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Accelerating Pavement Construction Using Innovative Tools and Techniques

Technical Report 0-6985-R1

Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE
COLLEGE STATION, TEXAS

in cooperation with the
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The researchers investigated innovative tools and techniques to accelerate pavement construction. In coordination with Texas Department of Transportation (TxDOT) districts, the researchers identified four roadway projects to perform case studies using innovative tools and techniques to accelerate pavement construction. The researchers tested these projects by employing advanced planning tools. A novel construction schedule–cost–traffic integration approach was implemented to help TxDOT make the most informed decisions with regard to balanced trade-offs to lessen traffic disruption to the traveling public while minimizing construction time and road user cost. The researchers prepared and presented training materials and guidance to include methodology, testing procedures, and other tools used in the selection and design of pavement for candidate projects.</td></tr>
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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

This report is not intended for construction, bidding, or permit purposes. The engineer (researcher) in charge of the project was Darlene C. Goehl, P.E. #80195.

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

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CHAPTER 1. LITERATURE REVIEW AND SURVEY

BACKGROUND

Texas Department of Transportation (TxDOT) is facing an increase in pavement reconstruction projects over the next 10 years, especially with the passage of the Proposition 7 funding. However, most of the roadways needing reconstruction and widening are in metro areas where traffic handling, user delay costs, and loss of income to adjacent businesses are a major expense. One approach to reducing user delay costs is to adopt accelerated construction techniques. In 2018, TxDOT released their accelerated construction guidelines document[1], which states that when the goals of accelerated construction are aligned among the DOT, contractor, and public, critical projects could be accelerated by 20 to 50 percent. However, there are few practical examples of accelerated construction on Texas roadways.

The goal of this research, therefore, was to investigate innovative tools and technique to accelerate pavement construction on actual active projects.

The researchers first conducted a literature review and distributed a survey to TxDOT districts about accelerated construction techniques. In coordination with the TxDOT districts, the researchers identified four roadway projects to perform case studies. The researchers tested these projects by employing advanced planning tools. A novel construction schedule-cost-traffic integration approach was implemented in an attempt to help the TxDOT make the most informed decisions with regards to balanced tradeoffs to lessen traffic disruption to the traveling public while minimizing constucton time and road user cost. The researchers prepared and presented training materials and guidance to include their methodology, testing procedures and other tools used in the selection and design of pavement for candidate projects.

An extensive literature review was performed as part of this study, and TxDOT employees were surveyed about accelerated construction tools and techniques. This chapter summarizes the key points from the survey and literature review.

LITERATURE REVIEW

The following resources provide guidance on accelerated construction philosophy and specific techniques for implementation, which is the basis for most of the literature review discussion:

- TxDOT – Accelerated Construction Guidelines[1].
- FHWA – Work Zone Management Program, Accelerated Construction: Design and Construction Strategies[2].
- NCHRP 20-68A, Scan 07-02 – Best Practices in Accelerated Construction Techniques[3].

Project identification

The first step is to properly identify projects that would benefit from accelerated construction. The agency should perform a rough direct and indirect cost comparison of construction approaches[2, 4-7]. Generally, projects that would benefit from acceleration are in high-traffic urban environments and projects that affect key intersections and bridges. These projects generate substantial indirect costs from traffic delays.

METHODS AND TOOLS FOR ACCELERATED CONSTRUCTION

The portion of the literature review described in this section focused on methods for accelerating construction, with an emphasis on pavement design and construction activities. Some general considerations that apply to any accelerated project are:

- Use simpler pavement designs to simplify construction phasing.
- Utilize as much existing material as possible.
- Create designs that maximize repeating features.
- Allow for ample working space on site.
- Maintain clear communication[2].

Specific techniques for the asphalt and concrete construction were reviewed. For asphalt, intermediate and surface lifts can be merged into a single lift, and flexible base can be replaced with a full-depth asphalt design. Full-depth reclamation and cold in-place recycling are both effective ways to reuse existing on-site materials. For concrete, construction can be accelerated with rapid set concrete[8], slipform paving, pre-fabricated panels[9], and off-site welded wire reinforcement[10]. Bridge construction can be accelerated with prefabricated sections and superstructures. Large superstructures must be moved into place using a self-propelled mobile transport. The result is a reduction time of onsite construction by as much as 98 percent[10].

In the planning stage, and agency must decide whether to maintain, rehabilitate, or reconstruct a roadway. It is critical, therefore, to evaluate the existing pavement condition. Some rapid pre-evaluation tools for rehabilitation are ground penetrating radar (GPR)[11], falling weight deflectometer (FWD), total pavement acceptance device (TPAD)[12], and mobile light detecting and ranging (LiDAR) system.

Innovative Tools for Contract Time Determination

Through a review of state transportation agencies' best practices, the researchers found that the adoption of decision support tools became increasingly common in recent years. Tools are utilized by engineers and planners to compare what-if rehabilitation alternatives and to devise project milestone numbers that need to be incorporated into feasibility studies, schematic designs, and/or plans, specifications, and estimate (PS&E) packages before letting approval. The research team conducted an intensive but concerted effort to gather comprehensive information about the current use of tools by individual agencies and the industry as a whole. The tools reviewed were:

- Primavera P6 Professional Project Management.
- Construction Analysis for Pavement Rehabilitation Strategies (CA4PRS).
- AASHTOWare Project (formerly American Association of State Highway and Transportation Officials [AASHTO] Transport).
- Illinois Construction Scheduling Expert System.

- Long Range Estimates (Florida Department of Transportation).
- Integrated Project Development (Nevada Department of Transportation).

Researchers believe the tool that will benefit TxDOT most when assisting with traffic control decisions for accelerated pavement construction projects is CA4PRS. It has been widely used in California's large-scale rehabilitation/reconstruction projects, proving the accuracy and reliability of its integrated schedule–cost–traffic estimates. The research team used CA4PRS to evaluate traffic control strategies in the case studies.

TXDOT SURVEY

A survey was sent to various TxDOT offices, and 21 people responded to the survey. Figure 1 shows the offices represented. The Design Division did not respond to the survey. The "Others" who responded were from district maintenance and district operations offices.

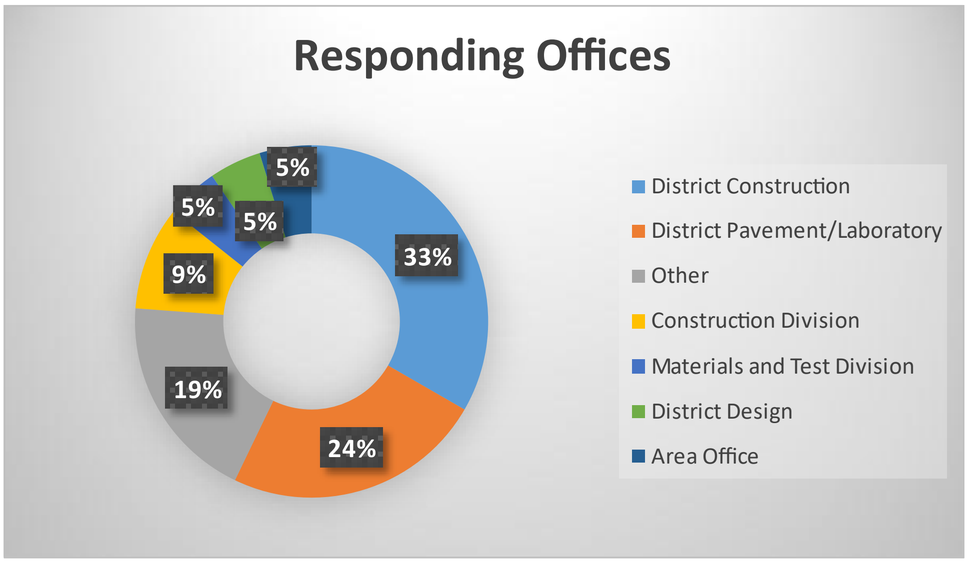


Figure 1. Responding Offices from the Survey.

The survey was broken into the following areas: planning and design, construction, and future work. All methods to accelerate pavement construction noted in the survey had been used on construction projects, with no others described. The most frequently used acceleration techniques and technologies were full-depth reclamation, full-depth hot-mix, and high early strength concrete. Figure 2 and Figure 3 display the full rankings. The items most frequently requested by contractors were to use high early strength concrete and full-depth hot-mix concrete. Figure 4 shows the methods requested by the contractor.

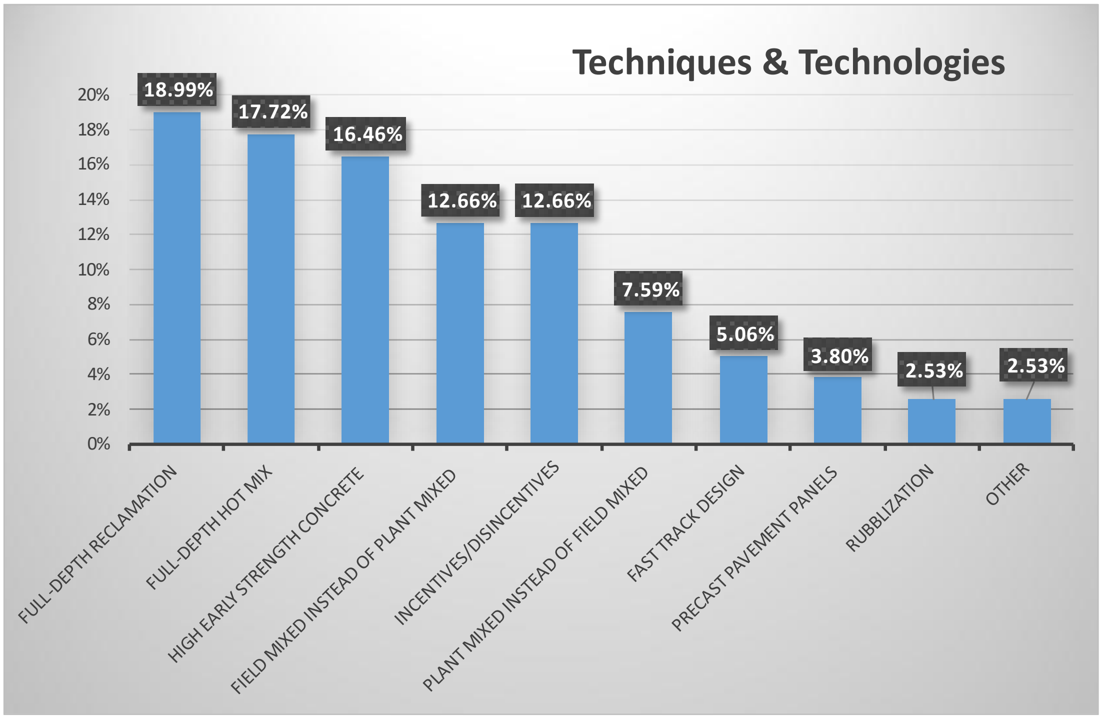


Figure 2. Techniques and Technologies for Planning and Design.

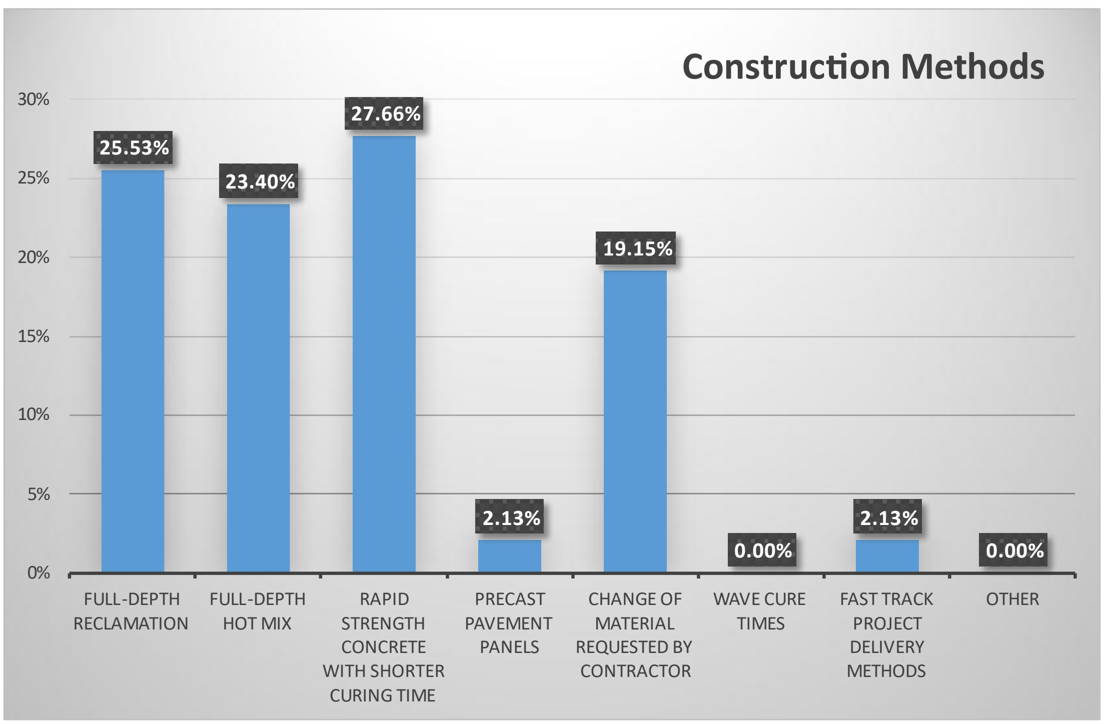


Figure 3. Accelerated Methods during Construction.

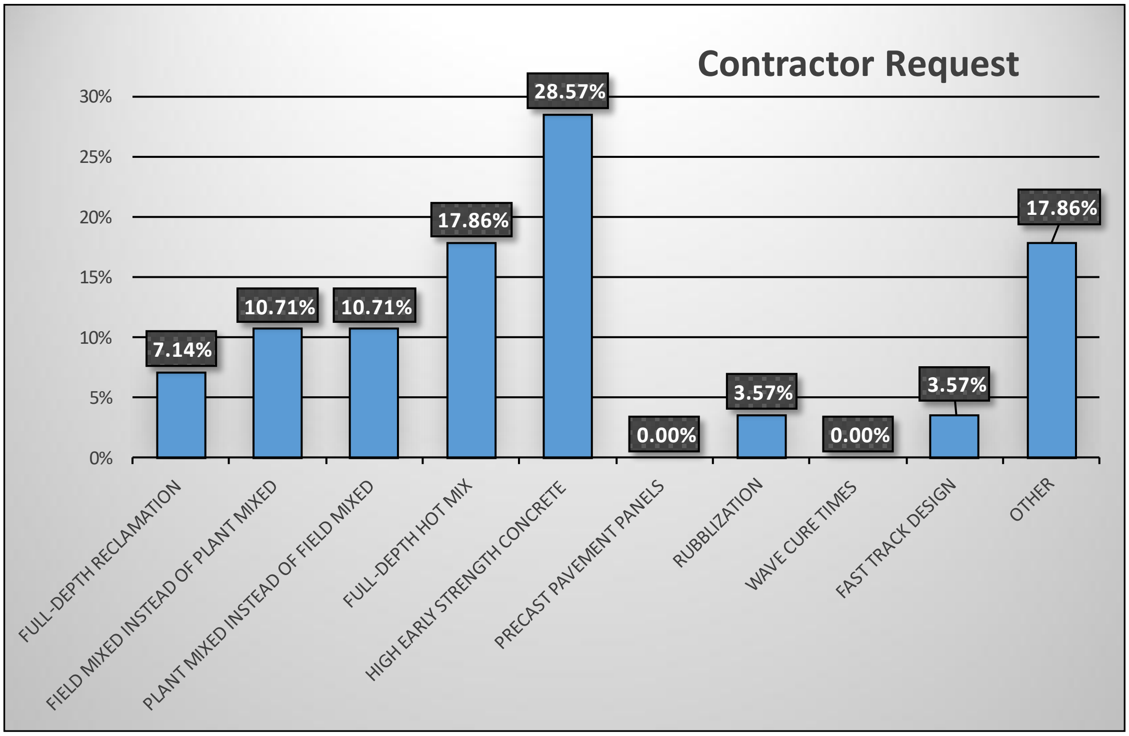


Figure 4. Contractor Requests.

All respondents indicated that the contractor had requested an alternate material or item of work to accelerate construction. Only 62 percent indicated that a change request started with TxDOT. When changes were made during construction, the respondents indicated that 64 percent verified the pavement design, while 36 percent only verified the pavement design sometimes.

For planning and design, the most frequently used pavement testing tools are the FWD, pavement cores, and soil samples. These tools were also the most frequently used during construction. Figure 5 and Figure 6 show the rankings of the tools and methods of pavement testing. In addition to the top three methods mentioned, the planning and design area also frequently used skid measurements, the dynamic cone penetrometer (DCP), the GPR, and the profiler.

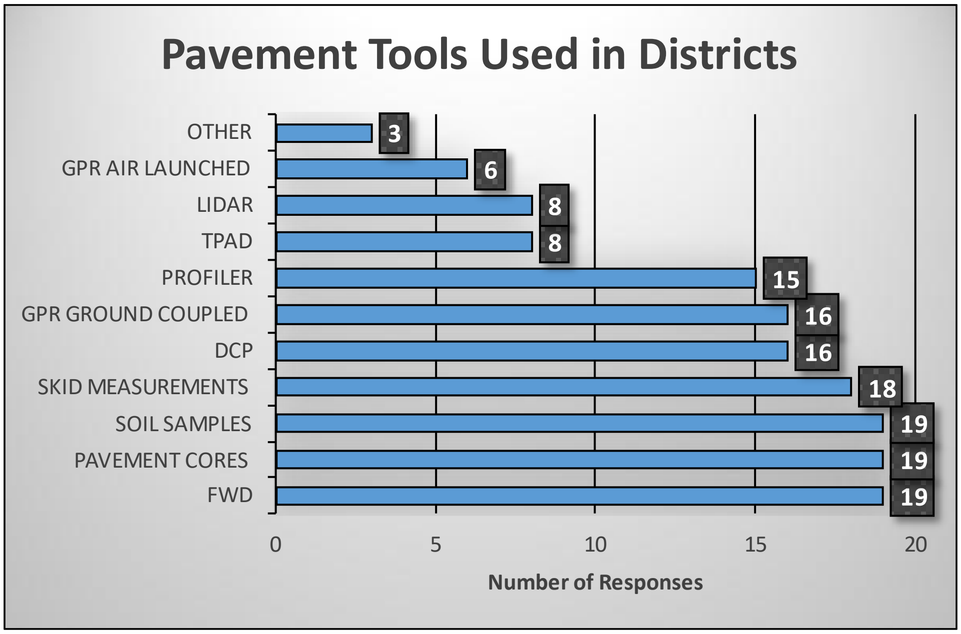


Figure 5. Pavement Testing for Planning and Design.

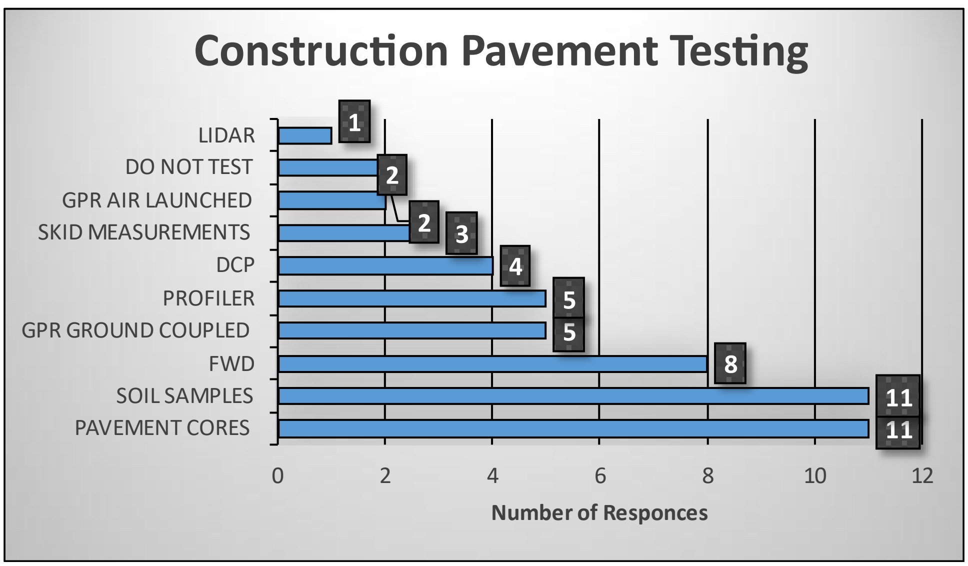


Figure 6. Pavement Testing during Construction.

The most common techniques to reduce contract times were the use of milestones and nighttime work. Figure 7 displays rankings of the use of the various items that affect construction time when developing a construction time schedule. Most designers used either a bar chart or the critical path method (CPM) to determine the number of working days, as shown in Figure 8. Only a few designers used other methods as a basis for the calculation of working days. There was not a consensus from those surveyed for the person responsible for determining the project construction schedule. However, most survey respondents agreed that the calculation is based on traffic control phases and the associated items of work within those phases (Figure 9 and Figure 10).

