passing the 0.375" sieve, only 1 bucket is needed.
Tex-116-E	Ball Mill Method	Bucket	1	
Tex-117-E Base	Triaxial Compression—Base	Bucket	4	Do not forget to sample for moisture–density curve (additional 3 buckets).
Tex-117-E Soils	Triaxial Compression—Disturbed Soils	Bucket	5	For material that has 100% passing the 0.375" sieve. Do not forget to sample for moisture–density curve (additional 3 buckets).
Part I of Tex-120-E, Tex-121-E, Tex127-E, or other methods (Draft Tex-122-E and Tex-134-E)	Laboratory Mix Design for Treatment, Cement, Lime, Lime Fly Ash, Foamed Asphalt, Emulsion, Cement Foam, Cement Emulsion, or Other Combinations	Bucket	9	When existing surfacing is greater than 2" thick, separate reclaimed asphalt pavement from base material. Obtain a representative portion of reclaimed asphalt pavement and a base for a minimum of 9 buckets. (Example: for 4" hot mix + 6" base, use 3.5 buckets for reclaimed asphalt pavement and 5.5 buckets for base).
		Bucket	0.5	Lime, cement, or fly ash (minimum of 25 lb). Store lime and fly ash samples in air-tight containers. Make sure the lid is secured tightly.
		Bucket	1	Emulsion (minimum of 3 gal).
		Bucket	2	Asphalt such as PG64-22 for foamed asphalt (minimum of 10 gal).
Tex-128-E	Determining Soil pH	Bucket	0.5	Only 1 bucket is needed when Tex-128-E and 129-E are performed at the same time.
Tex-129-E	Resistivity of Soil	Bucket	1	
Tex-145-E	Sulfate Content—Colorimetric Method	Bag	1	If performed in the field, the minimum sample size is 300 g.
Tex-146-E	Conductivity Test for Field Detection of Sulfates	Bag	1	
Tex-148-E	Soil Organic Content using UV-Vis Method	Bag	1	

Traffic Control

Timing Strategies

TxDOT Item 8.3 "Computation of Contract Time for Completion" (TxDOT, 2014) states the following:

> **3.1.1 Five-Day Workweek**. Working days will be charged Monday through Friday, excluding national holidays, regardless of weather conditions or material availability. The Contractor has the option of working on Saturdays. Provide sufficient advance notice to the Engineer when scheduling work on Saturdays. Work on Sundays and national holidays will not be permitted without written permission of the Engineer. If work requiring an Inspector to be present is performed on a Saturday, Sunday, or national holiday, and weather and other conditions permit the performance of work for 7 hr. between 7:00 A.M. and 6:00 P.M., a working day will be charged.
>
> **3.1.2 Six-Day Workweek**. Working days will be charged Monday through Saturday, excluding national holidays, regardless of weather conditions or material availability. Work on Sundays and national holidays will not be permitted without written permission of the Engineer. If work requiring an Inspector to be present is performed on a Sunday or a national holiday, and weather or other conditions permit the performance of work for 7 hr. between 7:00 A.M. and 6:00 P.M., a working day will be charged.
>
> **3.1.3 Seven-Day Workweek**. Working days will be charged Monday through Sunday, excluding national holidays, regardless of weather conditions or material availability. Work on national holidays will not be permitted without written permission of the Engineer. If work is performed on any of these holidays requiring an Inspector to be present, and weather or other conditions permit the performance of work for 7 hr. between 7:00 A.M. and 6:00 P.M., a working day will be charged.
>
> **3.1.4 Standard Workweek**. Working days will be charged Monday through Friday, excluding national or state holidays, if weather or other conditions permit the performance of the principal unit of work underway, as determined by the Engineer, for a continuous period of at least 7 hr. between 7:00 A.M. and 6:00 P.M., unless otherwise shown in the Contract. The Contractor has the option of working on Saturdays or state holidays. Provide sufficient advance notice to the Engineer when scheduling work on Saturdays. Work on Sundays and national holidays will not be permitted without written permission of the Engineer. If work requiring an Inspector to be present is performed on a Saturday, Sunday, or holiday, and weather or other conditions permit the performance of work for 7 hr. between 7:00 A.M. and 6:00 P.M., a working day will be charged.
>
> **3.1.5. Calendar Day**. Working days will be charged Sunday through Saturday, including all holidays, regardless of weather conditions, material availability, or other conditions not under the control of the Contractor.
>
> **3.1.6. Other**. Working days will be charged as shown on the plans.

Table 2 contains a summary of typical work time frames to consider; however, time frames can be adjusted based on local conditions.

Table 2. Work Time Frames.

Workweek Description	Time Frame		Weather Charged	Holidays Charged
5 Day	7:00 a.m.–6:00 p.m.	Monday–Friday	Yes	No
6 Day	7:00 a.m.–6:00 p.m.	Monday–Saturday	Yes	No
7 Day	7:00 a.m.–6:00 p.m.	Monday–Sunday	Yes	No
Standard	7:00 a.m.–6:00 p.m.	Monday–Friday	No	No
Calendar Day	7:00 a.m.–6:00 p.m.	Sunday–Saturday	Yes	Yes
Nighttime Only	30 minutes after sunset to 30 minutes before sunrise		No	No
Other—as shown on plans (examples as follows)				
24/7 (Continuous)	12:00 a.m.–12:00 p.m.	Sunday–Saturday	Yes	Yes
72-hr Weekday (Continuous)	12:00 a.m.–12:00 p.m.	Tuesday–Thursday	Yes	Yes
57-hr Weekend (Continuous)	8:00 p.m.–5:00 a.m.	Friday–Monday	Yes	Yes
Nighttime with Restricted Daytime	9:00 a.m.–4:00 p.m. 8:00 p.m. –5:00 a.m.	Monday–Friday	No	No

Weather and Holiday Impacts

The time frame of work allowed, weather, and holidays have a significant impact on the actual days available to work. Table 3 shows the effects of weekends, average rain days including days where it is too wet to work after rain, and holidays on the overall number of days available to work based on historical weather patterns in Tyler, Texas. This example has only 184 days out of 365 days (50 percent of the year) available to work. Establishing the work time frame and charges should involve the consideration of these factors.

Table 3. Working Day Example in Tyler, Texas.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Totals
Calendar Days	31	28	31	30	31	30	31	31	30	31	30	31	365
Weekend Days	8	8	8	8	10	8	10	10	8	10	8	8	104
Weekday Rain	3	4	4	4	6	4	3	4	2	4	4	5	47
Too Wet	2	2	2	2	1	1	1	1	1	1	2	3	19
Holidays	2	1			1		1		1		2	3	11
Working Days	15	15	14	14	18	13	15	15	12	15	16	19	181

Software

Software

Construction Analysis for Pavement Rehabilitation Strategies (CA4PRS) allows the designer to develop a schedule–cost–traffic integrated seven-step analytical procedure for determining the most *feasible* and *realistic* accelerated construction and traffic control options for a given project. This integrated analysis also enables the designer to determine contract times and daily incentive/disincentive (I/D) rates for A+B contracting projects. More specifically, when determining contract times for A+B projects involving incentive provisions, choices regarding lane closure schemes (e.g., single lane closure, double lane closure, or full lane closure with counterflow traffic) and construction windows (e.g., nighttime, weekdays, weekends, or around the clock) play an instrumental role. Some pioneering states like California already attempted to implement a similar schedule–traffic–cost integration analysis approach to make better informed contract time determination decisions.

A multistate consortium (California, Texas, Minnesota, and Washington) developed the CA4PRS tool under a Federal Highway Administration (FHWA) pooled fund research program. Validation studies using several major highway rehabilitation projects in California, Washington, and Minnesota proved the software's scheduling reliability and accuracy, and as a result, the program is more accepted on a national level including recent FHWA arrangements to distribute free group licenses to all 50 states (Choi et al., 2013). To boost nationwide deployment, FHWA and the American Association of State Highway and Transportation Officials arranged for free group licenses distributed to all state transportation agencies.

Appendix B contains a guidebook for performing a schedule–cost–traffic trade-off analysis using CA4PRS software. Figure 2 shows the steps to analyze time impacts.

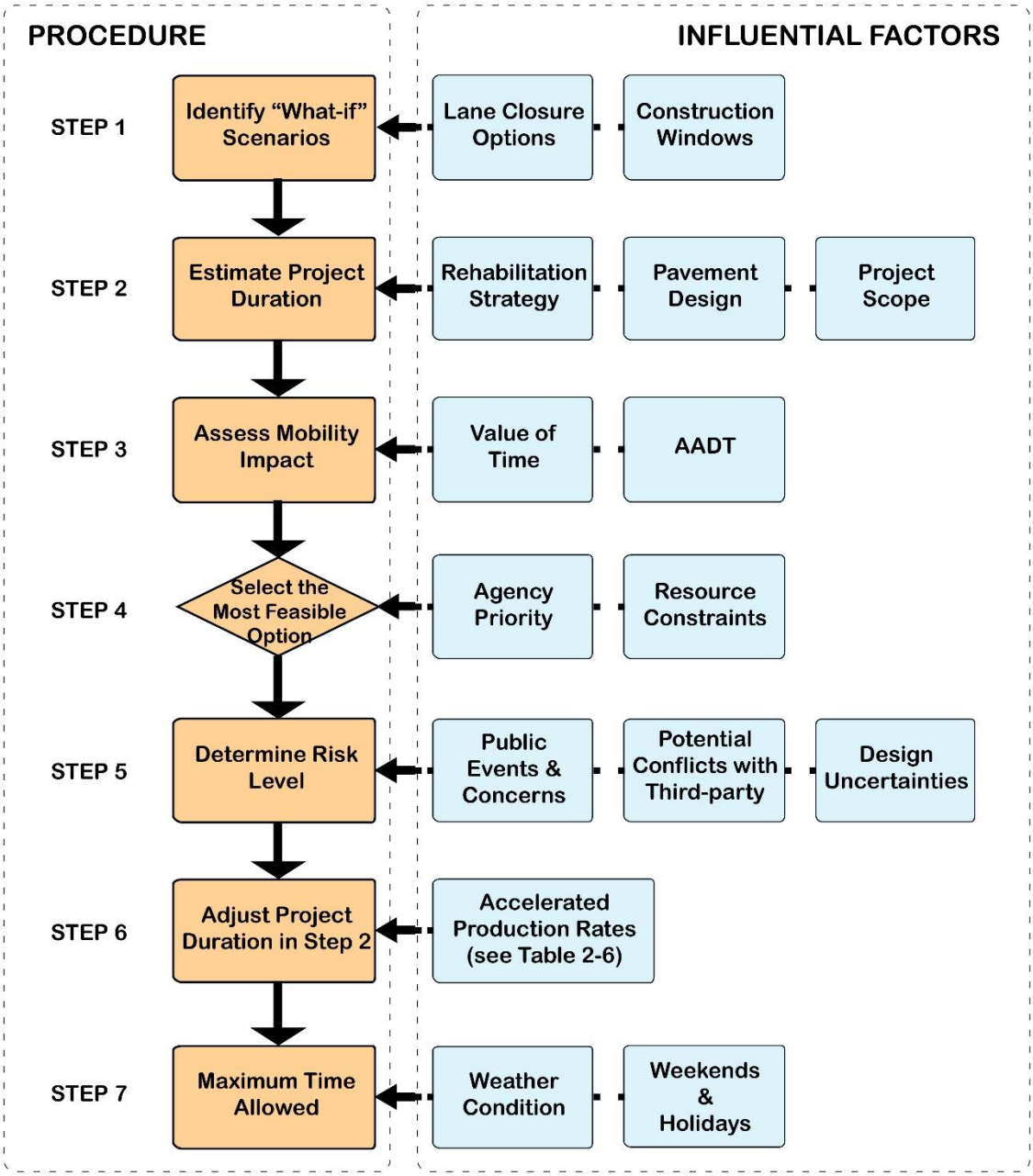


Figure 2. Time Analysis Process.

Analysis

Step 1: Identify What-If Construction and Traffic Control Options

Alternatives should be defined with respect to the duration and occurrence (e.g., nighttime, weekday, weekend, or 24/7). Each alternative can be executed through one of three standard lane closure scenarios (i.e., single lane, double lane, and full lane closure) with some variations.

Step 2: Estimate the Number of Workdays Needed for All Alternatives Being Considered

In the advanced planning stage (from the schematic to design document scoping phases), traffic assessments for each alternative should begin with an estimate of the number of workdays needed for the traffic control options being considered. The estimated number of workdays serves as the baseline for conducting mobility impact assessments.

Step 3: Assess the Mobility Impacts of All Alternatives Being Considered

These assessments should include estimates of road user cost and mobility impacts (i.e., delayed minutes due to lane closure options). Since these assessments are directly affected by project duration estimates, mobility impact assessments should be performed in close relation to the project duration estimates.

Step 4: Select the Most Economical Option Out of All Being Considered

After accounting for prioritized values and/or trade-offs with regard to project duration, cost, and the traffic disruption amount for each of the alternatives considered, the agency should select the most feasible and economical option for the given project.

Step 5: Determine the Risk (or Level of Uncertainty) for the Selected Option

The A+B bidding process increases the frequency and magnitude of contract change orders that result in substantial delays in contract time. Therefore, it is crucial to identify any potential risks associated with third-party conflicts, such as the scope of the project, design uncertainties, right of way, utilities, etc.

Step 6: Adjust the Initially Estimated Duration by Applying Accelerated Production Rates

The final alternative selected should apply an accelerated production rate with the expectation that the I/D project will use 15 to 20 percent more resources than a conventional schedule. The initially estimated project duration should then be adjusted accordingly for incorporating into the “B” value in the A+B bid. The Texas A&M Transportation Institute (TTI) has developed easy-to-follow lookup tables for accelerated production rates.

Step 7: Convert the Adjusted Workdays into Calendar Days

A+B+I/D projects should define workdays as calendar days and account for weather, holidays/weekends, and other non-workdays during the time that the construction is executed. Adjustments should also be made for weather.

Cost and Time Savings

General Information

When evaluating a project, the time and cost savings should include the following:

- The cost difference between placing the new material and keeping the existing material.
  - The cost of retaining the existing material for comparison purposes should capture any treatment of the existing material, such as stabilization.
- The time to remove the existing material and reconstruct the layers for all sections where the existing material will be reused into the new pavement structure.
  - The evaluation of days for comparison purposes should capture any time for treatment of the existing material, such as stabilization.
- An evaluation of traffic control closure options.
  - User delay costs.
  - Overall project time based on closure strategy.

Bryan District SH 6 Case Study

Background

SH 6 in Brazos County is a four-lane divided freeway with one-way frontage roads. Figure 3 shows the location map. The roadbeds are divided into sections based on pavement structural changes. The LiDAR analysis sections are also noted on the map. Figure 4 shows a picture of the section.

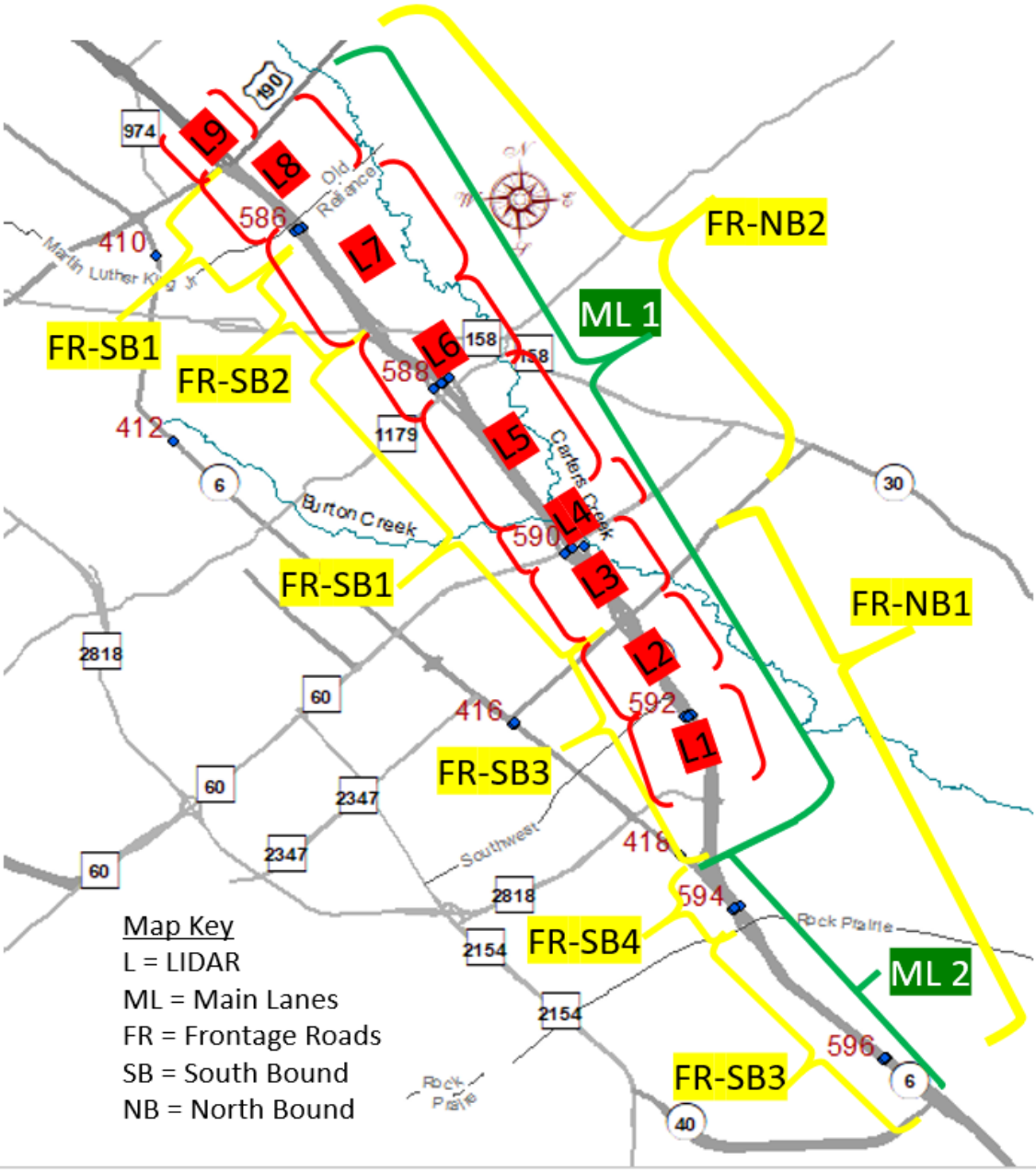


Figure 3. SH 6 Pavement Change Location Map.

Figure 4. SH 6 Southbound between FM 60 and SH30.

Figure 5, Figure 6, and Figure 7 show the existing typical sections for the main lanes and the frontage road. The section from US 190 to BS6-R has been overlaid with approximately 1.5-inch Type D and 1-inch permeable friction course (PFC) mixes since the typical section was drawn in the 1990 PS&E. Several sections of the frontage road have full-depth hot mixes that are approximately 12 inches thick.

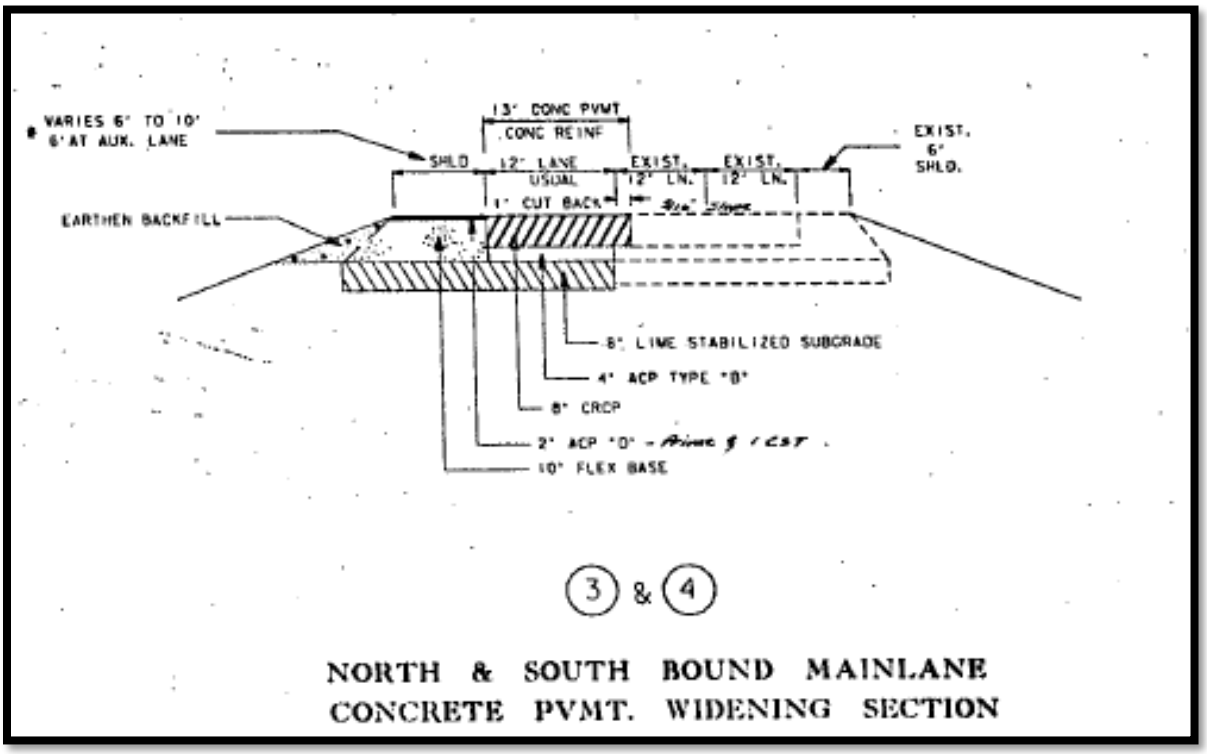


Figure 5. SH 6 Main Lane Typical Sections (1990) from US 190 to BS6-R.

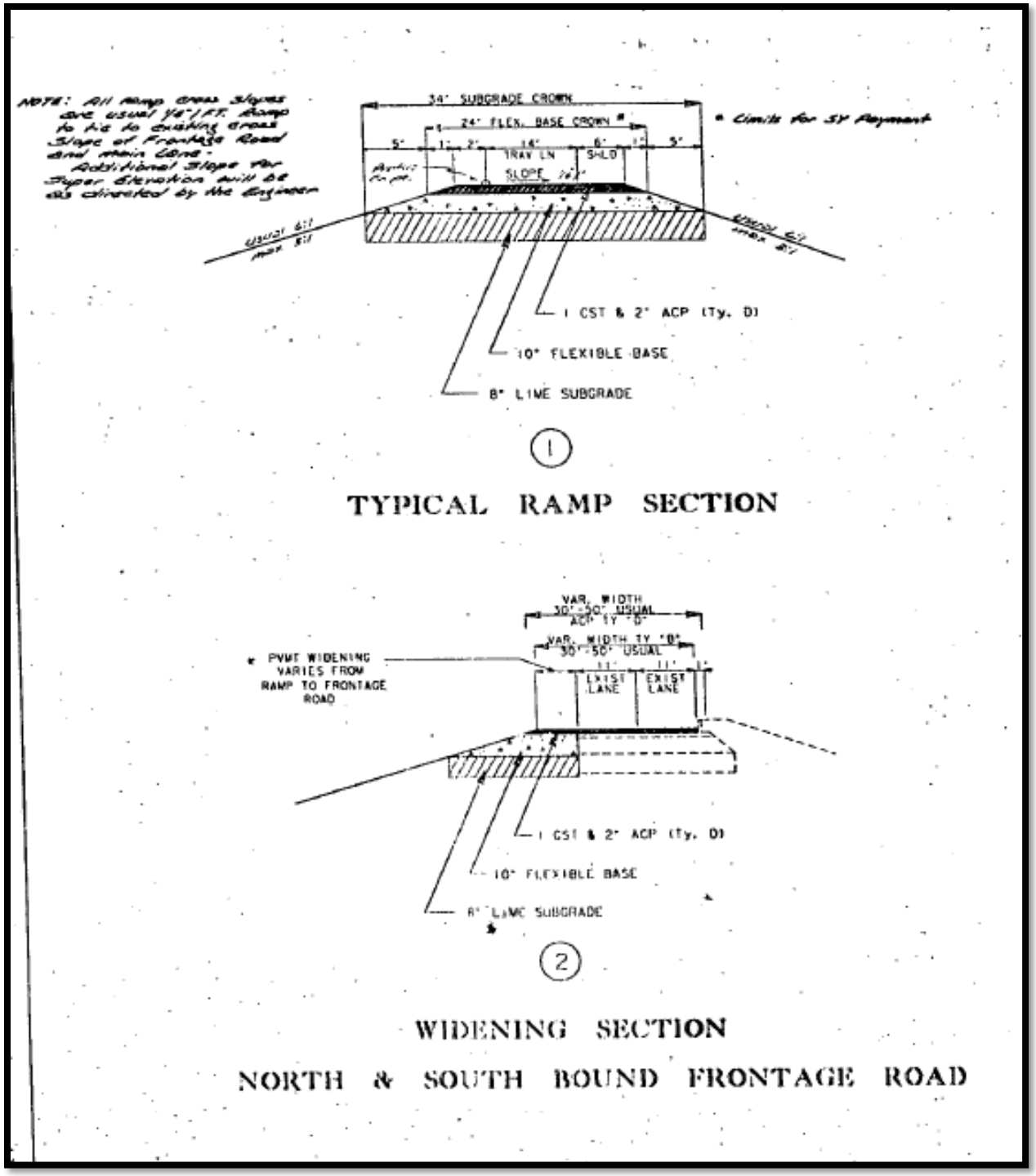


Figure 6. SH 6 Typical Sections of the Ramp and Frontage Road (1990).

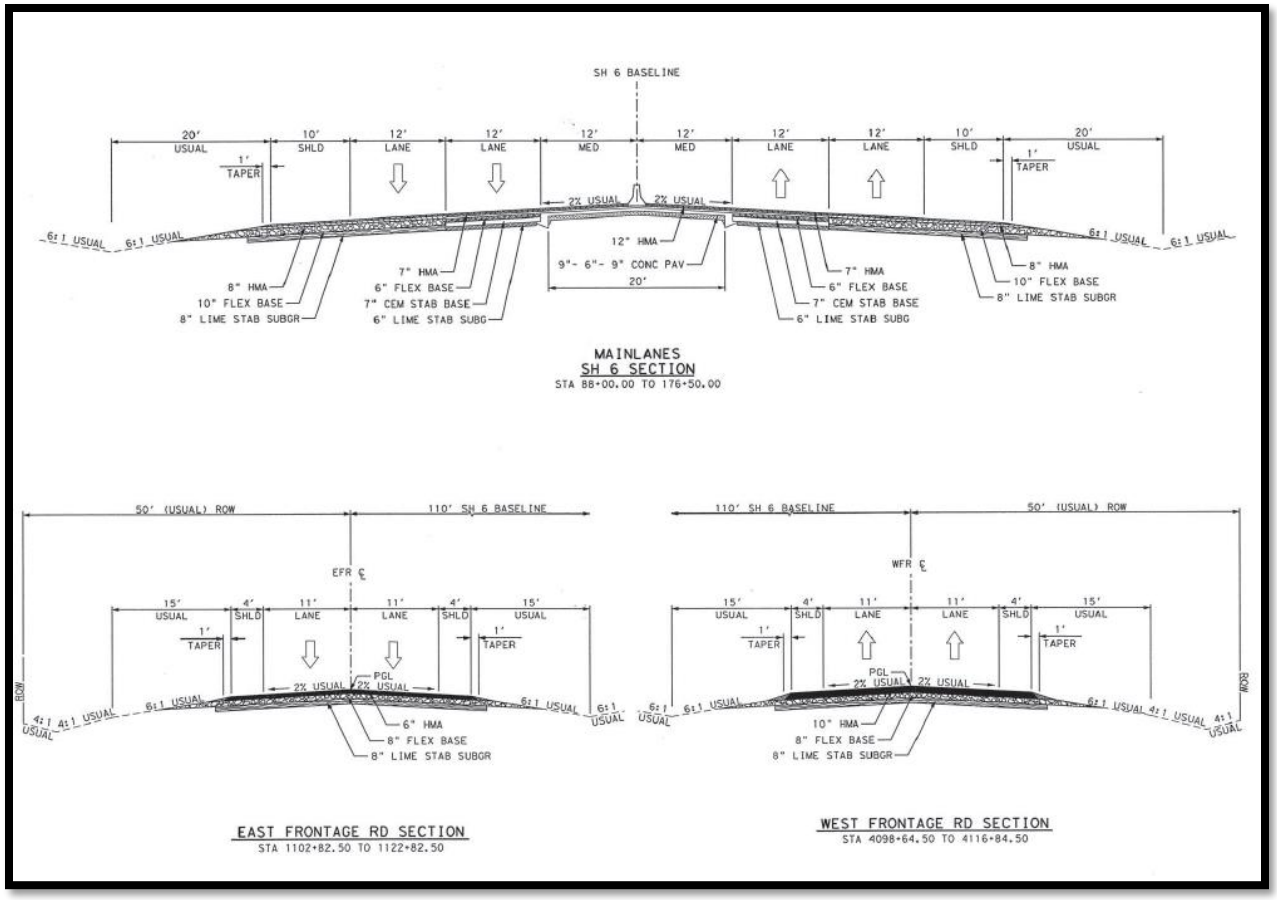


Figure 7. SH 6 Typical Sections from Approximately BS6-R to SH 40.

Estimated Traffic Data

Traffic data were not provided. The pavement analysis used the traffic data in Table 4. All pavement designs should be verified with the official traffic data once they are received from TxDOT's Transportation Planning and Programming Division. The data are broken out based on roadbeds. The FPS-21 inputs applied a 70 percent correction factor to the 20-year equivalent single axle loads (ESALs) based on TxDOT's Pavement Manual, Chapter 5, Table 5-2: Lane Distribution Adjustments. The TxCRCP-ME Design Program did not have any adjustments since it adjusts internally based on the number of lanes.

Table 4. Estimated Traffic Data.