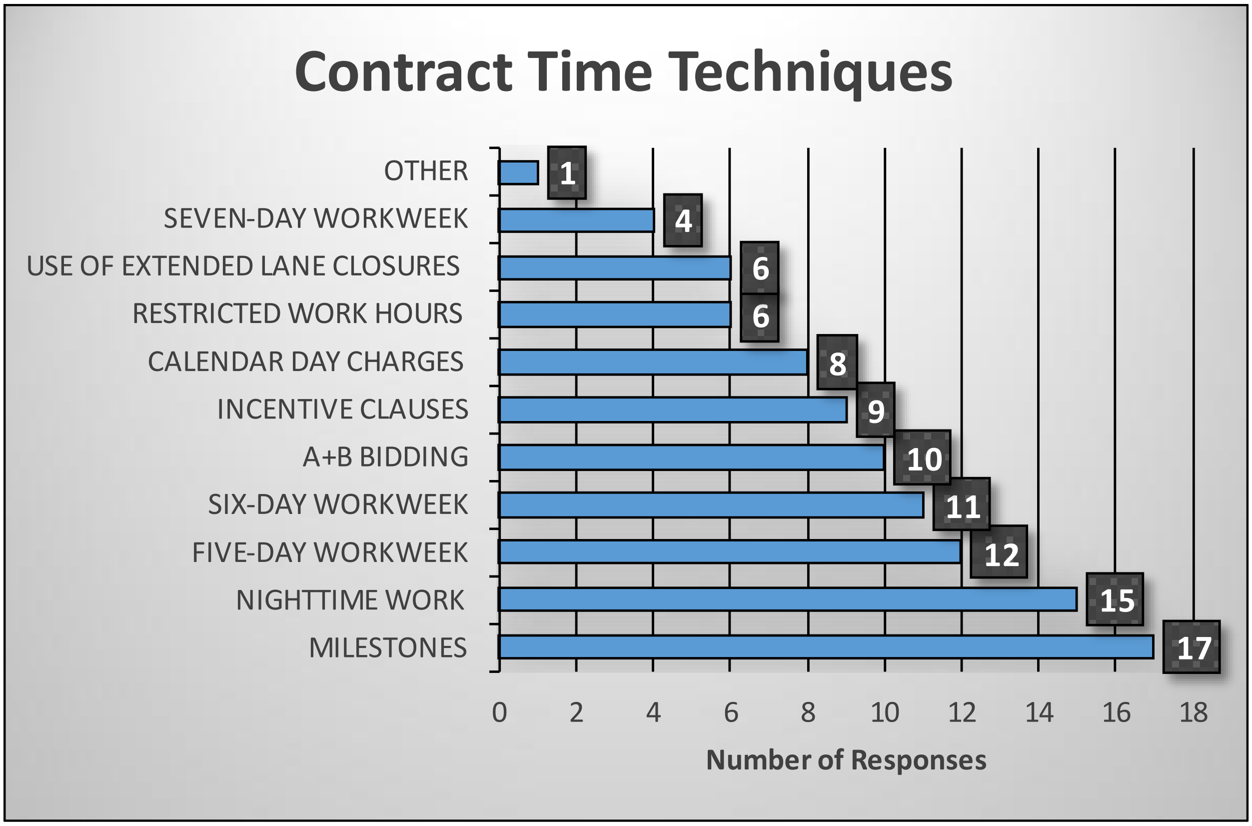


Figure 7. Schedule Items.

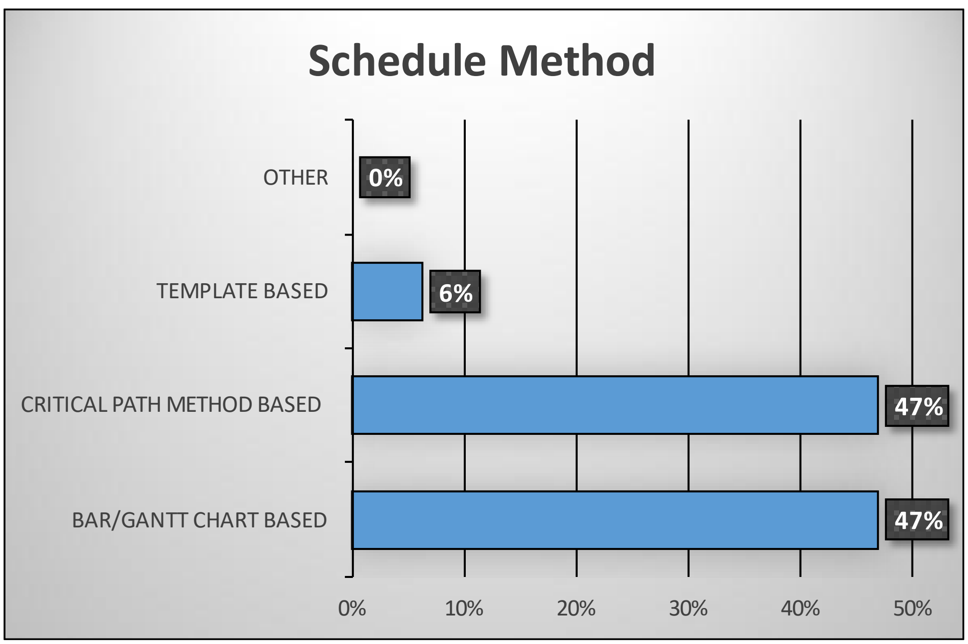


Figure 8. Schedule Method.

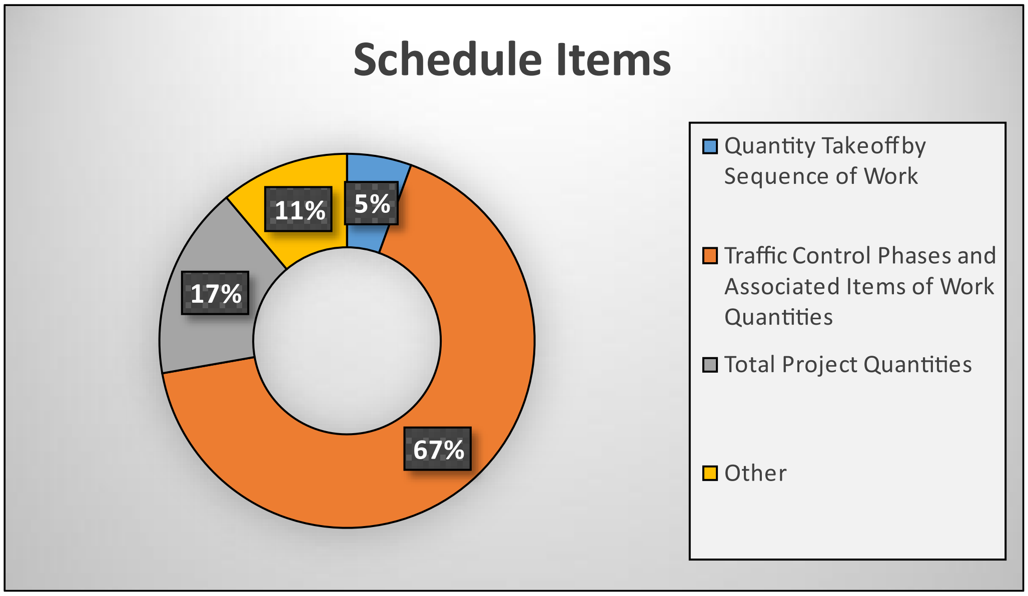


Figure 9. Working Day Basis.

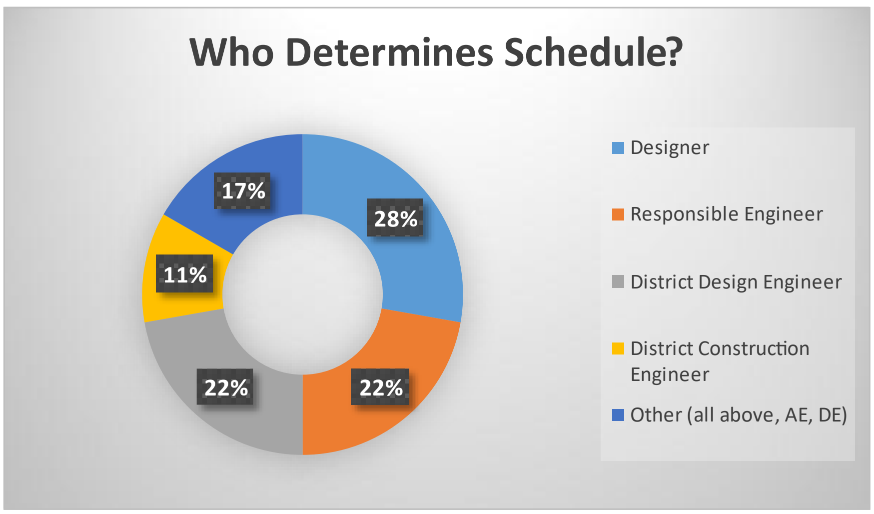


Figure 10. Who Determines Schedule?

Project development schedules do not always allot time for construction schedule development, and when they do, it is often not adequate (Figure 11). Figure 12 displays the responses for the review process and shows that 65 percent of those responding indicated that there is not a formal review process for time determination.

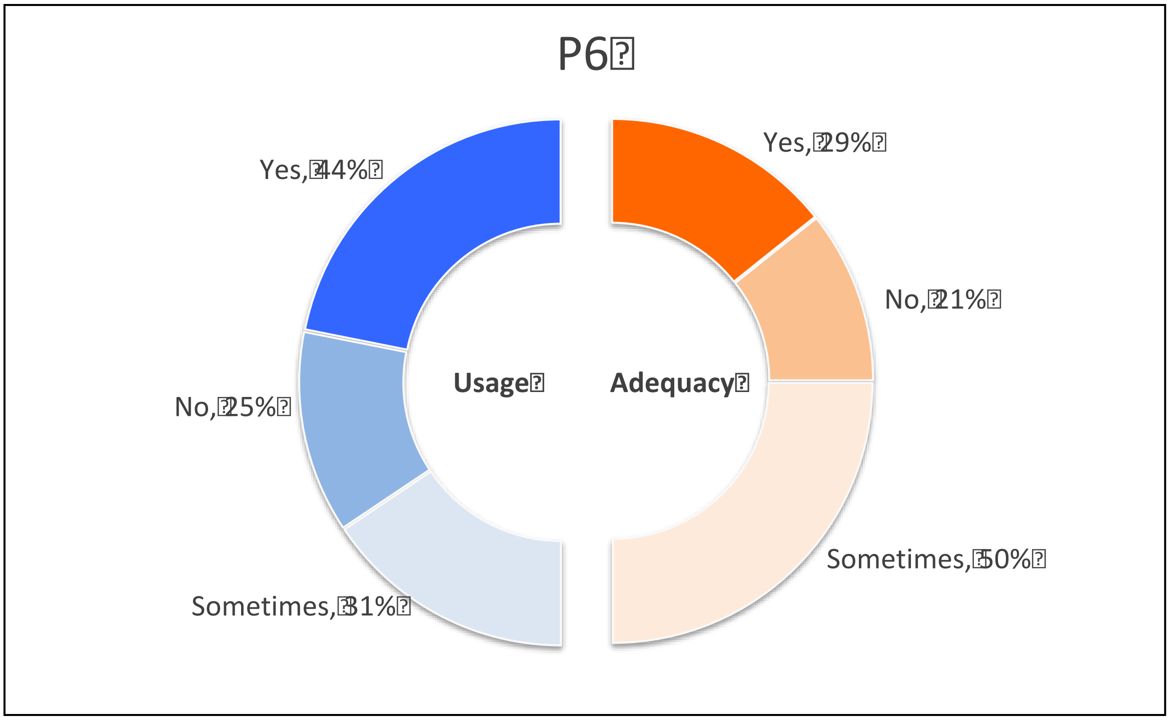


Figure 11. Schedule Determination.

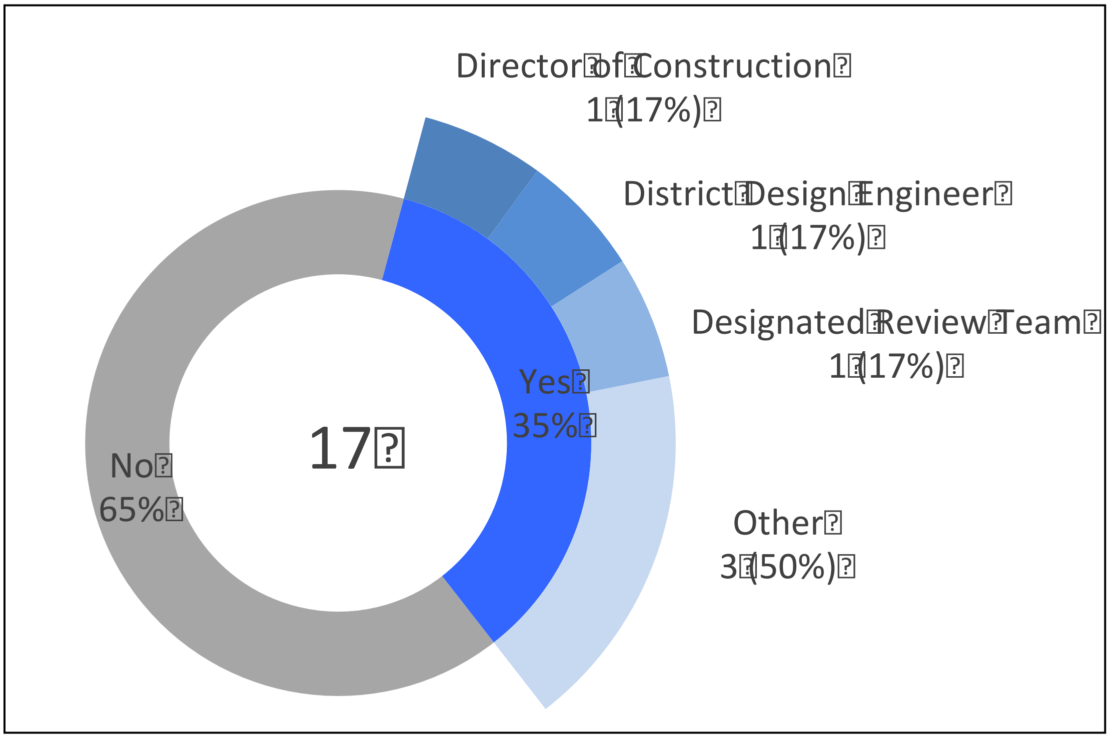


Figure 12. Schedule Review.

Figure 13 shows the scheduling tools available to TxDOT to help monitor construction time. Of the seven respondents who used a CPM method, only four had Primavera software.

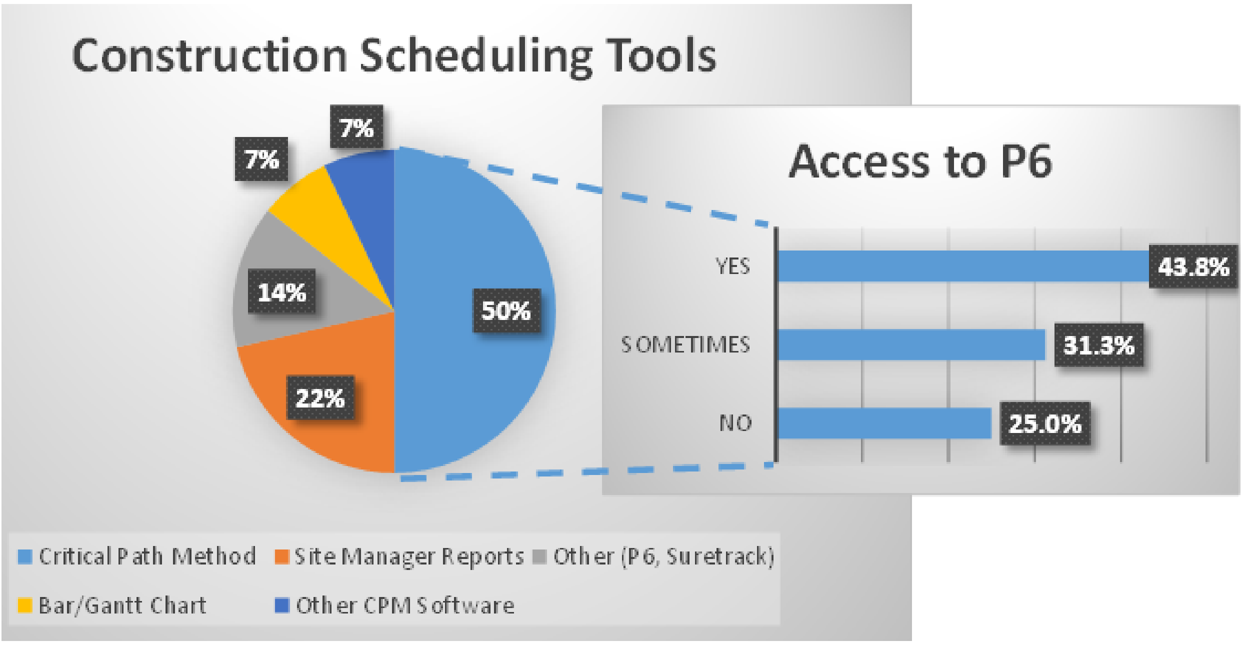


Figure 13. Monitor Construction Time.

SURVEY CONCLUSIONS

Besides project-specific/unique needs, three general areas of concern for accelerating pavement construction were identified by those responding to the survey: staffing, traffic control, and training.

The staffing levels were a concern for both TxDOT and the contractor. There was a strong indication from the responses that traffic control should be a consideration when accelerating construction. Training and guidance in accelerated pavement construction methods and strategies are needed for both TxDOT and the contractor. The following list shows the training and guidance needs identified by those surveyed:

- TxDOT training and guidance:
  - Production rates.
  - Material alternatives.
  - Construction techniques.
  - Working time based on traffic control.
  - Schedule monitoring during construction.
  - A+B bidding.
  - Time determination.

- Contractor training and guidance:
    - Work methods.
    - Scheduling of material deliveries.
    - Workload balancing when there are multiple projects.
    - Specific district requirements.

Based on the responses, the following are needed:

- More emphasis on the development and review of a construction schedule for the PS&E.
- Additional tools and software for TxDOT personnel's use in monitoring time during construction.

Meanwhile, the following concerns were raised for accelerating construction:

- The availability of pavement materials should be considered when selecting a pavement design strategy. For example, some areas of Texas do not have hot-mix plants.
- The contractors' knowledge and capabilities as well as their in-house resources to perform the accelerated work should be assessed and recorded.

CHAPTER 2. CASE STUDIES

INTRODUCTION

This chapter discusses the projects selected for case studies. Several districts provided candidate projects, including Austin, Bryan, Dallas, and Houston. Innovative tools and techniques for pavement evaluation were used on the candidate projects. More information about the pavement evaluation process can be found in report 0-6985-P8, where general guidelines regarding the use of different pavement evaluation systems are provided, along with one-page summaries for each system describing 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-to-construct design option that maximizes the reuse of existing materials is economically practical.

CANDIDATE PROJECTS

The October 2018 survey included a request for candidate projects. Based on the literature review, survey responses, guidance from the project team, and discussions with the districts, the candidate projects were narrowed down to the list in Table 1.

Table 1. Candidate Project List.

Status	District	County	Highway	From	To
Case Study	Bryan	Walker	I-45	SH 19	FM 1696
Case Study	Dallas	Dallas/ Kaufman	I-20	IH 635	SH 34
Case Study	Houston	Harris	FM 2920	Willow St.	BS 249
Not Included	Austin	Williamson	FM 734	RM 1431	SH 45
Case Study	Bryan	Brazos	SH 6	US 190	SH 40
Not Included	Bryan	Brazos	SH OSR	SH 6	Navasota River
Case Study—Traffic Control Analysis Only	Houston	Harris	I-45	I-610	Sims Bayou

INNOVATIVE TOOLS AND TECHNIQUES

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. The best-practice systematic procedure for determining contract times used in the case studies is presented in Figure 14 and is comprised of the following steps:

- **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, 24/7). Each alternative can be executed through one of three standard lane closure scenarios (i.e., single-, double-, 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. This process should be followed because the estimated number of workdays is needed to serve 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 such 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 of the options being considered**. After accounting for prioritized values and/or trade-offs with regards to project duration, cost, and amount of traffic disruption for each of the alternatives considered, the agency should then 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 process for bidding is known to increase the frequency and magnitude of contract change orders, resulting 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**. With regard to the final alternative selected, an accelerated production rate should be applied, with the expectation that the incentive/disincentive (I/D) project will use 15 percent to 20 percent more resources than a conventional schedule. The initially estimated project duration should then be adjusted accordingly to be incorporated into the B value in the A+B bid.
- **Step 7: Convert the adjusted workdays into calendar days**. It is recommended that A+B+I/D projects define workdays as calendar days and account for weather, holidays/weekends, and other non-workdays during the time construction is executed. Adjustments should also be made for weather.

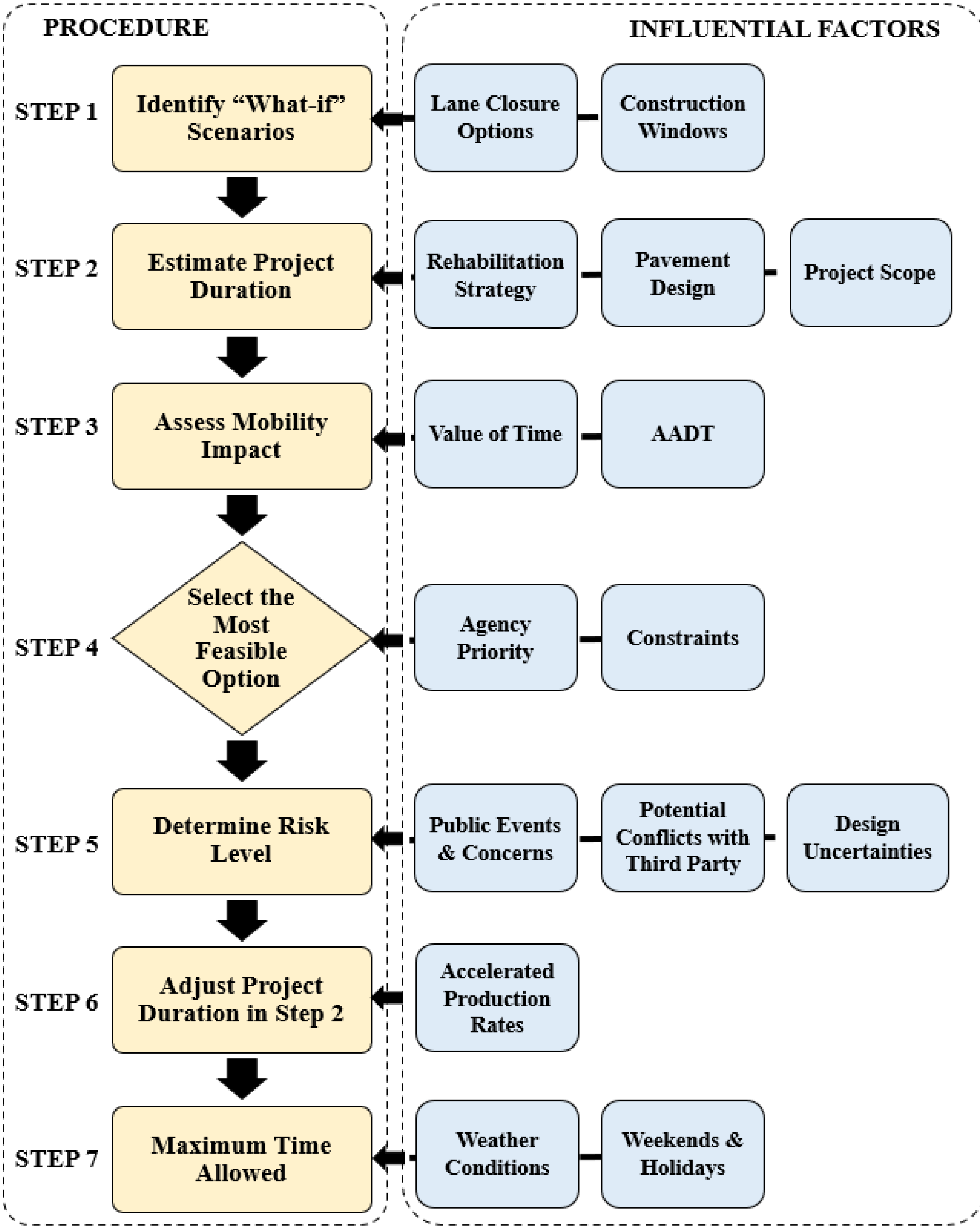


Figure 14. Flowchart for Accelerated Contracting Schedule Procedures.

The innovative tools and techniques used in this study included the following and are summarized in Table 2:

- The U.S. Department of Agriculture's Web Soil Survey (USDA-WSS).
- High-definition video (HDV).
- GPR.
- FWD.
- TPAD.
- LiDAR.
- Inertial profiler.
- Electrical resistivity tomography (ERT).
- DCP.
- CA4PRS.

Table 2. Case Study Pavement Evaluation Summary.

District	**County**	**Highway**	**USDA-WSS**	**GPR**	**HDV**	**FWD**	**TPAD**	**CA4PRS**	**ERT**	**LiDAR**	**Inertial Profiler**	**DCP**
Bryan	Walker	I-45	x	x	x	x	x	x	x			
Dallas	Dallas/ Kaufman	I-20		x	x	x	x	x			x	x
Houston	Harris	FM 2920	x	x	x	x	x	x				
Bryan	Brazos	SH 6	x	x	x	x	x	x		x		x
Houston	Harris	I-45						x				

CHAPTER 3. IH 20 IN THE DALLAS DISTRICT

IH 20 PROJECT DATA

IH 20 is a four-lane divided freeway with a current average daily traffic (ADT) count of 32,396. The programmed project information is shown in Table 3

Table 3. IH 20 Project Information.

. The location map is shown in Figure 15. Figure 16 displays a picture of the section. The limits are from IH 635 east to west of Rosehill Road.

Table 3. IH 20 Project Information.

Project ID	Description	From Limit	To Limit	County	Estimated Construction Cost	Low Bid	Project Length (mile)
9513043	Full-Depth Concrete Repair and Overlay Eastbound (EB) and Westbound (WB)	IH 635	Kaufman County Line	Dallas	$12,961,778	$11,231,721	6.218
9514031	Mill EB, Full-Depth Concrete Repair and Overlay EB and WB	Dallas County Line	Big Brushy Creek	Kaufman	$15,612,421	$13,210,235	8.649
9514029	Rehabilitate Existing Roadway	Big Brushy Creek	West of Rosehill Road	Kaufman	$16,636,110	$22,030,033	4.246

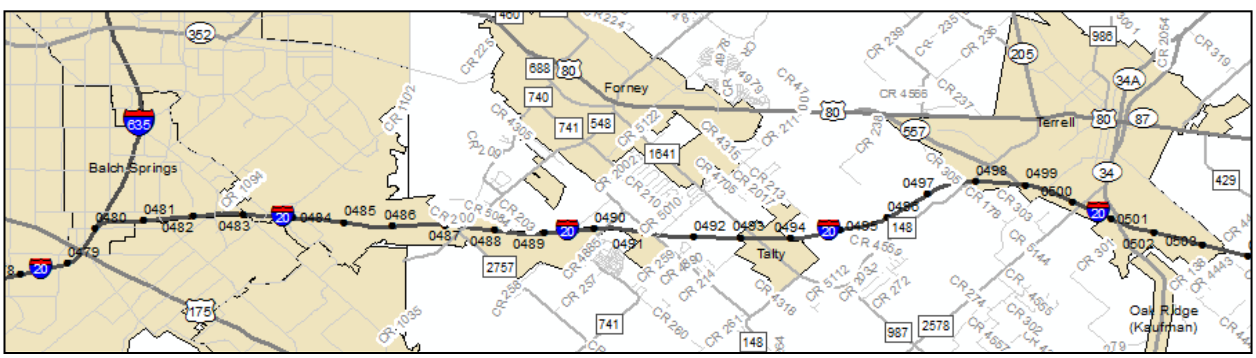


Figure 15. IH 20 Map.

Figure 16. IH 20 Image from Google Earth.

IH 20 PAVEMENT EVALUATION

The approximately 20-mi project was divided into three sections based on the pavement condition, as Figure 17 shows. The section breaks are approximately at reference marker 486 and 494 (limits from 481 to 500).

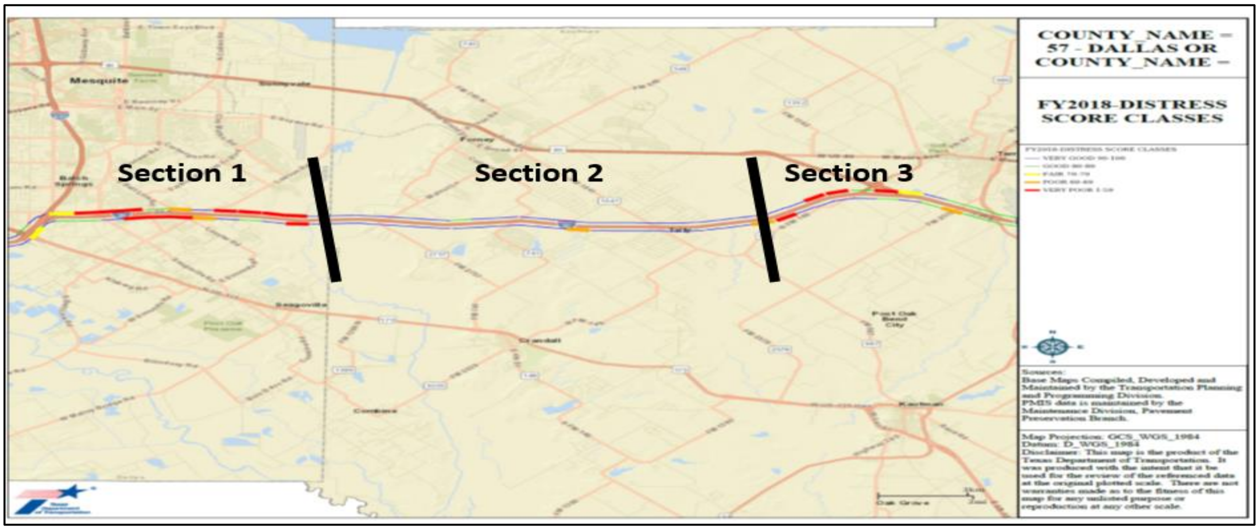


Figure 17. IH 20 Sections.

Section 1 and 2

Visually, the sections looked good. The TPAD deflection data analysis indicated that the structural strength was good and the repairs made are holding up well. It was concluded that the low pavement scores in the pavement management information system were a result of the extensive patching and pavement roughness. Overall, sections 1 and 2 were considered good candidates for a hot-mix asphalt (HMA) overlay. Profile data were collected by district forces, and the data reported by Dar-Hao Chen stated that a level up and 2-inch HMA overlay would suffice to return the ride value to an acceptable level. For section 1 and 2, the district placed a membrane underseal to provide bonding to the pavement, followed by 1 inch of crack attenuating mixture (CAM) (Item 3000) and 2 inches of stone matrix asphalt (SMA-D) (Item 346). This work was under construction during this research project.

Section 3

Section 3 was the area of main concern for the Dallas District. It has extensive severe longitudinal cracks. Earlier forensic investigations found that the source of the cracking was due to the fact that the longitudinal sawed joints did not crack because they were likely sawed too late (or not deep enough). Not only were the cracks bad, they were continuing to get worse. The district had also performed other repair options, such as crack stitching, but these were judged to be ineffective. The main question for this section was, “Is it a candidate for rubblization?”

The pavement structure for IH 20 consists of 12 inches of jointed concrete pavement (JCP) and 4 inches of asphalt-stabilized base (ASB) over a lime-stabilized subgrade. The key to determining if rubblization is an option was to assess if DCP testing of the strength of the material directly under the ASB was conducted. The DCP operation on IH 20 is shown in Figure 18, along with data from the six locations tested. The penetration rate for the DCP was converted into a California Bearing Ratio (CBR). The computed CBR values were found to range from 16 to 85 for the material at the top of the subgrade. This range clearly indicates that the lime layer is still present and effective. The go/no-go decision is made using the chart in Figure 19. All of the data collected are off the chart; therefore, it should be possible to successfully rubblize the concrete layer on IH 20.

	CBR
D1	25.29
D2	16.24
D3	34.04
D4	82.19
D5 (no crack)	80.77
D6	85.27

Figure 18. Dynamic Cone Penetrometer Testing.

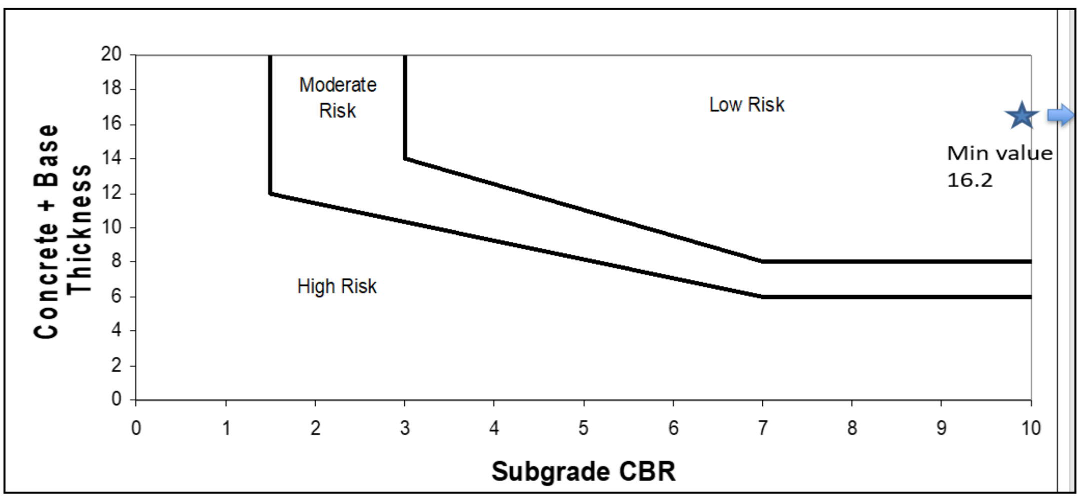


Figure 19. Rubblization Criteria Chart.

FWD data were collected to assess the in-situ layer moduli for the existing concrete pavement. The MODULUS 7 software results indicate that the ASB was computed to have an average modulus of 270 ksi with a subgrade value of 16 ksi; both of these values were used in the pavement design to determine what thickness of HMA would be required over the rubblized base layer.

Flexible Pavement System (FPS) 21 software was used to run pavement designs for the IH 20 project. Two different times (12 and 15 years) to the first overlay was used, and three different moduli values were assigned for the rubblized concrete. From earlier work in Texas, a conservative value of 200 ksi was initially proposed. However, work in Beaumont and other places found that the modulus of the rubblized layer is substantially higher than 200 ksi and that it increases with time as the broken concrete gains strength. A summary of the recommended overlay thicknesses is shown in Figure 20. The Dallas District decided to use a thickness of 6 inches of HMA. Construction on this project started in the fall of 2019 and will be completed in the spring of 2020.

Modulus of Rubblized Layer (ksi)	Time to First Overlay (years)	HMA Thickness SMA + SP (inches)
200	15	2 + 8.5
300	15	2 + 5.5
400	15	2 + 2.5
200	12	2 + 6.5
300	12	2 + 3.0
400	12	2 + 2.0

Figure 20. Flexible Pavement System Overlay Design on IH 20.

IH 20 TRAFFIC CONTROL STRATEGIES

Phase I

The scope of the project was to rebuild a damaged six-lane freeway section consisting of 37.2 lane miles near Dallas, Texas. The affected work zone carried approximately 55,000 annual average daily traffic (AADT) units, about 27 percent of which were heavy trucks. This project was contracted via I/D through a cost–plus–time bidding process, commonly referred to as A+B. A daily I/D rate of $4,000 was set for the estimated 270 workdays. The project did not include any additional structure and right-of-way costs.

The research team was tasked with calculating the appropriate number of workdays and daily I/D amounts for two alternatives: weekdays versus nighttime. The CA4PRS system was used to determine contract time, an effective and reliable B value for the A+B bidding, and daily road user costs.

After going through Step 1 through 6, the results of the trade-off analysis revealed that with the weekday closure option, the project would be completed 77 percent faster and result in a 68 percent savings in road user delay costs. The analysis showed that with the weekday option, the project would be completed in 210 working days instead of the 270 days estimated by the agency. In a preconstruction project meeting, the contracting agency acknowledged that the initial approximation of project duration was somewhat overestimated, and the contract time was amended to be 210 working days. This amendment resulted in an immediate savings of $324,892 (based on project overhead cost per day: construction cost = $24,441,956 with 6 percent overhead divided by the original 270 contract days = $5431.55/day for 60 days =$324,892), prior to commencement of the project. Figure 21 and Figure 22 show the analysis results.

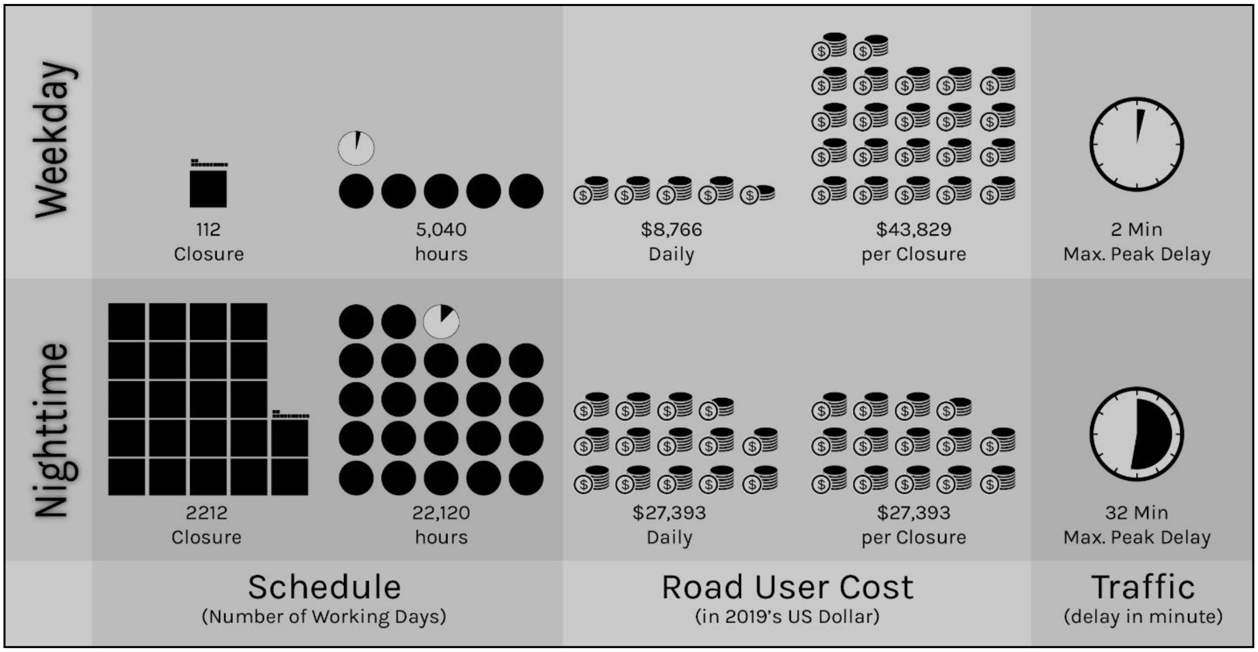


Figure 21. Best Use Case 1: Schedule–Cost–Traffic Integrated Analysis.

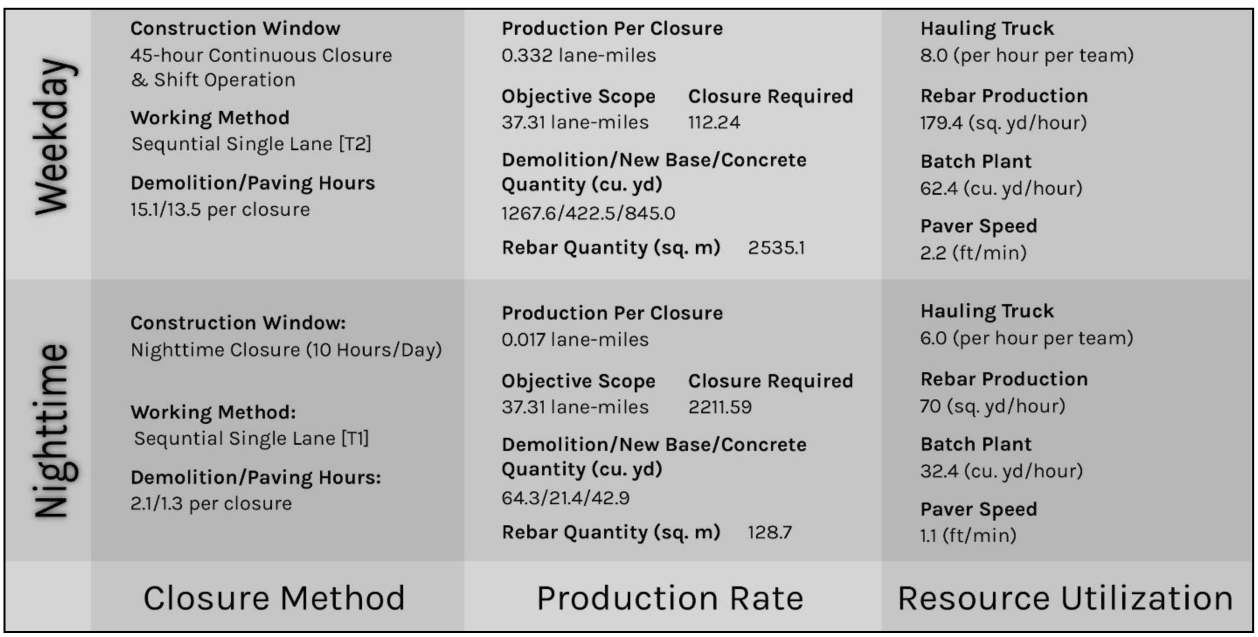


Figure 22. Best Use Case 1: Technical Details.

Phase II

This project provides an example of how CA4PRS, with its integrated schedule–cost–traffic analysis, could help district engineers and decision-makers make the most well-informed decisions regarding lane closure options. The scope of the project was to rubblize and resurface a damaged four-lane section of IH 20 with a centerline mile of 6.164 near Dallas, Texas.
The AADT of the impacted work zone was approximately 60,000, about 27 percent of which was comprised of heavy trucks. This project was contracted with I/D provisions through an A+B

bidding process. A daily I/D rate of $8,000 was established for the estimated 210 working days. The project did not include any additional structure or right-of-way costs.

The Texas A&M Transportation Institute (TTI) was tasked with evaluating the traffic impact and determining the appropriate workdays and daily I/D amounts for three alternatives: nighttime, weekends, and 24/7. The CA4PRS process was used to determine contract time, an effective and reliable B value for the A+B bidding, and daily road user costs.

After conducting Step 1 through 6, the researchers found that the nighttime closure option would cause significantly less traffic impact but substantially increase the project's duration. Both of the other two options would complete the project much faster but at the cost of an unacceptably high traffic delay. The research team recommended the nighttime option for the project, with 105 working days and an $8,000 I/D rate. However, the analysis also indicated that under the 24/7 option, the project would be completed in less than seven workdays. Though the daily road user cost would be extremely high ($2.5 million), the total road user cost would be comparable to that of the nighttime option throughout the entire duration of the project. Thus, if the agency's main goal was to accelerate construction, the 24/7 choice could be a viable option if it could be implemented during a low AADT period, such as a summer holiday (see Figure 23).