					Weigh-in-Motion History			
	Project Information				Flexible		Rigid	
Location	Initial ADT (2019)	Final ADT (2039)	% Truck	Design Period	ESAL/ Truck	Cumulative ESALs (Adj ESALs)	ESAL/ Truck	Cumulative ESALs
US 190 to SH 30								
SB or NB ML	57,948	81,127	13	20	1.22	82,366,454 (57,656,518)	1.41	95,194,017
SB FR	11,433	13,720	7.6	20	1.22	8,563,635	1.41	9,897,315
NB FR	19,891	27,847	7.4	20	1.22	16,093,596	1.41	18,599,976
SH 30 to Rock Pr.								
SB or NB ML	77,755	108,857	11.7	20	1.22	99,468,036 (69,627,625)	1.41	114,958,959
SB FR	11,691	23,382	7.6	20	1.22	13,452,582	1.41	15,547,656
NB FR	15,493	21,690	7.3	20	1.22	12,365,873	1.41	14,291,706
Rock Pr. to SH 40								
SB or NB ML	37,905	53,067	15.7	20	1.22	65,067,708 (45,547,395)	1.41	75,201,203
SB FR	19,646	23,575	7.4	20	1.22	14,327,820	1.41	16,559,202
NB FR	13,714	16,457	7.5	20	1.22	10,136,901	1.41	11,715,598
US 190 to SH 30								
SB or NB ML	**57,948**	**93,326**	**13**	**30**	**1.22**	**138,353,696**	**1.41**	**159,900,583**
SB FR	**11,433**	**14,924**	**7.6**	**30**	**1.22**	**13,566,966**	**1.41**	**15,679,854**
NB FR	**19,891**	**32,034**	**7.4**	**30**	**1.22**	**27,032,817**	**1.41**	**31,242,846**
SH 30 to Rock Pr.								
SB or NB ML	**77,755**	**125,226**	**11.7**	**30**	**1.22**	**167,079,970**	**1.41**	**193,100,621**
SB FR	**11,691**	**29,535**	**7.6**	**30**	**1.22**	**27,506,343**	**1.41**	**31,790,118**
NB FR	**15,493**	**24,952**	**7.3**	**30**	**1.22**	**20,771,313**	**1.41**	**24,006,189**
Rock Pr. to SH 40								
SB or NB ML	**37,905**	**61,047**	**15.7**	**30**	**1.22**	**109,296,525**	**1.41**	**126,318,115**
SB FR	**19,646**	**25,643**	**7.4**	**30**	**1.22**	**22,698,605**	**1.41**	**26,233,634**
NB FR	**13,714**	**17,901**	**7.5**	**30**	**1.22**	**16,059,325**	**1.41**	**18,560,367**

Note: ADT = average daily traffic.

Pavement Evaluation

The testing included the following:

- GPR data were collected on the main lanes, frontage roads, and all through lanes.
- FWD data were collected in the outside lane of the frontage roads throughout the project and the outside lane and outside shoulder of the main lanes from BS6-R to SH 40.
- TPAD data were collected on the outside lane of the main lanes from BS6-R to SH 21.
- Pavement cores were taken on the southbound frontage road from SH 21 to FM 158.
- LiDAR data were collected throughout the project.

The main lane pavement is structurally sound. There may be load transfer issues in the concrete patches on section ML1 since large changes were noted in the TPAD data at these locations. Figure 8 depicts an example of an area with a large spike in data corresponding to a transverse crack.

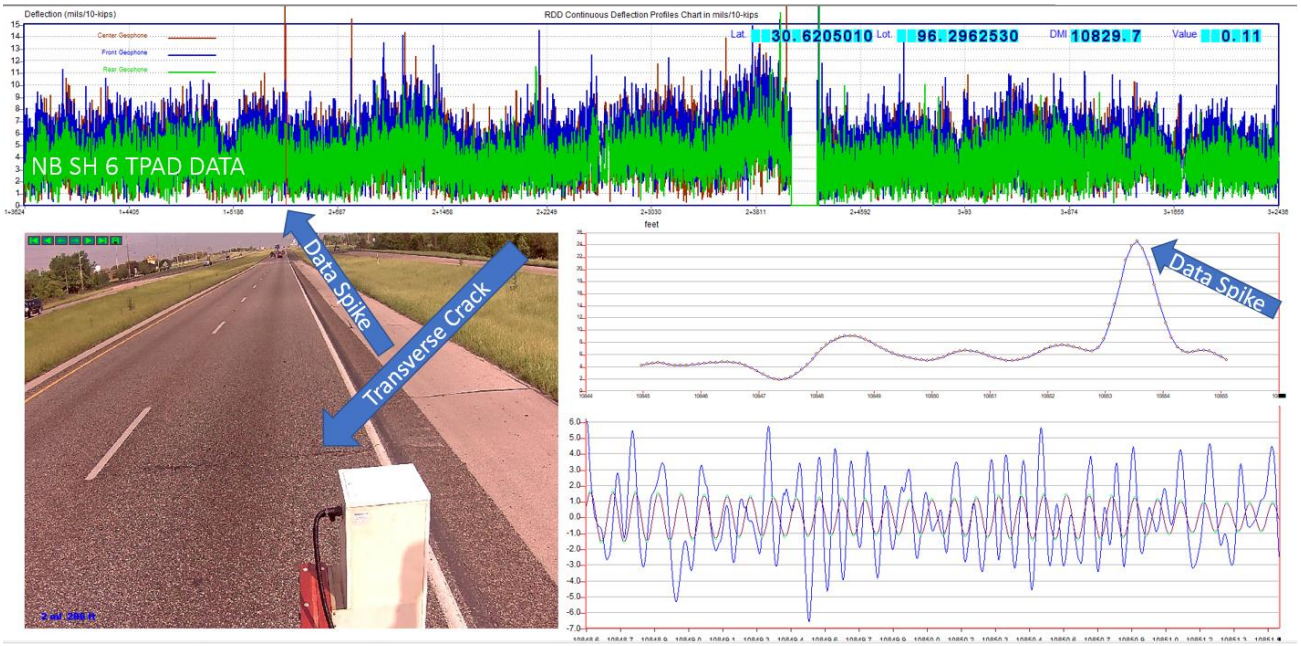


Figure 8. SH 6—TPAD Data Example.

The frontage road sections are all structurally sound except for a portion of SB1. SB1 has long sections with stripped hot mix layers from SH 21 to Water Locust Street that need to be repaired. Table 5 is a summary of the FWD results. Figure 9 shows the locations of the repairs and cores. All lanes need repairs in these sections based on the similar patterns in the GPR. Figure 10 provides GPR examples.

Table 5. FWD Testing Summary.

ML 2: About BS6-R to SH 40	SBOL		SBOshld		NBOL		NBOshld	
	Thickness (in)	Mod (ksi)	Thickness (in)	Mod (ksi)	Thickness (in)	Mod (ksi)	Thickness (in)	Mod (ksi)
Pavement:	8.00	1,060	8.00	1,580	8.00	1,258	8.00	1,085
Base:	10.00	724	10.00	163	10.00	611	10.00	229
Subgrade:	111.57 (by DB)	17.3	104.55 (by DB)	12.8	99.25 (by DB)	15.7	113.04 (by DB)	14.7
Sections:	SB 1		SB 2		SB 3		SB 4	
SB Frontage Road:	SB FR SH 30 to SH 21		SBFR–Water Locust to FM 158		SBFR SH 30 to SH 40		SBFR Tx Ave to Rock Pr.	
	Thickness (in)	Mod (ksi)	Thickness (in)	Mod (ksi)	Thickness (in)	Mod (ksi)	Thickness (in)	Mod (ksi)
Pavement:	12.00	943	5.00	763	8.00	1,245	2.00	708
Base:			6.00	103	8.00	136	10.00	1,143
Subbase:			6.00	2,000				
Subgrade:	125.55 (by DB)	9.3	111.5 (by DB)	10.2	111.31 (by DB)	10	284.38 (by DB)	21.9
Sections:	NB 1		NB 2					
NB Frontage Road:	NB FR SH 40 to SH 30		NB FR SH 30 to SH 21		Note: Pavement Manual, Chapter 5, for dense-graded mixes recommends: Combined hot mix asphalt thickness: ≤ 4 in. use 500 ksi. 4.0 in. < T ≤ 8 in. use 650 ksi. ≥ 8 in. use 850 ksi. Use default design values if field tested values are greater. Used DCP results for SB2 Base.			
	Thickness (in)	Mod (ksi)	Thickness (in)	Mod (ksi)				
Pavement:	8.00	1,750	12.00	1,623				
Base:	10.00	58						
Subbase:								
Subgrade:	284.38 (by DB)	10.9	111.31 (by DB)	7.1				

Figure 9. SH 6 SB Frontage Road Repair Area and Core Map.

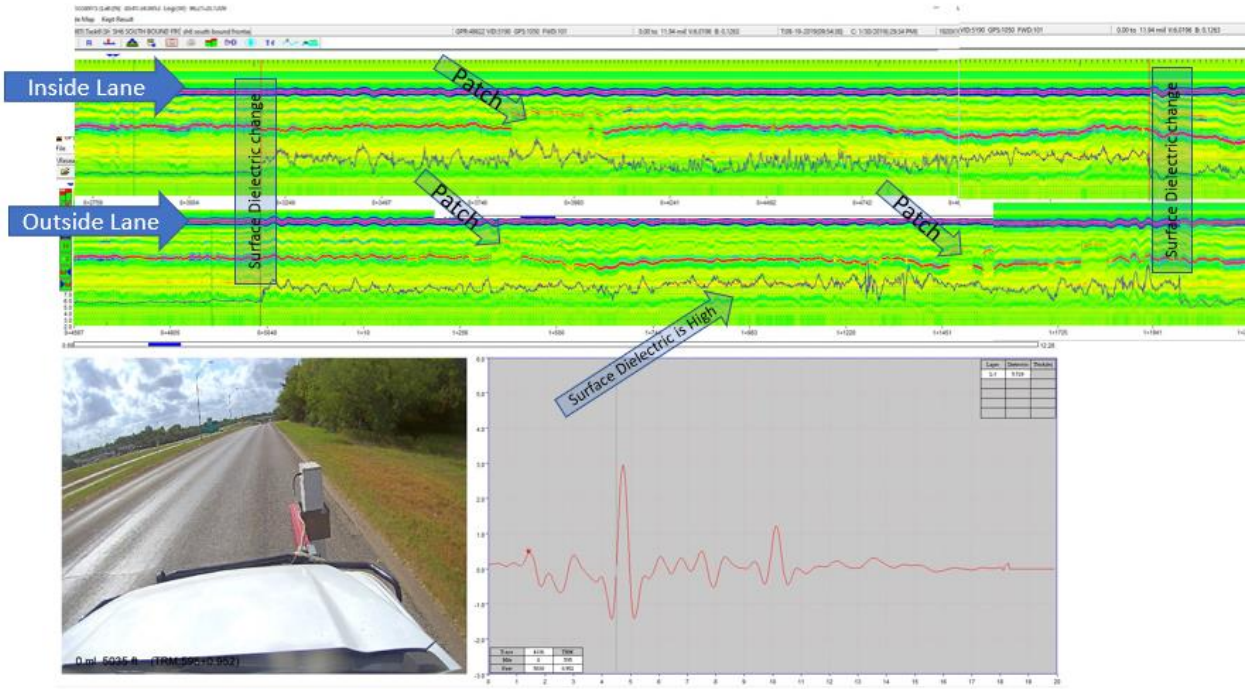


Figure 10. SH 6 SB Frontage Road GPR in Repair Area 1.

Proposed Pavement Design

Since the majority of the existing pavement is in good condition, that pavement can be used in all locations that the geometry will allow. Using the existing pavement will save removal time and costs. Complete removal is estimated at $12.31/sy, with a time of 2,000 sy per day for rigid and 3,000 sy per day for flexible. The existing concrete section is approximately 8.5 mi long and 38 ft wide per roadbed, and the flexible section is approximately 3 mi long and 44 ft wide per roadbed. The total is approximately 533,867 sy that would cost $6,571,900 for removal and 241 working days. At an average of 13 working days per month, this project would have a 19-month impact to the traveling public. The replacement subbase construction cost would be $26,903,800, for a total potential savings on the main lanes of $33,475,700.

The frontage road pavement is also in good structural condition except for approximately 2 mi on the southbound side from SH 21 to Water Locust Street. This section is approximately 344,960 sy that would cost $4,553,500 for removal and take 115 working days. At an average of 13 working days per month, this project would have a 9-month impact to the traveling public. The cost of reconstruction would have a savings of $26,737,900.

Retaining all structurally sound existing pavement (main lane and frontage road) would result in a savings of up to $65,766,950 and at least 260 days (20 months) for the project (some work items will take place simultaneously).

Table 6 and **Table 7** contain the proposed pavement work and cost estimate normalized to a cost per square yard of pavement. Table 8 through Table 18 break down the cost by pavement layer and the work for each option considered.

Table 6. SH 6—Summary of Main Lane Pavement Repair Options.

Keep Existing Pavement Options (Main Lanes)		$/sy	$/sy	Notes
Rigid Pavement Section ML1: Keep Existing	Pavement New	$78.40	$79.60	Use existing pavement as subbase. Remove PFC. Raises profile 13".
	Removal Cost	$1.20		
Rigid Pavement Section ML1: Widening	Pavement New	$107.97	$107.97	Widen to match existing pavement layers. Shoulder will have to be removed or cement treated in place. Cement-treated base plant mixed is preferred.
	Removal Cost			
Flexible Pavement Section: ML2—Overlay	Pavement New	$20.96	$24.87	Shoulder pavement is weaker than lane. Requires a 3" overlay.
	Removal Cost	$3.91		
Flexible Pavement Section: ML2—Widening	Pavement New	$91.33	$91.33	Widen to match existing pavement layers. Cement-treated base plant mixed is preferred.
	Removal Cost			
New Construction Options (Main Lanes)		$/sy	$/sy	Notes
Flexible Pavement Section: ML1 and 2—Perpetual Pavement	Pavement New	$101.35	$140.39	Reconstruct with perpetual pavement. (The removal for ML1 and 2 is approx. the same cost; ML1 is shown above.)
	Removal Cost	$12.31		
	Year 15 PM Work (net present value)	$26.73		The total thickness of pavement structures is the same.
Rigid Pavement Section: New Construction	Pavement New	$107.97	$128.80	
	Removal Cost	$12.31		Concrete repairs. Assume 1.5% of area at year 15.
	Year 15 PM Work (net present value)	$8.52		

Table 7. SH 6—Summary of Frontage Road Pavement Repair Options.

Options (Frontage Road)		$/sy	$/sy	Notes
Flexible Pavement Frontage Road Section: SB2, SB3, and NB1—Overlay	Pavement	$15.66	$15.66	2" overlay with underseal.
	Removal			
Flexible Pavement Frontage Road Section: SB1, SB4, and NB2—Mill and Inlay	Pavement	$15.66	$18.06	No additional structure is required. Replace surface layer.
	Removal	$2.40		
Flexible Pavement Frontage Road Section: SB1—Full-Depth Hot Mix Asphalt Repair	Pavement	$77.51	$90.71	Can match profile.
	Removal	$13.20		
	Year 15 PM Work (net present value)	$20.38	$111.09	Life-cycle cost analysis for full-depth hot mix asphalt frontage road section.
Flexible Pavement Frontage Road Section: SB1 Repairs—Full-Depth Reclamation	Pavement	$54.35	$54.35	Raises profile 7". Does not remove problem material (not a good option).
	Removal			
Rigid Pavement Section: Frontage Roads	Pavement	$90.52	$106.24	Concrete pavement for frontage roads (assumed top 6" could be milled for reclaimed asphalt pavement).
	Removal	$15.72		
	Year 15 PM Work (net present value)	$6.69	$112.93	Life-cycle cost analysis for concrete frontage road section.

Table 8. SH 6—Rigid Pavement Section ML1: Keep Existing.

Layer Description	Depth (in)	Item	Materials	Stabilizer (%)	$/sy	$/CY
Concrete	14	346	CRCP		$78.40	$201.60
Removal	1	354	Mill		$1.20	$43.20
	21.0	New Pavement TOTAL			$78.40	$/sy
		Removal Cost			$1.20	$/sy
Comments:	Use existing pavement as subbase. Remove PFC.					

Table 9. SH 6—Rigid Pavement Section ML1: Widening.

Layer Description	Depth (in)	Item	Materials	Stabilizer (%)	$/sy	$/CY
Concrete	14	346	Continuously Reinforced Concrete Pavement		$78.40	$201.60
Subbase (Hot Mix)	1.5	3076	DG Ty D		$7.21	$165.53
Prime		310	Prime		$0.65	
Treated Base	6	276	Plant Mix Cement Base		$15.06	$90.36
Subgrade Treatment	8	275	Road Mix Exist Subgr (Cmt)	2	$3.32	$14.93
		260	Road Mix Exist Subgr (Lime)	2	$3.34	$15.01
	29.5	TOTAL			$107.97	$/sy
Comments:	Widen to match existing pavement layers. Cement-treated base plant mixed is preferred due to mixing issues at the longitudinal construction joint. Shoulder will have to be removed or cement treated in place.					

Table 10. SH 6—Flexible Pavement Section ML2: Overlay.

Layer Description	Depth (in)	Item	Materials	Stabilizer (%)	$/sy	$/CY for Flexible Pavement System
Hot Mix	1.5	346	SMA D		$10.48	$244.08
	1.5	346	SMA D		$10.48	$244.08
Removal	1	354	Mill-Micro		$3.91	$140.76
	2.0	New Pavement TOTAL			$20.96	$/sy
		Removal Cost			$3.91	$/sy
Comments:	The shoulder pavement is weaker than the lane pavement. Requires a 3" overlay. This overlay is still less expensive than reconstructing the shoulder since the main lane needs 1.5" overlay. Milling is for PFC removal.					

Table 11. SH 6—Flexible Pavement Section ML2: Widening.

Layer Description	Depth (in)	Item	Materials	Stabilizer (%)	$/sy	$/CY for Flexible Pavement System
Hot Mix	1.5	346	SMA D		$10.48	$244.08
	9.5	3077	SP B		$46.66	$175.63
Underseal		316	SC-Ac modified with GR 4		$1.79	
Prime		310	Prime		$0.65	
Treat Existing or Existing and New Material	10	276	Plant Mix Cement Base		$25.10	$90.36
Subgrade Treatment	8	275	Road Mix Exist Subgr (Cmt)	2	$3.32	$14.93
		260	Road Mix Exist Subgr (Lime)	2	$3.34	$15.01
	19.0	New Pavement TOTAL			$91.33	$/sy
		Removal Cost				$/sy
Comments:	Widen to match existing pavement layers. Cement-treated base plant mixed is preferred due to mixing issues at the longitudinal construction joint.					

Table 12. SH 6—Flexible Pavement Frontage Road Section SB1, SB4, and NB2—Mill and Inlay.

Layer Description	Depth (in)	Item	Materials	Stabilizer (%)	$/sy	$/CY for Flexible Pavement System
Hot Mix	2	346	SMA D		$13.87	$244.08
Removal	2	354	Mill		$2.40	$43.20
Underseal		316	SC-Ac modified with GR 4		$1.79	
		New Pavement TOTAL			$15.66	$/sy
		Removal Cost			$2.40	$/sy
Comments:	No additional structure is required. Replace the surface layer.					

Table 13. SH 6—Flexible Pavement Frontage Road Section SB2, SB3, and NB1—Overlay.

Layer Description	Depth (in)	Item	Materials	Stabilizer (%)	$/sy	$/CY for Flexible Pavement System
Hot Mix	2	346	SMA D		$13.87	$244.08
Underseal		316	SC-Acmodified with GR 4		$1.79	
	2	New Pavement TOTAL			$15.66	$/sy
		Removal Cost				$/sy
Comments:	2" overlay with underseal.					

Table 14. SH 6—Flexible Pavement Frontage Road Section SB1 Repairs—Full-Depth Reclamation.

Layer Description	Depth (in)	Item	Materials	Stabilizer (%)	$/sy	$/CY for Flexible Pavement System
Hot Mix	2	346	SMA D		$13.87	$244.08
	5	3077	SP B		$24.70	$175.63
Underseal		316	SC-Acmodified with GR 4		$1.79	
Treat Existing or Existing and New Material	12	SS	Road Mix with Foam	2.4	$9.71	$29.14
	12	275	Road Mix with Cement	1	$4.28	$12.84
	19.0	New Pavement TOTAL			$54.35	$/sy
		Removal Cost				$/sy
Comments:	Raises profile 7".					

Table 15. Flexible Pavement Frontage Road Section SB1—Full-Depth Hot Mix Asphalt Repair.

Layer Description	Depth (in)	Item	Materials	Stabilizer (%)	$/sy	$/CY for Flexible Pavement System
Hot Mix	2	346	SMA D		$13.87	$244.08
	9	3077	SP B		$44.22	$175.63
Removal	11	354	Mill		$13.20	$43.20
Underseal		316	SC-Acmodified with GR 4		$1.79	
Subgrade Treatment	8	260	Road Mix Exist Subgr (Lime)	4	$4.43	$19.95
	8.0	New Pavement TOTAL			$77.51	$/sy
		Removal Cost			$13.20	$/sy
Comments:	Can match profile.					

Table 16. Frontage Road Rigid Pavement Section Design.

Layer Description	Depth (in)	Item	Materials	Stabilizer (%)	$/sy	$/CY
Concrete	11	346	Continuously Reinforced Concrete Pavement		$61.60	$201.60
Subbase (Hot Mix)	1.5	3076	DG Ty D		$7.21	$165.53
Treated Base	6	276	Plant Mix Cement Base		$15.06	$90.36
Subgrade Treatment	8	275	Road Mix Exist Subgr (Cmt)	2	$3.32	$14.93
		260	Road Mix Exist Subgr (Lime)	2	$3.34	$15.01
Removal	6	354	Mill		$7.20	$43.20
Removal	12	105	Remove Flex Pav		$8.52	$25.56
	20.5	New Pavement TOTAL			$90.52	$/sy
		Removal Cost			$15.72	$/sy
Comments:	Concrete pavement for frontage roads (assumed top 6" could be milled for reclaimed asphalt pavement).					

Table 17. Flexible Pavement Section ML1 and 2—Perpetual Pavement.

Layer Description	Depth (in)	Item	Materials	Stabilizer (%)	$/sy	$/CY for Flexible Pavement System
Hot Mix	3.5	346	SMA C		$22.06	$223.74
	12	3077	SP B		$58.85	$175.63
Removal	3.5	354	Mill		$4.20	$43.20
Removal	8	104	Remove Conc Pav		$5.27	
Removal	4	105	Remove Flex Pav		$2.84	$25.56
Underseal		316	SC-Acmodified with GR 4		$1.79	
Prime		310	Prime		$0.65	
Flex Base	6	247	Flexible Base		$11.34	$68.04
Subgrade Treatment	8	275	Road Mix Exist Subgr (Cmt)	2	$3.32	$14.93
		260	Road Mix Exist Subgr (Lime)	2	$3.34	$15.01
	29.5	New Pavement TOTAL			$101.35	$/sy
		Removal Cost			$12.31	$/sy
Comments:		Reconstruct with perpetual pavement (removal for ML1 and 2 is approximately the same cost; ML1 is shown above).				
	ML1 and 2—Perpetual Pavement YR 15 PM Work					
	Depth (in)	Item	Materials	Stabilizer (%)	$/sy	$/CY for Flexible Pavement System
	1.5	346	SMA D		$10.48	$244.08
	1	3077	SP Level-Up		$5.23	$177.21
	1.5	354	Mill		$1.80	$43.20
		316	SC-Acmodified with GR 4		$1.79	
		Pavement TOTAL			$19.30	$/sy
	Life-Cycle Cost Analysis					
		Proposed Work at Year		15.00		
		Rate		2.5%		
		Initial Cost PP			$113.66	**$/sy**
		Year 15 PM Work (Net Present Value)			$27.96	**$/sy**
		Net Present Value			$141.61	**$/sy**
	Comments:	**Replace Surface at Year 15.**				

Table 18. Rigid Pavement Main Lane Section—New Construction.

Layer Description	Depth (in)	Item	Materials	Stabilizer (%)	$/sy	$/CY
Concrete	14	346	Continuously Reinforced Concrete Pavement		$78.40	$201.60
Subbase (Hot Mix)	1.5	3076	DG Ty D		$7.21	$165.53
Prime		310	Prime		$0.65	
Treated Base	6	276	Plant Mix Cement Base		$15.06	$90.36
Subgrade Treatment	8	275	Road Mix Exist Subgr (Cmt)	2	$3.32	$14.93
		260	Road Mix Exist Subgr (Lime)	2	$3.34	$15.01
Removal	3.5	354	Mill		$4.20	$43.20
Removal	8	104	Remove Conc Pav		$5.27	
Removal	4	105	Remove Flex Pav		$2.84	$25.56
	29.5	New Pavement TOTAL			$107.97	$/sy
		Removal Cost			$12.31	$/sy
	Comments:	Concrete pavement for frontage roads.				

Rigid Pavement Section: PM Work					
Depth (in)	Item	Materials	Repair (%)	$/sy	$/CY
14	346	Continuously Reinforced Concrete Pavement Repair	1.5%	$5.88	$1,008.00
	PM Pavement TOTAL			$5.88	$/sy
Life-Cycle Cost Analysis					
	Proposed Work at Year		15.00		
	Rate		2.5%		
	Initial Cost Rigid Pavement			$120.28	$/sy
	Year 15 PM Work (Net Present value)			$8.52	$/sy
	Net Present Value			$28.80	$/sy
Comments:	Concrete repairs. Assume 1.5% of area at year 15.				

LiDAR Geometric Evaluation

Mobile LiDAR data were collected in January 2020. During the analysis, researchers segmented SH 6 based on the existing bridge structures along the route. Figure 11 shows an aerial view of the corridor, with six overpass bridges and two underpasses noted. The analysis spans the area from just north of the FM 2818 underpass where SH 6 flies over and the SH 21 overpass where SH 6 passes under.

Figure 11 Arial picture showing the State Highway 6 widening project.

TxDOT's *Roadway Design Manual* (2018) guided the geometric analysis. The design criteria recommend a 16-ft surface median or a 76-ft depressed median including the inner shoulders. However, minimum median widths are 4 ft for a surface median and 48 ft for a depressed median including the inner shoulders. The desirable inside or outside shoulder width is 10 ft. The design criteria also recommend a minimum inside shoulder width of 4 ft for a depressed median and a minimum outside shoulder width of 8 ft. The analysis used nine logical subsections. The analysis sections are:

1. Near FM 2818 to Southwest Parkway Overpass.
2. Southwest Parkway Overpass to Harvey Road Underpass.
3. Harvey Road Underpass to University Drive Overpass.
4. University Drive Overpass to Carter Creek Underpass.
5. Carter Creek Underpass to Briarcrest Drive Overpass.
6. Briarcrest Drive Overpass to William J. Bryan Parkway Overpass.
7. William J. Bryan Parkway Overpass to Martin Luther King (MLK) Road Overpass.
8. MLK Overpass to SH 21 Overpass.
9. A 25-ft Section after SH 21 Overpass.

The mobile LiDAR unit used for data collection provides transverse strings (i.e., cross sections) in approximately 10-inch increments. Summarizing these data into useful information presents a challenge. Using the nine analysis segments, Table 19 summarizes the existing condition and future condition when widening to the inside with a 12-ft lane and 6-ft inside shoulder. These segments were subdivided into 1,000-ft increments to provide a more detailed summary. The final length in the segment is the remaining length after all preceding segments are summarized on 1,000-ft lengths. Table 19 indicates that SH 6 can be widened to the inside and maintain a depressed median from FM 2818 to 1,000 ft north of the MLK overpass. Within this area, the average median width exceeds 48 ft; however, some isolated 1,000-ft sections have averages between 45 ft and 48 ft. Nonetheless, these widths do not violate the design criteria because the measurements in Table 19 are from edge of pavement to edge of pavement. Including the inside shoulders (i.e., 4 ft on each roadbed) achieves the required median width. Furthermore, Table 19 shows that after widening to the inside, the new front slopes along SH 6 will remain flatter than 4(H):1(V) and will mostly be flatter than 5(H):1(V).

Approximately 1,000 ft north of the MLK overpass, the existing median narrows and prevents widening to the inside while maintaining the necessary median width or an acceptable front slope. In this area, widening to the inside will require filling in the existing median and constructing a barrier to divide traffic.

Table 19. Existing and Future Median Widths, Front Slopes, and Future Median Types.