IH-20 Project Phase II

Texas A&M Transportation Institute

Project Analyst:
Darlene Goehl & KC Choi

Schedule/Cost/Traffic Integration Analysis

Project Scope:

24.656 lane-miles
6.164 centerline-mile x 2 lanes x 2 directions

AADT = 60,000 with 27% Truck

Value of Time (2014 TTI report)
$21.73 passenger cars $31.71 trucks

A+B+I/D: $8,000

210 working days

Project Objectives:

- Rubblizing existing CPCD and seating AC overlay.
- Cross-section: 6" HM (3-lift mixtures: 1" CAM, 3" SPMA C, 2" SMA D)
- Half-closure with partial completion, only one lane open each direction during construction.

Recommendations:

- Given that both weekend and 24/7 scenarios produce an intolerable traffic delay to daily commuters and travelers, the Performing Agency shall recommend that the ***nighttime*** strategy be adopted for this project.
- If the Receiving Agency's main goal is to accelerate construction to complete the project as early as possible in a viable way to minimize public inconvenience, ***24/7 around-the-clock operation*** **(alternative #3)** can be implemented during a summer holiday break time.
- If the Receiving Agency is intended to adopt a strategy that strikes a balanced tradeoff between schedule, cost and traffic, the weekend alternative can be implemented with extended closure hours (e.g., Friday 9:00 p.m. to Monday 6:00 a.m.).
- For both weekend and 24/7 alternatives, the Performing Agency further investigated the *effect of providing an additional travel lane* using outside shoulders: specifically, the concept of dynamic lane configuration by using a quickchange movable barrier (QMB) system. The simulation reveals an approximately 49% to 61% dramatic reduction in delayed minutes.

Alternative	Schedule Comparison		Road User Cost ($Million)		Max. Peak Delay (Min)	
	Closure Hours	Total Closure	Daily RUC	Closure RUC	→EB	←WB
Nighttime	788	105	**0.07**	0.02	**0.3**	**19**
Weekend	182	4.04	1.64	3.07	185	177
24/7	**79**	0.47	2.50	17.48	271	271

Figure 23. Schedule–Cost–Traffic Integrated Analysis of IH 20.

IH 20 SUMMARY

Based on the analysis and pavement evaluation, the project was divided into two pavement repair strategies. The key points associated with accelerated construction for this project were:

1) Pavement evaluation.
   a) Developed a rehabilitation strategy for approximately 20 mi that included two rehabilitation methods.
      i) Section 1 and 2 were approximately 14 of the 20 mi. The rehabilitation method included spot repair and an overlay.
      ii) Section 3 was approximately 6 of the 20 mi. The rehabilitation method was to rubblize the existing concrete pavement and add hot-mix overlays. Overall, the rehabilitation plan for Section 3 saved time and money based on a simple comparison of the main pavement items of work. Table 4 and Figure 24 show the timeline comparison using TxDOT production rates [13] and statewide average low bid prices [14]. The quantities for continuously reinforced concrete pavement (CRCP) are based on the rubblization quantities (34 ft wide) plus a 4-ft inside shoulder width added to both roadbeds (38 ft wide), and the hot-mix quantities are based on the bid quantity for CAM and then adjusted by depth.

Table 4. IH 20 Rehabilitation Options for Section 3.

Options	Item	Description	Units	Days	Pavement Cost
Rubblization	3072	RUBBLIZATION	SY	19	$385,674
	347	TOM	TON	25	$2,135,550
	346	STONE-MTRX-ASPH	TON	75	$9,934,950
			Totals	77	$12,456,174
Perpetual Pavement	104	REMOVING CONC PAV	SY	67	$731,451
	344	SUPERPAVE HMA	TON	164	$20,427,000
	346	STONE-MTRX-ASPH	TON	30	$3,973,980
			Totals	170	$25,132,431
Rigid Pavement	104	REMOVING CONC PAV	SY	67	$731,451
	344	SUPERPAVE HMA	TON	60	$7,428,000
	360	CONC PVMT (CRCP)	SY	50	$13,787,558
			Totals	79	$21,947,009

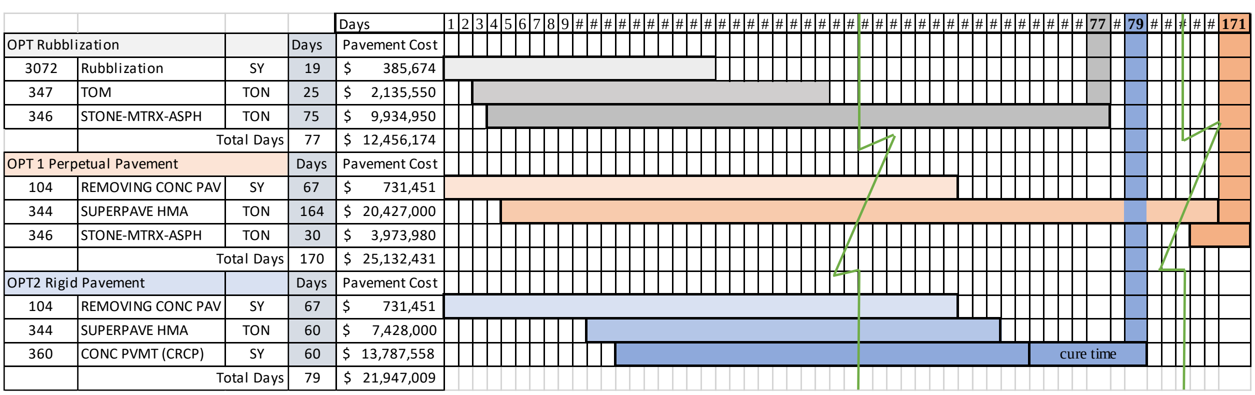


Figure 24. IH 20 Section 3 Rehabilitation Option Timeline.

2) Traffic control.
   a) The district chose to use the $8,000 per day cost that was estimated for Section 3, while $4,000 per day was used for Section 1 and 2. Section 1 and 2 were let in March 2019, and Section 3 was let in May 2019. The researchers met with the Dallas District on March 9, 2019, to provide the traffic analysis. The district chose to incorporate the results.
      i) Section 1 and 2 were set up as A+B bidding with a maximum of 310 days and low bidder, bid 300 days.
      ii) Section 2 was set up as a seven-day-a-week working day with 201 days and two milestones, each with 56 days.
3) Combination of pavement and traffic control.
   a) Defining sections with different rehabilitation allowed the project to be broken into two separate contracts.
   b) By designing the right process for the right section of roadway, this process allowed the overall project time to be decreased significantly assuming the same design strategy would have been used for the entire project (typical procedure). Table 5 provides a summary of the time and cost per mile for the projects.
      i) Additionally, rubbilization is not a frequently used process by TxDOT. Therefore, it would not be unreasonable to assume the design strategy would have been to remove and replace the existing pavement structure, which would have increased the project time and cost.

Table 5. IH 20 Contract Summary.

Sec	Project Cost	Working Days	Cost/Day	Delay Cost	Length (miles)	Roadbed (miles)	Days/ Mile	Cost/ Roadbed (miles)
Sec 1&2	$25,641,956	300	$85,473	$4,000	14.867	29.734	10.1	$862,378
Sec 3	$22,030,033	201	$109,602	$8,000	6.164	12.328	16.30	$1,786,992
Percent Increase If Same Design Was Used							62%	107%

4) Pavement Performance
   a) This project was completed during this research project. In July of 2021, TxDOT requested a follow up evaluation of Section 3, which is the rubblization project. The request was made since this was the first major rubblization project on an interstate highway pavement in Texas. The District is considering additional projects if it is determined that the IH 20 pavement is structurally sound and performing well.
   b) Testing was conducted with the FWD and GPR. The average backcalculated modulus for the 12 inch rubblized concrete was 600 ksi for the eastbound direction and 1030 ksi for the WB direction. This indicates the rubblized base layer provides excellent support and a lot higher modulus value than traditional TxDOT base materials. The high numbers are justified by the rubblization process, which does reduce the upper slab to small pieces where the maximum size allowable is 3 inches, but in the lower part of the slab large interlocking pieces (up to 15 inches) are anticipated.
   c) To provide a conservative modulus for future FPS designs a value of 270 ksi was proposed based on segmentation of the FWD data. This was in line with the value used in the initial pavement design.

d) The pavement condition at the time of testing was judged as excellent, with no rutting or cracking observed in the project after 18 months in service. More projects are being designed by the Dallas District based on the successful completing of IH 20.

CHAPTER 4. FM 2920 IN THE HOUSTON DISTRICT

FM 2920 PROJECT DATA

This project is in the city of Tomball, Texas. The current ADT is 24,481. This project is a four-lane urban section with a continuous two-way center turn lane. The location map is shown in Figure 25. Figure 26 presents a picture of the section.

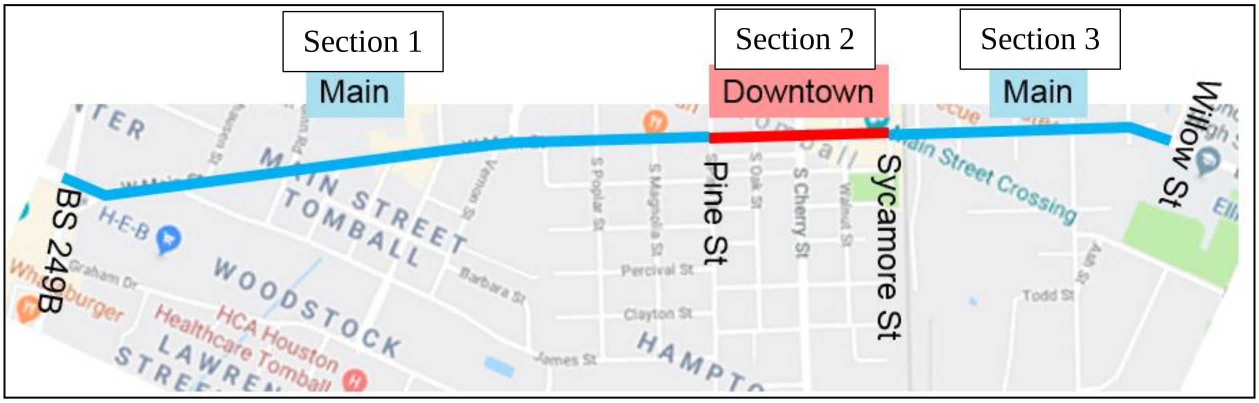


Figure 25. FM 2920 Map.

Figure 26. FM 2920 Pavement.

FM 2920 PAVEMENT EVALUATION

The pavement surface and subsurface defects were evaluated with the following tools:

- GPR was used in all lanes in the right wheelpath.
- FWD was used in the middle of the eastbound outside lane (EBOL) and westbound inside lane.
- Pavement cores were obtained in the downtown section.
- A milled trench cut was performed in the EBOL. Material from this location was taken back to the lab for a stabilization design.

- DCP was used to verify the base and subgrade modulus values.
- Modulus7, FPS 21, and Texas CRCP—Mechanistic–Empirical (TXCRCP-ME) were used for the pavement designs.

Main Section

The main section in Figure 25 is in good condition, with minor reflection cracks. The main distress is transverse cracks caused by shrinkage in the cement-treated base (CTB), as shown in Figure 26 and Figure 27. Typically, heavily stabilized bases crack at regular intervals, similar to JCP.

No structural work is needed in this section. Continuing preventive maintenance treatments is recommended.

Layer	Thickness (in)	Modulus (ksi)	Description
Surface	4.5	650+	TOM surface, multiple HMA and seal coat layers
Base	14	740	Cement-treated base
Subbase	6	29	Lime treated subgrade
Subgrade	-	24	Sandy clay

Figure 27. Main Pavement Core.

Downtown Section

Existing Condition

The downtown section in Figure 25 is in structurally poor condition. Localized fatigue cracking and patched failures exist at the intersection with Cherry Street in the EBOL (see Figure 28). In the center turn lane and half width of inner lanes, there is minor reflection cracking from an underlying concrete layer.

Figure 28. Eastbound Outside Lane at Cherry Street.

The existing pavement structure in this section had thin hot mix at the curb line (see Figure 29 and Figure 30).

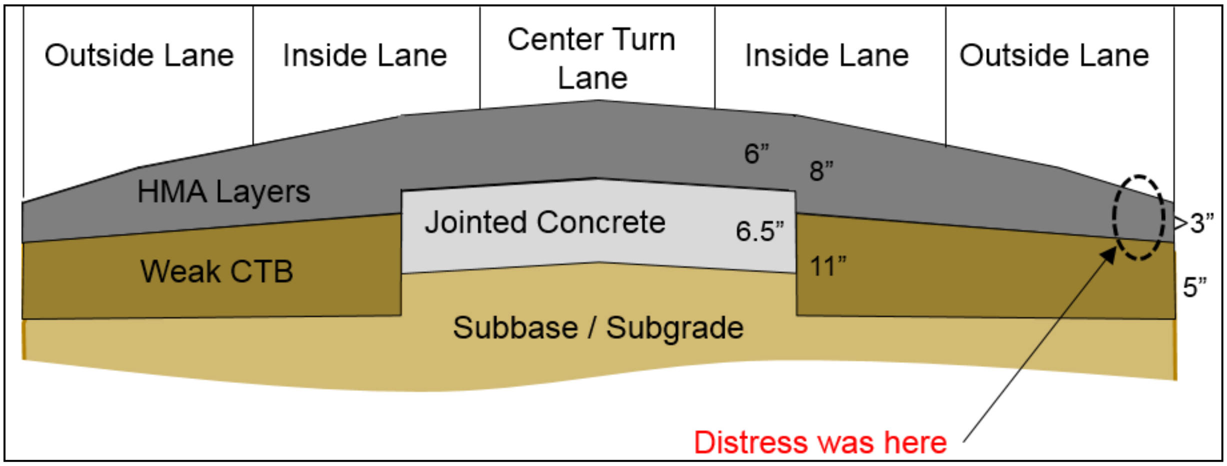


Figure 29. Typical Section.

Layer	Thickness (in)	Modulus (ksi)	Description
Surface	2.75 to 6	650+	TOM surface, multiple layers. Much thinner near curb
Base / Concrete	5 to 11 / 6.5	29 / NA	Outer/Inner Lns: Weak CTB Center/Inner Lns: Concrete
Subbase	6	15	Lime treated subgrade
Subgrade	-	14	Sandy clay

Figure 30. Downtown Cores.

The distresses in this section were caused by a weak base and subgrade and the hot-mix layer being significantly thinner in the outside half of the outside lane. Debonding of the hot mix above the petromat, which was approximately 2 inches above the base layer, also contributed to the distresses.

Full-Depth Reclamation Option

The options for in-place stabilization of the existing pavement included cement and cement/foamed asphalt. Based on the pavement cores, the pavement was assumed to be 30 percent recycled asphalt pavement (RAP) with 70 percent base. Figure 31 shows the strength results of the stabilization design. Based on the testing, 4 percent cement would meet the dry and wet strength requirements. Curbs and gutters restricted the profile of the pavement for this method. Since the profile cannot be significantly raised, the pavement will have to be excavated to the depth of overlay needed to treat the existing pavement. Based on FPS 21, a total overlay of 7 inches is needed to meet the minimum structural design for the life of the pavement.

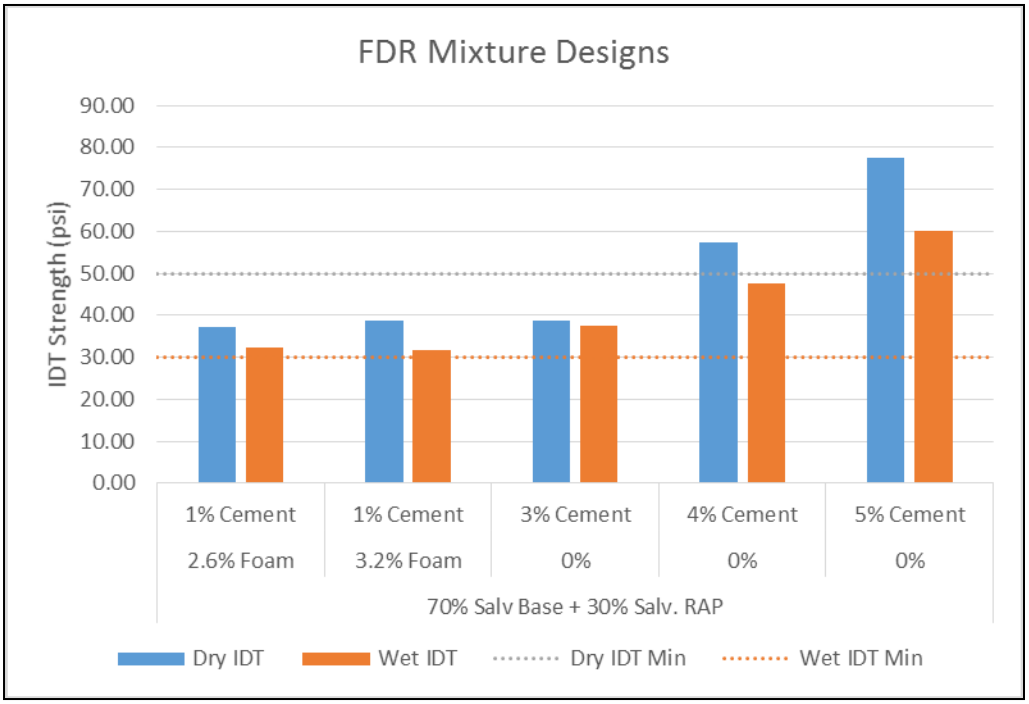


Figure 31. Full-Depth Reclamation Tests.

Match Existing Section Option

Another option considered was to match the existing section, as shown on the as-built PS&E, of 3.5 inches of HMA and 14 inches CTB over subgrade/stabilized subgrade, as shown in Figure 32. This option requires the removal of all failed pavement and replacement with new materials.

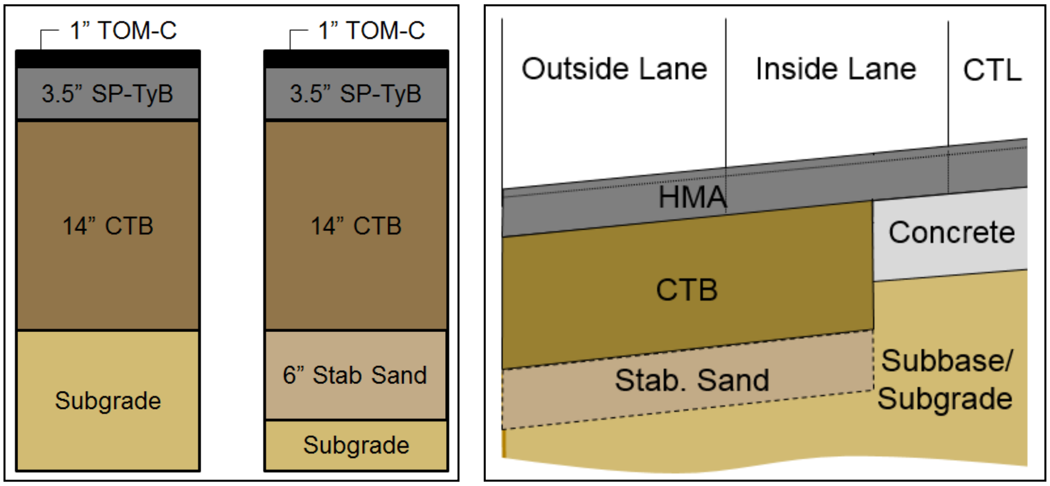


Figure 32. Match Existing Typical Pavement.

Optimized Section Option

The next option considered was to match, at a minimum depth, the existing curb depth with hot mix and have one lift of CTB. Both of these criteria are best practices. Figure 33 depicts the optimized section. This option requires the removal of all failed pavement and replacement with new materials.

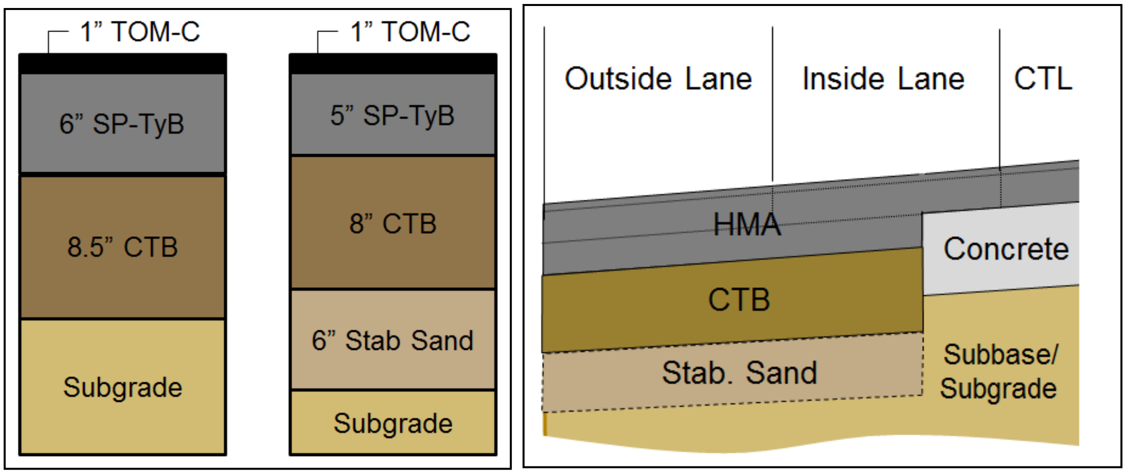


Figure 33. Optimized Layers.

Full-Depth Hot-Mix Option

The final repair option considered was to use a full-depth hot mix because generally using one material type will accelerate construction time. To meet the modified triaxial check, a layer of stabilized sand is proposed below the hot mix; otherwise, an additional 6 inches of the hot mix will be required. This change will provide subgrade improvement as well as a working platform to compact the hot mix against, but it will impact the construction time. Figure 34 shows the full-depth hot-mix section. This option requires the removal of all failed pavement and replacement with new materials.

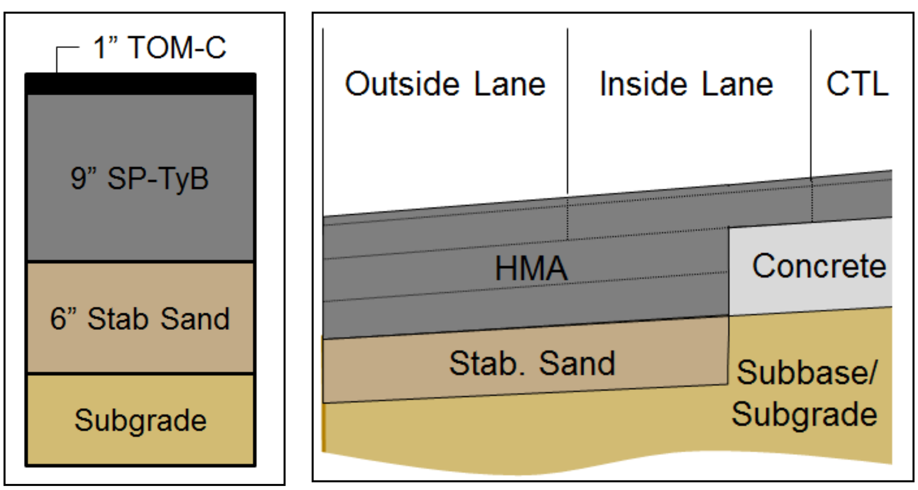


Figure 34. Full-Depth Hot Mix.

Ultimate Design Option

An ultimate pavement design for the entire project was developed. This design is a CRCP design for the full limits of the project, not just the downtown area. The concrete pavement design is 9 inches CRCP over 1-inch hot mix over a minimum of 6 inches of CTB, as shown in Figure 35. To accelerate construction and cost savings, the lower lift of the existing CTB may be used as the CTB for the new pavement (see Figure 36).

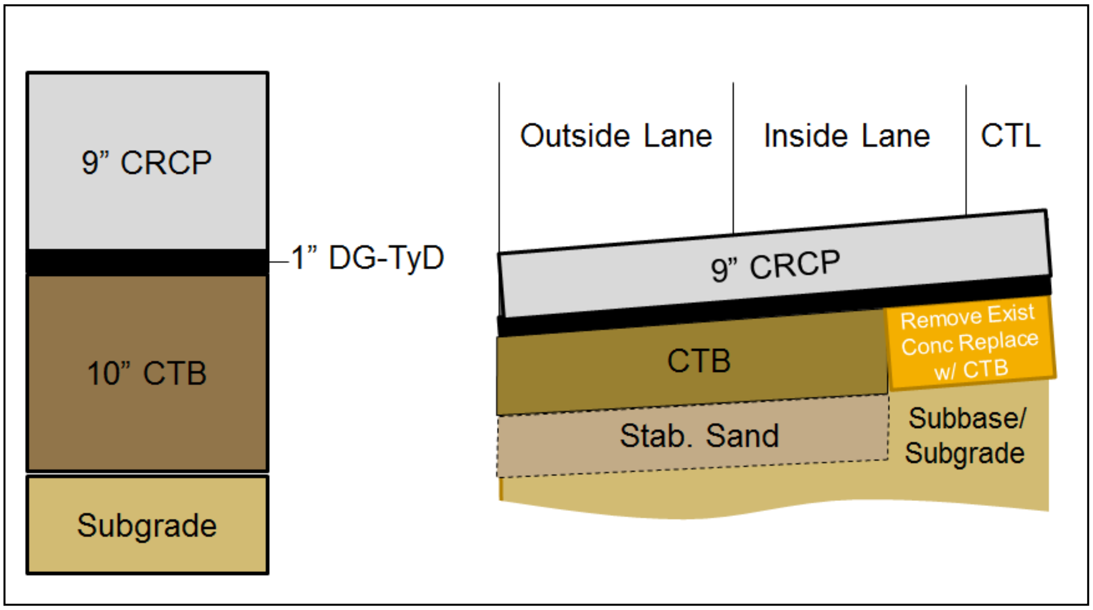


Figure 35. Continuously Reinforced Concrete Pavement.

Figure 36. Existing Pavement Core.

Cost Comparison

The cost comparisons of the options discussed are normalized by the price per square yard of pavement surface (see Table 6 and Table 7). In the table descriptions, Superpave type B (SP-B), thin overlay mixes, and CRCP are used.

Table 6. Cost Comparison—Flexible Pavement.

Description	Rate ($/sy/in)	Depth (inch)	Cost ($/sy)	Description	Rate ($/sy/in)	Depth (inch)	Cost ($/sy)
Option FDR: In-Place Stabilization				**Option: Match Existing**			
Remove Existing	0.65	10	6.51	Remove Existing	0.65	24.5	15.95
Add RAP Back	0.65	3	1.95	Stabilized Sand	1.14	6	6.86
Cement Treat Exist		10	6.50	CTB	1.35	14	18.90
SP-B	3.55	6	21.30	SP-B	4.25	3.5	14.86
TOM	6.50	1	6.50	TOM	6.50	1	6.50
Total Pavement Cost			**42.76**	**Total Pavement Cost**			**63.06**
				Without Stabilized Sand—Total Pavement Cost			**52.30**
Option: Optimized Layers				**Option: Full-Depth Hot Mix**			
Remove Existing	0.65	20	13.02	Remove Existing	0.65	16	10.41
Stabilized Sand	1.14	6	6.86	Stabilized Sand	1.14	6	6.86
CTB	1.35	8	10.80	SP-B	4.25	9	38.21
SP-B	4.25	5	21.23	TOM	6.50	1	6.50
TOM	6.50	1	6.50				
Total Pavement Cost			**58.40**	**Total Pavement Cost**			**61.97**
Without Stabilized Sand—Total Pavement Cost			**56.53**				

Table 7. Cost Comparison—Rigid Pavement.

Description	Rate ($/sy/in)	Depth (inch)	Cost ($/sy)	Description	Rate ($/sy/in)	Depth (inch)	Cost ($/sy)
Option: CRCP (over existing good-condition CTB section)				**Option: CRCP (over section with JCP existing)**			
Remove Existing	0.65	10	6.50	Remove Flexible	0.65	19.5	12.69
Bond Breaker	4.13	1	4.13	Remove Concrete Pavement	—	6.5	5.41
CRCP	4.41	9	39.69	Stabilized Sand	1.14	6	6.86
				Cement-Treated Base	1.35	10	13.50
				Bond Breaker	4.13	1	4.13
				CRCP	4.41	9	39.71
Total Pavement Cost			**50.32**	**Total Pavement Cost**			**82.29**

Note: — means not applicable.

FM 2920 TRAFFIC CONTROL STRATEGIES

The scope of the project was to reconstruct a badly deteriorated 0.3-mi five-lane section of FM 2920 in downtown Tomball, near Houston, Texas. The affected work zone had an AADT of 26,800, approximately 7 percent of which were heavy trucks.

The research team was tasked with evaluating the traffic impact and determining the appropriate workdays and daily I/D amount for four alternatives: nighttime, weekends, weekdays, and 24/7. The CA4PRS process was used to determine contract time, an effective and reliable B value for the A+B bidding, and daily road user costs.

Steps 1 through 6 of CA4PRS were followed to analyze the schedule, road user costs, and peak traffic delays for each alternative. Given the relatively low AADT, TTI recommended that 24/7 operation be adopted, with full-lane closure. Based on the results of the analysis, the traffic congestion during construction was not a concern for any of the alternatives for this project. Under the 24/7 option, the project would be completed within one week with minimal traffic impact, while the other three options would take significantly longer and incur substantially higher road user costs (see Figure 37 and Figure 38).

Alternative	Schedule Comparison		Road User Cost ($,000)		Max. Peak Delay (Min)
	Closure Hours	Total Closure	Total RUC	Closure RUC	
Nighttime Single-lane closure	620	78	16.2	0.2	0.7
Weekend Full closure	168	3	131.0	44.2	14.4
Weekday Full closure	945	27	136.4	5.1	0.7
24/7 Full closure	102	1	7.7	7.7	0.7

Figure 37. Results of the Integrated Schedule–Cost–Traffic Analysis for FM 2920.

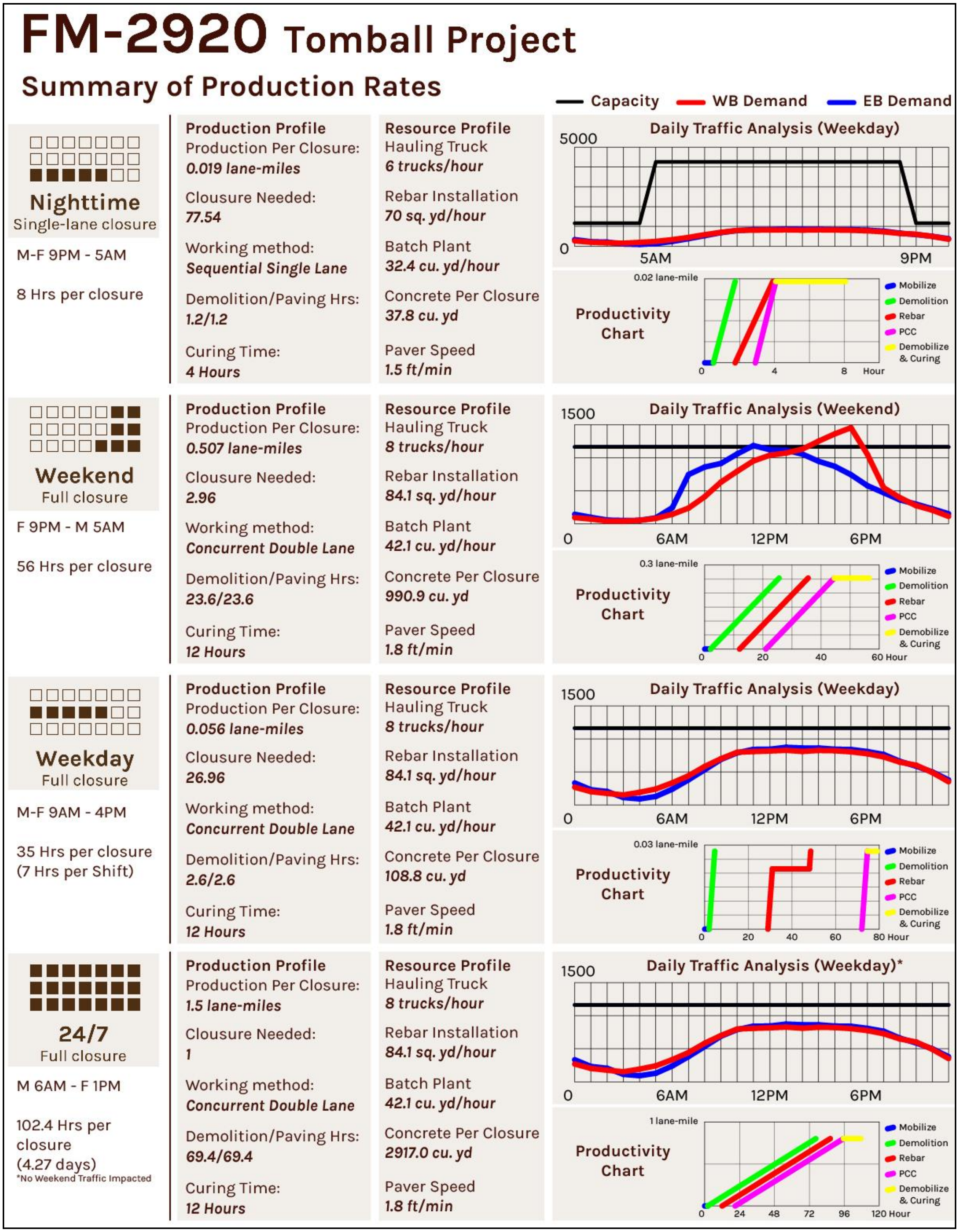


Figure 38. Best Use Case 4: Production Rate and Daily Traffic Analysis Summary.

FM 2920 SUMMARY

Based on the analysis and pavement evaluation, the project was divided into two distinct pavement repair strategies. The key points associated with accelerated construction for this project were:

1) Pavement.
   a) The pavement section was variable, with both concrete and CTB overlaid with hot mix over the approximately 1.7 mi.
   b) Rehabilitation strategies included two distinct rehabilitation methods with the limits shown in Figure 25.
      i) Section 1 and 3 (Main) were approximately 1.5 of the 1.7 mi. This section is structurally adequate and does not require any structural repairs.
      ii) Section 2 (Downtown) was approximately 0.2 of the 1.7 mi. This section is currently failing and in need of structural repairs. The rehabilitation method proposed was to rehabilitate the outside lane and a portion of the inside lane.
   c) Additionally, an ultimate rigid pavement design was proposed for the full limits of the project that used a portion of the existing pavement as the subbase for a new concrete pavement.
2) Traffic control.
   a) No benefit was shown to modify the traditional work schedule because the delay time was not significant for this level of traffic.
   b) The construction time allowed to work within will impact the time to complete the project, with the 24/7 option being the fastest, at five days to complete the repair work. All other options will require significantly longer closures to complete the work.
3) Combination of pavement and traffic control.
   a) Defining sections with different rehabilitation will allow the project to be broken into two separate contracts if needed.
   b) Since the repair area is small (about 1,000 ft), a separate maintenance contract may be appropriate.

By designing the right process for the right section of roadway, this strategy allowed the overall project time to decrease significantly, assuming the same design strategy would have been used for the entire project (typical procedure). It would not be unreasonable to assume the design strategy would have been to remove and replace the existing pavement structure for the full limits of the project, which would have increased the project time and cost significantly.

Since most of the existing pavement is in good condition, reuse of a portion of it is feasible for an ultimate rigid pavement design. Taking this direction would accelerate construction by not requiring the removal and replacement of all of the pavement structure.

CHAPTER 5. IH 45 IN THE BRYAN DISTRICT

IH 45 (BRYAN) PROJECT DATA

This section is a four-lane divided freeway with one-way and two-way frontage roads (FRs). The two-way FR is north of the SH 75 intersection. The location map is shown in Figure 39. The roadbeds are divided into sections based on mainlane (ML) pavement structural changes. Figure 40 displays a picture of the section.

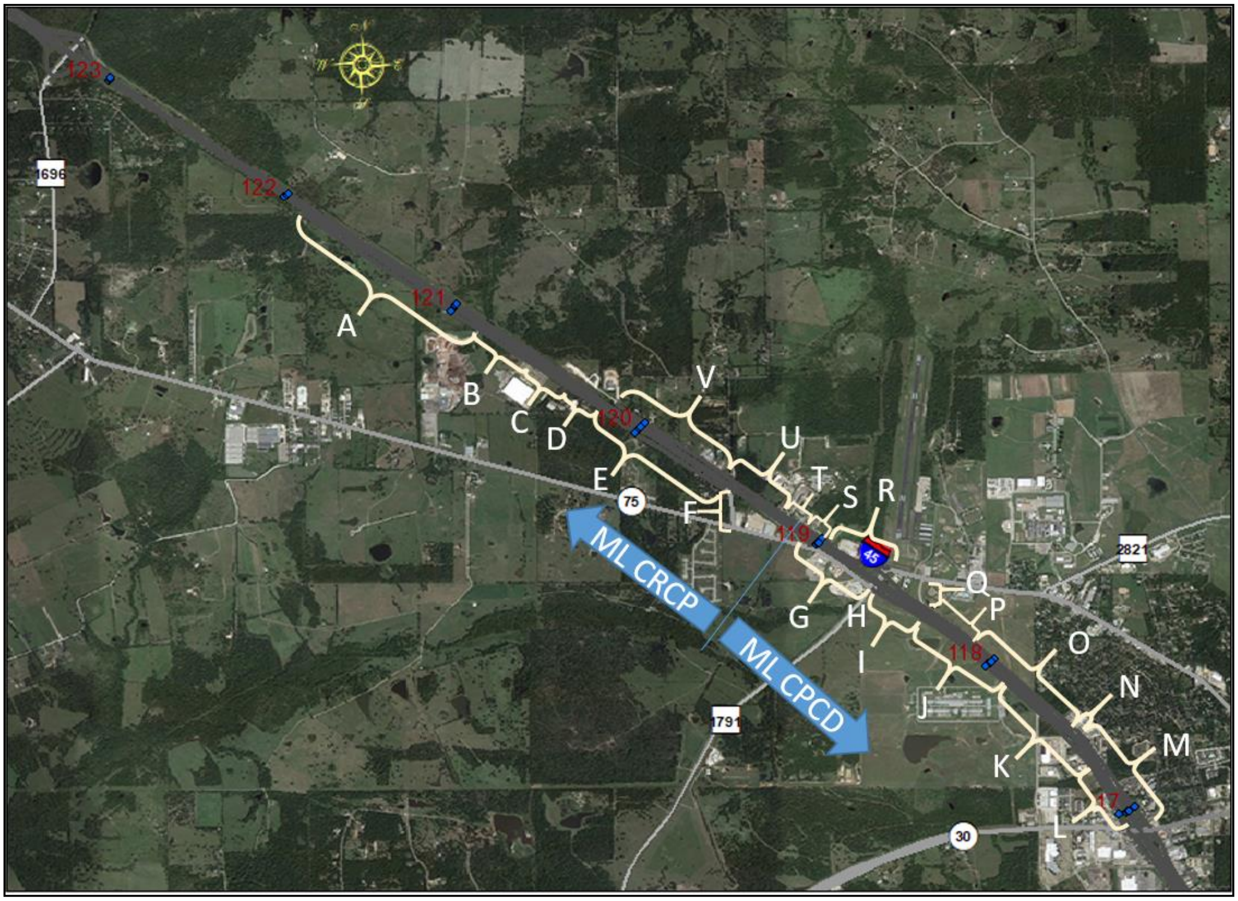


Figure 39. IH 45 Location Map.

Figure 40. IH 45.

Several sources of traffic data are summarized in Table 8 through Table 10. The portable weigh-in-motion adjusted data were used for the pavement designs. The district should verify with TxDOT's Transportation Planning and Programming Division (TPP) that the data included all roadbeds combined and request the information based on roadbeds.

Table 8. IH 45 TPP Traffic Data—All Roadbeds Together.

			TPP roadway Jan. 4, 2017		**TPP roadway Dec. 17, 2018**	
TPP Data		Initial ADT (2024)	68,000	68,000	57,050	57,050
		Final ADT (2054)	91,000	102,500	76,825	86,375
		% Trucks	18.8	18.8	27.5	27.5
		Design Period	20	30	20	30
	Flexible	18-kip Equivalent Single-Axle Load (18k ESAL)	59,832,000	96,239,000	75,554,000	119,804,000
	Rigid	18k ESAL	86,675,000	139,415,000	107,647,000	172,982,000
WIM Adjusted T_f	**Flexible**	Traffic Factor (T_f)	1.15	1.15	1.15	1.15
		18k ESAL	127,565,704	209,352,827	157,237,769	257,840,699
		Lane Distribution Factor (L_f)	**0.70**		**0.70**	
		Adjusted 18k ESAL	**89,295,993**		**110,066,439**	
	Rigid	T_f	1.38	1.38	1.38	1.38
		18k ESAL	153,078,845	251,223,392	188,685,323	309,408,839

Note: T_f is the assumed ESALs/truck.

Table 9. IH 45 Mainlane Adjusted Traffic Estimates.

			SH 30 to FM 1791/SH 75		**FM 1791/SH 75 to FM 1696**	
Project Information			**Highest per Roadbed**		**Highest per Roadbed**	
	Initial ADT 2024		23,000	23,000	21,250	21,250
	Final ADT 2054		31,000	34,875	28,500	32,100
	% trucks		27.5	27.5	27.5	27.5
	Design Period		20	30	20	30
TPP Tf	**Flexible**	T_f	0.53	0.53	0.53	0.53
		18k ESAL	29,233,395	47,965,895	26,915,541	44,180,836
	Rigid	T_f	0.77	0.77	0.77	0.77
		18k ESAL	42,471,158	69,686,301	39,103,710	64,187,252
WIM Adjusted T_f	**Flexible**	T_f	1.15	1.15	1.15	1.15
		18k ESAL	63,430,950	104,076,943	58,401,645	95,864,077
		Lf	0.70		0.70	
		Adjusted 18k ESAL	44,401,665		40,881,152	
	Rigid	T_f	1.38	1.38	1.38	1.38
		18k ESAL	76,117,141	124,892,331	70,081,974	115,036,893

Note: T_f is the assumed ESALs/truck.

Table 10. IH 45 Traffic Data—Frontage Roads and Intersecting Roadways.