Sec Start (m)	Sec End (m)	Sec Length (ft)	Existing Soft Median Width (ft)	Existing NB Front Slope	Existing SB Front Slope	Future Soft Median Width (ft)	Future NB Front Slope	Future SB Front Slope	Median Type
SEC_1_NEAR_FM2818_TO_SW_PKWY									
134.518	439.013	1,000	67.49	14.67	14.04	53.49	8.75	7.18	Depressed Median
439.318	743.813	1,000	63.26	13.38	11.16	49.26	7.09	5.42	Depressed Median
744.118	1,048.61	1,000	65.82	14.23	10.42	51.82	7.89	4.93	Depressed Median
1,048.92	1,353.41	1,000	63.32	12.18	12.72	49.32	6.04	6.64	Depressed Median
1,353.72	1,658.21	1,000	59.21	12.92	11.94	45.21	6.53	5.31	Depressed Median
1,658.52	1,835.91	583	62.13	11.51	11.32	48.13	6.15	5.41	Depressed Median
SEC_2_SW_PKWY_TO_HARVEY_RD									
1,857.55	2,162.05	1,000	61.71	12.49	12.38	47.71	6.5	6.01	Depressed Median
2,162.35	2,466.85	1,000	64.33	11.15	10.09	50.33	5.97	5	Depressed Median
2,467.15	2,771.65	1,000	61.34	13.73	10.34	47.35	7.42	4.44	Depressed Median
2,771.95	3,076.45	1,000	61.03	10.97	11.47	47.03	5.24	5.63	Depressed Median
3,076.75	3,220.92	474	61.48	17.36	12.86	47.63	9.54	6.26	Depressed Median

Sec Start (m)	Sec End (m)	Sec Length (ft)	Existing Soft Median Width (ft)	Existing NB Front Slope	Existing SB Front Slope	Future Soft Median Width (ft)	Future NB Front Slope	Future SB Front Slope	Median Type
SEC_3_HARVEY_RD_TO_UNIV_BLVD									
3,281.88	3,586.38	1,000	61.52	12.03	12.05	47.49	6.78	5.69	Depressed Median
3,586.68	3,891.18	1,000	63.14	11.69	11.7	49.14	6.41	5.81	Depressed Median
3,891.48	4,195.98	1,000	61.56	10.71	12.48	47.58	5.38	6.42	Depressed Median
4,196.28	4,500.78	1,000	61.76	10.02	10.97	47.76	5.11	5.87	Depressed Median
4,501.08	4,660.49	524	62.16	10.23	12.37	48.16	5.15	6.69	Depressed Median
SEC_4_UNIV_BLVD_TO_CARTER_CK									
4,674.21	4,978.7	1,000	62.89	8.93	11.13	47.33	4.49	5.62	Depressed Median
4,979.01	5,139.94	529	62.15	11.25	12.71	51.26	6.27	7.14	Depressed Median
SEC_5_CARTER_CK_TO_BRCREST_DR									
5,187.8	5,492.29	1,000	62.84	11.66	14.94	48.84	5.15	8.2	Depressed Median
5,492.6	5,797.09	1,000	61.92	9.99	10.96	47.92	5.16	5.58	Depressed Median
5,797.4	6,101.89	1,000	60.87	11.98	12.36	46.87	5.81	6.06	Depressed Median
6,102.2	6,406.69	1,000	59.43	9.68	9.98	45.43	4.56	5.1	Depressed Median
6,407	6,711.49	1,000	65.42	9.76	11.7	51.42	4.75	6.7	Depressed Median
6,711.8	7,016.29	1,000	65.53	10.7	11.77	51.53	5.39	6.52	Depressed Median
7,016.6	7,321.09	1,000	62.94	10.59	11	48.95	5.18	5.77	Depressed Median
7,321.4	7,625.89	1,000	58.97	11.95	11.26	44.97	6.04	5.59	Depressed Median
7,626.2	7,680.45	179	61.29	14.4	11.99	47.29	7.11	6.35	Depressed Median
SEC_6_BRCREST_DR_TO_WJ_BRYAN									
7,692.95	7,997.44	1,000	63.51	12.64	13.93	49.51	5.91	7.5	Depressed Median
7,997.75	8,302.24	1,000	65.91	10.99	10.18	51.91	5.86	5.4	Depressed Median
8,302.55	8,607.04	1,000	64.07	9.26	12.62	50.07	4.41	7.05	Depressed Median
8,607.35	8,911.84	1,000	61.73	10.96	13.09	47.73	5.51	6.95	Depressed Median
8,912.15	9,109.35	648	61.75	12.65	12.58	47.75	6.66	6.22	Depressed Median
SEC_7_WJ_BRYAN_TO_MLK_RD									
9,129.78	9,434.27	1,000	64.11	11.14	11.72	50.11	5.81	6.19	Depressed Median
9,434.58	9,739.07	1,000	63.32	11.04	11.97	49.32	5.57	6.26	Depressed Median
9,739.38	10,043.9	1,000	62.21	10.07	12.11	48.21	4.89	6.47	Depressed Median
10,044.2	10,348.7	1,000	62.51	10.14	12.34	48.51	4.78	6.81	Depressed Median
10,349	10,653.5	1,000	63.43	10.14	13.66	49.43	4.39	7.62	Depressed Median

Sec Start (m)	Sec End (m)	Sec Length (ft)	Existing Soft Median Width (ft)	Existing NB Front Slope	Existing SB Front Slope	Future Soft Median Width (ft)	Future NB Front Slope	Future SB Front Slope	Median Type
10,653.8	10,958.3	1,000	63.23	8.86	10.62	49.23	4.33	5.89	Depressed Median
10,958.6	11,182.9	737	64.08	11.95	13.33	50.08	6.04	7.09	Depressed Median
SEC_8_MLK_RD_TO_SH21_HW									
11,215.2	11,519.7	1,000	56.06	9.89	10.98	42.06	4.35	5.26	Depressed Median
11,520	11,824.5	1,000	40.5	9.57	11.34	26.53	2.56	3.72	Surfaced Median
11,824.8	12,129.3	1,000	38.62	10.62	10.96	24.67	2.51	3.18	Surfaced Median
12,129.6	12,434.1	1,000	37.25	12.48	11.64	23.26	2.61	3.04	Surfaced Median
12,434.4	12,487.1	174	36.31	12.56	12.55	22.37	2.24	2.99	Surfaced Median
SEC_9_AFTER_SH21_HW									
12,510.3	12,517.6	25	34.84	11.52	13.73	21.92	1.83	3.25	Surfaced Median
12,517.9	12,517.9	1	32	10.7	12.51	18	0.56	2.53	Surfaced Median

With SH 6 having six overpasses above the highway and two bridges within the analysis area, widening presents concerns for the impact to the structures. Using mobile LiDAR data, researchers measured the horizontal clearance to the bridge columns for overpasses. Additionally, the widths of the bridges along SH 6 were measured. Table 20 summarizes these measurements. Table 20 shows that widening SH 6 to the inside can be done without moving the interior bents of the Southwest Parkway, University Drive, Briarcrest Drive, William J. Bryan Parkway, and MLK Rd. overpasses. These interior bents will likely require additional protection, but geometrically speaking, the interior lane and shoulder can be constructed. The interior lane cannot be constructed without modifying the interior bent of the SH 21 overpass. The most cost-effective solution along SH 6 would be to use the SH 21 location as the transition point and establish an interior lane south of SH 21. Table 20 also shows that the SH 6 bridges over Harvey Road and Carter Creek are approximately 42 ft from face of rail to face of rail. Adding a third lane on these bridges would create narrow inside and outside shoulders.

Table 20. Details of Overpasses and Bridges of SH 6 Study Section.

Bridges (Overpass or Underpass)	Clearance to Columns for Overpasses for NB (ft)	Clearance to Columns for Overpasses SB (ft)	Width of Bridges at the Underpasses NB (ft)	Width of Bridges at the Underpasses SB (ft)
Southwest Parkway Overpass	29.86	31.17	N/A	N/A
Harvey Road Underpass	N/A	N/A	42.3	42.3
University Drive Overpass	30.84	30.84	N/A	N/A
Carter Creek Bridge	N/A	N/A	42.61	42.48
Briarcrest Drive Overpass	30.51	31.5	N/A	N/A
William J Bryan Parkway Overpass	30.51	31.17	N/A	N/A
MLK Overpass	29.2	30.51	N/A	N/A
SH 21 Overpass	15.42	16.73	N/A	N/A

SH 6 Traffic Control Strategies—CA4PRS Analysis

The main lanes on SH 6 from US 190 to BS6-R is an 8.5-mi section with a proposed continuously reinforced concrete pavement (CRCP). The project duration and traffic delay are highly interdependent. The agency can find a balanced trade-off on the weekend option. This option reduces traffic disruption at an acceptable range (24 minutes) while accelerating construction time (5,230 closure hours) and road user costs ($80,000 daily) compared to the 24/7 option that has 4,216 closure hours and road user costs of $138,000 per day.

The main lanes from BS 6R to SH 40 is a 3.4-mi section. The integrated trade-off analysis shows that all four options will produce a minimal level of traffic delay if the resurfacing work can be executed after the completion of the widening project.

Figure 12 through Figure 24 contain the CA4PRS analysis summaries.

SH-6 BCS Project

Schedule-Cost-Traffic Integrated Tradeoff Analysis

Texas A&M Transportation Institute

Project Analysts:
Darlene Goehl & Kunhee Choi

Alternatives

	Nighttime	Weekend	Weekdays	24/7
Construction Staging	M-F 9PM-5AM 8 Hrs per closure	F 8PM- M 6AM 58 Hrs per closure	T 8AM- R 8AM 72 Hrs per closure	M-Sun 24 hrs/d 168 Hrs per closure
ML1 CRCP Widening 17 lane-miles	Schedule 1,860 Closure | 14,880 Hours Road User Cost $1.4k Closure | $1.4k Days Peak Delay 2.6 Min	Schedule 90 Closure | 5,230 Hours Road User Cost $194k Closure | $80k Days Peak Delay 23.6 Min	Schedule 68 Closure | 4,886 Hours Road User Cost $481k Closure | $160k Days Peak Delay 57.3 Min	Schedule 25 Closure | 4,216 Hours Road User Cost $966k Closure | $138k Days Peak Delay 57.5 Min
ML1 CRCP Resurfacing 34 lane-miles	Schedule 2,488 Closure | 19,902 Hours Road User Cost $0.5k Closure | $0.5k Days Peak Delay 0.2 Min	Schedule 148 Closure | 8,554 Hours Road User Cost $8.8k Closure | $3.1k Days Peak Delay 0.2 Min	Schedule 112 Closure | 8,008 Hours Road User Cost $11.4k Closure | $3.8k Days Peak Delay 0.2 Min	Schedule 42 Closure | 6,959 Hours Road User Cost $34.4k Closure | $4.9k Days Peak Delay 0.4 Min
ML2 HMA Widening 6 lane-miles	Schedule N/A Closure | N/A Hours Road User Cost N/A Closure | N/A Days Peak Delay N/A Min	Schedule 11 Closure | 627 Hours Road User Cost $195k Closure | $81k Days Peak Delay 23.6 Min	Schedule 8 Closure | 575 Hours Road User Cost $483k Closure | $161k Days Peak Delay 57.5 Min	Schedule 3 Closure | 481 Hours Road User Cost $978k Closure | $140k Days Peak Delay 57.7 Min
ML2 HMA Resurfacing 12 lane-miles	Schedule 68 Closure | 538 Hours Road User Cost $1.6k Closure | $1.6k Days Peak Delay 0.2 Min	Schedule 6 Closure | 343 Hours Road User Cost $21.1k Closure | $8.7k Days Peak Delay 0.5 Min	Schedule 5 Closure | 337 Hours Road User Cost $29.5k Closure | $9.8k Days Peak Delay 0.6 Min	Schedule 2 Closure | 330 Hours Road User Cost $75.6k Closure | $10.8k Days Peak Delay 0.6 Min

Figure 12. SH 6 CA4PRS Summary Page 1.

SH-6 BCS: ML-1 Widening

Schedule-Cost-Traffic Integrated Tradeoff Analysis

Texas A&M Transportation Institute

Project Analysts:
Darlene Goehl & Kunhee Choi

Project Scope:

17 lane-miles
8.5 miles x 1 lanes x 2 directions

57,948 AADT with **13%** Truck

Traveller's Value of Time (2020)

$30.12 Passenger Car **$41.33** Truck

Project Objectives:

Widening the existing 2-lane section of SH-6 from US190 to BS 6-R with 1 extra lane with new CRCP pavement to the inside.

Recommendations:

- Widening a 8.5-mile stretch of an existing mainlane on both directions can be built over 25 around-the-clock closures (4,216 closure hours) under the 24/7 option.
- The same project would have taken 4,886 closure hours to complete with traditional weekday (14,880 closure hours with nighttime closures).
- The analysis turns out that a nominal traffic demand reduction during construction will still produce maximum peak delay as along as about 58 minutes for the 24/7 extended closure option.
- However, it is noticeable that the actual traffic delay during construction could be much tolerable due to the Covid-19 pandemic (no-shows).
- The project duration and traffic delay are highly interdependent: the agency can find a balanced tradeoff on the weekend option: it reduces traffic disruption at an acceptable range (24 minutes) while accelerating construction time (5,230 closure hours) and road user costs ($80k daily, compared to $138k for the 24/7 option).

Four Alternatives

Nighttime	Weekend	Weekdays	24/7
Single-lane Closure	Single-lane Closure	Single-lane Closure	Single-lane Closure
M-F 9PM-5AM	F 8PM- M 6AM	T 8AM- R 8AM	M-Sun 24 hrs/d
8 Hrs per Closure	58 Hrs per closure	72 Hrs per closure	168 Hrs per closure

Analysis Assumptions:

- AADT was assumed to be identical on each direction.
- Typical production rates were assumed for the construction.
- A typical urban weekday traffic pattern was assumed for weekday traffic analysis and a typical urban weekend traffic pattern was assumed for weekend traffic analysis.
- A 20% travel demand reduction and 20% detour rate with 20 minutes extra travel time is assumed for weekday traffic during construction (except nighttime).
- A 20% travel demand reduction and 15% detour rate with 20 minutes extra travel time is assumed for weekend traffic during construction.
- The staging plan splits the project into two segments such as ML 1 and ML 2. In each staging project, prioritizing widening construction over resurfacing would be a viable strategy to minimize the impact of traffic on affected communities, and it was assumed accordingly.

Figure 13. SH 6 CA4PRS Summary Page 2.

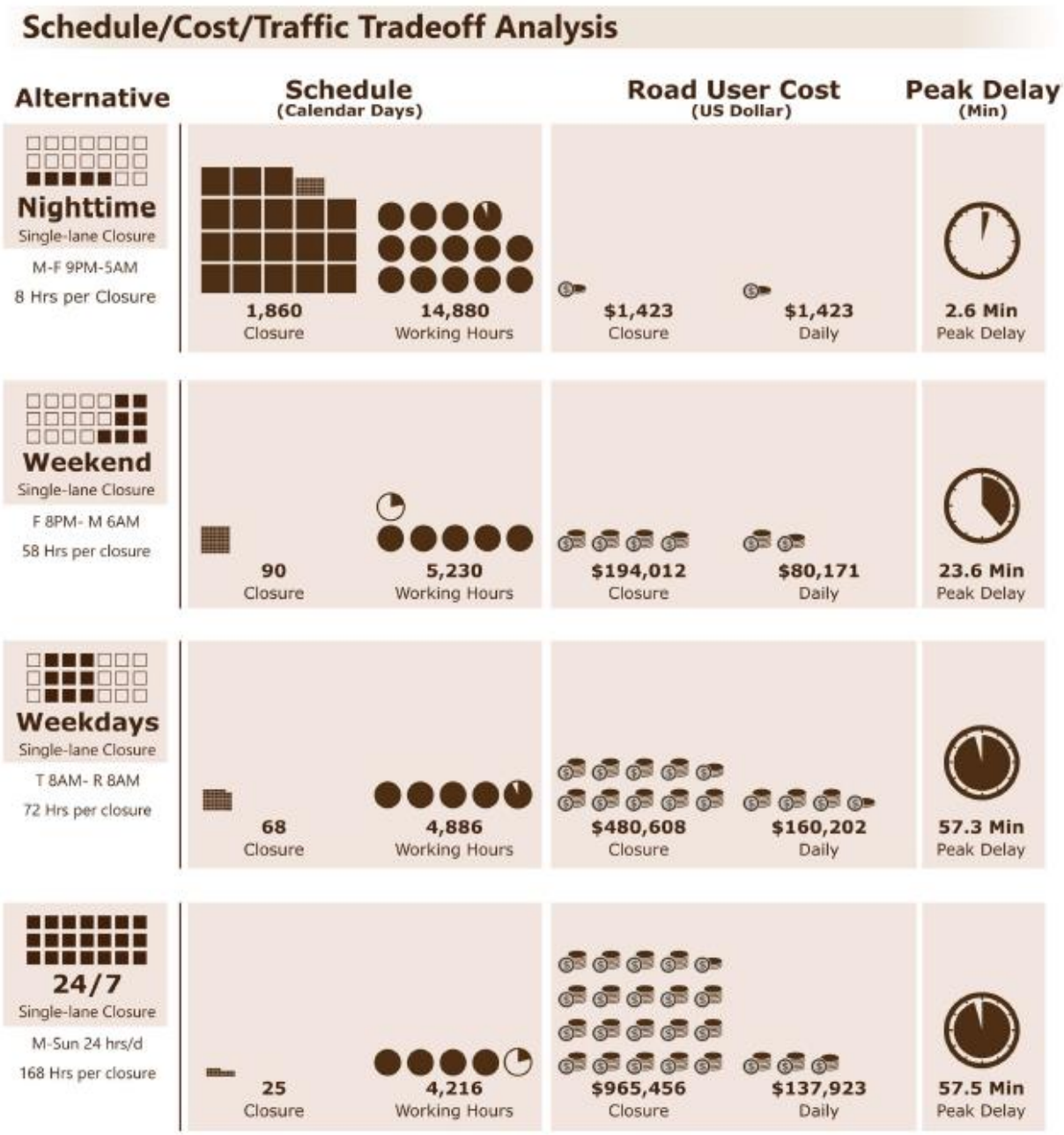


Figure 14. SH 6 CA4PRS Summary Page 3.

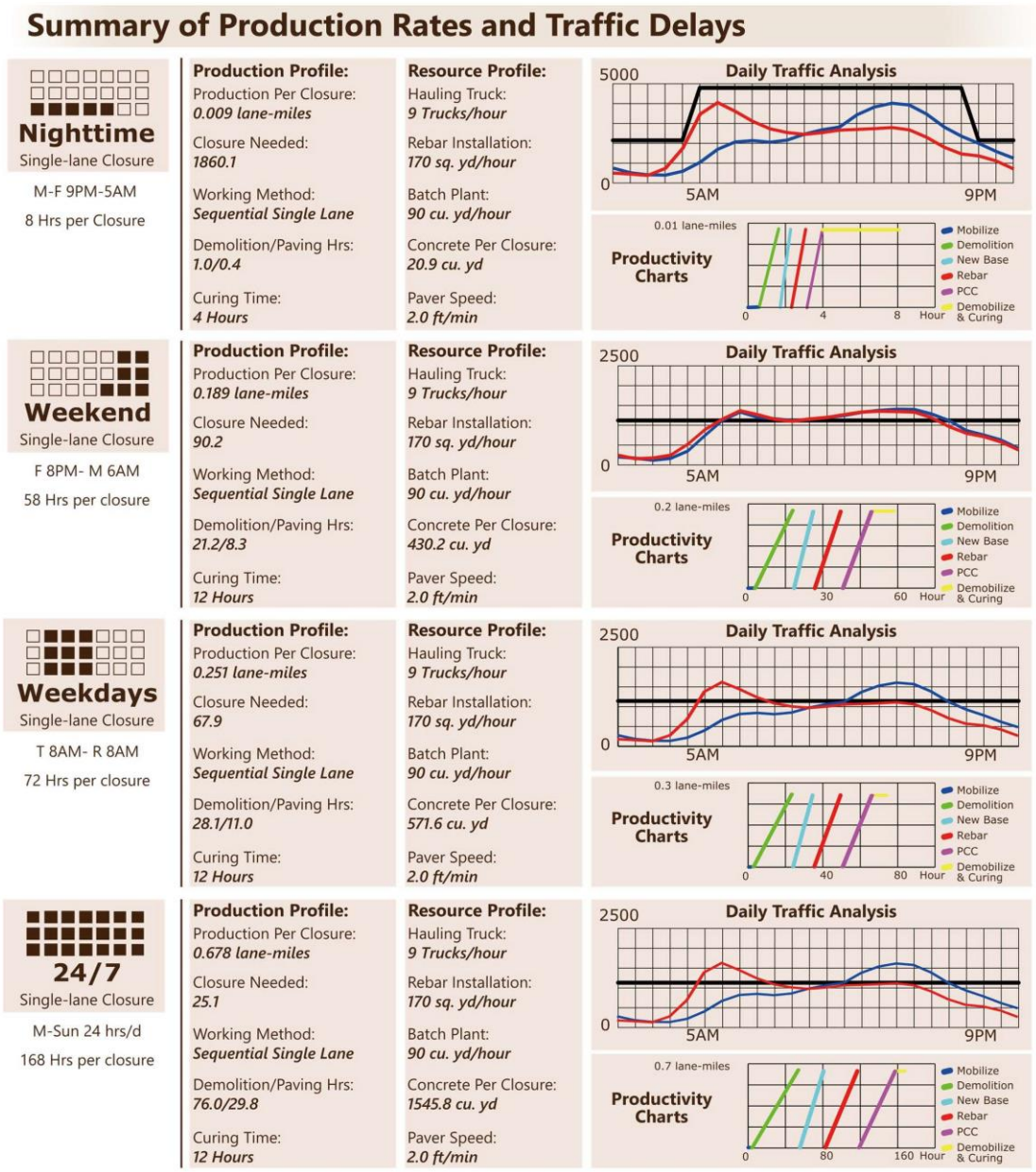


Figure 15. SH 6 CA4PRS Summary Page 4.

SH-6 BCS: ML-1 Resurfacing

Schedule-Cost-Traffic Integrated Tradeoff Analysis

Texas A&M Transportation Institute

Project Analysts:
Darlene Goehl & Kunhee Choi

Project Scope:

34 lane-miles
8.5 miles x 2 lanes x 2 directions

57,948 AADT with **13%** Truck

Traveller's Value of Time (2020)

$30.12 Passenger Car **$41.33** Truck

Project Objectives:

Overlaying the existing 2 lanes of SH-6 from US 190 to BS 6-R with new CRCP pavement on both directions.

Recommendations:

- The integrated tradeoff analysis shows that all four options will produce a minimal level of traffic delay if the resurfacing work can be executed after the widening project is first completed.
- Since traffic disruption during construction should not be a concern, the analysis indicates that an extended closure option (either weekday or 24/7) be considered.

Four Alternatives

Nighttime	Weekend	Weekdays	24/7
Single-lane Closure	Single-lane Closure	Single-lane Closure	Single-lane Closure
M-F 9PM-5AM	F 8PM- M 6AM	T 8AM- R 8AM	M-Sun 24 hrs/d
8 Hrs per closure	58 Hrs per closure	72 Hrs per closure	168 Hrs per closure

Analysis Assumptions:

- AADT was assumed to be identical in each direction.
- A typical urban weekday traffic pattern was used for the weekday option, while a generic urban weekend traffic pattern was adopted for the weekend closure option.

Figure 16. SH 6 CA4PRS Summary Page 5.

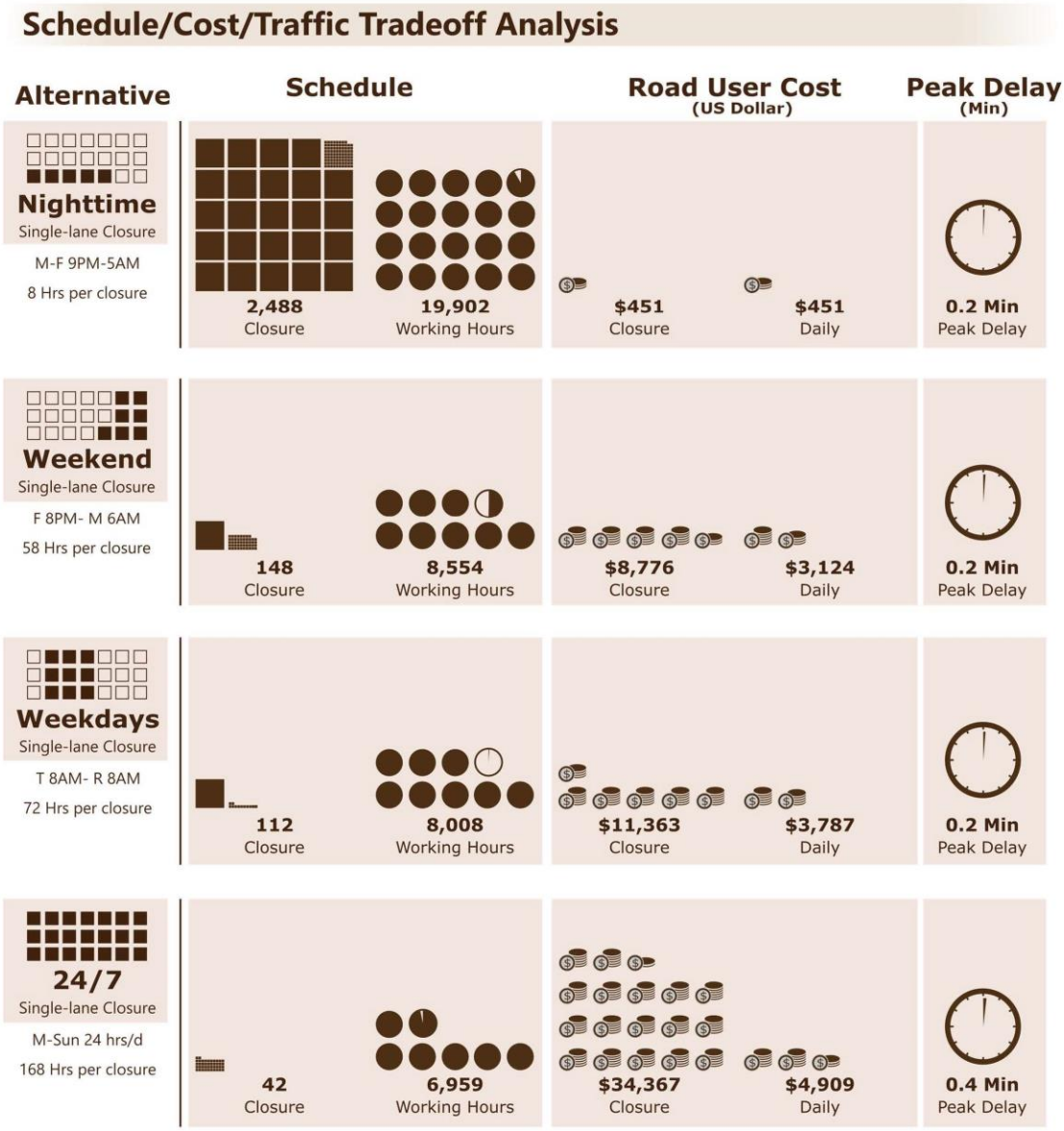


Figure 17. SH 6 CA4PRS Summary Page 6.

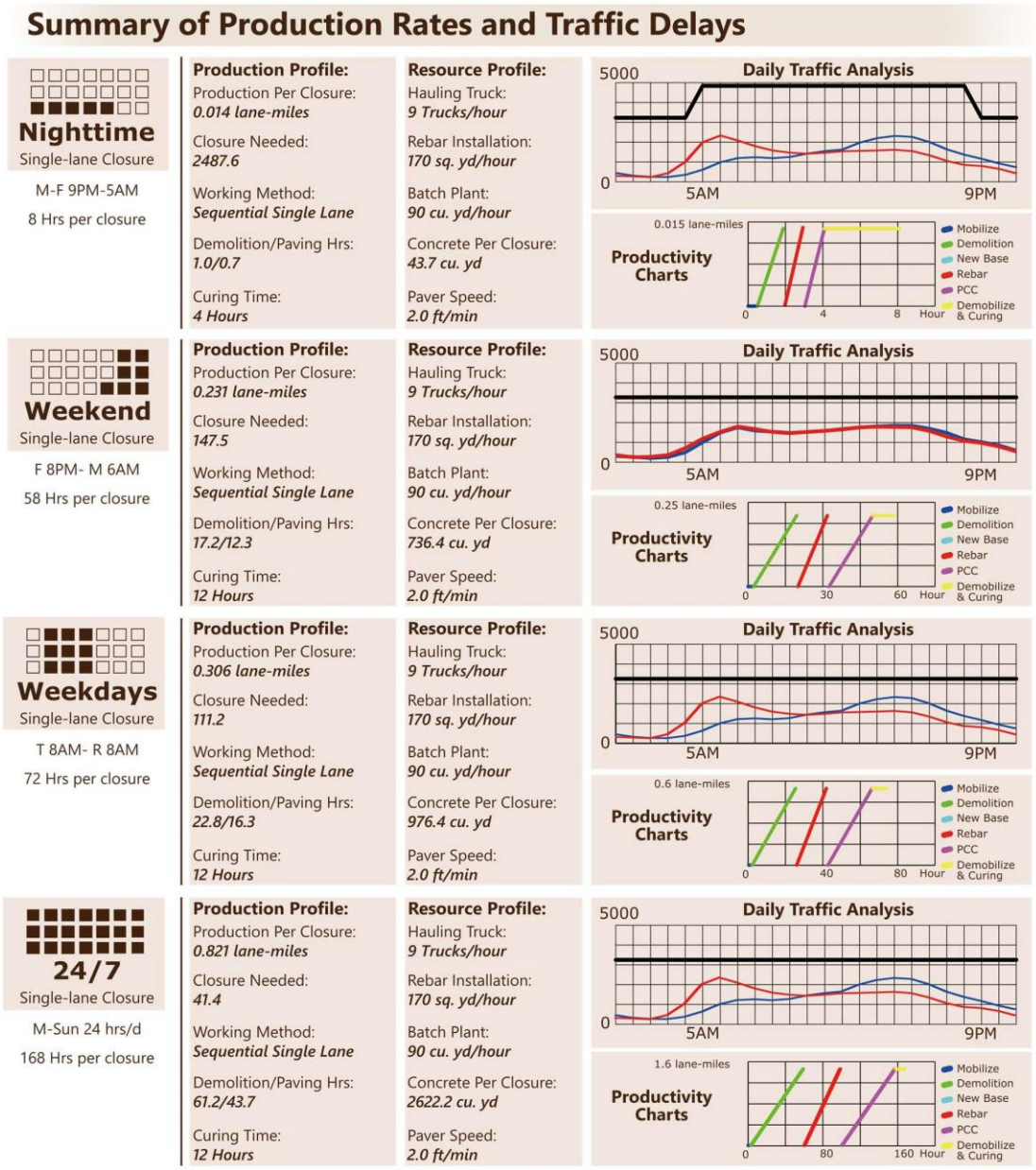


Figure 18. SH 6 CA4PRS Summary Page 7.

SH-6 BCS: ML-2 Widening

Schedule-Cost-Traffic Integrated Tradeoff Analysis

Texas A&M Transportation Institute

Project Analysts:
Darlene Goehl & Kunhee Choi

Project Scope:

6 lane-miles
3 miles x 1 lanes x 2 directions

57,948 AADT with **13%** Truck

Traveller's Value of Time (2020)

$30.12 Passenger Car **$41.33** Truck

Project Objectives:

Widening the existing 2-lane section of SH-6 from BS 6-R to SH-40 with 1 extra lane with HMA pavement to the outside.

Recommendations:

- This staging construction can be built over three (3) around-the-clock one-roadbed extended closures.
- The same project would require 8 weekday closures or 11 weekend closures to be completed.
- A nominal traffic demand reduction would still produce maximum peak delay as along as 58 minutes for the 24/7 and weekday extended closure options: yet the actual traffic delay during construction could be lower due to the Covid-19 pandemic.
- When pursuing a balanced tradeoff between contract time and level of traffic disruption, the weekend option appears preferable: 627 closure hours at 24-minute traffic delay.
- The 8-hour nighttime option did not produce any meaningful outcome due to cooling time constraints.

Four Alternatives

Nighttime	Weekend	Weekdays	24/7
Single-lane Closure	Single-lane Closure	Single-lane Closure	Single-lane Closure
M-F 9PM-5AM	F 8PM- M 6AM	T 8AM- R 8AM	M-Sun 24 hrs/d
8 Hrs per closure	58 Hrs per closure	72 Hrs per closure	168 Hrs per closure

Analysis Assumptions:

- AADT was assumed to be identical in each direction.
- A typical urban weekday traffic pattern was used for the weekday option, while a generic urban weekend traffic pattern was adopted for the weekend closure option.
- Asphalt cooling times were computed with MultiCool, an asphalt pavement cooling time prediction program endorsed by the National Asphalt Pavement Association (NAPA).

Figure 19. SH 6 CA4PRS Summary Page 8.

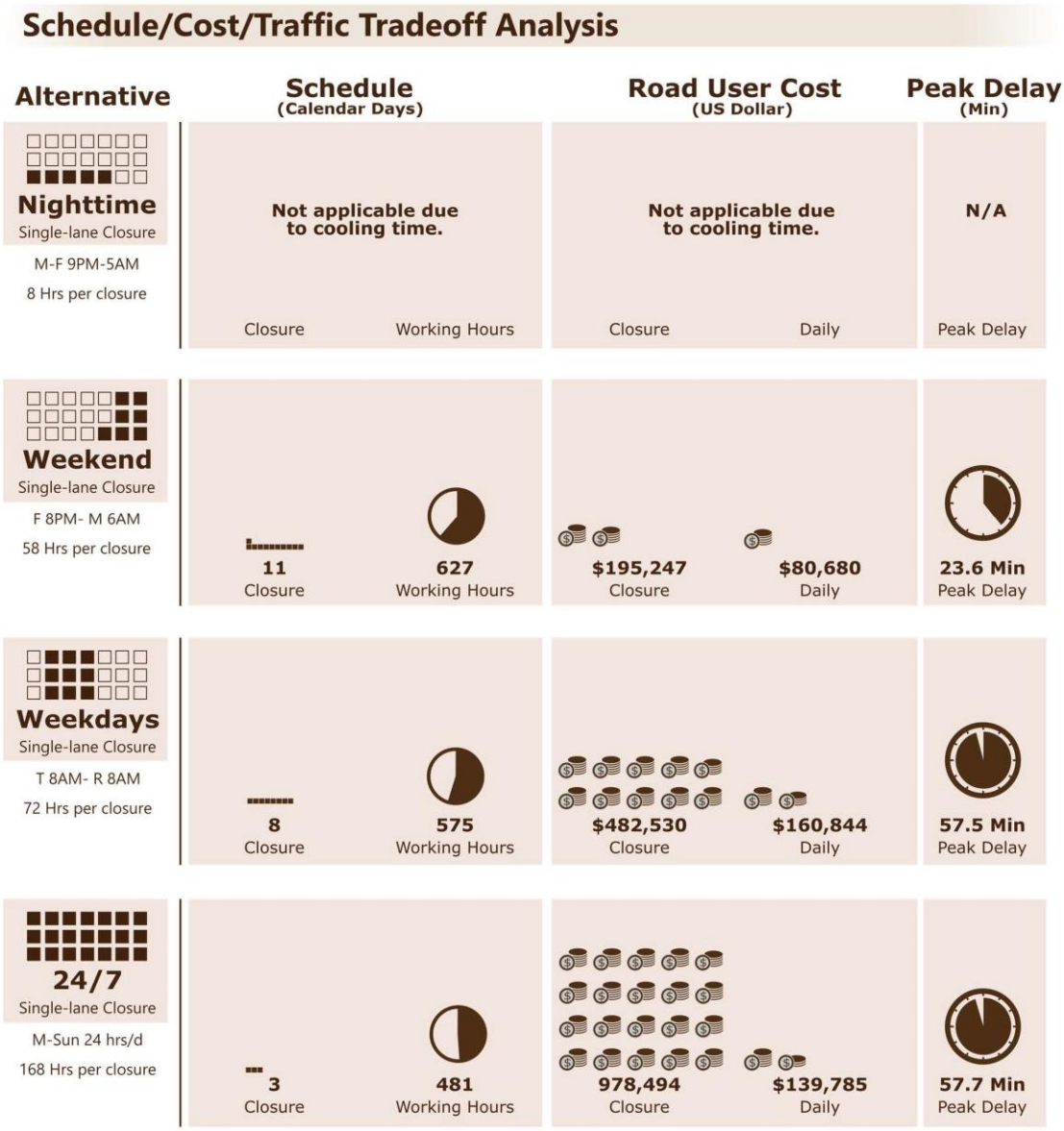


Figure 20. SH 6 CA4PRS Summary Page 9.

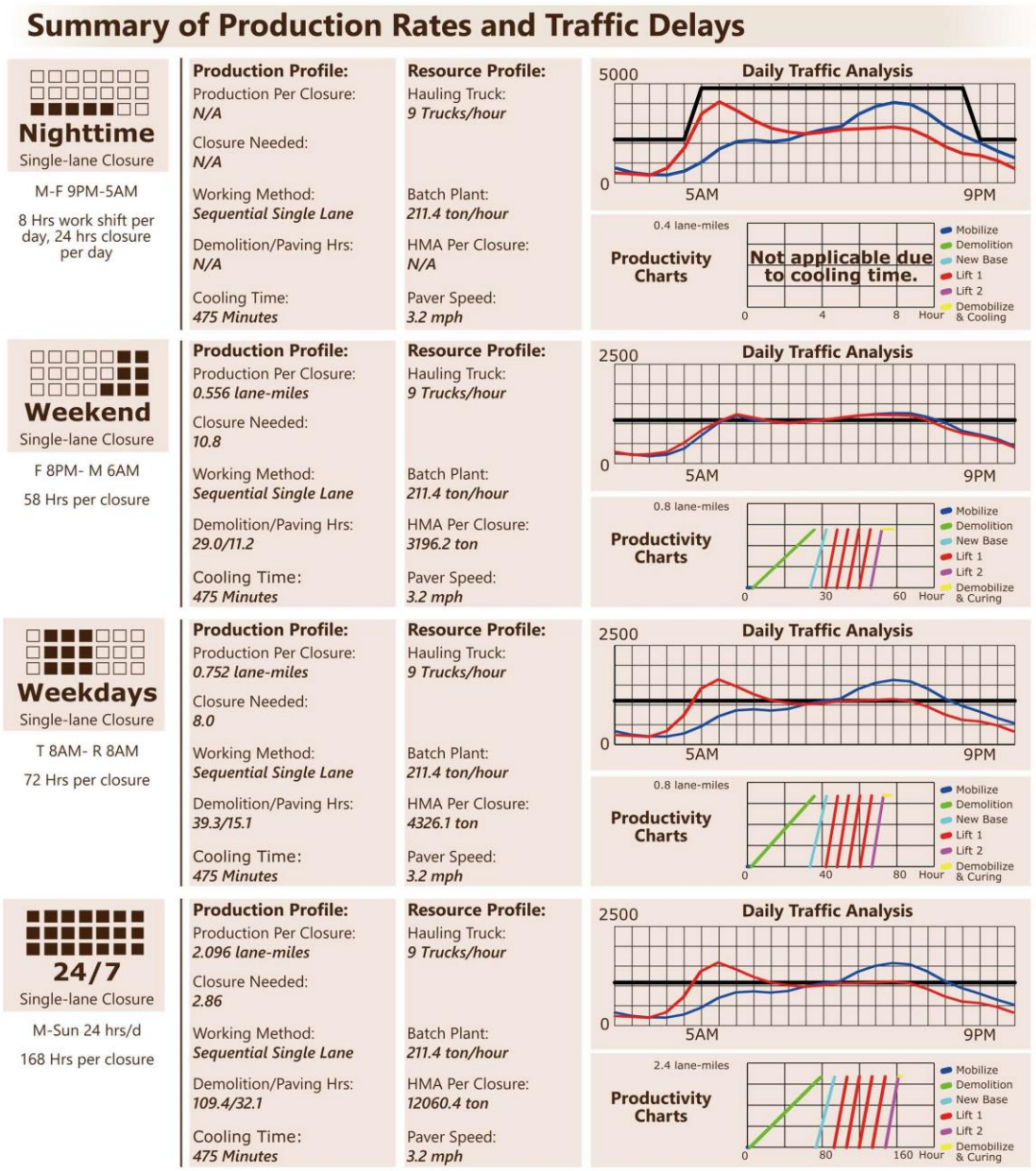


Figure 21. SH 6 CA4PRS Summary Page 10.

SH-6 BCS: ML-2 Resurfacing

Schedule-Cost-Traffic Integrated Tradeoff Analysis

Texas A&M Transportation Institute

Project Analysts:
Darlene Goehl & Kunhee Choi

Project Scope:

12 lane-miles
3 miles x 2 lanes x 2 directions

57,948 AADT with **13%** Truck

Traveller's Value of Time (2020)

$30.12 Passenger Car **$41.33** Truck

Project Objectives:

Overlaying the existing 2 lanes of SH-6 from BS 6-R to SH 40 with HMA pavement on both Northbound and Southbound directions.

Recommendations:

- The analysis reveals that traffic flows freely under all four different options if the resurfacing work is executed after the widening project is completed.
- Since traffic disruption during construction should not be a concern, the analysis indicates that one of the extended closure options be pursued.

Four Alternatives

Nighttime	Weekend	Weekdays	24/7
Single-lane Closure	Single-lane Closure	Single-lane Closure	Single-lane Closure
M-F 9PM-5AM	F 8PM- M 6AM	T 8AM- R 8AM	M-Sun 24 hrs/d
8 Hrs per closure	58 Hrs per closure	72 Hrs per closure	168 Hrs per closure

Analysis Assumptions:

- AADT was assumed to be identical in each direction
- A typical urban weekday traffic pattern was used for the weekday option, while a generic urban weekend traffic pattern was adopted for the weekend closure option.
- Asphalt cooling times were computed with MultiCool, an asphalt pavement cooling time prediction program endorsed by the National Asphalt Pavement Association (NAPA).The resurfacing work was assumed to be conducted after the completion of the widening work.

Figure 22. SH 6 CA4PRS Summary Page 11.

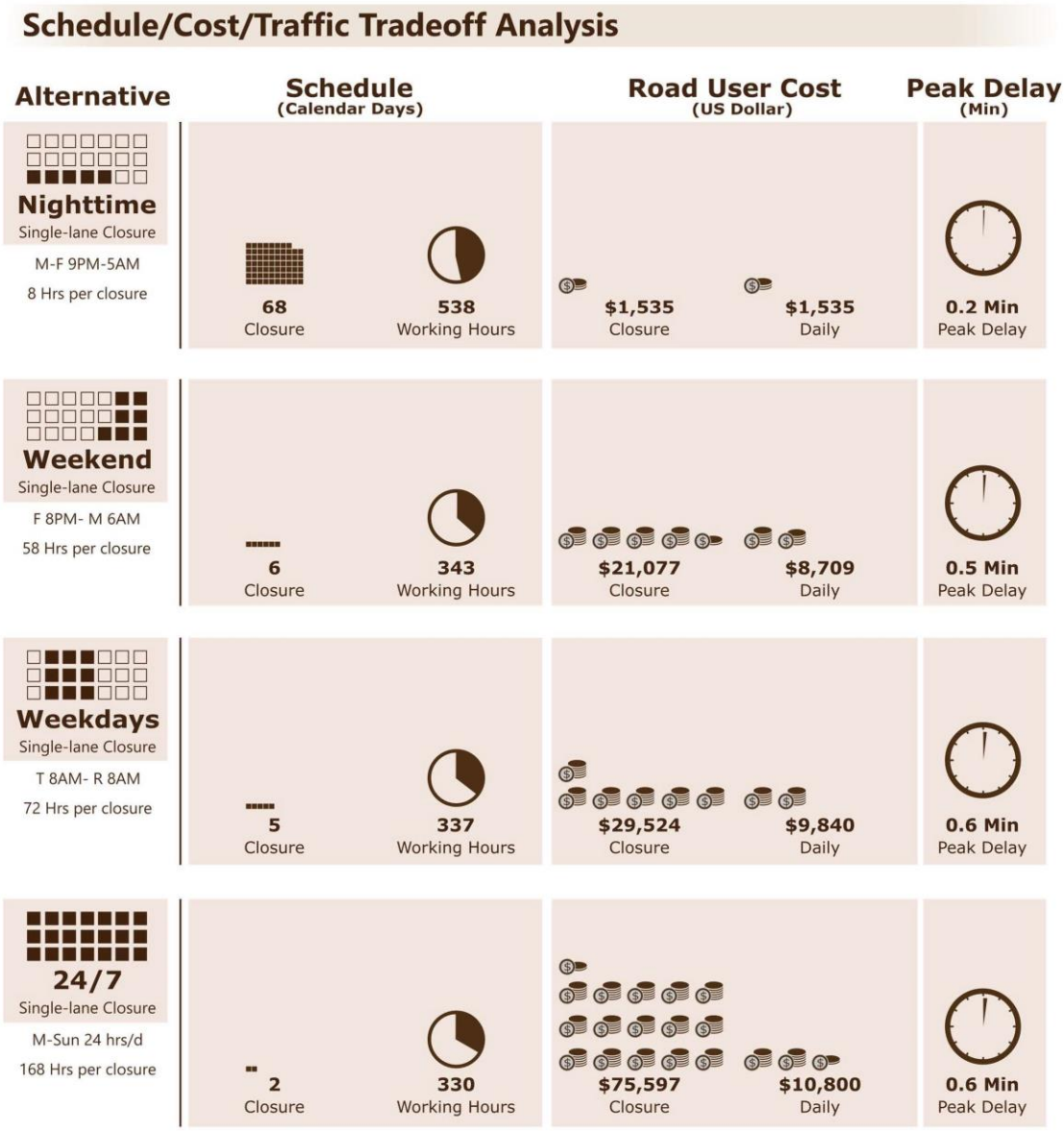


Figure 23. SH 6 CA4PRS Summary Page 12.

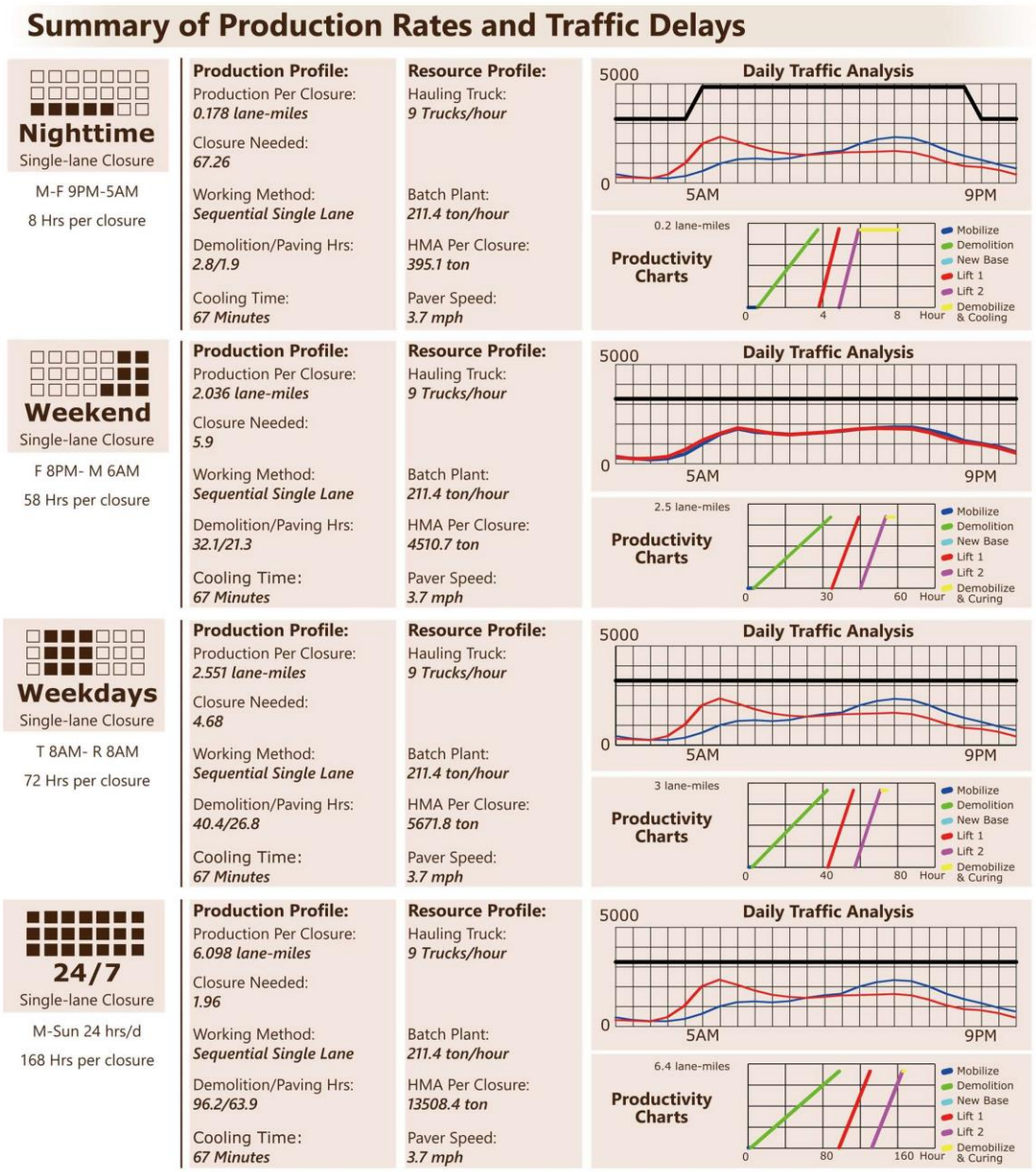


Figure 24. SH 6 CA4PRS Summary Page 13.

SH 6 Recommendations Summary

The following is a summary of the pavement recommendations assuming that the proposed geometry allows for existing pavement reuse (**Figure 25**):

- Main lanes.
  - Use a rigid pavement section for any areas that need to be fully reconstructed.
  - From BS 6R to SH 40:
    - The existing pavement is in good structural condition; however, the shoulder requires an overlay. Overlay main lanes and shoulders with 3 inches of hot mix and widen to match the existing structure.
    - Widen to the outside.
  - From BS 6R to SH 21:
    - Use the existing main lane pavement as subbase for new concrete pavement.
      - This subbase will raise the profile approximately 13 inches, which will create a problem for vertical clearance of the overpasses.
    - Flexible shoulders will need to be treated or reconstructed to hold detoured traffic and used as cement-treated subbase for the new concrete pavement.
    - Widen to the inside.
- Frontage roads.
  - Use a rigid pavement section for any areas that need to be fully reconstructed.
  - The frontage road pavement is also in good structural condition except for approximately 2 mi on the southbound side from SH 21 to Water Locust Street.
    - SB2, SB3, and NB1—Overlay with 2 inches of hot mix.
    - SB1, SB4, and NB2—Mill and inlay the surface or overlay.
  - Reconstruct/rehabilitate the southbound section from SH 21 to Water Locust Street (SB1 spot repairs).
- All.
  - All flexible surfaces should be PG76-22 with SAC A aggregate for both the main lanes and frontage roads.

Section	Notes	Widening	Estimated Pavement Cost
M1	Remove PFC. Use remaining existing pavement as subbase. Raises profile 13".	*Widen to Inside.* Widen to match existing pavement layers. Shoulder will have to be reconstructed or cement treated in place.	On existing $79.60/sy Widen $108.00/sy
M2	Remove PFC. 3" Overlay	*Widen to Outside.* Widen to match existing pavement layers. CTB plant mixed is preferred.	On existing $24.90/sy Widen $91.35/sy
FR- SB2, SB3 & NB1	2" overlay with underseal	*Widen to the inside* towards mainlanes since most is already close to the ROW line. Match pavement section. Widening cost will be similar to the FDH repair cost.	$15.70/sy
FR-SB1, SB4 & NB2	No additional structure is required. Replace Surface Layer.		$18.10/sy
FR-SB1 Spot Repairs	FDR raises profile or Full Depth HMA (FDH) can match profile.		FDR = $54.35/sy FDH = $90.70/sy
Any reconstruction or new construction, consider rigid section since it will minimize the traffic impacts of future work and LCCA is approximately the same for the Frontage Roads (Rigid LCCA = $112.95 and Flexible LCCA = $111.10) and the rigid is more cost effect for the mainlanes (ML Rigid LCCA = $128.80 and Flexible LCCA = $140.40).			

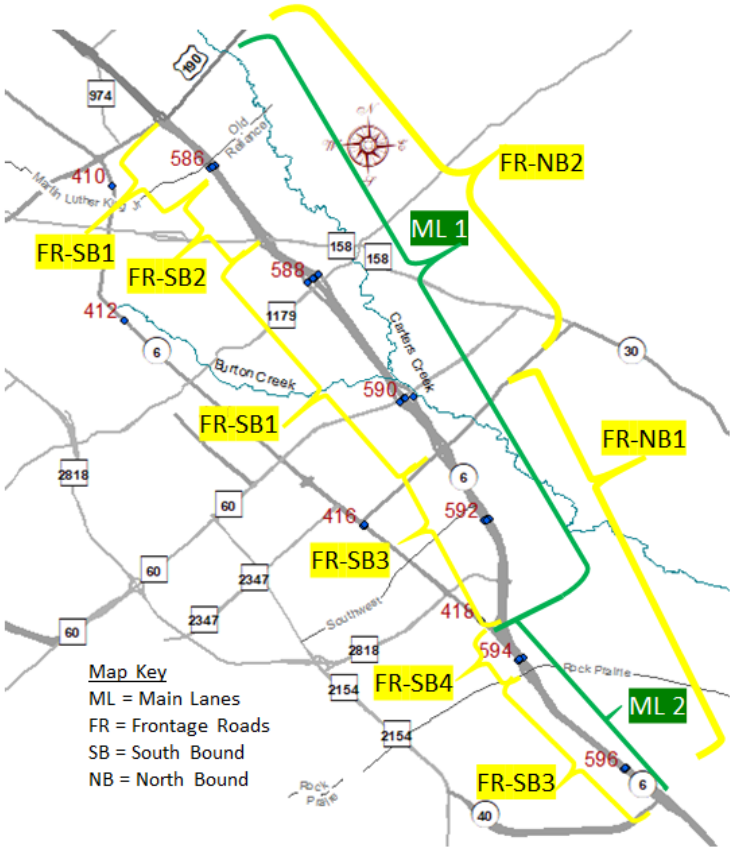


Figure 25. SH 6 Summary.

The total potential savings on the main lanes were more than $31,000,000. These savings would also result in up to 19 months of time impact to the traveling public (Table 21). Retaining the structurally sound frontage road pavement and flexible main lane pavement (ML2) can offer additional cost and time savings.

Table 21. Cost Summary.

	ML1	ML2	ML1 and 2
Keep ($/sy)	$79.60	$24.90	
Build New ($/sy)	$128.80	$140.40	
Savings ($/sy)	$40.68	$88.78	
sy	378,987	175,531	
Total Savings	$15,417,177.60	$15,583,612.59	**$31,000,790.19**
Estimated Time Savings			19 months

References

K. Choi, E. S. Park, and J. Bae. *Decision-Support Framework for Quantifying the Most Economical Incentive/Disincentive Dollar Amounts for Critical Highway Pavement Rehabilitation Projects.* Publication SWUTC/13/600451-00016-1. Southwest Region University Transportation Center, 2013.

TxDOT. *Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges Adopted by the Texas Department of Transportation*. TxDOT, November 1, 2014.

TxDOT. *Roadway Design Manual* TxDOT, 2018.

Appendix A: Equipment Summaries

USDA Web Soil Survey

General Description

- USDA-WSS provides soil data and information produced by the National Cooperative Soil Survey.
- USDA Natural Resources Conservation Service operates USDA-WSS, which provides access to the largest natural resources information system in the world.
- https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

Measured Properties

- USDA Natural Resources Conservation Service has soil maps and data available online for more than 95 percent of the nation's counties and anticipates having 100 percent in the near future.
- The site is updated and maintained online as the single authoritative source of soil survey information.

Data Analysis

- Online soil data explorer.
- Soil data that are relevant to pavement design and construction, such as:
  - Plasticity index.
  - Gypsum content.
  - Organic content.
  - Depth to the water table.

Benefits for Accelerated Construction

- Identification of potential problem areas as well as good areas.
- Timely decisions to assist with field sampling locations due to the data availability and ease of analysis.

Limitations and Availability

- Free-access website supported by USDA.
- Limitations in the data occur when using the website based on the identified area of interest.

Reference

USDA. (2019). *Web Soil Survey*. https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm. Accessed November 8, 2019.

High-Definition Video (HDV)

General Description

- HDV is a high-definition video system that is used to document the pavement surface condition. HDV can provide data for design, performance monitoring, and construction.
- HDV collects data at highway speeds. Traffic control is typically not required.

Measured Properties

- HDV is captured and saved as images.
- The operator can adjust the image spacing before collecting the video.
- GPS location and distance from the start of the collection is recorded.

Data Analysis

- TxDOT uses the PaveView program, which was developed by TTI, to view and document the pavement condition.

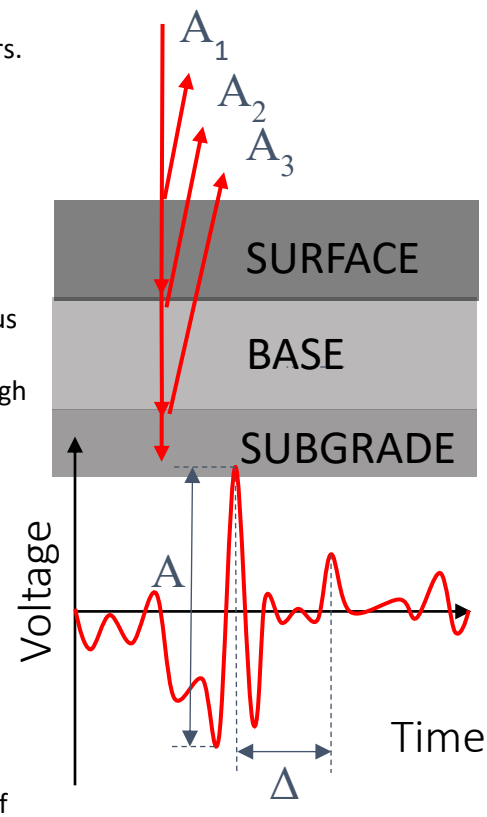
Benefits for Accelerated Construction

- Forensic investigations of existing pavement structures.
- Timely decisions due to the ease of data collection and analysis.
- Data used to support the following functions:
  - Forensic studies.
  - Support for pavement management activities at both project and network levels.
  - Supplementary material for other testing data.
- Information for construction.

Limitations and Availability

- PaveCheck software is needed to view as a video; otherwise, individual images can be viewed.
- TxDOT currently owns several systems in various districts.

Ground Penetrating Radar Systems (Overview)



General Description

- GPR is used for in-situ characterization of pavement layers. GPR is widely used in pavement engineering to evaluate surface and subsurface pavement condition.

Measured Properties

- The antenna transmits electromagnetic radar waves into the pavement. These waves are reflected at significant pavement layer interfaces; the system captures and displays these reflections as a plot of return voltage versus arrival time.
- High-frequency radar will measure shallow depths at a high resolution. A 2-GHz radar has good resolution for hot mix asphalt overlays less than 2 inches thick. A 1-GHz radar has good resolution for the full pavement structure down to 20 inches.
- Low-frequency radar can penetrate deep into the pavement and subgrade. Under ideal conditions, the 200-MHz antenna can penetrate up to 30 ft.

Data Analysis

- Estimate the locations of subsurface defects and the limits of the defects.
- Estimate variations in surface density and the presence of subsurface moisture.
- Estimate the density within the hot mix asphalt layer.
- Use various software packages for data analysis depending on the GPR system.

Benefits for Accelerated Construction

- Forensic investigations of existing pavement structures to help determine the appropriate maintenance or rehabilitation strategy.
- Timely decisions due to the ease of data collection and analysis.

Limitations and Availability

- Some materials, such as lightweight or slag aggregate, will give false positive indications of potential problem areas.
- The test surface must be dry.
- Experienced personnel will need to collect and analyze data.
- The need for pavement coring is not eliminated; however, GPR data are helpful when developing a strategic coring plan.

Coupled Ground-Penetrating Radar 1-GHz Antenna

General Description

- A vehicle-mounted 1-GHz antenna transmits pulses of radar energy into the pavement. The system has an integrated HDV logging system to provide images to complement the GPR data.
- The antenna collects data at highway speeds. Traffic control is typically not required.

Measured Properties

- The antenna transmits electromagnetic radar waves into the pavement at a frequency of 1 GHz. These waves are reflected at significant pavement layer interfaces; the system captures and displays these reflections as a plot of return voltage versus arrival time.
- The effective depth of penetration is 20 inches.

Data Analysis

- PaveCheck software, which was developed by TTI, assists with data analysis. The software integrates a video with a color plot of the waveforms. The software allows the user to:
  - Find anomalies visually.
  - Calculate the layer thickness.
  - Calculate the layer dielectric values.
  - Estimate locations of subsurface defects and the limits of the defects.
  - Estimate variations in surface density and the presence of subsurface moisture.

Benefits for Accelerated Construction

- Forensic investigations of existing pavement structures to help determine the appropriate maintenance or rehabilitation strategy.
- Timely decisions due to the ease of data collection and analysis.

Limitations and Availability

- Some materials, such as lightweight or slag aggregate, will give false positive indications of potential problem areas.
- The need for pavement coring is not eliminated; however, GPR data are helpful when developing a strategic coring plan.
- Experienced personnel will need to collect and analyze data.
- TxDOT currently owns five antennas.

Step-Frequency Ground-Penetrating Radar
3D-Radar System

General Description

- Vehicles mounted with 24 step-frequency channels have the capability of scanning a 6-ft-wide strip in one pass.
- An HDV logging system can provide images to complement the GPR data.
- This system collects data at highway speeds. Traffic control is typically not required.

Measured Properties

- The antenna transmits a continuous radar wave and steps the frequencies within a range of 200 MHz to 3 GHz. These waves are reflected at significant pavement layer interfaces; the system captures and displays these reflections as a plot of return voltage versus arrival time.
- The effective depth of penetration with good resolution is 1 inch to 30 ft and along the 6-ft width of the multichannel antenna system.

Data Analysis

- Examiner software, developed by 3D-Radar, is used for data analysis. The program provides a plot of the waveforms. The program allows the user to:
  - Find anomalies visually.
  - Estimate the layer thickness based on an assumed dielectric value.
  - Estimate locations and limits of subsurface defects.

Benefits for Accelerated Construction

- Forensic investigations of existing pavement structures to help determine the appropriate maintenance or rehabilitation strategy.
- Timely decisions due to the ease of data collection and analysis.

Limitations and Availability

- Some materials, such as lightweight or slag aggregate, will give false positive indications of potential problem areas.
- Software currently does not allow dielectric value calculations. The layer thickness calculation is based on an assumed dielectric value.
- The need for pavement coring is not eliminated; however, GPR data are helpful when developing a strategic coring plan.
- Experienced personnel will need to collect and analyze data.
- TxDOT currently owns one antenna.

Ground-Coupled Ground-Penetrating Radar Antenna Frequency Range of 200 MHz to 2.5 GHz

General Description

- A cart-mounted antenna transmits pulses of radar energy into the pavement.
- The antenna collects data while moving at walking speed. Typical traffic control is a lane closure.

Measured Properties

- The antenna transmits pulses of radar energy with a central frequency based on the antenna selected. This wave is reflected at significant layer interfaces in the pavement.
- The antenna frequencies range from 200 MHz to 2.5 GHz into the pavement.

Data Analysis

- Data analysis is performed with RADAN® software by Geophysical Survey. The program allows the user to:
  - Find anomalies visually.
  - Locate utilities, sink holes and voids, honeycombing in concrete, depth of concrete above the reinforcement, buried fuel tanks, archeological sites, and aquatic springs.
  - Calculate the layer thickness and dielectric value of layers.
  - Estimate locations and limits of subsurface defects.
  - Estimate variations in surface density and presence of subsurface moisture.

Benefits for Accelerated Construction

- Forensic investigations of existing subsurface conditions.
- Timely decisions due to the ease of data collection and analysis.

Limitations and Availability

- The effective depth of penetration depends on the antenna frequency, soil type, and degree of saturation.
  - High-frequency antennas provide higher near-surface resolution but lower penetration depths.
  - Lower-frequency antennas can penetrate much deeper, at up to 30 ft.
- The need for pavement coring is not eliminated; however, GPR data are helpful when developing a strategic coring plan.
- Several antennas are needed at different frequencies based on the depth range that the evaluation requires.
- Experienced personnel will need to collect and analyze data.
- TxDOT currently owns one set of antennas.