TPP Statewide Planning Map Data Adjusted 2024 to 2054 Design Period						WIM History			
Project Information				Flexible		Flexible		Rigid	
Location	Initial ADT (2024)	Final ADT (2054)	% Trucks	T_f	Cumulative 18k ESAL	T_f	Cumulative 18k ESAL	T_f	Cumulative 18k ESAL
East FR	909	1,272	9.4	1.14	870,000	1.22	933,922	1.61	1,232,471
West FR	1,247	1,745	7.4	1.03	850,000	1.22	1,008,605	1.61	1,331,028
SP 59	1,191	1,670	7.3	0.41	323,000	1.22	951,704	1.61	1,255,938
FM 1791	3,679	5,150	5.2	0.37	638,000	1.22	2,091,536	1.61	2,760,141
FM 1696	920	1,290	10.4	0.38	330,000	1.22	1,047,337	1.61	1,382,142
SH 75	5,855	8,200	27.2	0.60	8,634,000	1.22	17,417,349	1.61	22,985,190
SP 59	1,191	1,670	10	0.30	323,000	1.22	1,303,705	1.61	1,720,463
FM 1791	3,679	5,150	10	0.19	638,000	1.22	4,022,184	1.61	5,307,964
FM 1696	920	1,290	10	0.40	330,000	1.22	1,007,055	1.61	1,328,982
SH 75	5,855	8,200	10	1.64	8,634,000	1.22	6,403,437	1.61	8,450,437

Note: T_f is the assumed ESALs/truck.

The as-built typical sections and concrete pavement details are shown in Figure 41 through Figure 45. The concrete pavement has been overlaid with an average of 6 inches of hot mix.

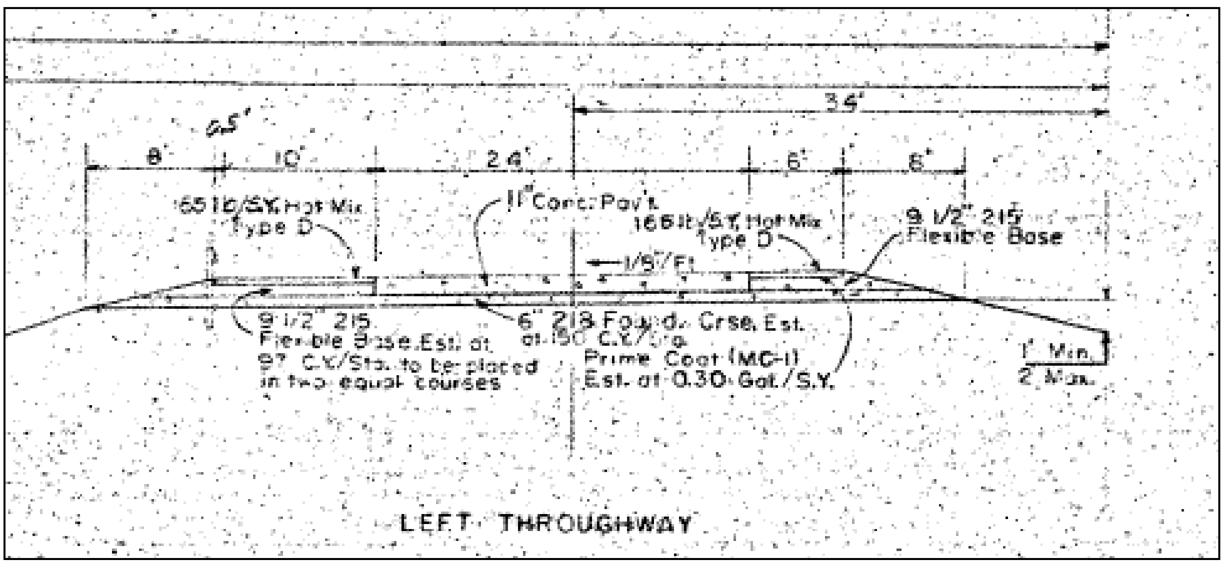


Figure 41. 1957 Typical Section—Left Throughway from SH 30 to North of SH 75.

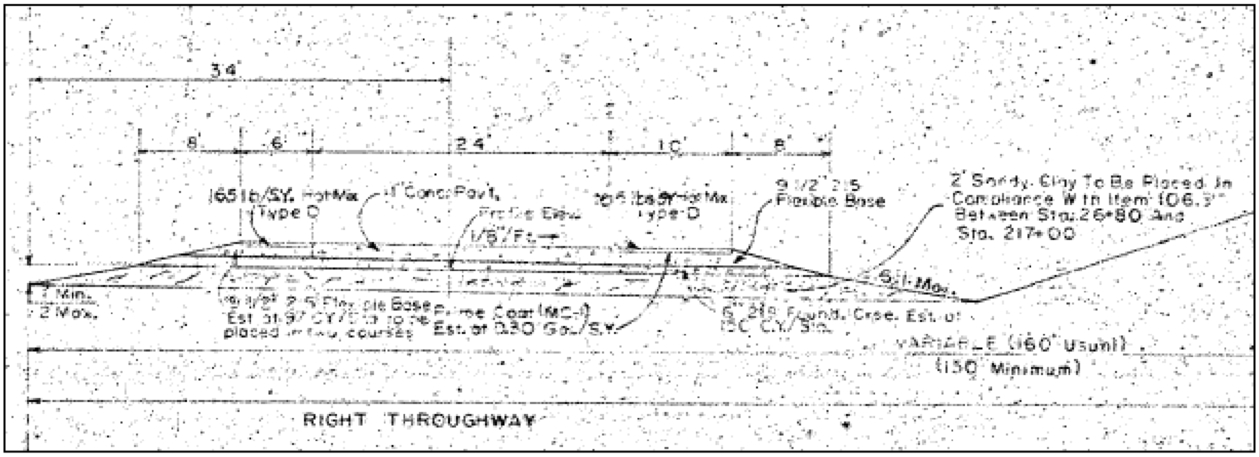


Figure 42. 1957 Typical Section—Right Throughway from SH 30 to North of SH 75.

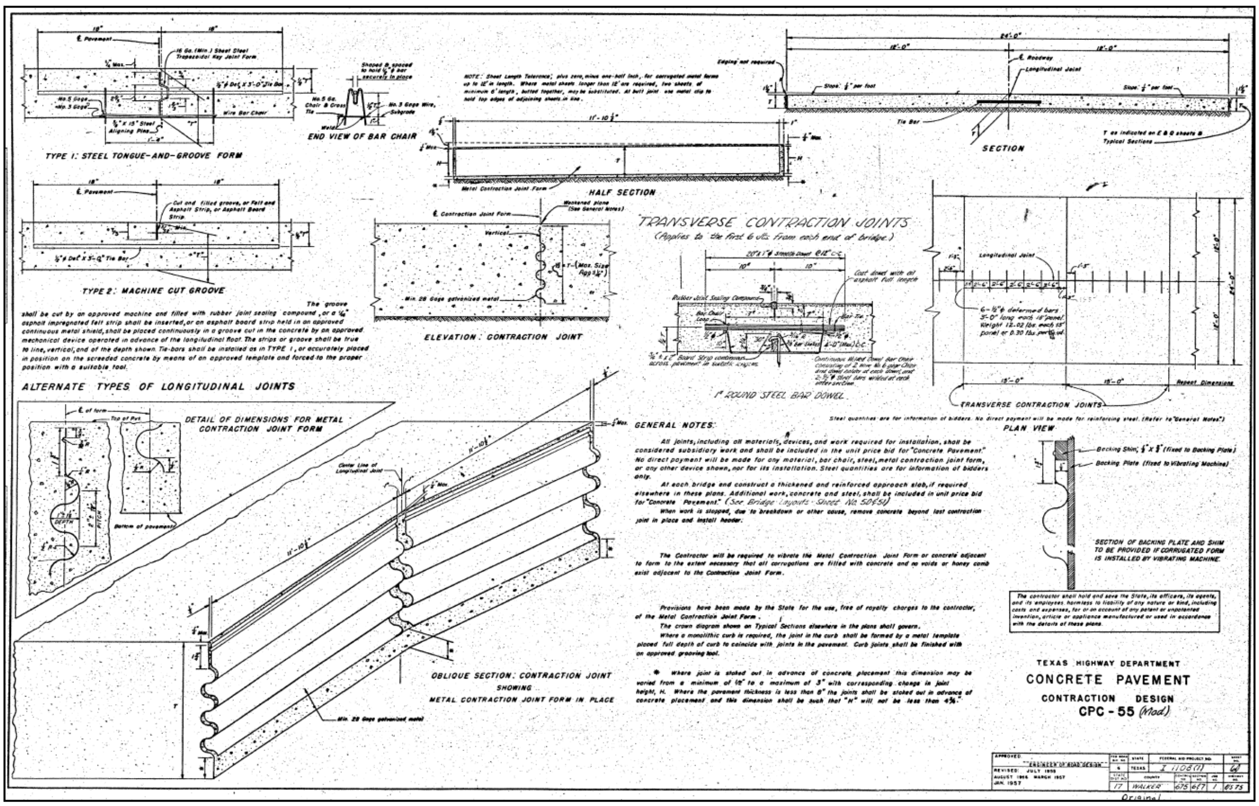


Figure 43. Concrete Pavement Standard (1957) from SH 30 to North of SH 75.

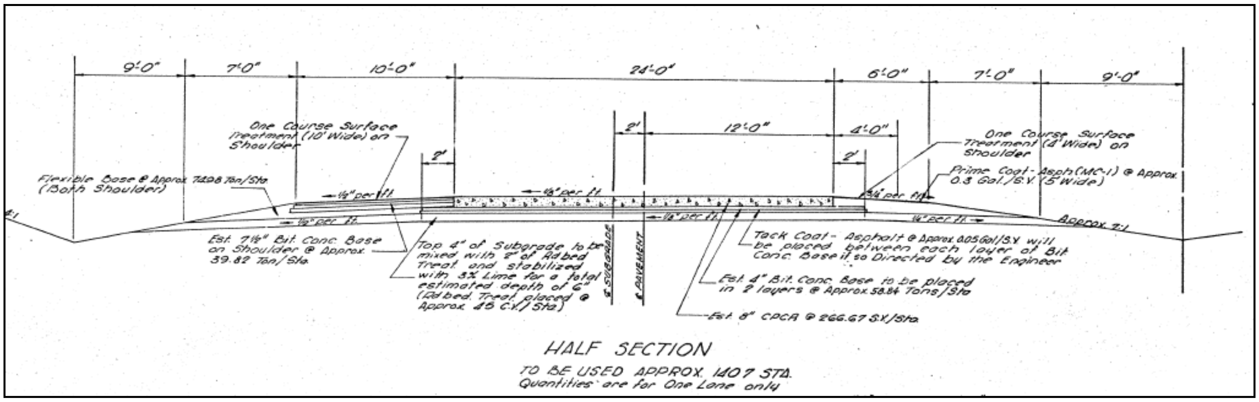


Figure 44. 1962 Mainlane Half Section from North of SH 75 to FM 1696.

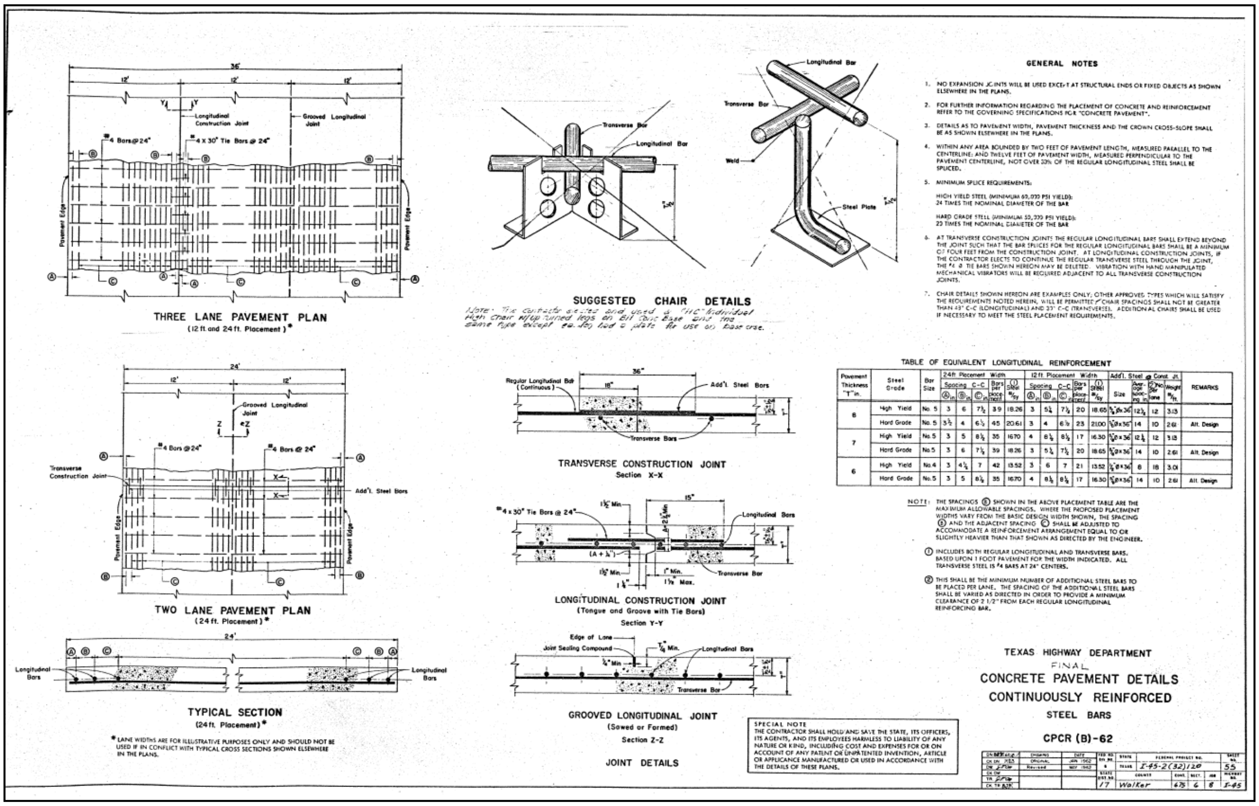


Figure 45. Concrete Pavement Standard (1962) from North of SH 75 to FM 1696.

IH 45 (BRYAN) PAVEMENT EVALUATION

The following testing was performed:

- GPR data were collected on the MLs and FRs.
- FWD was collected in the outside lane of the FRs throughout the project.
- ERT was performed around the Moffat Springs Road proposed interchange.
- Pavement cores and samples were taken on the west side FR from SP 59 to the north end.

There is a significant traffic volume change on the MLs at the SH 75/FM 1791 interchange along with the existing pavement change. The condition of the FRs is also significantly different north and south of the interchange. Therefore, the proposed work will be broken into two sections, Section 1 from SH 30 to the SH 75/FM 1791 interchange and Section 2 from the SH 75/FM 1791 interchange to FM 1696. Figure 46 shows approximate section changes.

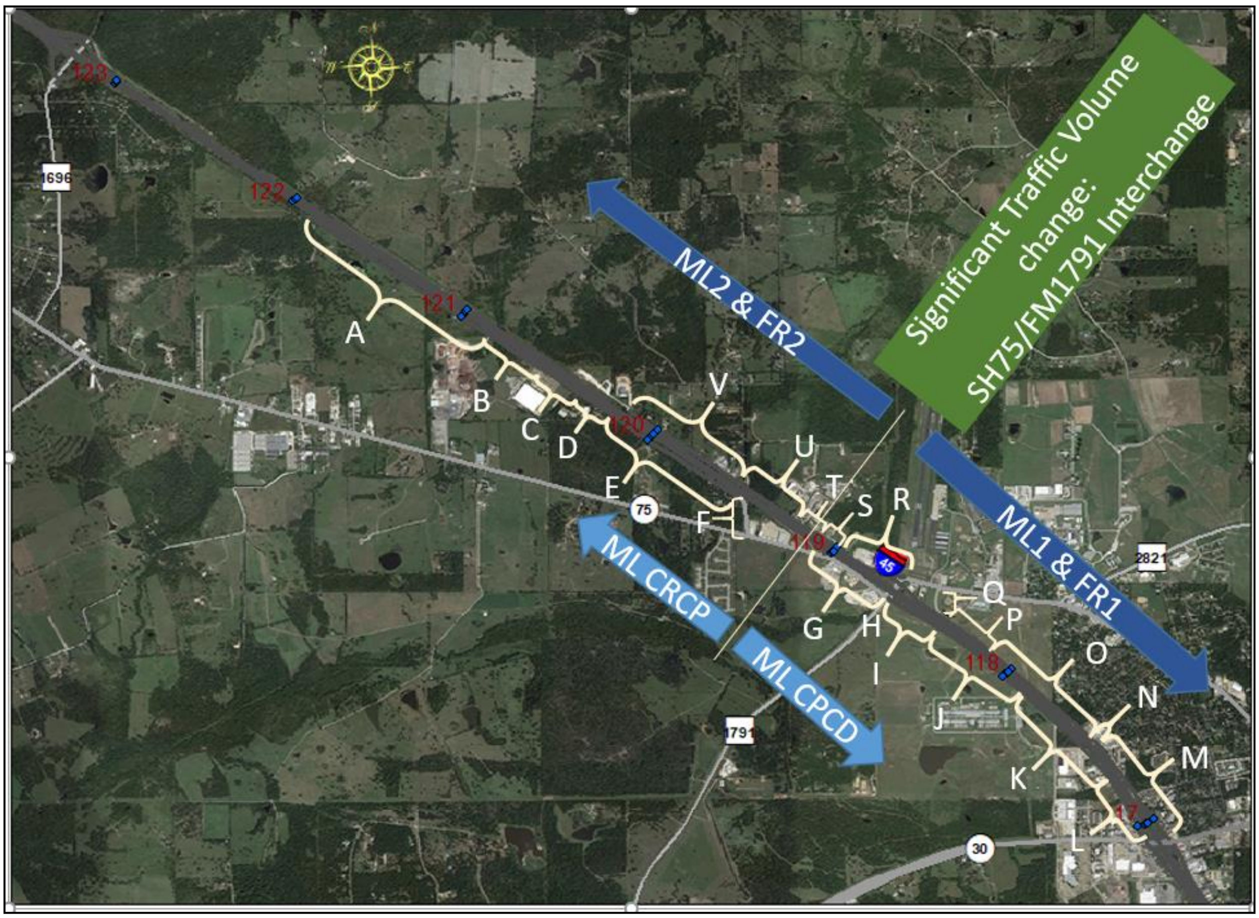


Figure 46. Pavement Section Map of IH 45.

IH 45 Mainlane

The ML pavement structure is in good condition in the travel lanes, except for the transverse joints in the jointed concrete section. The flexible shoulders will not hold up under detour or ML traffic and need to be reconstructed if used for traffic handling. This is based off the historical testing and corridor studies performed in the past. The wrinkled-tin joints used in the jointed concrete section from SH 30 to just north of SH 75 have not held up well. While they have not faulted, the joints are wide and reflect through the hot-mix overlays. Figure 47 displays results from the GPR data collection.

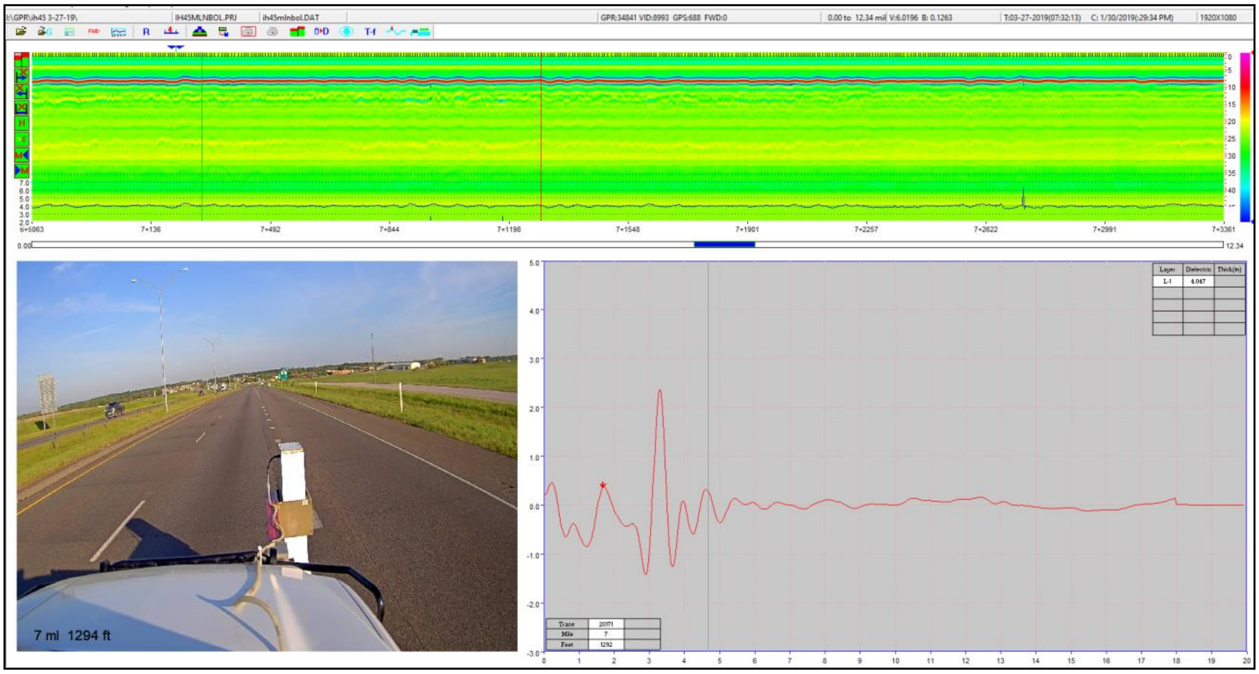


Figure 47. Ground-Penetrating Radar Image of Northbound Jointed Concrete Section.