Ground-Penetrating Radar
Rolling Density Meter

General Description

- A cart- or vehicle-mounted system of three 2-GHz antennas transmit pulses of radar energy into the pavement.
- The system collects data while moving at slow speed. Typical traffic control is a lane closure.

Measured Properties

- The antenna transmits electromagnetic radar waves into the pavement at a frequency of 2 GHz. These waves are reflected at significant pavement layer interfaces; the system captures these reflections as a plot of return voltage versus arrival time.
- Continuous surface dielectric values along three profiles are measured.
  - The surface dielectric can be correlated to layer density.
- Measurements are made every 6 inches along the path.

Data Analysis

- The PaveScan program by TTI is used to collect and present the dielectric data.
  - The software was designed specifically for measuring the density for asphalt construction; the data are presented in terms of lots, sublots, stations, etc.
- Results are shown in terms of dielectric or density/air voids.
- The result statistics are shown for data's mean and distribution.

Benefits for Accelerated Construction

- Only one data collection pass is needed to collect measurements in and between the wheel paths.
- The non-destructive method ensures compaction uniformity over the entire mat.
- This system has the potential to replace nuclear and nonnuclear density equipment.
- Engineers can make timely decisions due to the ease of data collection and analysis.

Limitations and Availability

- Coring is needed to develop a calibration between dielectric and density.
- Experienced personnel will need to collect data.
- TxDOT currently owns one system.

Falling Weight Deflectometer

General Description

- FWD is a load-deflection response testing system that is widely used to evaluate pavement structural condition. The system can provide data for design, performance monitoring, and remaining life estimation.
- The system collects data in static position for approximately 1 minute before moving to the next location. A moving traffic control operation is typically used; however, a lane closure may be needed.

Measured Properties

- A series of geophone sensors (usually seven) measure the pavement response (vertical deflection) at various distances from the dropped load. The applied load simulates a single heavy-moving wheel.
- The combined deflections away from the load are used to define the deflection basin.

Data Analysis

- TxDOT uses the MODULUS program, which was developed by TTI, to back-calculate the layer moduli.

Benefits for Accelerated Construction

- Forensic investigations of existing pavement structures.
- Timely decisions due to the ease of data collection and analysis.
- Data that are used to support the following functions:
  - Routine pavement design.
  - Forensic studies and rehabilitation strategies.
  - Routing of super-heavy loads and an evaluation of their effect on pavement.
  - Evaluation of the pavement for load zones.
  - Support of pavement management activities at both project and network levels.
- Information or acceptance testing for new construction.

Limitations and Availability

- The MODULUS back-calculation of thin layers should be less than 3 inches thick.
- The approximate layer thickness should be known in order to perform the back-calculation.
- Experienced personnel will need to perform the data collection and analysis.
- TxDOT currently owns 15 FWDs.

Total Pavement Acceptance Device

General Description

- TPAD is a rolling dynamic deflectometer that collects a continuous deflection profile.
- The device collects data while moving at approximately 2 mph. A moving operation is typically used; however, a lane closure may be needed.

Measured Properties

- TPAD collects the following types of data at the same time:
  - Continuous deflection.
  - GPR.
  - GPS location.
  - HDV.

Data Analysis

- TxDOT uses the TPADana program, which was developed by TTI, to analyze the combined data.

Benefits for Accelerated Construction

- Forensic investigations of existing pavement structures.
- Indication of load transfer in jointed concrete pavement.
- Identification of weak areas and potential voids underneath the concrete pavement.

Limitations and Availability

- Since this is a relatively new and unique technology, the analysis procedures of the continuous deflections are still being developed.
- Experienced personnel will need to collect and analyze the data.
- TxDOT currently owns one TPAD.

Mobile Laser Scanner
LiDAR

General Description

- LiDAR is a laser-based imaging system for right-of-way geometric evaluation.
- The system is comprised of the following:
  - A SICK laser scanner.
  - Road Doctor® CamLink camera.
  - NovAtel GPS.
  - NovAtel inertial measurement unit.
  - 3D accelerometer.
- Finland-based Roadscanners constructed the laser scanner package.
- The system collects data at highway speeds. Traffic control is typically not required.

Measured Properties

- Two primary pieces of data are generated by the laser:
  - The reflectivity of the target object.
  - The straight-line distance to the object in relation to the angle of the laser.

Data Analysis

- Programs are being developed to assist with the following:
  - Calculation of rutting depths.
  - Estimation of the cross slope.
  - Determination of the location of patches.
  - Identification of pavement surface changes.
  - Calculation of ditch depths and grade.
  - Estimate of the surface drainage behavior.

Benefits for Accelerated Construction

- Geometric information for new construction.
- Forensic evaluation of pavement and drainage conditions within the right of way.

Limitations and Availability

- The data analysis is complex.
- Experienced personnel will need to perform the data collection and analysis.
- TxDOT currently owns one system.

Inertial Profiler

General Description

- The inertial profiler uses a laser and inertial roughness profiler to quantify ride quality.
- Ride data are collected in accordance with TxDOT test method Tex-1001-S and at highway speeds. Traffic control is typically not required.

Measured Properties

- The inertial profiler measures the surface profile for computing any number of smoothness statistics:
  - The locations of localized roughness and amplitudes.
  - The surface texture depending on the equipped laser.

Data Analysis

- Ride data are analyzed using TxDOT's Ride Quality computer program.
- Profile data can be used for a variety of analyses, such as:
  - Vehicle simulation.
  - Profilograph simulation.
  - Power spectral analysis.
  - Grinding simulation.
  - Straightedge simulation.

Benefits for Accelerated Construction

- The ride quality and localized roughness can determine the need for maintenance or rehabilitation.
- Engineers can make timely decisions due to the ease of data collection and analysis.

Limitations and Availability

- The inertial profiler is not appropriate for stop-and-go environments.
- Splash and spray on wet surfaces will adversely affect the profile data.
- The inertial profiler requires periodic verification of accelerometer and laser calibration. The profiler should be certified on at least an annual basis, particularly for profilers used for construction quality control/quality assurance and for network-level inventory of pavement smoothness.
- Experienced personnel will need to collect the data.
- TxDOT currently owns five inertial profilers.

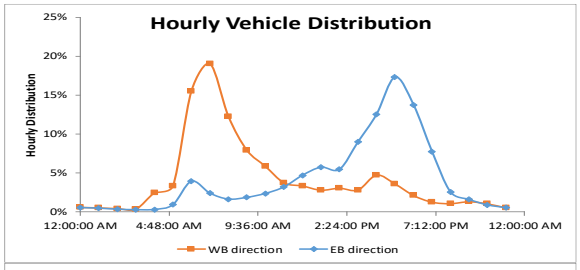
Portable Weigh in Motion

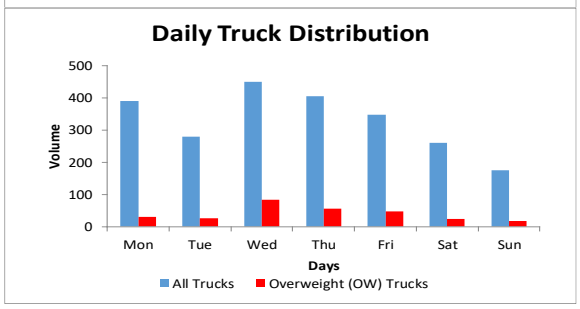
General Description

- The portable weigh-in-motion (p-WIM) traffic data collection system is used to measure traffic loading. The system can provide traffic data for planning and design purposes.
- The system has a modem communication system that allows for remote monitoring, viewing, and downloading of traffic data in real time.

Measured Properties

- Site-specific field traffic measurements include the following:
    - Traffic volume.
    - Vehicle speed.
    - Axle spacings.
    - Vehicle classification.
    - Axle loads.
    - Vehicle weights.





Data Analysis

- An Excel spreadsheet has been developed to calculate and generate ready-to-use traffic data characteristics for pavement design and analysis.
- Generated outputs include ADT, ADTT, %trucks, ATHWLDs, TFs, ESALs, etc. for use in the Flexible Pavement System, TxCRCP-ME Design Program, TxME software, etc.

Benefits for Accelerated Construction

- Site-specific traffic data.
- Timely decisions due to the ease of data collection and analysis.
- p-WIM data that are used to support the following functions:
    - Planning.
    - Pavement design and rehab.
    - Forensic studies.
    - Support of pavement management activities at both project and network levels.
    - Supplementary material for other testing data.

Limitations and Availability

- This system is an emerging technology from recent and ongoing research work.
- Traffic control is required for 1.5 hr during setup and 0.5 hr during removal.
- TTI has five operational p-WIM systems.

Electrical Resistivity Tomography

General Description

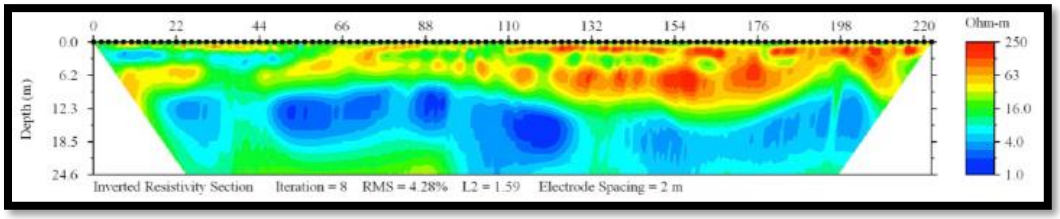
- ERT is used to conduct a geophysical survey that can indicate subsurface geological conditions.
- ERT is a geophysical method that provides an image of the bulk electrical resistivity structure in a vertical plane beneath a linear array of metal electrodes planted in the ground and connected by a multicore cable.

Measured Properties

- A predefined sequence of measurements is comprised of the voltages that develop across selected pairs of electrodes:
  - For any single measurement, the pair of electrodes that are chosen to measure voltage act as a receiver; the pair of electrodes chosen to inject and withdraw current act as the transmitter.
  - The dipole–dipole measurement protocol is typically used for this type of survey.

Data Analysis

- Customized software generates a graphical display of the voltages measured in the field that are normalized by the injected current and multiplied by a geometric array factor that is appropriate for the dipole–dipole configuration:
  - An automated inversion procedure is executed in the software to generate an Earth resistivity section (tomogram as follows).



- The tomogram shows bulk resistivity that can indicate potentially saturated soils.

Benefits for Accelerated Construction

- Engineers can make timely decisions in the design phase that will mitigate construction delays caused by subgrade with high moisture content.

Limitations and Availability

- Experienced personnel will need to collect and analyze the data.
- TTI can schedule the testing.

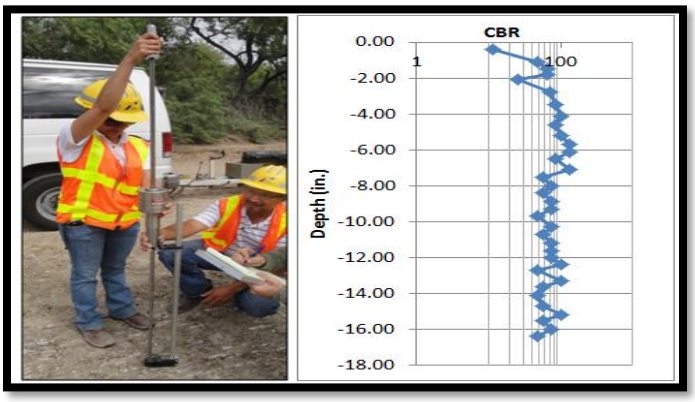
Reference

M. E. Everett. *Near-Surface Applied Geophysics*. Cambridge University Press, 2013, 24–29.

Dynamic Cone Penetrometer

General Description

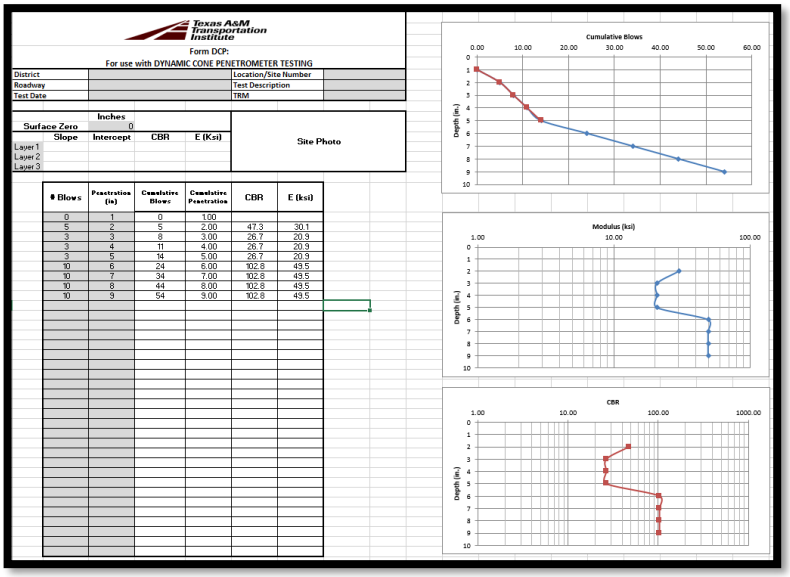
- DCP uses the penetration depth per blow to assess the in-situ strength of undisturbed soil or compacted materials.
- Applications include forensic investigations, compaction uniformity checks, and layer moduli verification.



Measured Properties

- DCP measures the depth of penetration per number of hammer drops (blows):
  - A 17.6-lb hammer is dropped from a set height.
  - The number of blows and penetration depth is recorded.
- Refer to American Society for Testing and Materials test method D6951/D6951-18.

Data Analysis



- Excel spreadsheet developed to assist with data analysis.
- Identification of the layer thickness.
- Estimation of the relative strength with depth.
- Estimations:
  - Layer Moduli Verification.
    - $M_r = 2.55 \times CBR^{0.64}$
    - Where:
      - M_r is = ksi
  - California Bearing Ratio (CBR).
    - $CBR = 292 \div P_r^{1.12}$
    - Where:
    - CBR = %
    - Penetration Rate, P_r = depth/blow (recorded depth in inches, inches*25.4 ÷ no. blows)

Benefits for Accelerated Construction

- Check the uniformity of the layer compaction.
- Estimate the layer moduli.

Limitations and Availability

- This cost-effective tool is commercially available for purchase.
- Several TxDOT districts own DCPs; DCPs are available by contacting the district laboratory.

Appendix B: CA4PRS Guidebook

Background

Use of innovative software analysis programs has furthered agency efforts for the betterment of transportation planning. A more recent tool arising from these efforts is a state-of-the-art tool called CA4PRS, which has come into use because of its ability to analyze schedules, road user and construction costs, and work zone traffic impacts together. CA4PRS was developed under the FHWA pooled fund research program with a multistate consortium (California, Texas, Minnesota, and Washington).

CA4PRS has been widely used in California. Demonstrations show that CA4PRS is user friendly, easy to learn, and valuable in any project phase. CA4PRS's greatest value lies in its capability to provide information to the planner/designer to optimally balance pavement design, construction constraints, traffic operations, and agency budget for transportation agencies. As an example, CA4PRS was used with traffic simulation models to select the most economical rehabilitation scenario for the I-15 Devore Project in California. The 2.8-mi concrete reconstruction project that would have taken 10 months using traditional nighttime closures was completed over two 9-day periods using one-roadbed continuous closures and around-the-clock construction. Implementing continuous closures rather than repeated nighttime closures in this project resulted in significant savings of $6 million in agency costs and $2 million in road user costs (Table 1).

Table 22 provides an example of outputs from CA4PRS on the I-15 Devore Project; this example demonstrates CA4PRS's applicability to a trade-off analysis among project schedules, costs, and benefits. More specifically, CA4PRS will be used in this project to select the most feasible and economical accelerated pavement construction strategies with regard to the following research questions:

- How many working days will it take to construct?
- How much road user cost will be incurred?
- How much construction cost will be needed?
- What are the effects of different construction windows on schedule/cost/traffic (e.g., nighttime versus weekend)?
- What are the effects of different lane closure options on schedule/cost/traffic (e.g., partial versus full closure)?

Table 22. Results from CA4PRS on the I-15 Devore Project near Los Angeles by California Department of Transportation.

Construction Scenario	Schedule Comparison		Cost Comparison ($M)			Max. Peak Delay (Min)
	Total Closure	Closure Hours	User Delay	Agency Cost	Total Cost	
One Roadbed Continuous (24/7)	2	400	5.0	15.0	20.0	80
72-Hour Weekday	8	512	5.0	16.0	21.0	50
55-Hour Weekend	14	770	14.0	17.0	31.0	80
10-Hour Night-time Closures	220	2,220	7.0	21.0	28.0	30

Example Project: IH 45 in Huntsville

Assume that you are tasked with determining the most feasible accelerated construction scenarios by exploring the trade-off effects of different lane closure scenarios on project duration, road user delay cost, and traffic inconvenience. Following are brief descriptions of the five-step self-study project.

The freeway has three lanes in each direction. The scope of the IH 45 Huntsville Project is to expand and rebuild a 4.451 centerline-mi stretch of two badly deteriorated concrete truck lanes in both directions. The old pavement structure has a 205-mm (8-inch) Portland cement concrete slab, 100-mm (4-inch) cement-treated base, and 205-mm (12-inch) aggregate base. The new pavement cross section has 305-mm (12-inch) new slabs with a 12-hr curing time of early age strength Type III Portland cement concrete and 150-mm (6-inch) new aggregate base. Dowel bars and tie bars that last more than 30 years with minimal maintenance will be installed in the new jointed concrete pavement. The new outer truck lane is 14 ft (4.3 m) widened. The normal width of truck lanes is 12 ft (3.7 m).

1. **Determine Appropriate Accelerated contract techniques (ACT)**

   1.1. With regard to the project type, size, complexity, and urgency of accelerated construction, determine the most appropriate ACT or combination of ACTs:

   ☐ **I/D**—Rewards contractors with bonuses for early completion and levies fines for delays on a daily basis.

   ☐ **A+B**—Rewards the group with the lowest total cost plus time bid.

   ☐ **No-Excuse Bonus**—Rewards a large, fixed amount to a contractor who can complete a project in an accelerated time frame.

   ☐ **Lane Rental**—Adds a rental fee on lane closure per lane per hour. The intention is to encourage contractors to optimize the work schedule to minimize traffic impact.

   1.2. Identify the project objective/scope:

   The total scope of this project is _____ **lane-mi**.

   1.3. Pursue a rehabilitation strategy:

- ☐ **Jointed plain concrete pavement.**
- ☐ **CRCP.**
- ☐ **PreCast.**
- ☐ **Hot mix asphalt overlay**.
- ☐ **Full depth hot mix asphalt.**
- ☐ **Other** (please specify) _____.

1.4. In CA4PRS, please create a new project file based on the rehabilitation strategy (Figure 26).

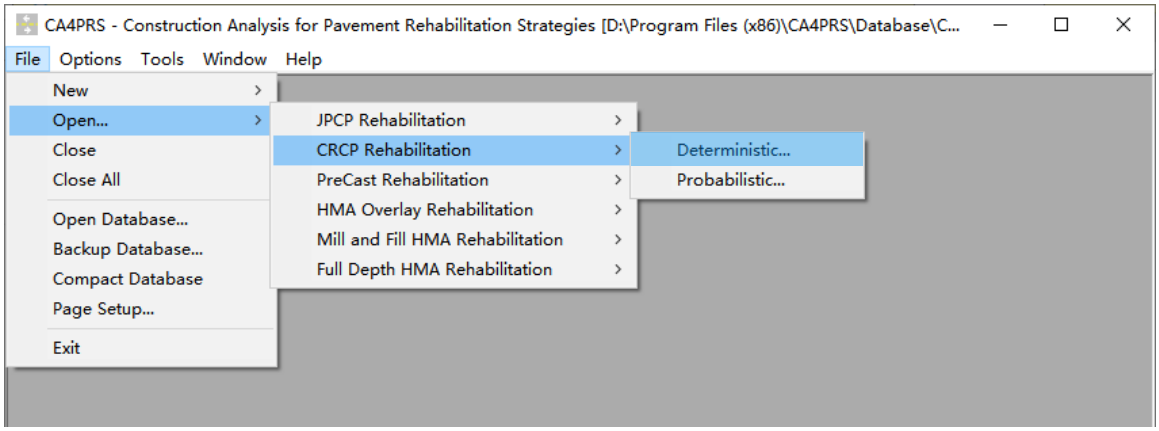


Figure 26. CA4PRS Menu.

1.5. Fill in the information in the Project Details accordingly (Figure 27).

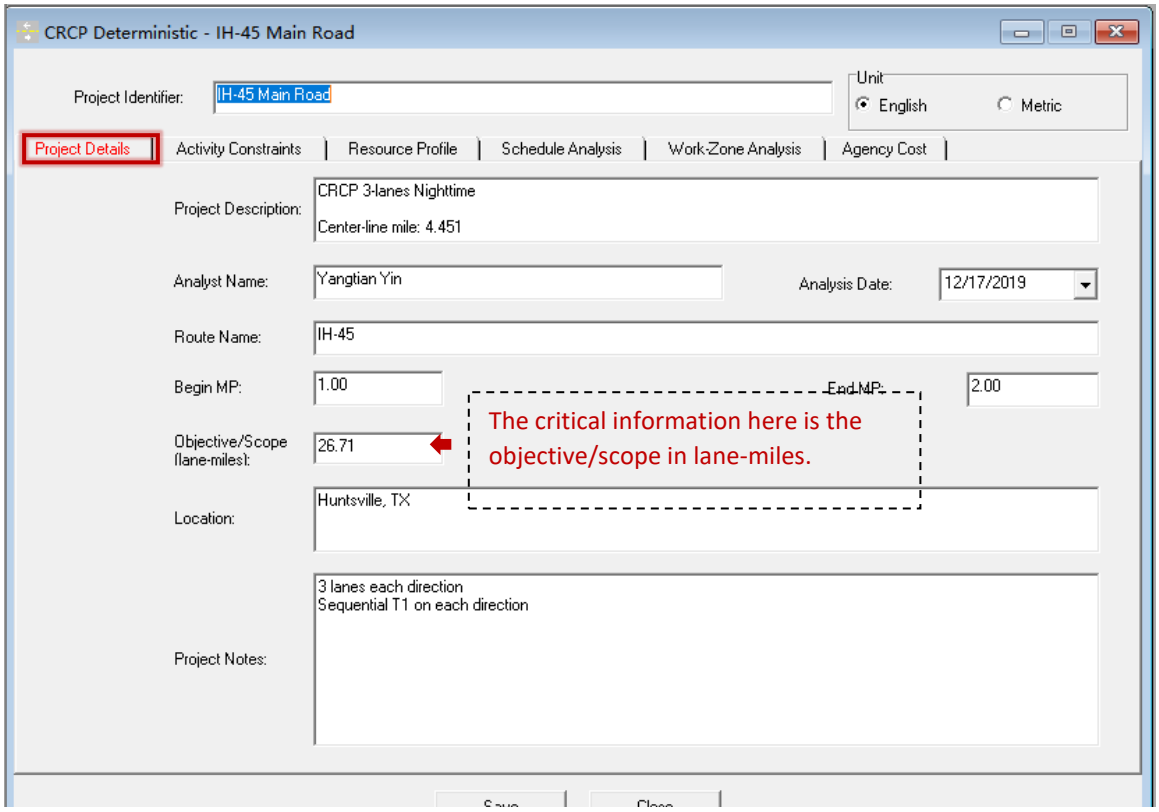


Figure 27. CA4PRS Project Details.

2. Identify What-If Alternative Scenarios

Review local and state laws and regulations; identify project constraints. Then, based on all influential factors and the project's purpose and goal, define scenario conditions accordingly.

2.1. Select construction windows that the agency wants to explore:

- ☐ **Weekend**—A continuous closure and operation during each weekend.
- ☐ **Nighttime**—Closure and operation every night. Normal traffic will resume at the end of each night.
- ☐ **Continuous Operation**—A 24-hr nonstop operation during a period of time each week.
- ☐ **Shift Operation with Continuous Closure**—Lane closures during a period of time. Only work during a limited time each day in a single closure.

2.2. In CA4PRS, please specify Construction Window in the Activity Constraints (Figure 28).

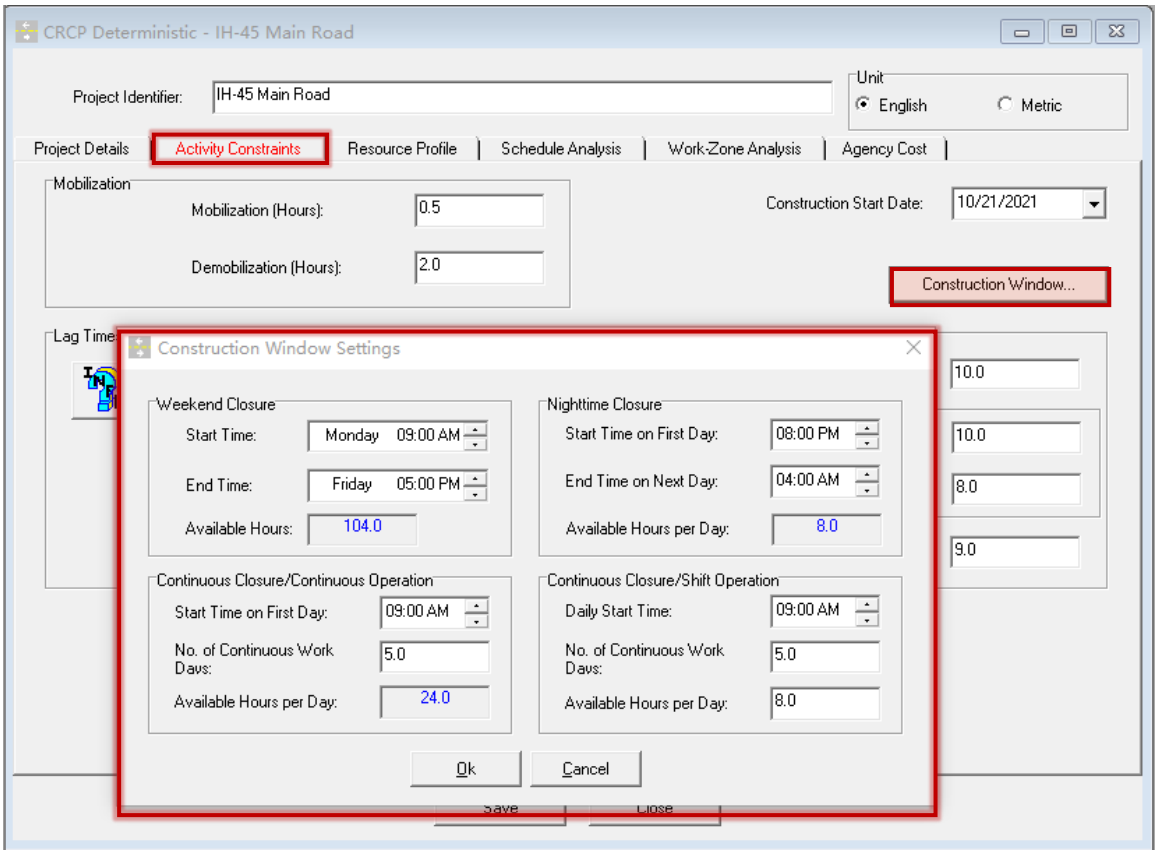


Figure 28. CA4PRS Construction Window Settings.

Note: Specifying multiple construction windows in a single file is allowed. If possible, set up different files for different scenarios since other construction parameters might differ.

2.3. Select the lane closure and working method:

- ☐ **Sequential Single Lane (T1)**—Construction will sequentially progress by one team with an additional lane closure for access.
- ☐ **Concurrent Double Lane (T1+T2)**—Construction will concurrently progress by two teams with two additional lane closure for access.
- ☐ **Full Closure**—All lanes will close for construction for maximum acceleration of the construction speed.

3. Estimate the Number of Working Days

Determine reasonable production rates for the pursued alternatives. Then adjust the production rates based on risk analysis and conduct the CA4PRS project duration estimation (PDE).

3.1. Fill in the detailed Activity Constraints based on the determined estimate basis (Figure 29).

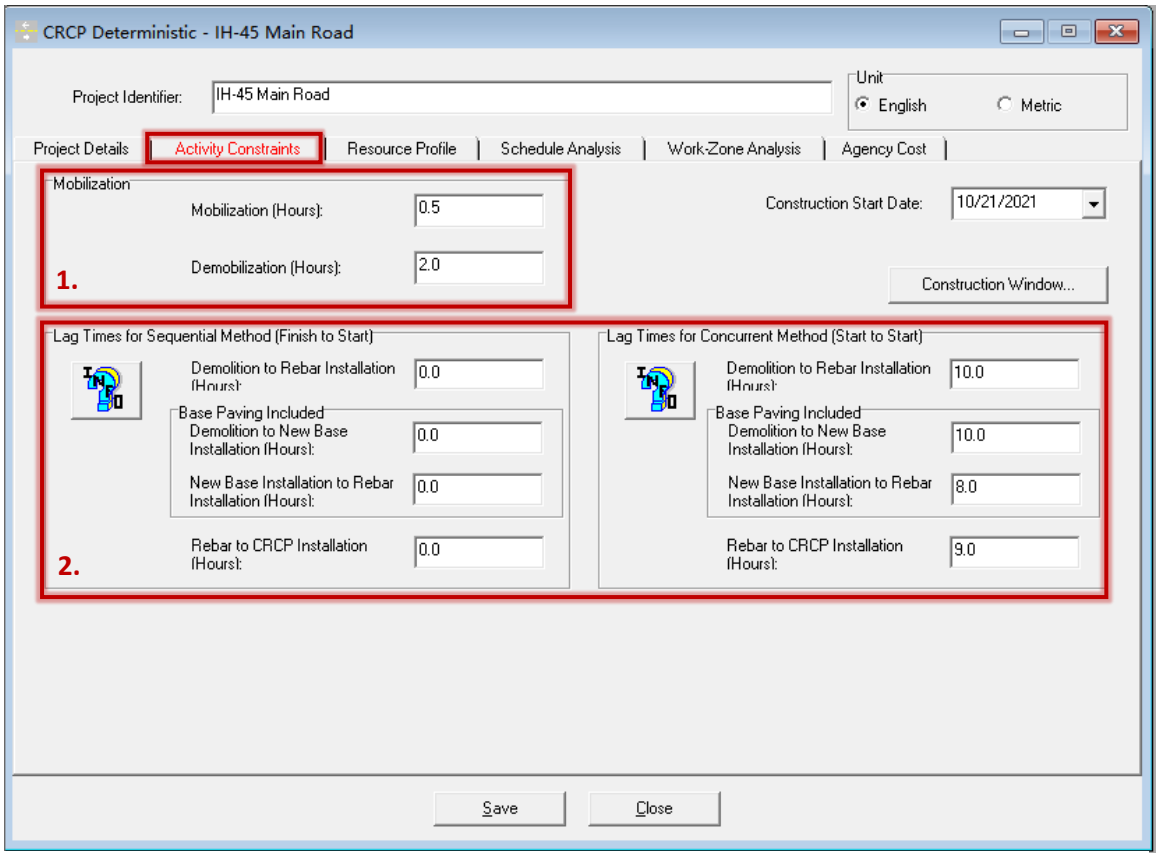


Figure 29. CA4PRS Activity Constraints.