Since the majority of the existing pavement is in good condition, it is recommended that it be used in all locations that the geometry will allow. This process will save in removal time and cost. Complete removal is estimated at $14.11/sy with a time of 3,000 sy per day. The existing concrete section is approximately 6.3 mi long and 38 ft wide per roadbed. This is approximately 280,896 sy, which would cost $3,963,500 for removal and 94 working days. At an average of 13 working days per month, this process would have 8 months' impact on the traveling public. The construction of subbase to replace the existing pavement would be $8,306,100 plus the time to construct of approximately 130 days (assuming overlapping items of work).

The potential savings to the project is $12,300,000 and 140 working days (assuming overlap), which would be 10 months' impact to the traveling public for ML work. Additional savings in cost and time can be found by retaining the structurally sound FR pavement. The proposed pavement designs and cost estimates are shown in Table 11 through Table 17. In addition, new pavement construction costs for both a rigid and perpetual pavement design are provided along both sections of the ML. In the tables, HMA dense-graded type D or type B (DG-D or DG-B), cement-treated subgrade, lime-treated subgrade, stone matrix asphalt type C (SMA-C), Superpave type B or type level-up (SP-B or SP-Lv), and seal coat using a modified asphalt cement with a grade 4 or 3 pre-coated aggregate (SC-AC with PGR 4 or SC-AC with PGR 3) are shown.

Table 11. Mainlane 1 Proposed Pavement on IH 45.

Rigid Pavement Section ML1: Keep Existing					
Layer Description	Depth (in)	Item	Materials	Stabilizer (%)	$/sy
Concrete	15	346	CRCP		$ 84.00
Removal	1	354	Mill		$ 1.20
	14.0	**New Pavement TOTAL**			**$ 84.00**
		Removal Cost			$ 1.20
Comments:	Use existing pavement as subbase. Remove PFC.				

Rigid Pavement Section ML1: Widening					
Layer Description	Depth (in)	Item	Materials	Stabilizer (%)	$/sy
Concrete	15	346	CRCP		$ 84.00
Subbase	1.5	3076	DG-D		$ 7.21
Prime		310	Prime		$ 0.65
Treated Base	6	276	Plant Mix CTB		$ 15.06
Subgrade Treatment	8	275	Road Mix CTS	2	$ 3.32
		260	Road Mix LTS	2	$ 3.34
	30.5	**TOTAL**			**$ 113.57**
Comments:	Widen to match existing pavement layers. CTB 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 12. Mainlane 1 New Construction Life-Cycle Cost Analysis on IH 45.

Rigid Pavement Section ML1: New Construction						
Layer Description	Depth (in)	Item	Materials	Stabilizer (%)	$/sy	$/CY
Concrete	15	346	CRCP		$ 84.00	$201.60
Subbase	1.5	3076	DG Ty D		$ 7.21	$165.53
Prime		310	Prime		$ 0.65	
Treated Base	6	276	Plant Mix CTB		$ 15.06	$ 90.36
Subgrade Treatment	8	275	Road Mix CTS	2	$ 3.32	$ 14.93
		260	Road Mix LTS	2	$ 3.34	$ 15.01
Removal	5	354	Mill		$ 6.00	$ 43.20
Removal	8	104	Remove Concrete Pavement		$ 5.27	$ –
Removal	4	105	Remove Flexible Pavement		$ 2.84	$ 25.56
	30.5	**New Pavement TOTAL**			**$113.57**	**$/sy**
		Removal Cost			$ 14.11	**$/sy**
Comments:	Match thickness for adjacent southern project. Concrete pavement for mainlanes.					

Rigid Pavement Section: PM Work					
Depth (in)	Item	Materials	Repair (%)	$/sy	
15	346	CRCP Repair	1.5%	$ 6.30	
	PM Pavement TOTAL			**$ 6.30**	**$/sy**
Life-Cycle Cost Analysis					
	Proposed work at Year		15.00		
	Rate		2.5%		
	Initial Cost Rigid Pavement			$ 127.68	**$/sy**
	Year 15 PM work (NPV)			$ 9.12	**$/sy**
	Net Present Value			$ 136.80	**$/sy**
	Net Present Value			$ 136.80	**$/sy**
Comments:	Concrete repairs. Assume 1.5% of area at year 15.				

Table 13. Mainlane 2 Proposed Pavement on IH 45.

Rigid Pavement Section ML2: Keep Existing						
Layer Description	Depth (in)	Item	Materials	Stabilizer (%)	$/sy	$/CY
Concrete	13	346	CRCP		$ 72.80	$201.60
Removal	1	354	Mill		$ 1.20	$ 43.20
	12.0	**New Pavement TOTAL**			**$ 72.80**	**$/sy**
		Removal Cost			$ 1.20	**$/sy**
Comments:	Use existing pavement as subbase. Remove PFC.					

Rigid Pavement Section ML2: Widening						
Layer Description	Depth (in)	Item	Materials	Stabilizer (%)	$/sy	$/CY
Concrete	13	346	CRCP		$ 72.80	$201.60
Subbase	1.5	3076	DG- D		$ 7.21	$165.53
Prime		310	Prime		$ 0.65	
Treated Base	6	276	Plant Mix CTB		$ 15.06	$ 90.36
Subgrade Treatment	8	275	Road Mix CTS	2	$ 3.32	$ 14.93
		260	Road Mix LTS	2	$ 3.34	$ 15.01
	28.5	**TOTAL**			**$102.37**	**$/sy**
Comments:	Widen to match existing pavement layers. CTB 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 14. Mainlane 2 New Construction Life-Cycle Cost Analysis on IH 45.

Rigid Pavement Section ML2: New Construction						
Layer Description	Depth (in)	Item	Materials	Stabilizer (%)	$/sy	$/CY
Concrete	13	346	CRCP		$ 72.80	$ 201.60
Subbase	1.5	3076	DG- D		$ 7.21	$ 165.53
Prime		310	Prime		$ 0.65	
Treated Base	6	276	Plant Mix CTB		$ 15.06	$ 90.36
Subgrade Treatment	8	275	Road Mix CTS	2	$ 3.32	$ 14.93
		260	Road Mix LTS	2	$ 3.34	$ 15.01
Removal	5	354	Mill		$ 6.00	$ 43.20
Removal	8	104	Remove Concrete Pavement		$ 5.27	$ –
Removal	4	105	Remove Flexible Pavement		$ 2.84	$ 25.56
	28.5	**New Pavement TOTAL**			**$ 102.37**	**$/sy**
		Removal Cost			$ 14.11	**$/sy**
Comments:	Concrete pavement for mainlanes.					

Rigid Pavement Section: PM Work					
Depth (in)	Item	Materials	Repair (%)	$/sy	
14	346	CRCP Repair	1.5%	$ 5.88	
	PM Pavement TOTAL			**$ 5.88**	**$/sy**
Life-Cycle Cost Analysis					
	Proposed work at Year		15.00		
	Rate		2.5%		
	Initial Cost Rigid Pavement			$ 116.48	**$/sy**
	Year 15 PM work (NPV)			$ 8.52	**$/sy**
	Net Present Value			$ 125.00	**$/sy**
	Net Present Value			$ 125.00	**$/sy**
Comments:	Concrete repairs. Assume 1.5% of area at year 15.				

Table 15. Mainlane 1 Perpetual Pavement and Life-Cycle Cost Analysis at IH 45.

Flexible Pavement Section: ML1—Perpetual Pavement						
Layer Description	Depth (in)	Item	Materials	Stabilizer (%)	$/sy	$/CY for FPS
Hot Mix	2	346	SMA-C		$ 12.74	$ 223.74
	12	3077	SP-B		$ 58.85	$ 175.63
Removal	5	354	Mill		$ 6.00	$ 43.20
Removal	8	104	Remove Concrete Pavement		$ 5.27	$ –
Removal	4	105	Remove Flexible Pavement		$ 2.84	$ 25.56
Underseal		316	SC-AC w/PGR 4		$ 1.79	
Prime		310	Prime		$ 0.65	
Flex Base	6	247	Flexible Base		$ 11.34	$ 68.04
Subgrade Treatment	8	275	Road Mix CTS	2	$ 3.32	14.9306
		260	Road Mix LTS	2	$ 3.34	$ 15.01
	23.0	**New Pavement TOTAL**			**$ 92.02**	**$/sy**
		Removal Cost			$ 14.11	**$/sy**
Comments:	Shoulder pavement is weaker than lane—requires a 3-inch overlay. This is still less expensive than reconstructing the shoulder since the mainlane needs a 1.5-inch overlay.					

ML1 and 2—Perpetual Pavement YR 15 PM Work					
Depth (in)	Item	Materials		$/sy	$/CY for FPS
1.5	346	SMA-D		$ 10.48	$ 244.08
1	3077	SP-Lv		$ 5.23	$ 177.21
1.5	354	Mill		$ 1.80	$ 43.20
	316	SC-AC w/PGR 4		$ 1.79	
		Pavement TOTAL		**$ 19.30**	**$/sy**

Life-Cycle Cost Analysis			
Proposed work at Year	15		
Rate	2.5%		
Initial Cost PP		$106.13	**$/sy**
Year 15 PM work (NPV)		$ 27.96	**$/sy**
Net Present Value		$134.09	**$/sy**

Comments:	Replace surface at year 15.

Table 16. Mainlane 2 Perpetual Pavement on IH 45.

Flexible Pavement Section: ML2—Perpetual Pavement						
Layer Description	Depth (in)	Item	Materials	Stabilizer (%)	$/sy	$/CY for FPS
Hot Mix	2	346	SMA-C		$ 12.74	$223.74
	11.5	3077	SP-B		$ 56.41	$175.63
Removal	5	354	Mill		$ 6.00	$ 43.20
Removal	10	104	Remove Concrete Pavement		$ 5.27	$ –
Removal	4	105	Remove Flexible Pavement		$ 2.84	$ 25.56
Underseal		316	SC-AC w/PGR 4		$ 1.79	
Prime		310	Prime		$ 0.65	
Flex Base	6	247	Flexible Base		$ 11.34	$ 68.04
Subgrade Treatment	8	275	Road Mix CTS	2	$ 3.32	$ 14.93
		260	Road Mix LTS	2	$ 3.34	$ 15.01
	22.5	**New Pavement TOTAL**			**$ 89.58**	**$/sy**
		Removal Cost			$ 14.11	**$/sy**
Comments:	Shoulder pavement is weaker than lane, requires a 3-inch overlay. This is still less expensive than reconstructing the shoulder since the mainlane needs 1.5-inch overlay.					

IH 45 Frontage Road

For the FRs, the study area included several pavement segments with different structural conditions, which are detailed in Figure 39 and Figure 46. For design purposes, these segments were reduced to four segments, as illustrated in Figure 48: Spur 59—South; Spur 59—North; IH 45 FR, Northbound–South; and IH 45 FR, Northbound–North. There was no immediate corrective work recommended for FRs south of FM 1791, but a new surface should be considered.

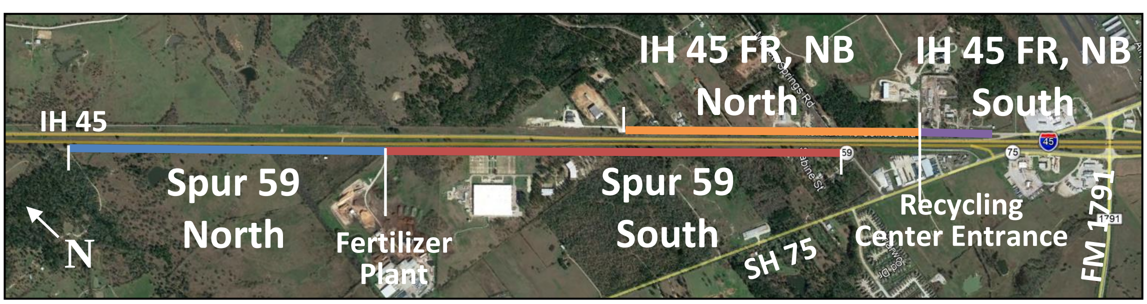


Figure 48. Segmented Design Areas for Northbound Frontage Road and Spur 59 on IH 45.

It is anticipated that the traffic will increase on the north section after construction. Since the geometry will change and the existing pavement is in poor structural condition, the existing pavement cannot be used. The proposed pavement for the reconstructed section listed from bottom to top and the cost summary are shown in Table 17.

Table 17. Frontage Road Reconstruction Cost Estimate.

Option: FR N-1 10" Lime- or Cement-Treated Subgrade 6" Flexible Base Prime and Seal Coat 3" SP-D					Option: FR N-2 8" Lime- or Cement-Treated Subgrade 14" Flexible Base Prime and Two-Course Seal Coat				
Depth (in)	Item	Materials	Stabilizer (%)	$/sy	Depth (in)	Item	Materials	Stabilizer (%)	$/sy
3	346	SMA-D		$20.65					
						316	SC-AC w/PGR 4		$ 1.79
	316	SC-AC w/PGR 4		$ 1.79		316	SC-AC w/PGR 3		$ 2.19
	310	Prime		$ 0.65		310	Prime		$ 0.65
6	247	Flexible Base		$11.34	14	247	Flexible Base		$26.46
10	275	Road Mix CTS	2	$ 4.15	8	275	Road Mix CTS	2	$ 3.32
	260	Road Mix LTS	2	$ 4.17		260	Road Mix LTS	2	$ 3.34
19	**New Pavement TOTAL**			**$42.75**	**22**	**New Pavement TOTAL**			**$37.74**

There was a concern with shallow groundwater in the Moffat Springs Road area where a new interchange is being constructed. Figure 49 shows the areas indicated by the USDA-WSS that may have a shallow water table. ERT was performed to try to identify areas of shallow water tables. Figure 50 is the location map of the testing, with the yellow lines indicating the testing limits. Mark Everett from Texas A&M University's Department of Geology and Geophysics, Potpreecha Pondthai, Jacob Martin, Hector Saenz, and the researchers collected the ERT data. Figure 51 shows the results of the data analysis for both lines of testing. The results based on the analysis and report are as follows:

> . . . indicate zones of very low resistivity at depths below 8-10 m suggestive of water-saturated clay soils. Line 2 directly crosses over a box culvert, apparently containing standing water. The surficial zones to depths ~5-8 m show resistivities appropriate for variable saturated sandy loam soils. The SE halves of both lines show lower surficial resistivities than the NW halves, suggesting the near-surface water is present in greater amounts toward the southeast of the study area. From a roadway maintenance perspective, the zone of highest concern identified by ERT would be the interval ~0-50 m from the start of the ERT Line 1 transect. Finally,

it must be noted that any interpretation of ERT tomograms, like that of other geophysical images, contains an element of subjectivity due to the inherent ambiguities of geophysical reconstructions and on the overlapping ranges of electrical resistivity exhibited by geological materials. Any cause for concern identified in ERT images should be followed up by further corroborating studies including direct ground-truthing by borings and excavations. [15]

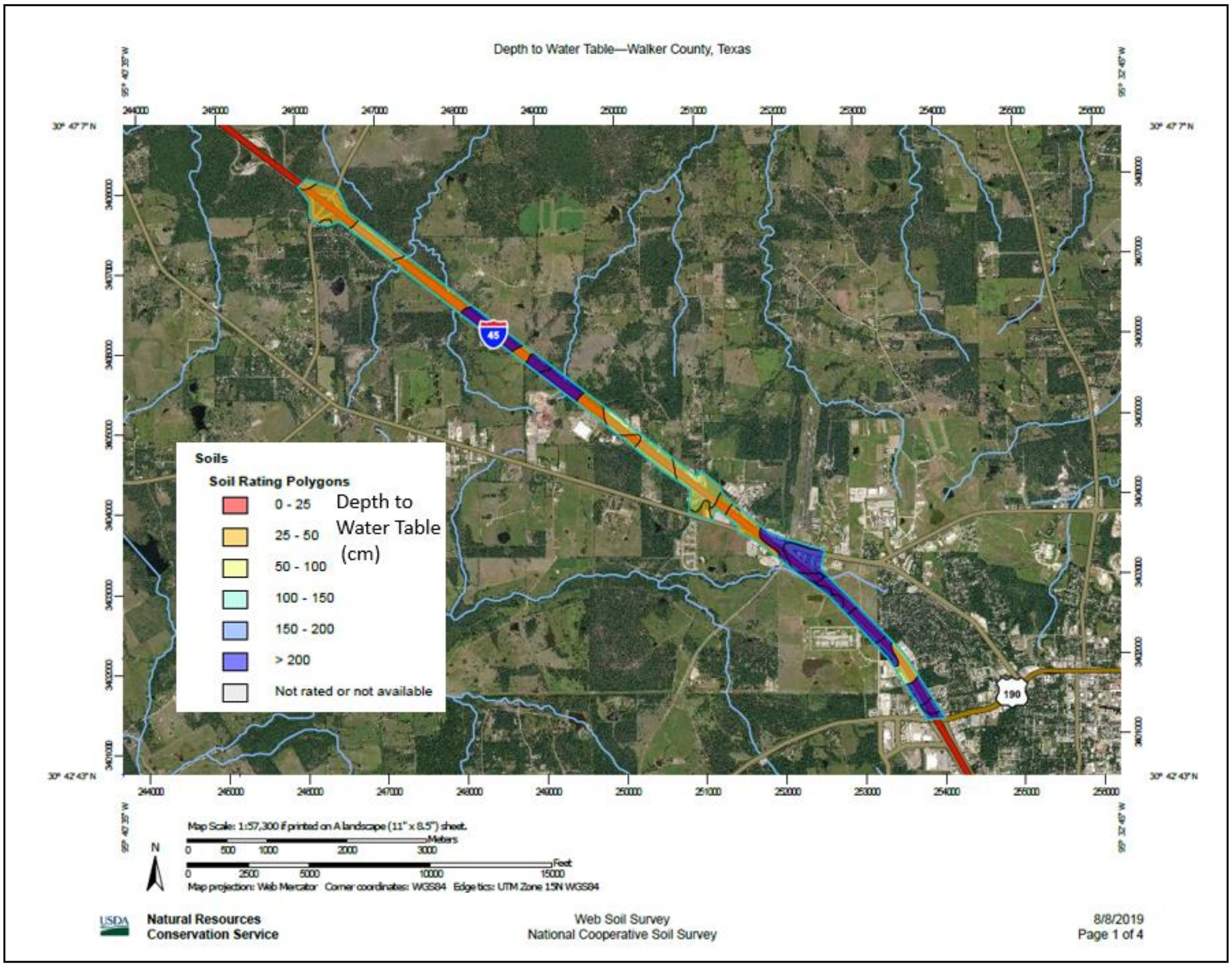


Figure 49. USDA Web Soil Survey Depth to Water Table along IH 45.

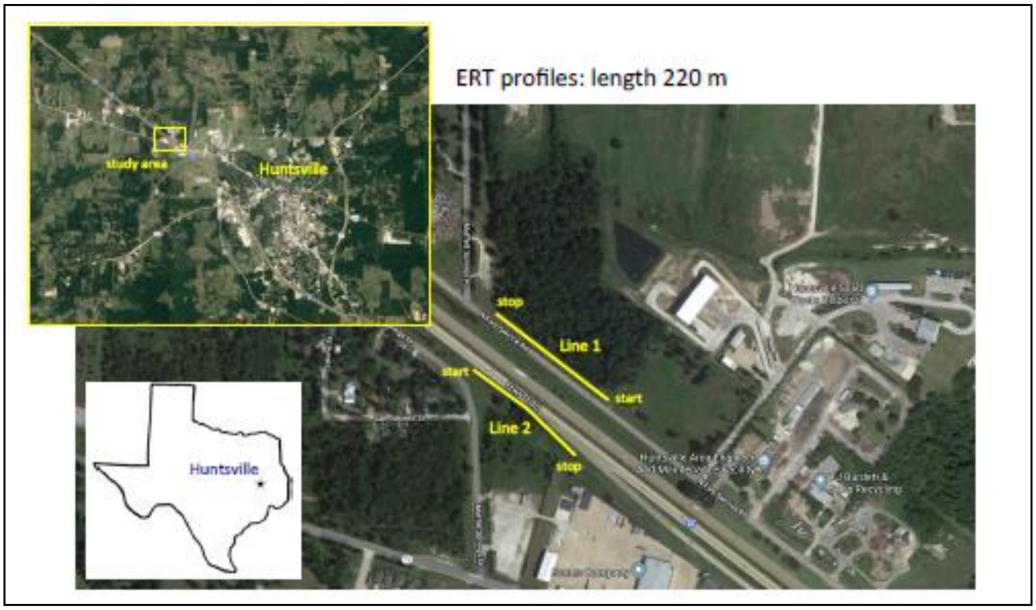


Figure 50. Electrical Resistivity Tomography Testing Locations on IH 45 [15].