1. Estimate reasonable mobilization and demobilization hours based on the alternative and construction method.
2. Fill in the activity lag times based on the construction method (sequential or concurrent).

3.2. In the Resource Profile tab, fill in the resource profile according to the determined estimate basis (Figure 30).

CRCP construction involves four main procedures:

1. Demolition.
2. Base construction.
3. Rebar installation.
4. Concrete paving.

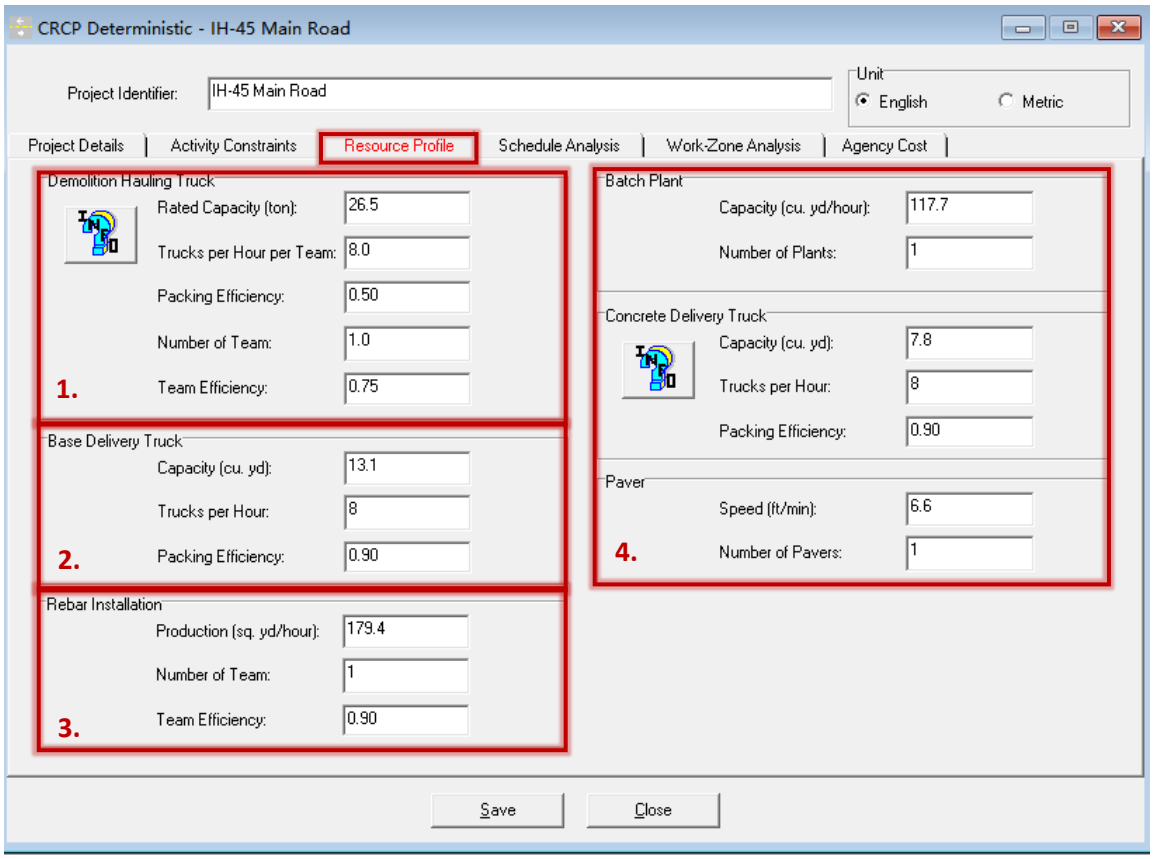


Figure 30. CA4PRS Resource Profile.

1. Fill in the information for the demolition hauling truck. CA4PRS will use this information to determine the demolition rate.
2. Fill in the information for CA4PRS to determine the base construction rate.
3. Fill in the information for CA4PRS to determine the rebar installation rate.
4. Fill in the information for CA4PRS to determine the concrete paving rate.

3.3. For each pursued alternative, fill in the schedule information for the final preparation of PDE in the Schedule Analysis tab in CA4PRS (Figure 31).

For example, the information as follows is for a nighttime construction alternative with rapid-strength concrete assumed to cure in 4 hr and a working method of sequential single lane (T1).

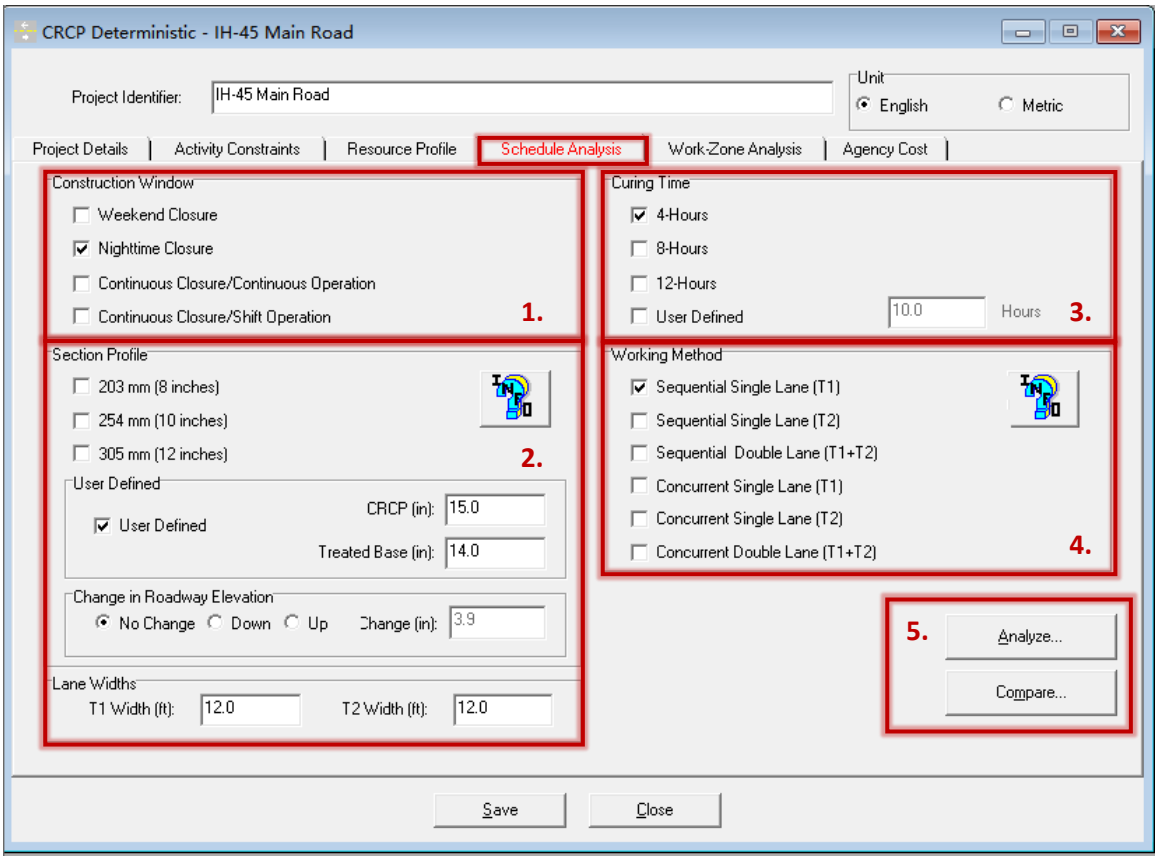


Figure 31. CA4PRS Schedule Analysis.

1. Select the construction window(s) to conduct the schedule analysis.
2. Fill in the section profile detail and land widths based on the design documents.
3. Choose the appropriate curing time based on the concrete cement used for this alternative.
4. Select the corresponding working method based on the alternative scenario determined in Step 2.3.
5. Double-check all inputs in Project Details, Activity Constraints, Resource Profile, and Schedule Analysis. Next, press Analyze to conduct PDE analysis for all selected construction windows; press Compare to have a quick overview of the estimated project duration for each alternative.

3.4. Review the schedule analysis results from CA4PRS; next, document the findings. Figure 32 is an example of a schedule analysis from CA4PRS.

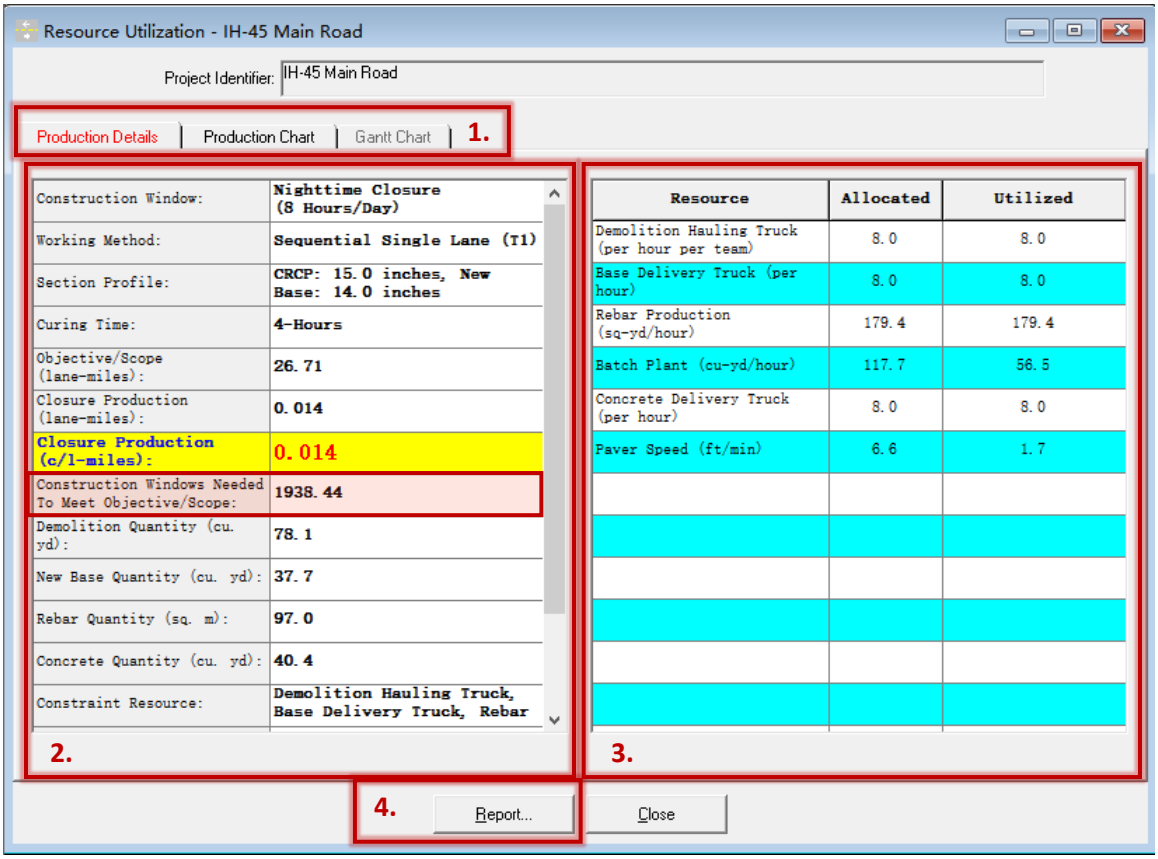


Figure 32. CA4PRS Analysis Results.

1. Select different tabs to review the technical details or the production chart.
   a. Production Details shows the estimated duration and all production rates used for CA4PRS in the project duration estimate.
   b. Production Chart shows the construction progress of each production activity in a linear scheduling line-of-balance chart (Figure 33).
   c. Gantt Chart is not available for the deterministic estimation process.
2. **Review the estimated project duration. Record the number of Construction Windows Needed to Meet Objective/Scope.**

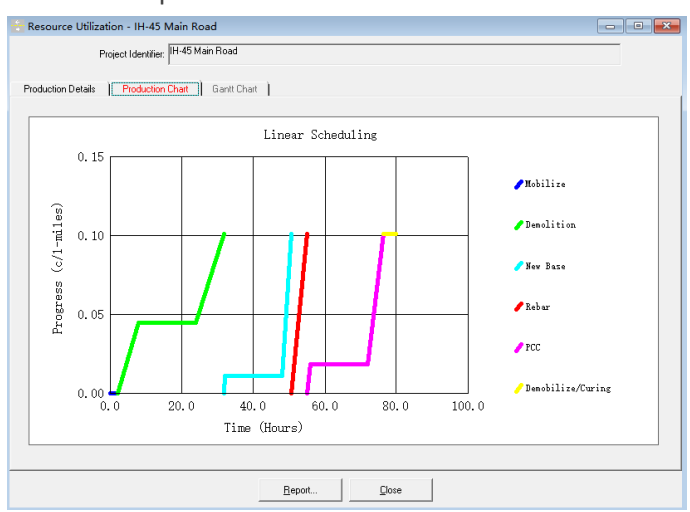


Figure 33. CA4PRS Production Chart.

3. The resource utilization details display which types of resources are fully utilized (and constrains the project duration).
4. After reviewing the analysis, click Report to generate a full document in PDF format by CA4PRS.

4. Assess the Mobility Impact

The objective of this step is to assess and quantify the traffic mobility impact. The assessments include estimates of daily and total road user costs and mobility impacts in terms of delayed minutes and queue length for each alternative.

4.1. In CA4PRS, click the Work-Zone Analysis tab; next, fill in traffic-related information based on the project and alternative scenario. Figure 34 shows the traffic information and estimate basis for the IH 45 project example.

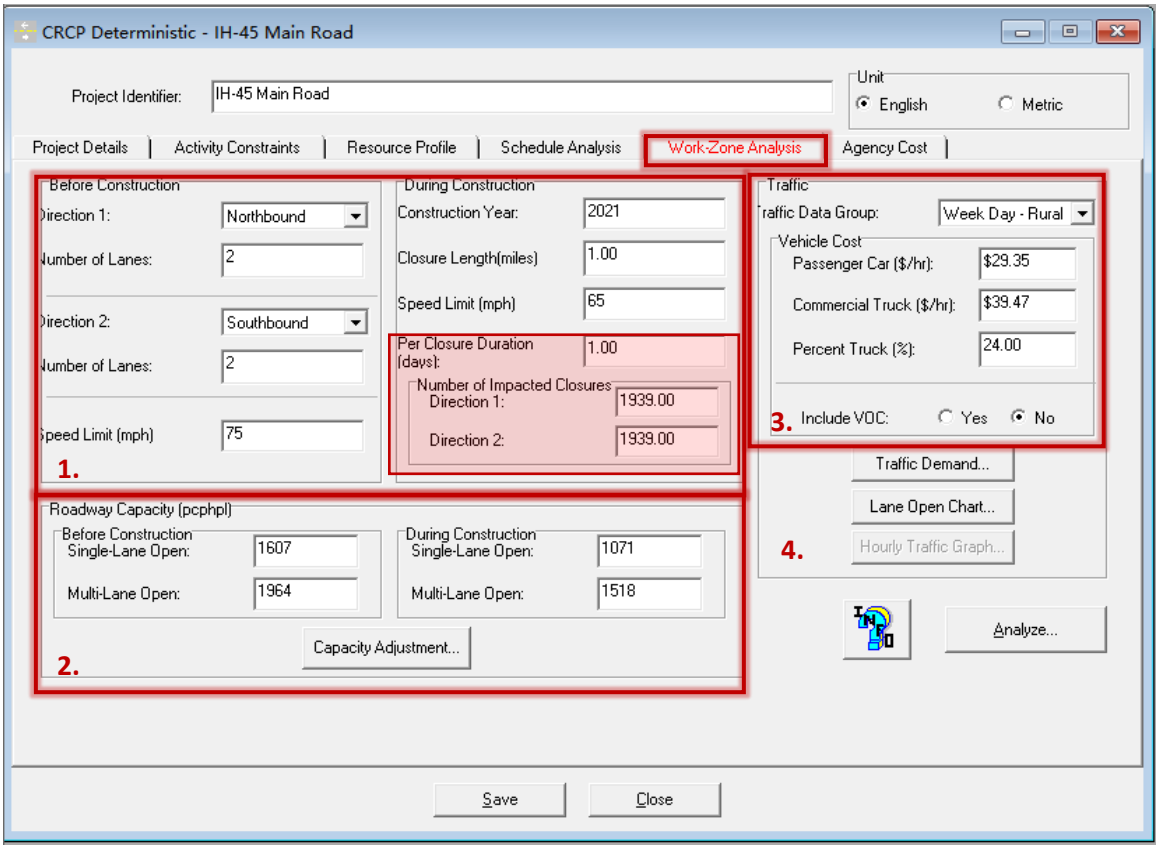


Figure 34. CA4PRS Work-Zone Analysis.

1. Input the traffic information of the work zone before and during the construction:
   a. Per Closure Duration should be based on the construction window input in Step 2.2.
   b. Number of Impacted Closures should be based on the schedule report in Step 3.4.
2. Determine the Roadway Capacity based on *Highway Capacity Manual* or engineer's calculations. Use Capacity Adjustment to assist the estimation process (Figure 35).
3. Determine the **value of time** of traffic delay for the road user charges calculation. Include the vehicle operation cost if needed.
4. Double-check all inputs in Step 1–3. Then click Traffic Demand to proceed.

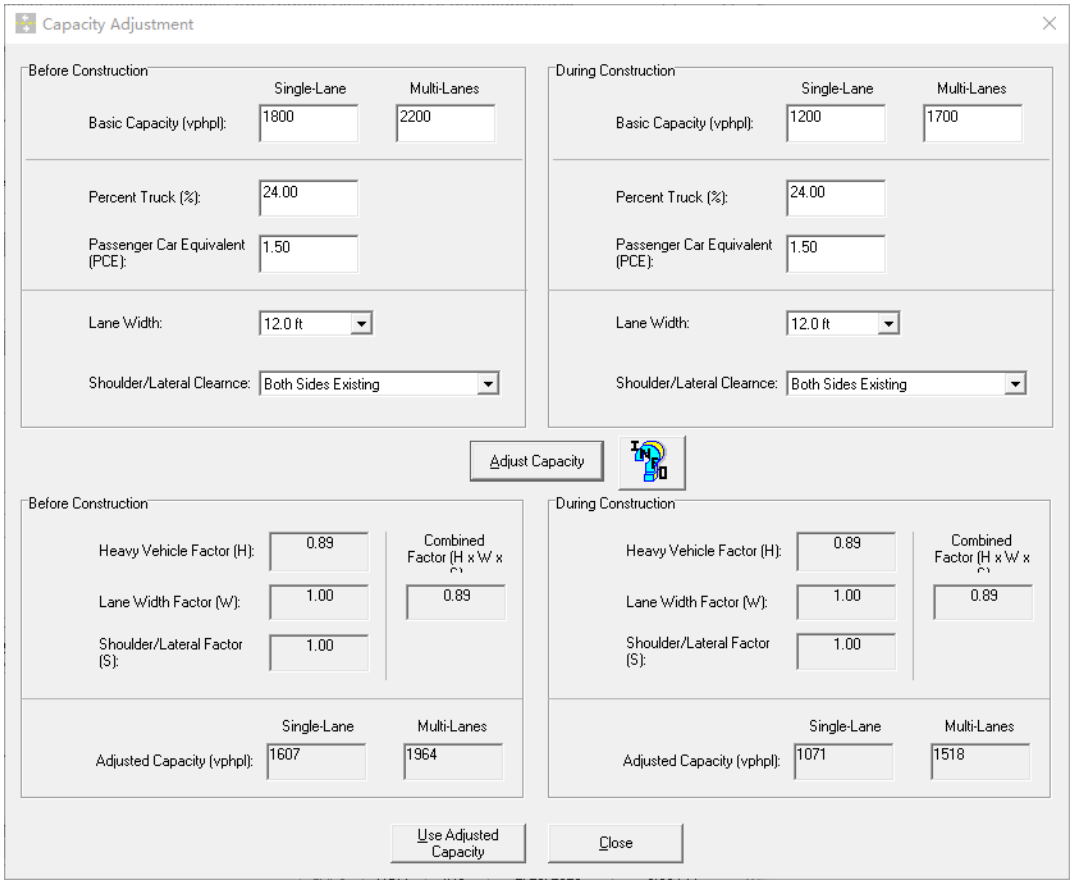


Figure 35. CA4PRS Capacity Adjustment.

4.2. When Traffic Demand is clicked, CA4PRS will open a new window to input all traffic demand information based on history traffic data of the work zone. If no data are available, select the appropriate traffic data group and use the default performance measurement system (PeMS) data.

Figure 36 is the hourly traffic demand estimated from the annual average daily traffic of the work zone and the default PeMS week–day rural traffic data group.

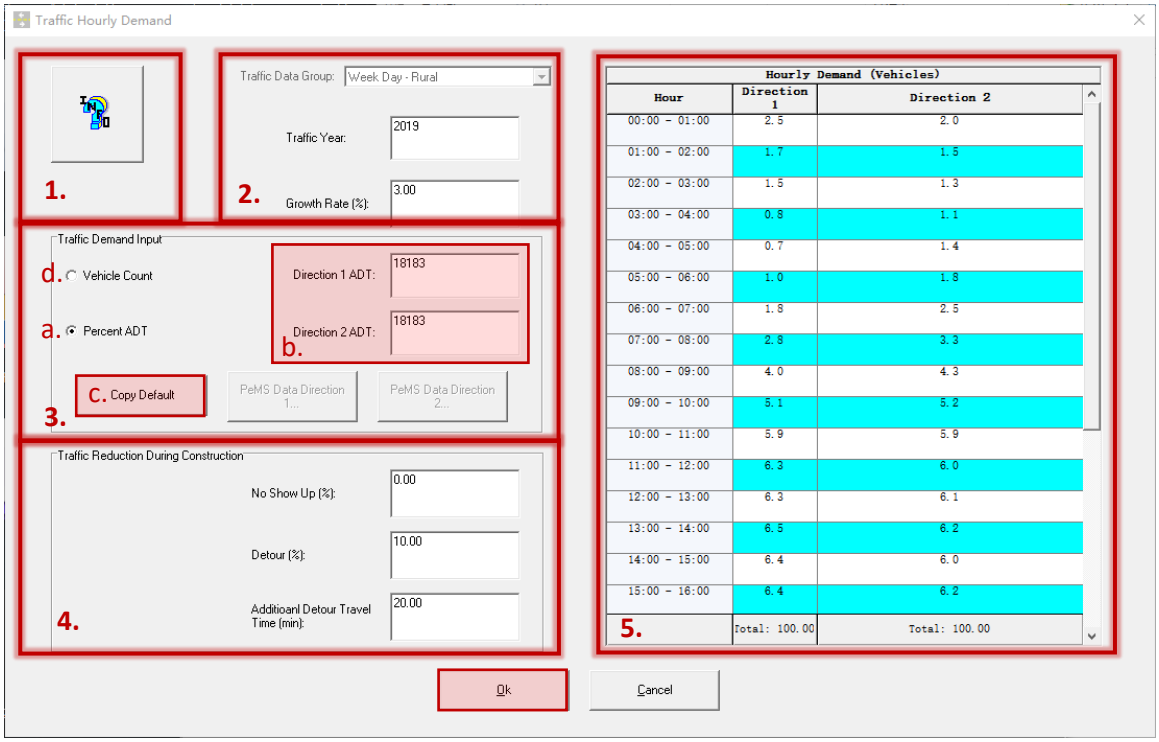


Figure 36. CA4PRS Hourly Traffic Demand.

1. If using the default PeMS data, click Info to see the traffic pattern in hourly detail.
2. Set the Traffic Year to the year when the input annual average daily traffic data were acquired. Then determine an appropriate annual Growth Rate (%) of traffic demand.
3. Input work zone average daily traffic (ADT) information based on historic record:
   - **a.** Click Percent ADT first.
   - **b.** Fill in ADT for each direction.
   - **c.** Click Copy Default (if using the default data*).
   - **d.** Click Vehicle Count to convert percent ADT into hourly traffic demand.
4. On many occasions during highway rehabilitation, it is reasonable to assume a certain percentage of traffic demand reductions by no-shows, detours, and travel mode changes promoted by public outreach efforts. Assign a reasonable number of No Show Up and Detour while inputting the estimated Additional Detour Travel Time.
5. Double-check the Hourly Demand (Vehicles) after Step 3 and 4. Then press OK to proceed.

*Note: If hourly traffic demand data are available for the work zone, import the data by clicking PeMS Data Direction 1 and 2; next, locate the txt file in the local drive.

4.3 After OK is clicked in Step 4.2, CA4PRS will close the Traffic Hourly Demand window and return to the Work-Zone Analysis tab (Figure 37).

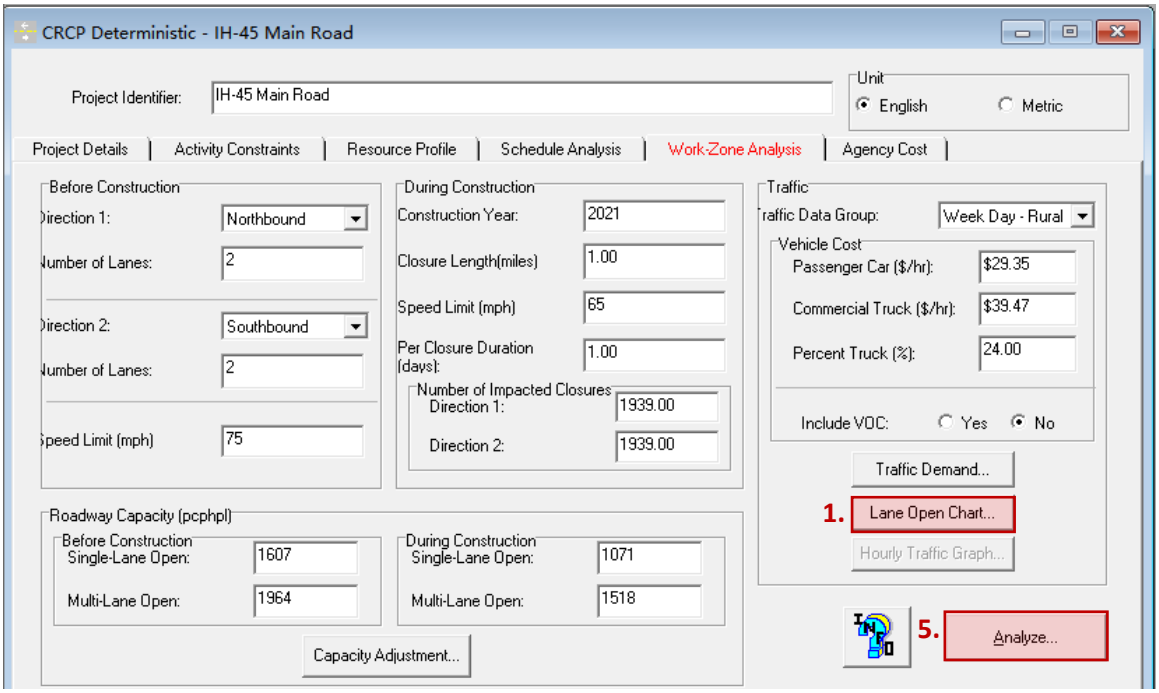


Figure 37. CA4PRS Work-Zone Analysis Tab.

1. Click Lane Open Chart in the Work-Zone Analysis tab (Figure 38).
2. Input Number of Lanes Open for each hourly duration on both directions based on the construction window in Step 2.2 and the lane closure and working method in Step 2.3 (Yellow Column).
3. Based on the construction window in Step 2.2 and the lane closure and working method in Step 2.3, if there is a work zone with a lane closure set up during this hourly period in this direction, click the mark to set the WZ to true (Blue Column).
4. Click OK after double-checking all input information.
5. After reviewing all input traffic information, click Analyze to start the traffic impact analysis.

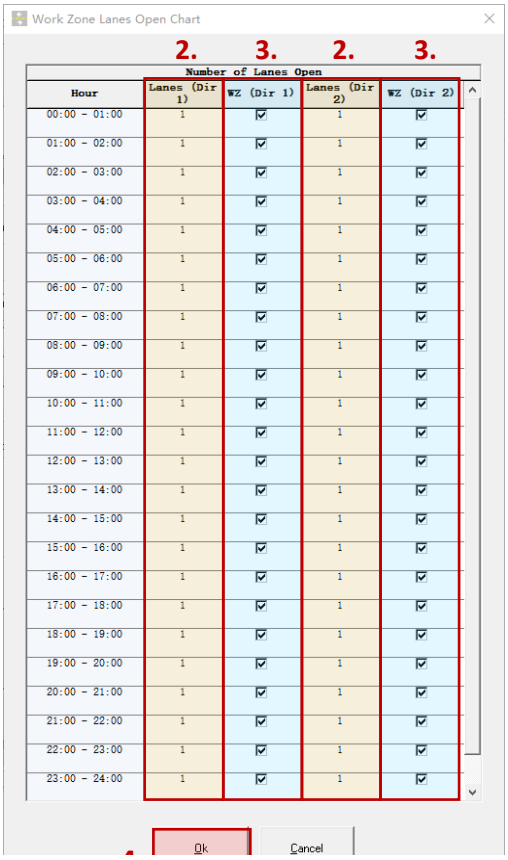
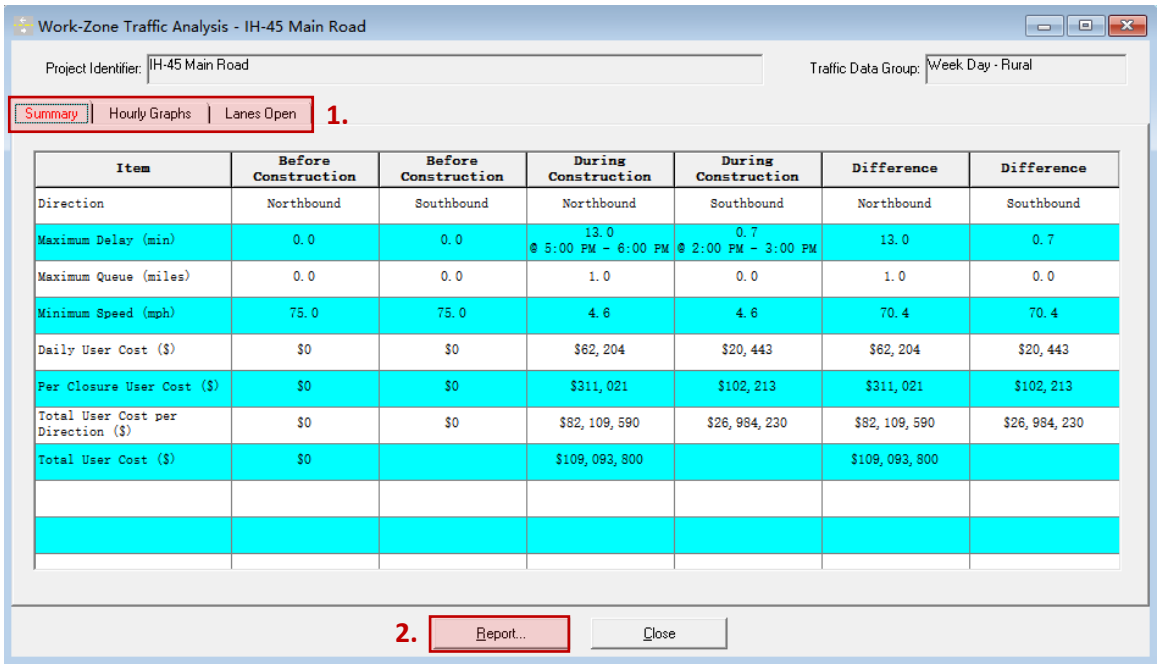


Figure 38. CA4PRS Lane Open Chart.

4.4 After Analyze is clicked in Step 4.3, the software will start analyzing and return the results of the Work-Zone Traffic Analysis (Figure 39).



Item	Before Construction	Before Construction	During Construction	During Construction	Difference	Difference
Direction	Northbound	Southbound	Northbound	Southbound	Northbound	Southbound
Maximum Delay (min)	0.0	0.0	13.0 @ 5:00 PM - 6:00 PM	0.7 @ 2:00 PM - 3:00 PM	13.0	0.7
Maximum Queue (miles)	0.0	0.0	1.0	0.0	1.0	0.0
Minimum Speed (mph)	75.0	75.0	4.6	4.6	70.4	70.4
Daily User Cost ($)	$0	$0	$62,204	$20,443	$62,204	$20,443
Per Closure User Cost ($)	$0	$0	$311,021	$102,213	$311,021	$102,213
Total User Cost per Direction ($)	$0	$0	$82,109,590	$26,984,230	$82,109,590	$26,984,230
Total User Cost ($)	$0		$109,093,800		$109,093,800	

Figure 39. CA4PRS Work-Zone Traffic Analysis.

1. Select each tab to review different aspects of the analysis outcomes:
   a. **Summary** is the major outcome of the analysis that shows the Daily Road User Charges (User Cost), Peak Delay duration and occurring time period, and Total User Cost.
   b. Hourly Graphs shows the detailed traffic volume around the work zones (Figure 40).
   c. Lanes Open shows how many lanes opened in this alternative and how many lanes need to be opened to avoid major traffic delays.
2. After reviewing the analysis, click Report to generate a full document of the traffic analysis in PDF format by CA4PRS.

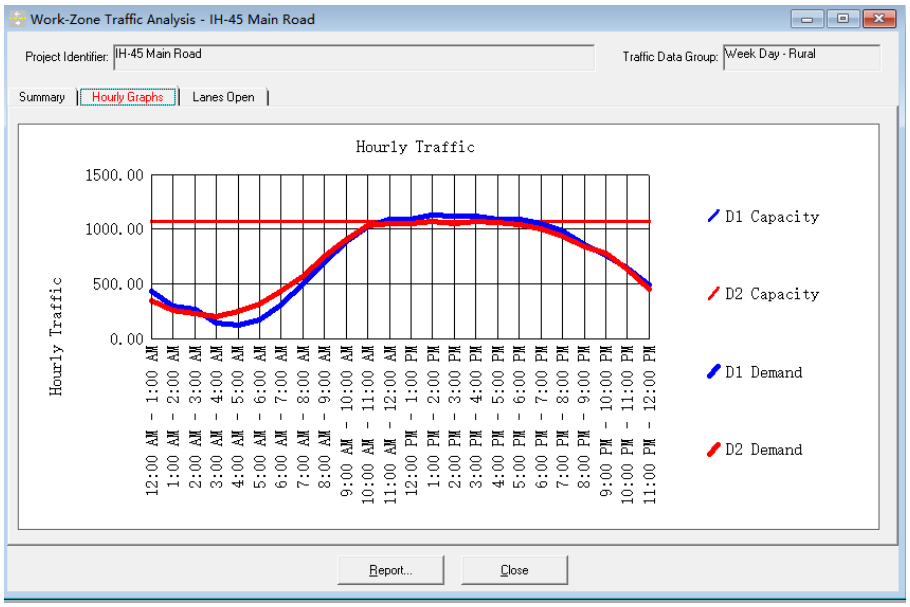


Figure 40. CA4PRS Work-Zone Traffic Hourly Graph.

5. Select the Most Feasible Option

5.1. Compare the results of each alternative with regard to the project duration, the road user cost, and the amount of traffic disruption. Then select the most feasible option based on the agency's criteria and the project's goal and purpose.

Figure 41 is an example of an alternative comparison for the IH 45 Huntsville sample project.

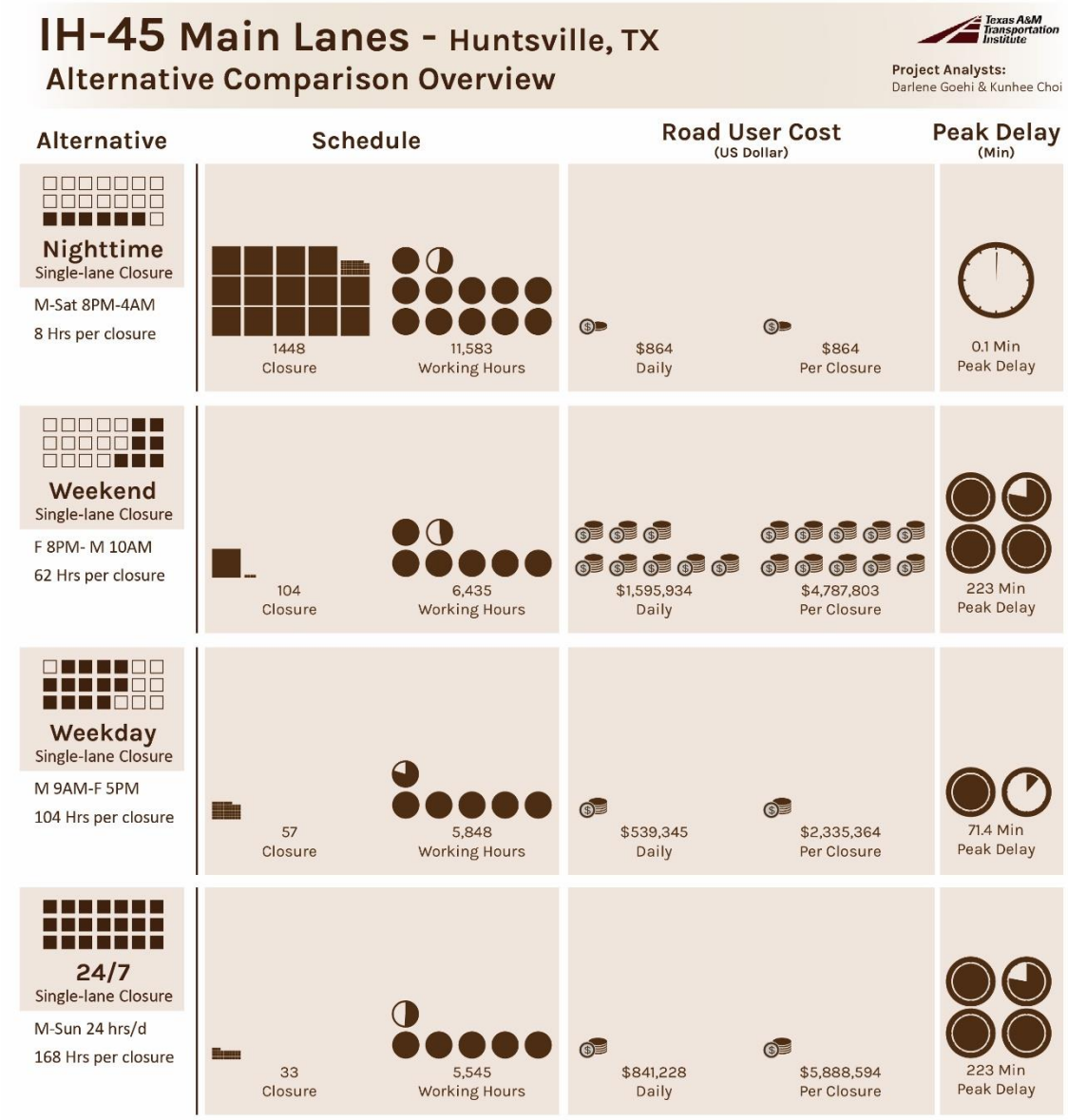
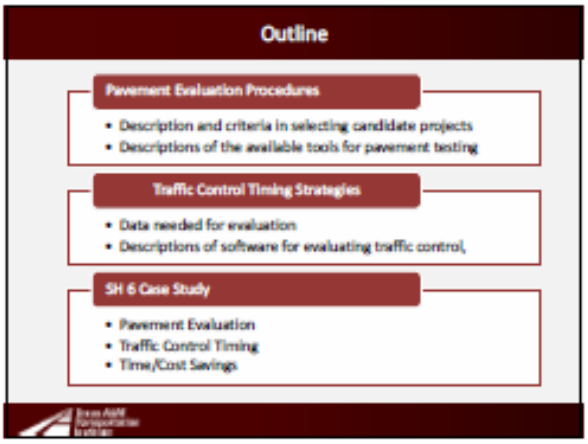


Figure 41. Example Summary of Alternatives.

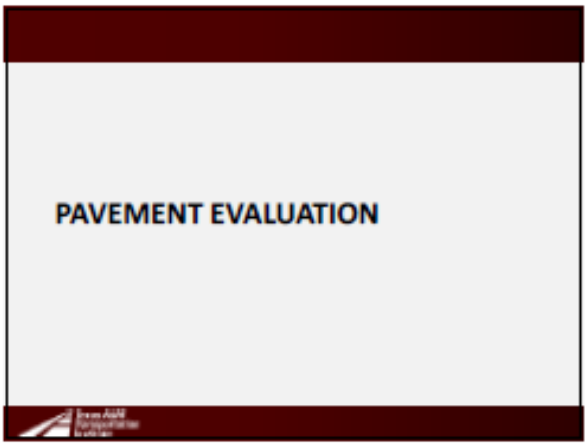
Appendix C: PowerPoint Slides

Saving Lives, Time and Resources
Innovative Tools and Techniques to Accelerate Pavement Construction Workshop
Project 0-6985
Perform Feasibility Study on Use of Innovative Tools and Techniques to Accelerate Pavement Construction
DATE April 9,2021
TTI Team
Darlene Goehl (PI)
Tom Scullion
K.C. Choi

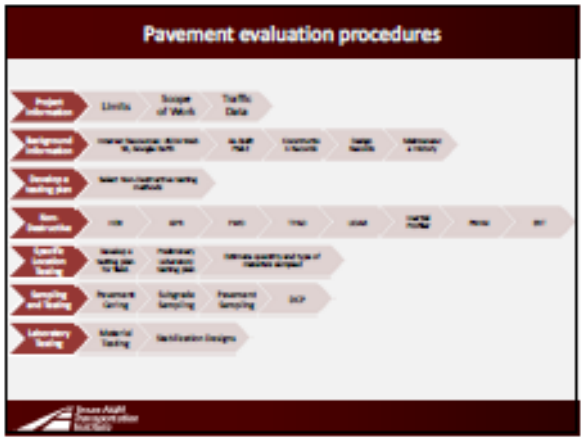
1


Outline
Pavement Evaluation Procedures
• Description and criteria in selecting candidate projects
• Descriptions of the available tools for pavement testing
Traffic Control Timing Strategies
• Data needed for evaluation
• Descriptions of software for evaluating traffic control,
SH 6 Case Study
• Pavement Evaluation
• Traffic Control Timing
• Time/Cost Savings

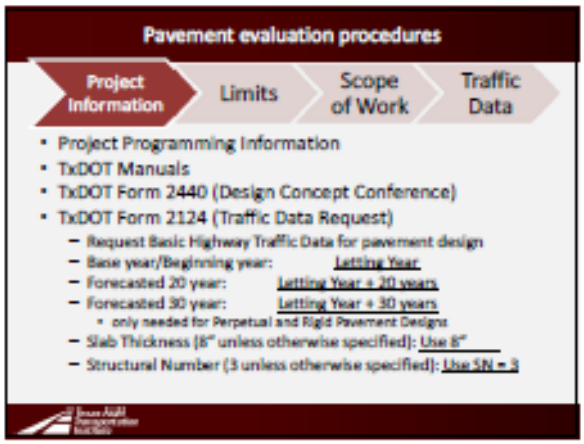
2


PAVEMENT EVALUATION

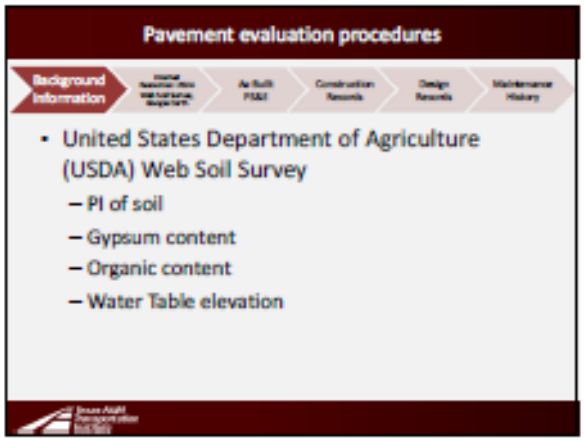
3


Pavement evaluation procedures

4


Pavement evaluation procedures
Project Information
Limits
Scope of Work
Traffic Data
• Project Programming Information
• TxDOT Manuals
• TxDOT Form 2440 (Design Concept Conference)
• TxDOT Form 2124 (Traffic Data Request)
– Request Basic Highway Traffic Data for pavement design
– Base year/Beginning year: Letting Year
– Forecasted 20 year: Letting Year + 20 years
– Forecasted 30 year: Letting Year + 30 years
• only needed for Perpetual and Rigid Pavement Designs
– Slab Thickness (8" unless otherwise specified): Use 8"
– Structural Number (3 unless otherwise specified): Use SN = 3

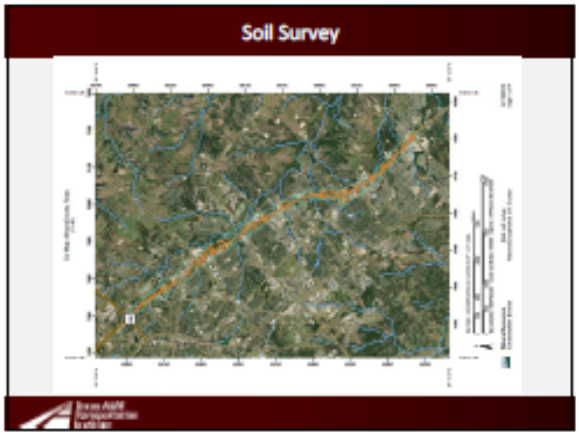
5


Pavement evaluation procedures
Background Information
• United States Department of Agriculture (USDA) Web Soil Survey
– PI of soil
– Gypsum content
– Organic content
– Water Table elevation

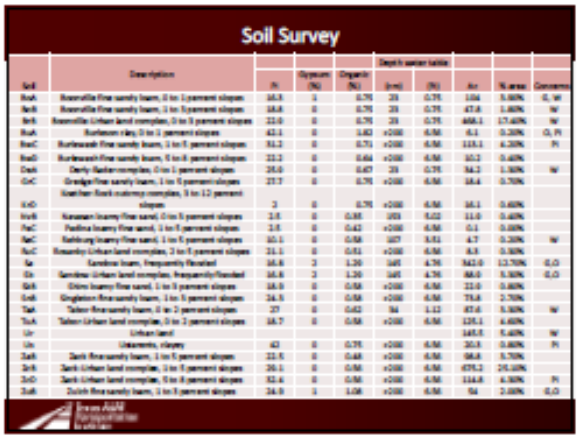
6

Web Soil Survey -
https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm
Web Soil Survey

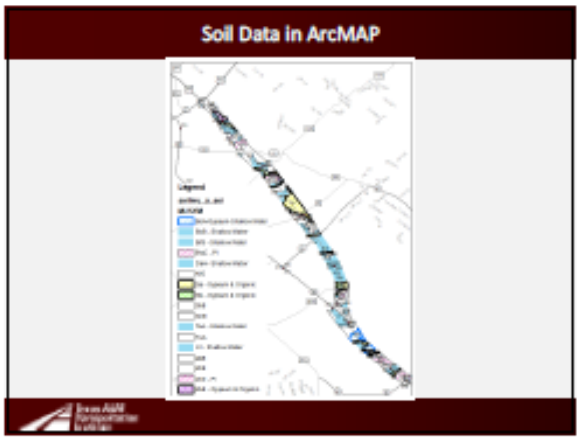
7


Soil Survey

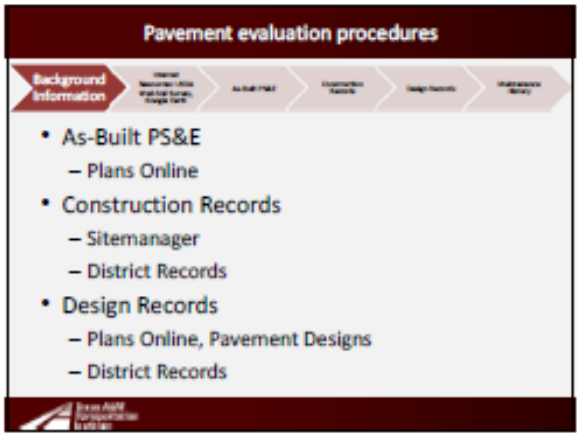
8


Soil Survey

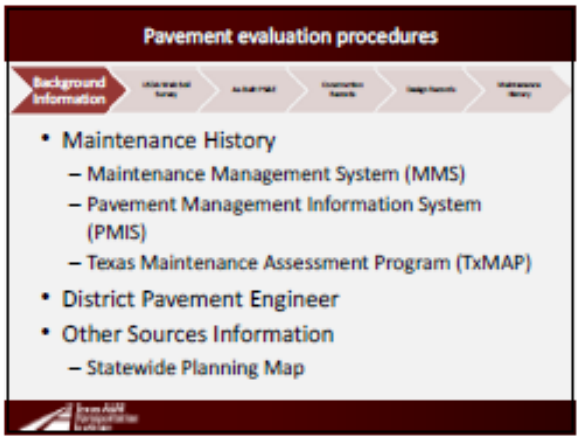
9


Soil Data in ArcMAP

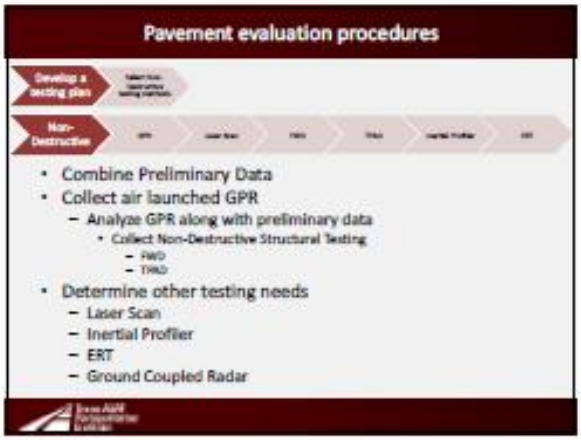
10


Pavement evaluation procedures
Background Information
• As-Built PS&E
– Plans Online
• Construction Records
– Sitemanager
– District Records
• Design Records
– Plans Online, Pavement Designs
– District Records

11


Pavement evaluation procedures
Background Information
• Maintenance History
– Maintenance Management System (MMS)
– Pavement Management Information System (PMIS)
– Texas Maintenance Assessment Program (TxMAP)
• District Pavement Engineer
• Other Sources Information
– Statewide Planning Map

12


Pavement evaluation procedures
Develop a testing plan
Non-Destructive
Combine Preliminary Data
Collect air launched GPR
Analyze GPR along with preliminary data
Collect Non-Destructive Structural Testing
FWD
TRRD
Determine other testing needs
Laser Scan
Inertial Profiler
ERT
Ground Coupled Radar

13

Pavement Evaluation Tools

14

High-Definition Video (HDV)
The HDV is a high-definition video system to document the pavements surface condition.
Data for design, performance monitoring, and construction.
Collected at highway speeds, traffic control is not needed.

15

HDV

- Benefits for Accelerated Construction
  - Forensic investigations of existing pavement structures.
  - Engineers can make timely decisions due to the ease of data collection and analysis.
  - Data is used to support the following functions:
    - Forensic Studies.
    - Support pavement management activities at both project and network levels.
    - Supplements other testing data.
  - Information for construction.
- Limitations and Availability
  - PaveCheck software is needed to view as a video, otherwise individual images can be viewed.
  - TxDOT currently owns several systems in various districts.

16

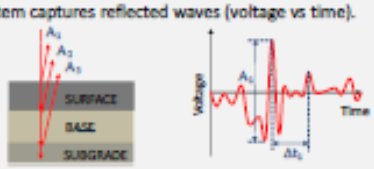
Ground Penetrating Radar (General)

- Radar systems to characterize pavement layer quality, thicknesses, and subsurface anomalies.

17

Ground Penetrating Radar (General)

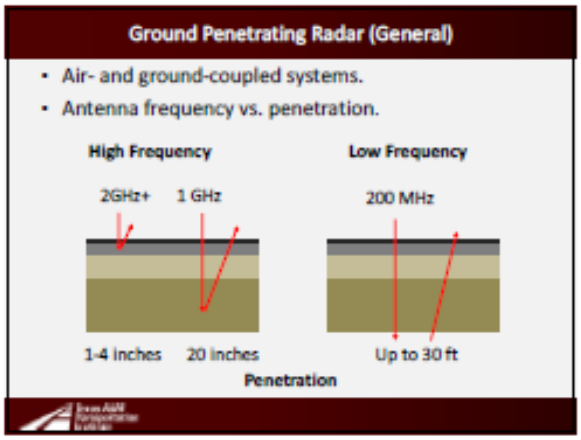
- Method
  - Transmits pulses of radar energy.
  - Pulse is reflected at significant layer interfaces.
  - System captures reflected waves (voltage vs time).



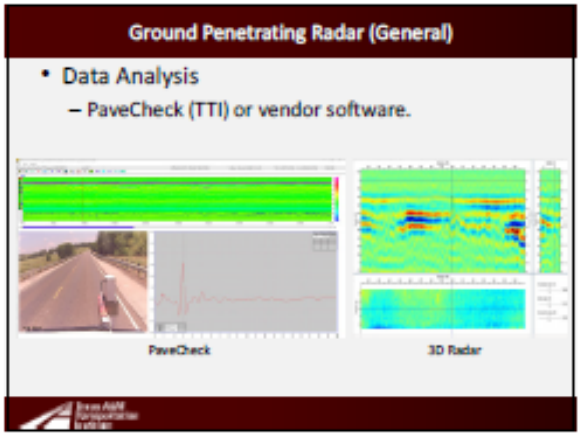
- Dielectric (ε) and distance (d) calculation:

$$\varepsilon_1 = \left[\frac{1+A_1/A_{in}}{1-A_1/A_{in}}\right]^2 \qquad d_1 = \frac{c\Delta t_1}{2\sqrt{\varepsilon_1}}$$

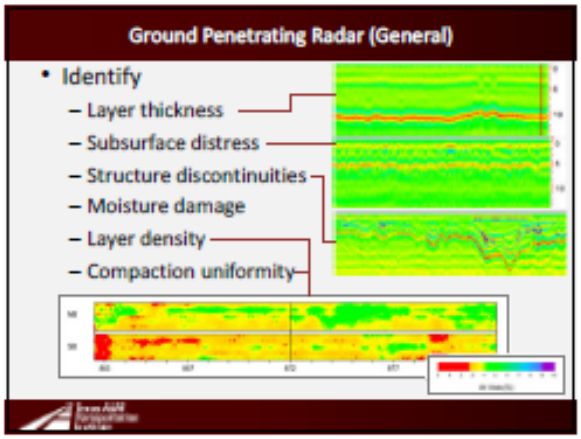
18


Ground Penetrating Radar (General)
• Air- and ground-coupled systems.
• Antenna frequency vs. penetration.
High Frequency
Low Frequency
2GHz+
1 GHz
200 MHz
1-4 inches
20 inches
Up to 30 ft
Penetration

19


Ground Penetrating Radar (General)
• Data Analysis
– PaveCheck (TTI) or vendor software.
PaveCheck
3D Radar

20


Ground Penetrating Radar (General)
• Identify
– Layer thickness
– Subsurface distress
– Structure discontinuities
– Moisture damage
– Layer density
– Compaction uniformity

21

Ground Penetrating Radar (General)

- Benefits for Accelerated Construction
  - Efficient forensic investigations.
  - Assess alternative M&R strategies.
  - Timely decision making.
- Limitations and Availability
  - Technical expertise required.
  - Light weight or slag, false problem areas.
  - Coring is not eliminated (need reference truth).

22

Air-Coupled GPR, 1GHz Antenna System

- Integrated HD video, GPS.
- Highway speed data collection.
- 20-inch penetration depth.
- Data analysis with PaveCheck.
- TxDOT owns 5 antennas

23

Air-Coupled GPR, Step-Frequency 3D Radar

- 32-channels, 200 MHz to 3 GHz step freq.
- Integrated video possible.
- Highway speed data collection.
- 6-ft wide, high resolution for shallow and deep layers, up to 2.5 ft.
- Data analysis with Examiner software.
- TxDOT owns 1 system.

24

Ground-Coupled GPR, 200 MHz to 2.5 GHz

- Walking speed data collection (traffic control needed).
- Data analysis with Radan by GSSI.
- Between Surface to 30 ft penetration depth, depending on antenna.
- Locate sink holes, honeycombing, buried fuel tanks, archeological sites, aquatic springs.
- Multiple systems needed to characterize at different depths.
- TxDOT owns 5 systems.

25

Air-Launched GPR, 2 GHz Rolling Density Meter

- Cart or vehicle mounted, 1 to 3 antennas.
- Walking or slow vehicle data collection, traffic control needed.
- Surface dielectric correlated to density.
- Requires coring to correlate for each unique mix design.
- TxDOT owns 1 three-channel system.
- Potential replacement for density testing.

26

Falling Weight Deflectometer

- Load-deflection response testing system.
- Used to characterize pavement layer stiffness.
- Static data collection (traffic control required).

27

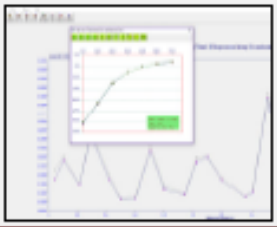
Falling Weight Deflectometer

- Method
  - Heavy falling weight creates deflection basin (Simulates a heavy moving wheel load)
  - Geophones on surface record deflections.
  - Layer stiffnesses are back-calculated using a linear elastic model.
- Collection
  - Collect at least 30 drops per section
  - Typical test spacing 0.1 mi

28

Falling Weight Deflectometer

- Data Analysis
  - MODULUS® program by TTI.
  - Identify layer stiffness and uniformity.



29

Falling Weight Deflectometer

- Benefits for Accelerated Construction
  - Efficient forensic investigations.
  - Assess alternative M&R strategies.
  - Timely decision making.
  - Useful for project and network level analysis.
- Limitations and Availability
  - Not suitable for layers <3 inches thick.
  - Traffic control required.
  - TxDOT owns 15 FWD's.

30

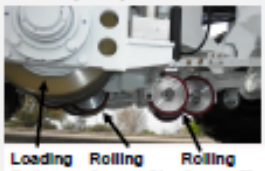
Total Pavement Acceptance Device (TPAD)

- Rolling dynamic deflectometer for continuous deflection profiling.
- Slow driving speed. (Traffic control needed).

31

TPAD

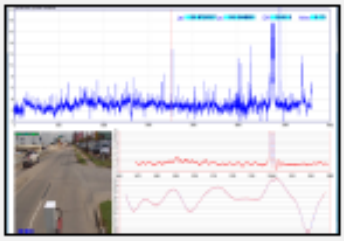
- Method
  - Heavy vibrating wheel creates continuous deflection basin, measured by 2 rolling sensors.
  - Layer stiffness back-calculated similar to FWD.
  - Integrated GPR, GPS, and HD video.



32

TPAD

- Data Analysis
  - Custom program developed by TTI.
  - Note outlier deflections or back calculate moduli.



33

TPAD

- Benefits for Accelerated Construction
  - Efficient forensic investigations.
  - Assess alternative M&R strategies.
  - Timely decision making.
  - Test of load transfer in jointed concrete.
- Limitations and Availability
  - Not suitable for layers <3 inches thick.
  - Traffic control required.
  - TxDOT owns 1 TPAD.

34

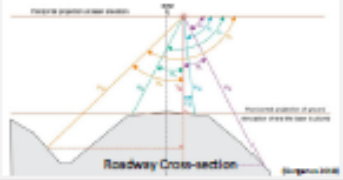
Mobile LiDAR Scanner

- Laser-based imaging system
- Provides a right-of-way geometric evaluation to predict surface drainage behavior.
- Freeway speed data collection.

35

Mobile LiDAR System

- Method
  - Scanning array of laser pulses.
  - Returning pulse provides reflectivity of surface and distance in relation to the angle.
  - Correction with inertial and accelerometer data.



36

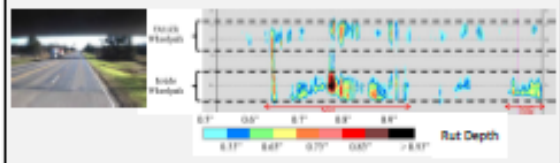
Mobile LiDAR System

- Equipment
  - SICK Laser Scanner
  - Cameras,
  - GPS,
  - Inertial measurement unit,
  - 3D accelerometer.
- Constructed by Roadscanners (Finland)

37

Mobile LiDAR System

- Measures
  - Rutting
  - Cross-slope
  - Ditch depths and grade
  - Drainage basins
- Data analysis programs under development



38

Mobile LiDAR System

- Benefits for Accelerated Construction
  - Forensic evaluation for drainage problems.
  - Information for new construction.
  - More suited for asset management.
- Limitations and Availability
  - Complexity of data analysis.
  - TxDOT owns 1 system.

39

Inertial Profiler

- Laser and inertial roughness profiler to quantify ride quality.
- Data collection at high speeds.

40

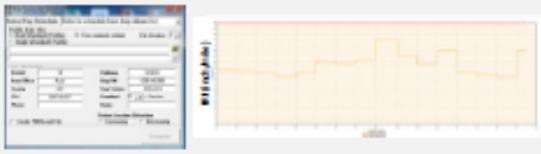
Inertial Profiler

- Method
  - Tex-1001-S.
  - The profile in each wheel path is collected with spot lasers and corrected with inertial data.
  - Profiles can be used to calculate the international roughness index (IRI).

41

Inertial Profiler

- Data Analysis
  - TxDOT Ride Quality software.
  - Various simulations with profile data:
    - Vehicle dynamics
    - Profilograph
    - Power spectral analysis
    - Grinding
    - Straightedge



42

Inertial Profiler

- Benefits for Accelerated Construction
  - Identify location and severity of rough spots to then select an appropriate treatment for long term functionality.
  - Timely decision making.
- Limitations and Availability
  - Not suitable for stop-and-go environments.
  - Annual certification for QC/QA and network inventory.
  - TxDOT owns 5 profilers.

43

Portable Weigh In Motion (p-WIM)

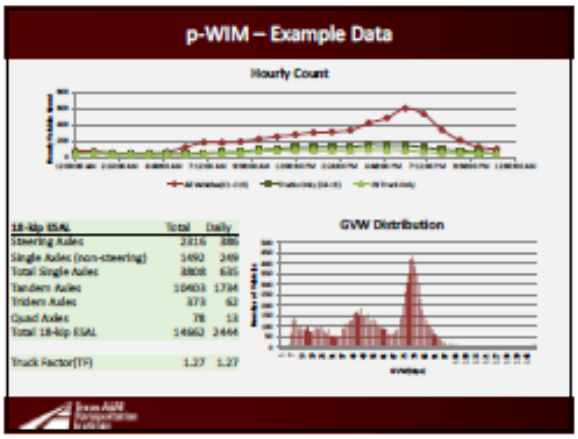
General
- The p-WIM is a traffic data collection system that is used to measure traffic characteristics.
- Traffic control is required for the setup and removal of the system however, it is not required during data collection.

Measured Properties
- Site-specific field traffic measurements including
- Traffic Volume
- Vehicle Classification
- Axle loads
- Vehicle weights.

44

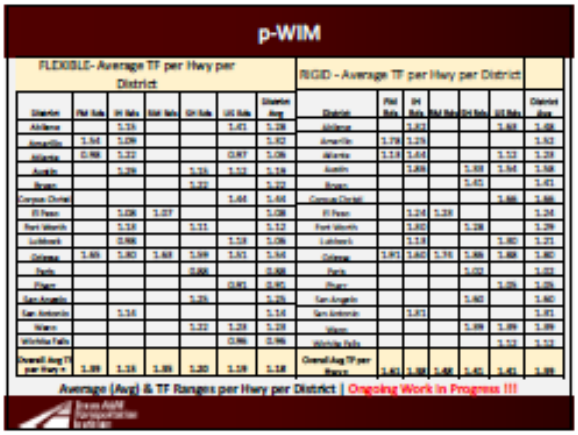
p-WIM

45

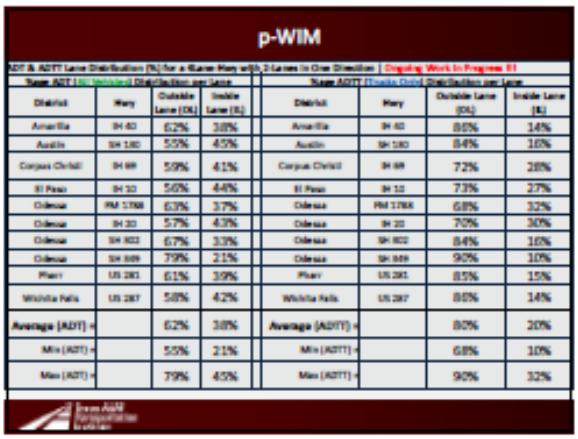


18-kip ESAL	Total	Daily
Steering Axles	2816	886
Single Axles (non-steering)	1492	249
Total Single Axles	3808	635
Tandem Axles	10403	1734
Tridem Axles	373	62
Quad Axles	78	13
Total 18-kip ESAL	14662	2444
Truck Factor(TF)	1.27	1.27

46



47



District	Hwy	Outside Lane (OL)	Inside Lane (IL)	District	Hwy	Outside Lane (OL)	Inside Lane (IL)
Amarillo	IH 40	62%	38%	Amarillo	IH 40	86%	14%
Austin	SH 130	55%	45%	Austin	SH 130	84%	16%
Corpus Christi	IH 69	59%	41%	Corpus Christi	IH 69	72%	28%
El Paso	IH 10	56%	44%	El Paso	IH 10	73%	27%
Odessa	FM 1788	63%	37%	Odessa	FM 1788	68%	32%
Odessa	IH 20	57%	43%	Odessa	IH 20	70%	30%
Odessa	SH 302	67%	33%	Odessa	SH 302	84%	16%
Odessa	SH 349	79%	21%	Odessa	SH 349	90%	10%
Pharr	US 281	61%	39%	Pharr	US 281	85%	15%
Wichita Falls	US 287	58%	42%	Wichita Falls	US 287	86%	14%
Average (ADT) →		62%	38%	Average (ADTT) →		80%	20%
Min (ADT) →		55%	21%	Min (ADTT) →		68%	10%
Max (ADT) →		79%	45%	Max (ADTT) →		90%	32%

48

p-WIM

- **Benefits for Accelerated Construction**
  - Site-specific data.
  - Engineers can make timely decisions due to the ease of data collection and analysis.
  - Data is used to support the following functions:
    - Planning
    - Design
    - Forensic Studies.
    - Support pavement management activities at both project and network levels.
    - Supplements other testing data.
- **Limitations and Availability**
  - This is an emerging technology from recent research. TTI has five (5) systems.

49

Electrical Resistivity Tomography (ERT)

- ERT is used to conduct a geophysical survey that can indicate subsurface geological conditions.
- ERT is a geophysical method(1) that provides an image of the bulk electrical resistivity structure in a vertical plane beneath a linear array of metal electrodes planted in the ground and connected by a multi-core cable.

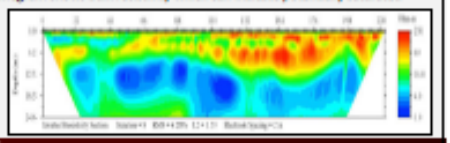
References:

1) USDA 2018. Web Soil Survey. www.websoilsurvey.nrcs.usda.gov, accessed November 6, 2018

50

ERT

- Measured Properties
  - A pre-defined sequence of measurements is made of the voltages that develop across selected pairs of electrodes.
    - For any single measurement, the pair of electrodes chosen to measure voltage acts as a "receiver" (RX) whereas the pair of electrodes chosen to inject and withdraw current acts as the "transmitter" (TX).
    - The "dipole-dipole" measurement protocol is typically used for this type of survey.
  - Data Analysis
  - Customized software is used to generate a graphical display of the voltages measured in the field, normalized by the injected current and multiplied by a geometric array factor that is appropriate for the dipole-dipole configuration.
    - An automated inversion procedure is executed in the software to generate an Earth resistivity section (tomogram, shown below)
  - The tomogram shows bulk resistivity which can indicate potentially saturated soils.



51

ERT

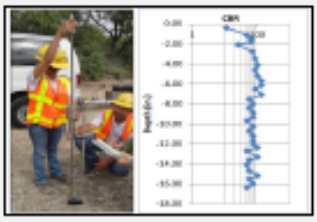
- Benefits for Accelerated Construction
  - Engineers can make timely decisions in the design phase that will mitigate construction delays caused by subgrade with high moisture content.
- Limitations and Availability
  - Experienced personnel are needed to collect and analyze the data.
  - Contact TTI to schedule testing.

52

Dynamic Cone Penetrometer (DCP)

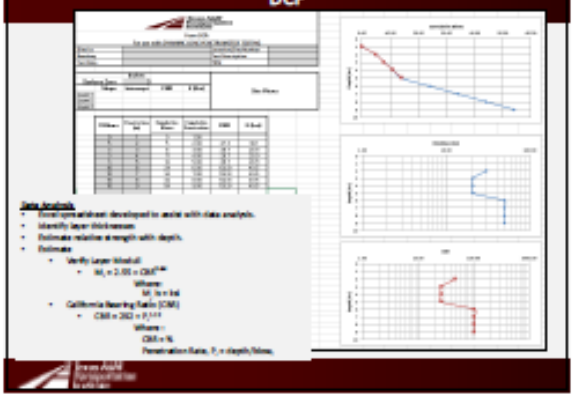
General Description

- Penetration depth per blow to assess the in- situ strength of undisturbed soil or compacted materials.
- Applications for use include
  - forensic investigations,
  - checking compaction uniformity and
  - verifying layer moduli.



53

DCP



54

DCP

- Benefits for accelerated construction
  - Check uniformity of layer compaction
  - Estimate layer moduli
- Limitations and availability
  - Cost-effective tool that is commercially available for purchase
  - Several TxDOT districts own DCPs; contact district laboratory

55

Additional Training Workshops - TxDOT

1. Flexible Pavement Design

Covers both FPS 21 and MODULUS 7
- Collection and processing of Falling Weight Data
- Running FPS21
- Students work numerous problems
- Content of pavement design Report

Available to be taught in TxDOT Offices (2 days) or Virtually (1.5 days)

TxDOT Contact Roberto Trevino-Flores Maintenance Division

2. Ground Penetrating Radar Collection and Analysis

Covers both data collection and processing of GPR data
- Computing Layer thickness and identifying defects
- Identify section breaks
- First step in Pavement rehabilitation process

Available to be taught in TxDOT offices (1.5 days) or Virtually (1 day)

TxDOT Contact Jenny Li Maintenance Division

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Additional Training Workshops - TTI

3. Rubbilization of Concrete Pavements
- Project selection including up-front testing required
- Running FPS21 to get HMA thicknesses
- Review of Specifications

Available to be taught in TxDOT Offices (1 day) or Virtually (1 day)
TTI Contact: Tom Scullion

4. Full Depth Reclamation of Flexible Pavements
- Project selection including up-front testing required
- Pavement Thickness Design
- Lab testing
- Details of construction and inspection

Available to be taught in TxDOT offices (1 day) or Virtually (1 day)
TTI Contact Stephen Sebesta

57

TRAFFIC CONTROL TIMING STRATEGIES

58

Work Time Frames

Work Week Description	Time Frame		Weather Charged	Holidays Charged
5-Day	7:00 am–6:00 pm	Monday-Friday	Yes	No
6-Day	7:00 am–6:00 pm	Monday-Saturday	Yes	No
7-Day	7:00 am–6:00 pm	Monday-Sunday	Yes	No
Standard	7:00 am–6:00 pm	Monday-Friday	No	No
Calendar Day	7:00 am–6:00 pm	Sunday-Saturday	Yes	Yes
Nighttime Only	30 min. after sunset to 30 min. before sunrise		No	No
Other – as shown on plans (examples below)				
24/7 (Continuous)	12:00 am to 12:00 pm	Sunday-Saturday	Yes	Yes
72-Hr Weekday (Continuous)	12:00 am to 12:00 pm	Tuesday-Thursday	Yes	Yes
53-Hr Weekend (Continuous)	8:00 pm to 5:00 am	Friday-Monday	Yes	Yes
Nighttime with Restricted Daytime	9:00 am to 4:00 pm 8:00 pm to 5:00 am	Monday-Friday	No	No

59

Understanding Time

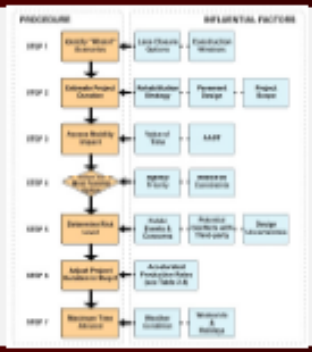
- Weather and holiday impacts
  - Significant impact based on time frame of work allowed, weather, and holidays to actual days available to work
  - Table shows effects of weekends, average rain days including too wet to work after rain, and holidays on overall number of days available to work based on Tyler, Texas, historical weather
  - For this example, only 184 days out of 365 (50% of year) available to work; when establishing the work time frame and charges, consider these factors

Table 3: Working Day Example, Tyler Texas

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Totals
Calendar Days	31	28	31	30	31	30	31	31	30	31	30	31	365
Weekend Days	8	8	8	8	10	8	10	10	8	10	8	8	104
Weekday Rain	3	4	4	4	6	4	3	4	2	4	4	5	47
Too Wet	2	2	2	2	1	1	1	1	1	1	2	3	
Holidays	2	1			1		1		1		2	3	11
Working Days	16	13	17	16	13	17	16	16	18	16	14	12	184

60

Evaluating Time and Traffic Control Scenarios



61

Cost and Time Savings

- When evaluating a project, the time and cost savings should include the following:
  - Cost difference between placing new material and keeping the existing material
    - Any treatment of the existing, such as stabilization, should be captured in the cost of retaining the existing material for comparison purposes
  - Time to remove existing and reconstruct the layers, for all sections where the existing will be reused in the new pavement structure
    - Any time for treatment of the existing, such as stabilization, should be captured in the evaluation of days for comparison purposes
  - An evaluation of traffic control closure options
    - User delay costs
    - Overall project time based on closure strategy

62

Software

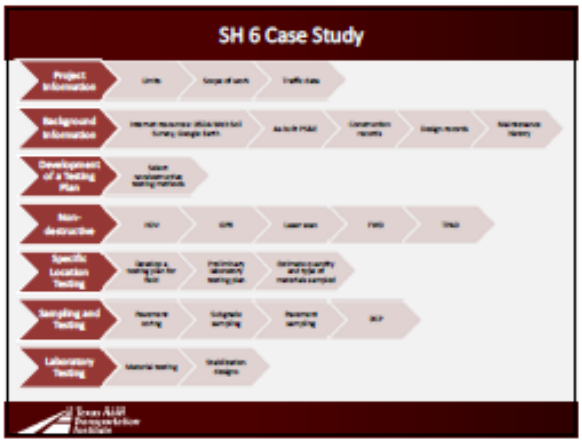
- CA4PRS
  - In production – update to web-based program

Construction Scenario	Schedule Comparison		Cost Comparison ($M)			Max. Peak Delay (Min)
	Total Closure	Closure Hours	User Delay	Agency Cost	Total Cost	
One Roadbed Continuous (24/7)	2	400	5.0	15.0	20.0	80
72-Hour Weekday	8	512	5.0	16.0	21.0	50
55-Hour Weekend	14	770	14.0	17.0	31.0	80
10-Hour Night-time Closures	220	2,218	7.0	21.0	28.0	30

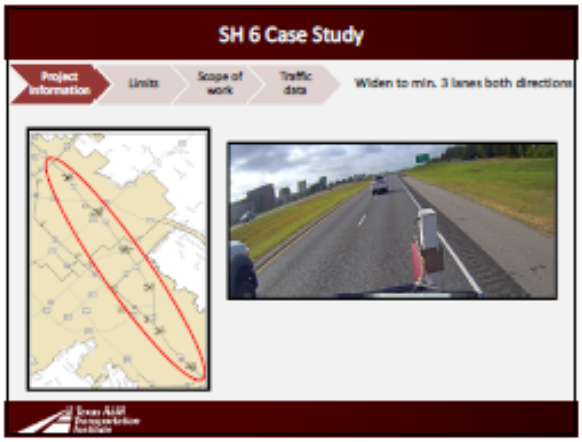
63

SH 6 CASE STUDY

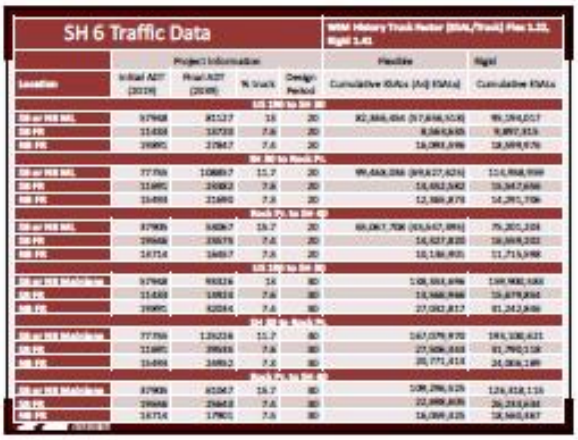
64


SH 6 Case Study
Project Information
Background Information
Development of a Testing Plan
Non-destructive
Specific Location Testing
Sampling and Testing
Laboratory Testing

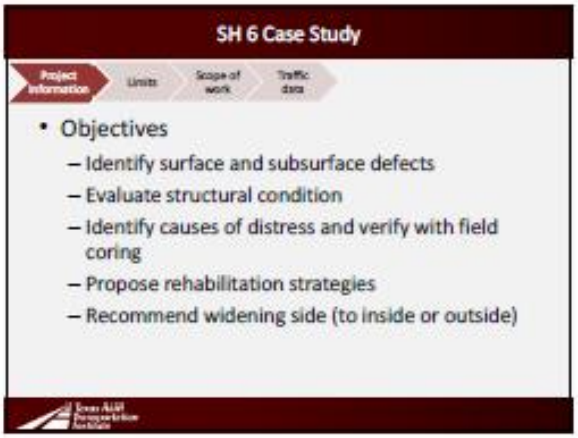
65


SH 6 Case Study
Project Information
Limits
Scope of work
Traffic data
Widen to min. 3 lanes both directions

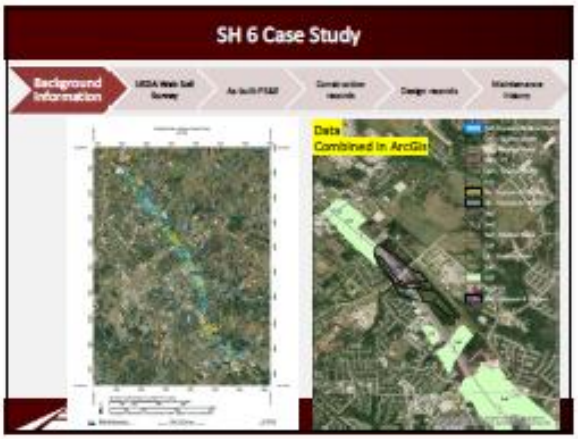
66


SH 6 Traffic Data

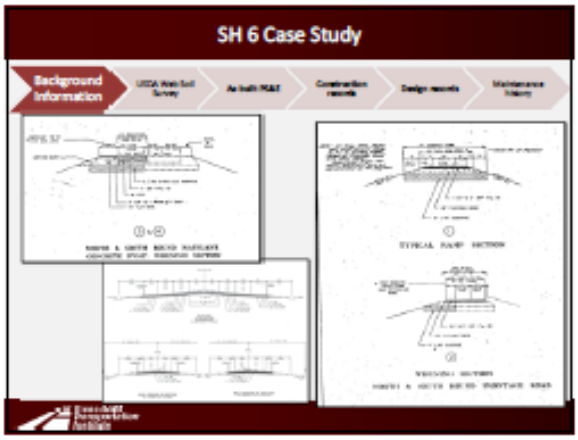
67


SH 6 Case Study
Project information
Limits
Scope of work
Traffic data
• Objectives
– Identify surface and subsurface defects
– Evaluate structural condition
– Identify causes of distress and verify with field coring
– Propose rehabilitation strategies
– Recommend widening side (to inside or outside)

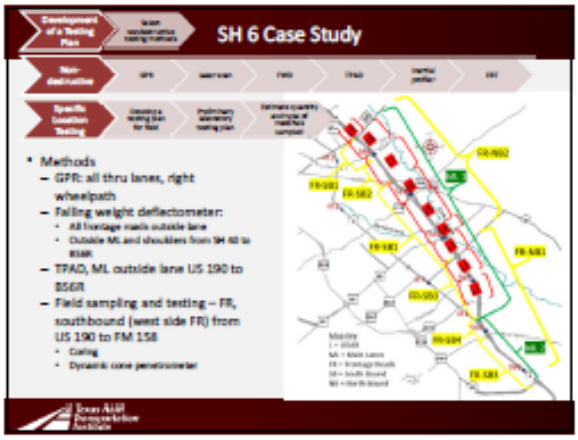
68


SH 6 Case Study
Background information
Data Combined in ArcGis

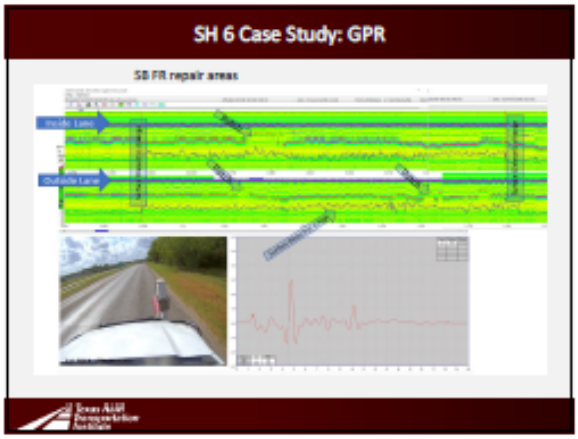
69


SH 6 Case Study
Background Information

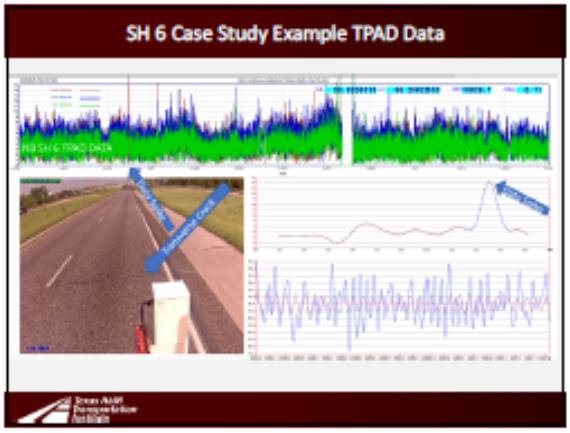
70


SH 6 Case Study
Methods
– GPR: all thru lanes, right wheelpath
– Falling weight deflectometer:
– TFAD, ML outside lane US 190 to BS6R
– Field sampling and testing – FR, southbound (west side FR) from US 190 to FM 158
Coring
Dynamic cone penetrometer

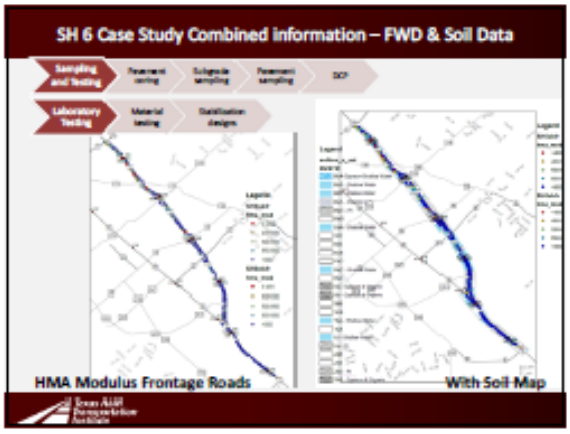
71


SH 6 Case Study: GPR
SB FR repair areas

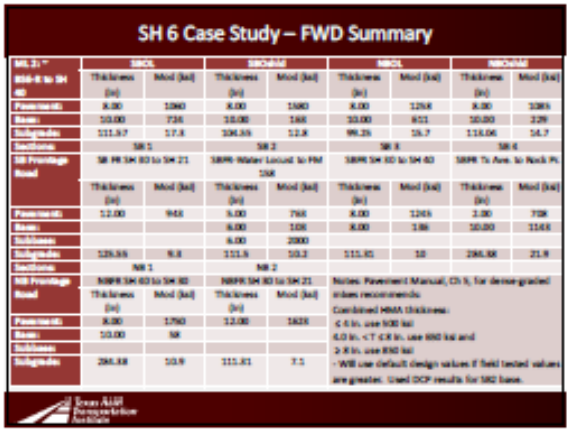
72



73



74



SH 6 Case Study – FWD Summary

MS 3: *	SBOL		SBOAM		NBOL		NBOAM	
BM-R to SH 40	Thickness (in)	Mod (ksi)	Thickness (in)	Mod (ksi)	Thickness (in)	Mod (ksi)	Thickness (in)	Mod (ksi)
Pavement:	8.00	1060	8.00	1680	8.00	1258	8.00	1385
Base:	10.00	726	10.00	168	10.00	651	10.00	229
Subgrade:	111.67	17.8	104.16	12.8	99.26	16.7	116.06	14.7
Sections:	SB 1		SB 2		SB 3		SB 4	
SB Frontage Road	SB FR SH 80 to SH 21		SBFR Water Locust to FM 156		SBFR SH 80 to SH 40		SBFR To Ave. to Rock Pt.	
	Thickness (in)	Mod (ksi)	Thickness (in)	Mod (ksi)	Thickness (in)	Mod (ksi)	Thickness (in)	Mod (ksi)
Pavement:	12.00	948	6.00	768	8.00	1245	3.00	708
Base:			6.00	108	8.00	186	10.00	1144
Sections:			6.00	2000				
Subgrade:	126.36	9.8	111.6	10.2	111.81	10	286.88	21.8
Sections:	NB 1		NB 2					
NB Frontage Road	NBFR SH 80 to SH 40		NBFR SH 80 to SH 21		Notes: Pavement Manual, Ch 5, for dense-graded mixes recommends: Combined HMA thickness: ≤ 4 in. use 500 ksi; 4.0 in. < T ≤ 8 in. use 850 ksi and > 8 in. use 850 ksi - Will use default design values if field tested values are greater. Used DCP results for SB2 base.			
	Thickness (in)	Mod (ksi)	Thickness (in)	Mod (ksi)				
Pavement:	8.00	1750	12.00	1828				
Base:	10.00	58						
Sections:								
Subgrade:	286.88	10.9	111.81	7.1				

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Pavement Design

- Pavement designs
  - Modulus
  - Flexible: FPS-21 pavement design
  - Rigid: TxCRCP-ME

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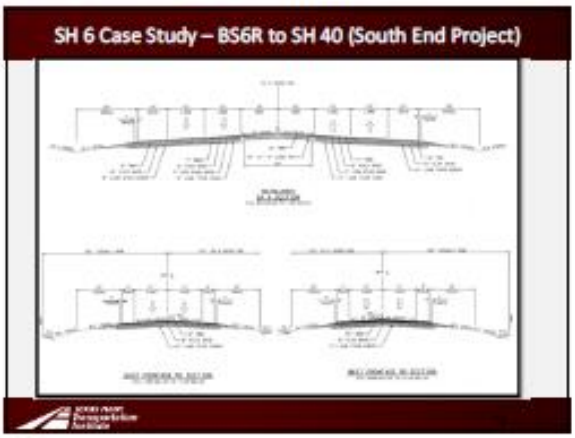

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SH 6 Case Study – Pavement Designs

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SH 6 Case Study – Innovative Tool Summary

- Structural properties
  - Pavement layer thickness and deterioration
    - GPR
  - Structural condition
    - FWD
    - TPAD
    - DCP
  - Traffic data
    - Statewide planning map
    - p-WIM data
- Functional properties
  - Subgrade properties
    - USDA Web Soil Survey
  - Geometry
    - LiDAR
      - Bridge clearances (horizontal and vertical)
      - Widening potential
  - Visual check
    - HDV

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SH 6 Case Study

- ML1 from US 190 to BS 6R is an 8.5-mile section with a proposed CRCP pavement
  - The project duration and traffic delay are highly interdependent
  - The agency can find a balanced tradeoff on the weekend option
    - Reduces traffic disruption at an acceptable range (24 minutes) while accelerating construction time (5230 closure hours) and road user costs ($80,000 daily) compared to the 24/7 option, which has 4,216 closure hours and road user costs of $138,000 per day
- ML2 from BS 6R to SH 40 is a 3.4-mile section
  - The integrated tradeoff analysis shows that all four options will produce a minimal level of traffic delay if the resurfacing work can be executed after the widening project is first completed

	ML 1	ML2	ML1 + ML2
Keep ($/sy)	$ 79.60	$ 24.90	
Build New ($/sy)	$ 128.80	$ 140.40	
Savings ($/sy)	$ 40.68	$ 88.78	
SY	378,987	175,531	
Total Savings	$15,417,177.60	$15,583,612.59	$31,000,790.19
Estimated Time Savings			19 months

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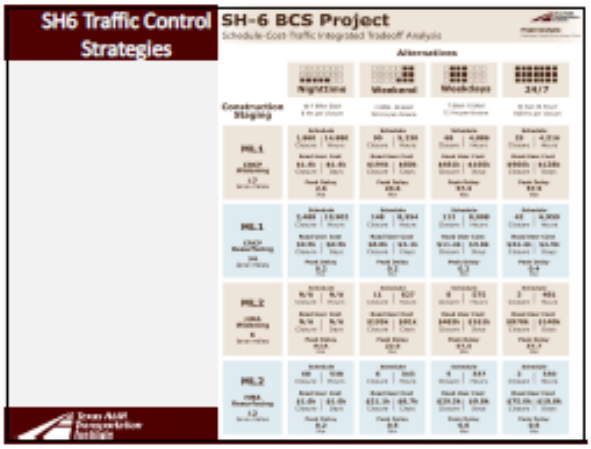
SH6 Traffic Control Strategies
SH-6 BCS Project
Schedule-Cost-Traffic Integrated Tradeoff Analysis
Alternatives
Nightime
Weekend
Weekdays
24/7
Construction Staging
ML1
ML1
ML2
ML2

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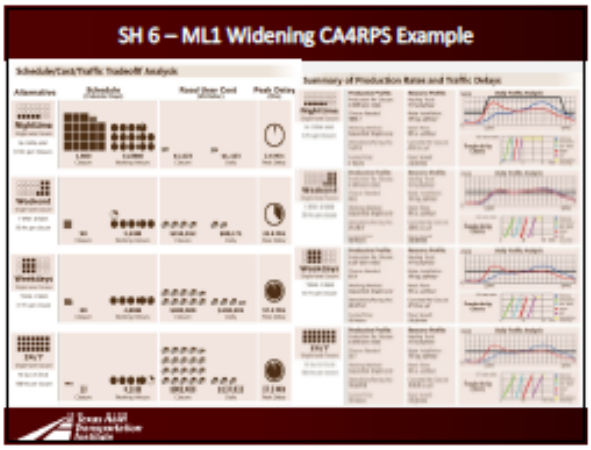
SH 6 – ML1 Widening CA4RPS Example
Schedule/Cost/Traffic Tradeoff Analysis
Summary of Production Rates and Traffic Delays

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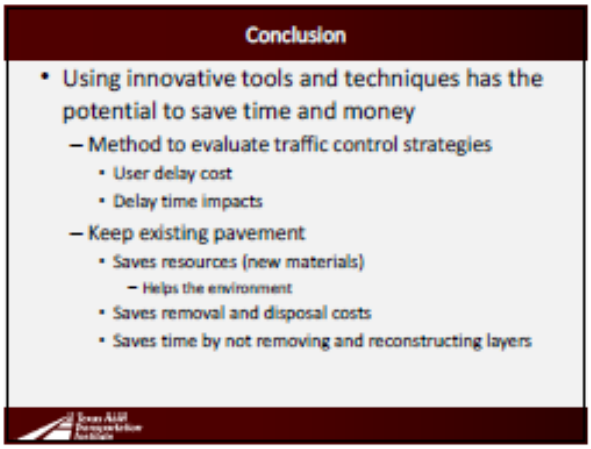
Conclusion
• Using innovative tools and techniques has the potential to save time and money
– Method to evaluate traffic control strategies
• User delay cost
• Delay time impacts
– Keep existing pavement
• Saves resources (new materials)
– Helps the environment
• Saves removal and disposal costs
• Saves time by not removing and reconstructing layers

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