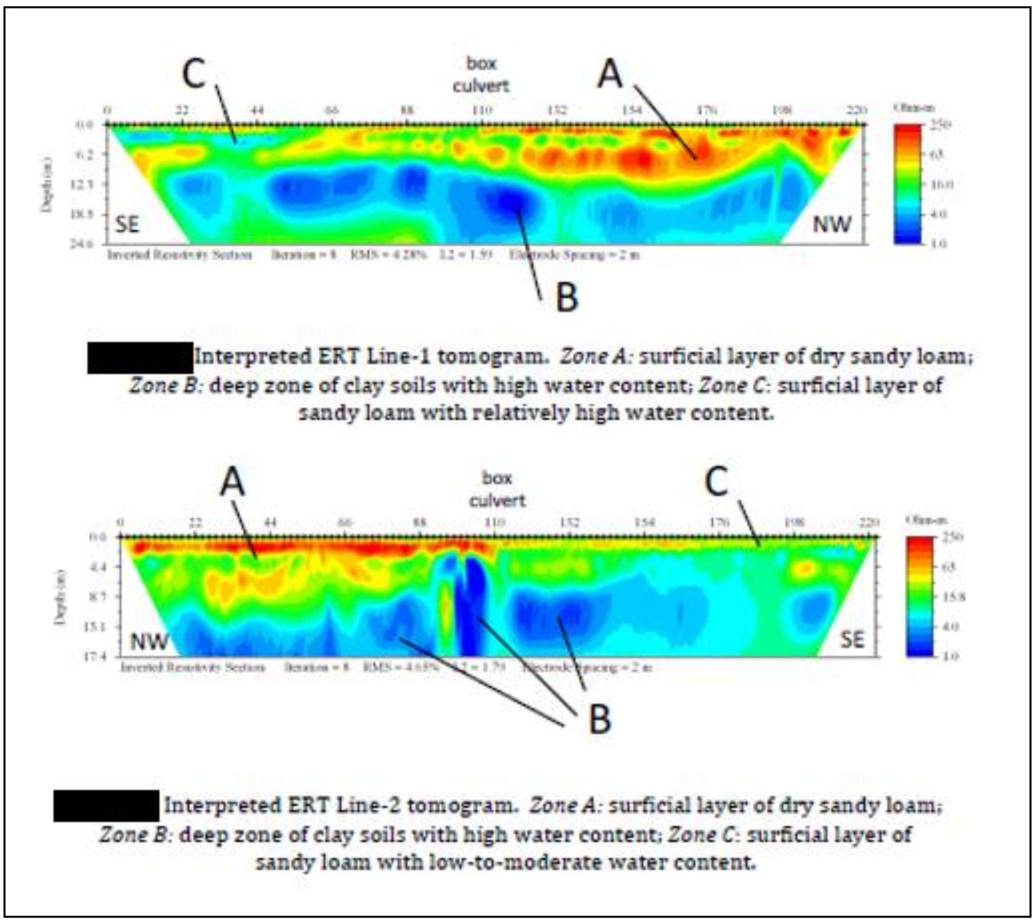


Figure 51. Electrical Resistivity Tomography Results for IH 45 [15].

IH 45 (BRYAN) TRAFFIC CONTROL STRATEGIES

The current ADT is 62,899. This section is a four-lane divided freeway with partial FRs. The FRs are not continuous through the limits, with sections that are both one way and two way. The location map is shown in Figure 52. Figure 53 displays a picture of the section.

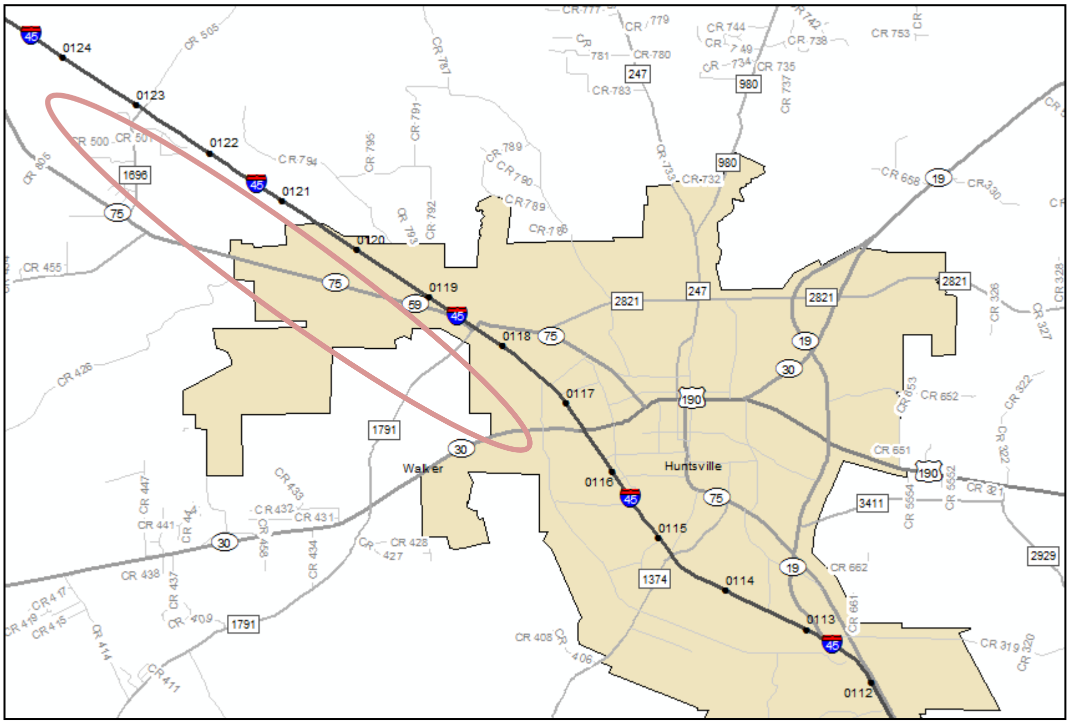


Figure 52. IH 45 Map.

Figure 53. IH 45 Image from Google Earth.

The traffic analysis is shown in Figure 54 through Figure 59. In this case, changing traffic control strategies will not make a significant difference in delay time.

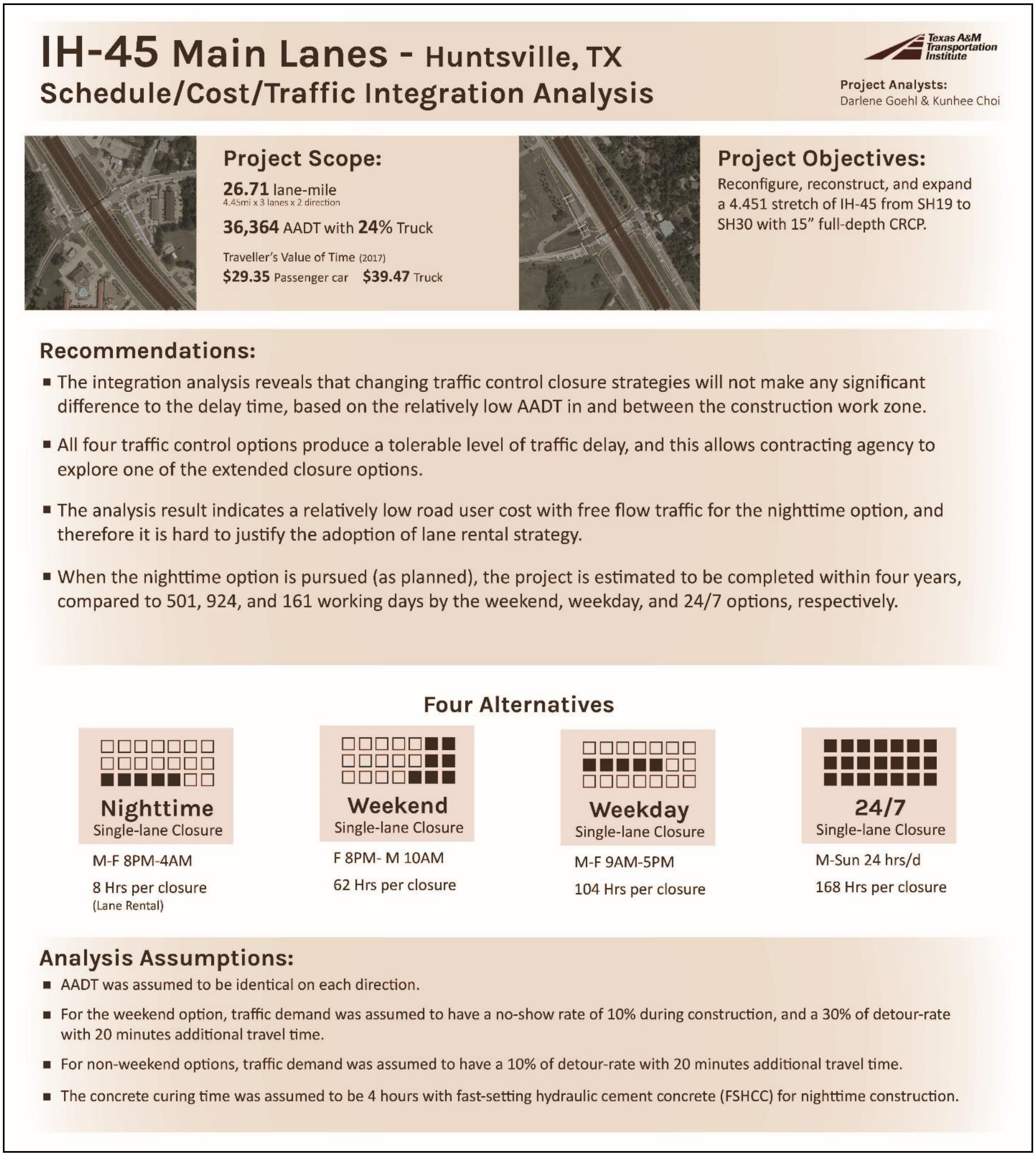


Figure 54. Traffic Analysis in Huntsville.

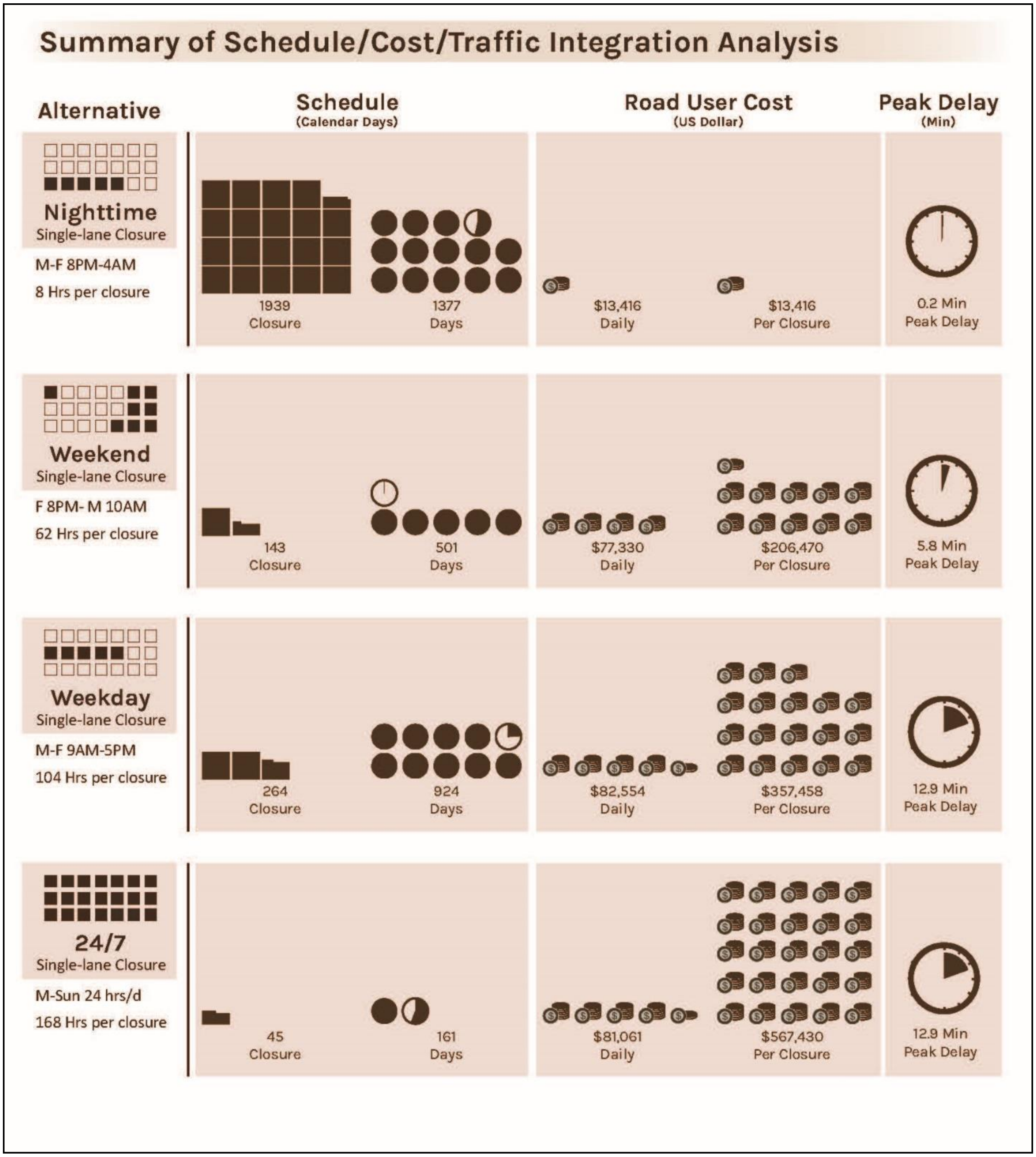


Figure 55. IH 45 Traffic Analysis Page 2.

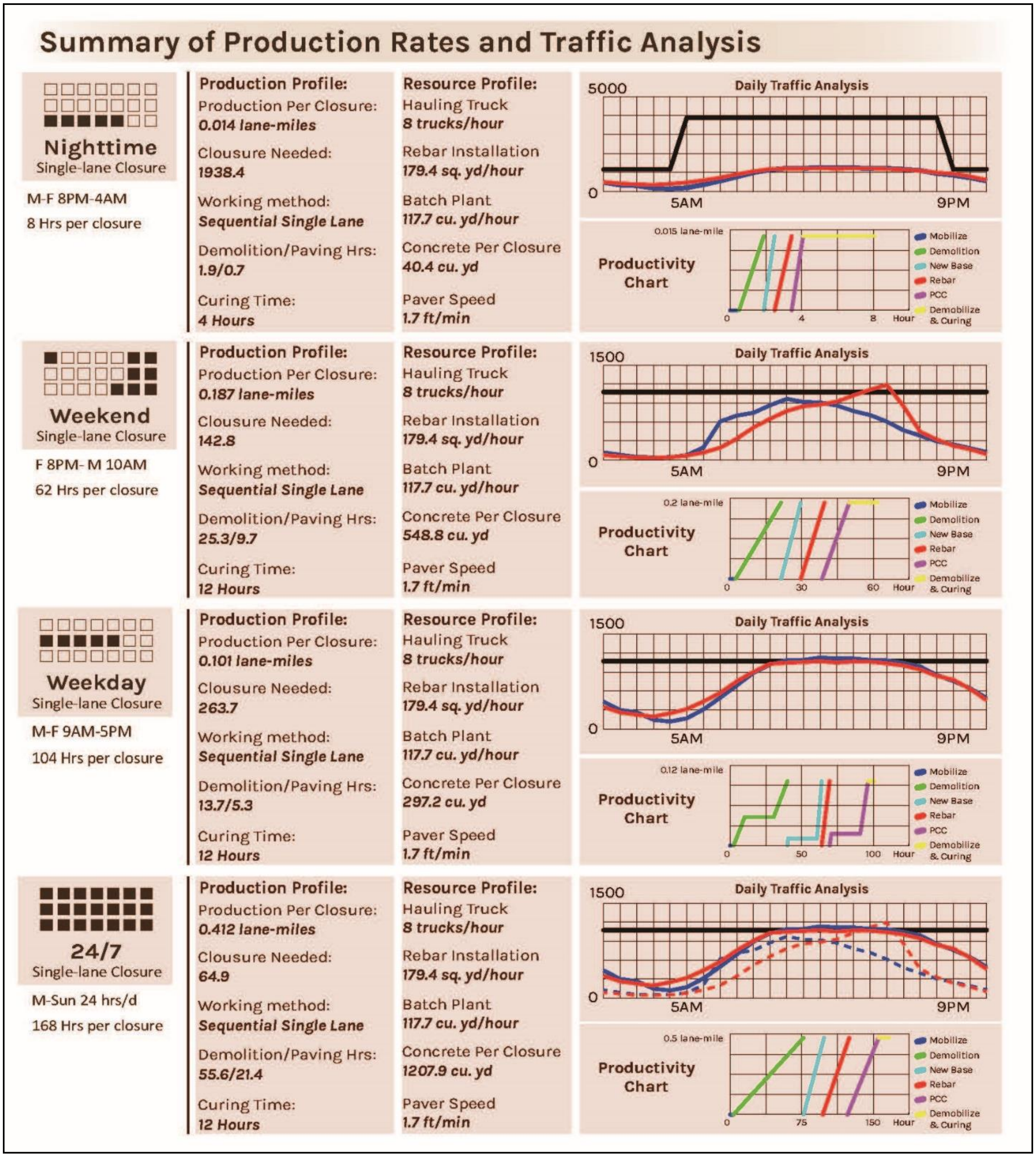


Figure 56. IH 45 Traffic Analysis Page 3.

IH-45 Frontage Lanes - Huntsville, TX
Schedule/Cost/Traffic Integration Analysis

Texas A&M Transportation Institute

Project Analysts:
Darlene Goehl & Kunhee Choi

Project Scope:

17.80 lane-mile
4.45mi x 2 lanes x 2 direction

24,000 AADT with **6%** Truck
(Estimated Values based on existing information)

Traveller's Value of Time (2017)
$29.35 Passenger car **$39.47** Truck

Project Objectives:

Reconfigure, expand, and reconstruct the two existing frontage roads of IH-45 from SH19 to SH30 with full-depth HMA.

Recommendations:

- The nighttime option is recommended for this HMA project when considering a tradeoff between project duration and road user cost; traffic is almost free flow for all four alternatives analyzed.

Four Alternatives

Nighttime	Weekend	Weekday	24/7
Single-lane Closure	Single-lane Closure	Single-lane Closure	Single-lane Closure
M-F 8PM-6AM	F 8PM- M 10AM	M 9AM-F 5PM	M-Sun 24 hrs/d
10 Hrs per closure	62 Hrs per closure	104 Hrs per closure	168 Hrs per closure

Analysis Assumptions:

- The full-depth HMA was assumed to be 6 inch thick with 3 lifts.
- The HMA cooling condition was assumed to be under humid and unfrozen climate with surface temperature of 70F.

Figure 57. IH 45 Traffic Analysis Page 4.

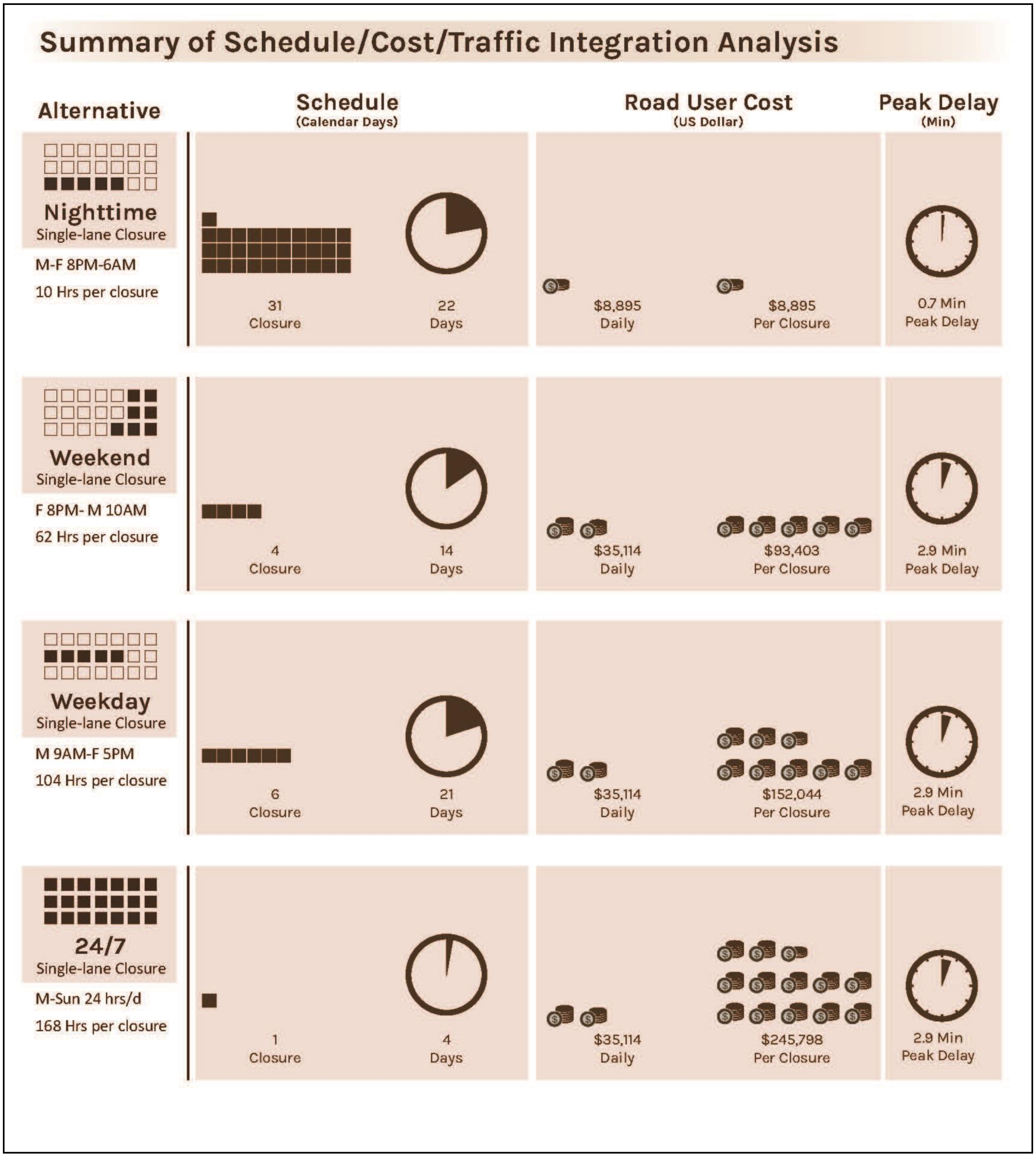


Figure 58. IH 45 Traffic Analysis Page 5.

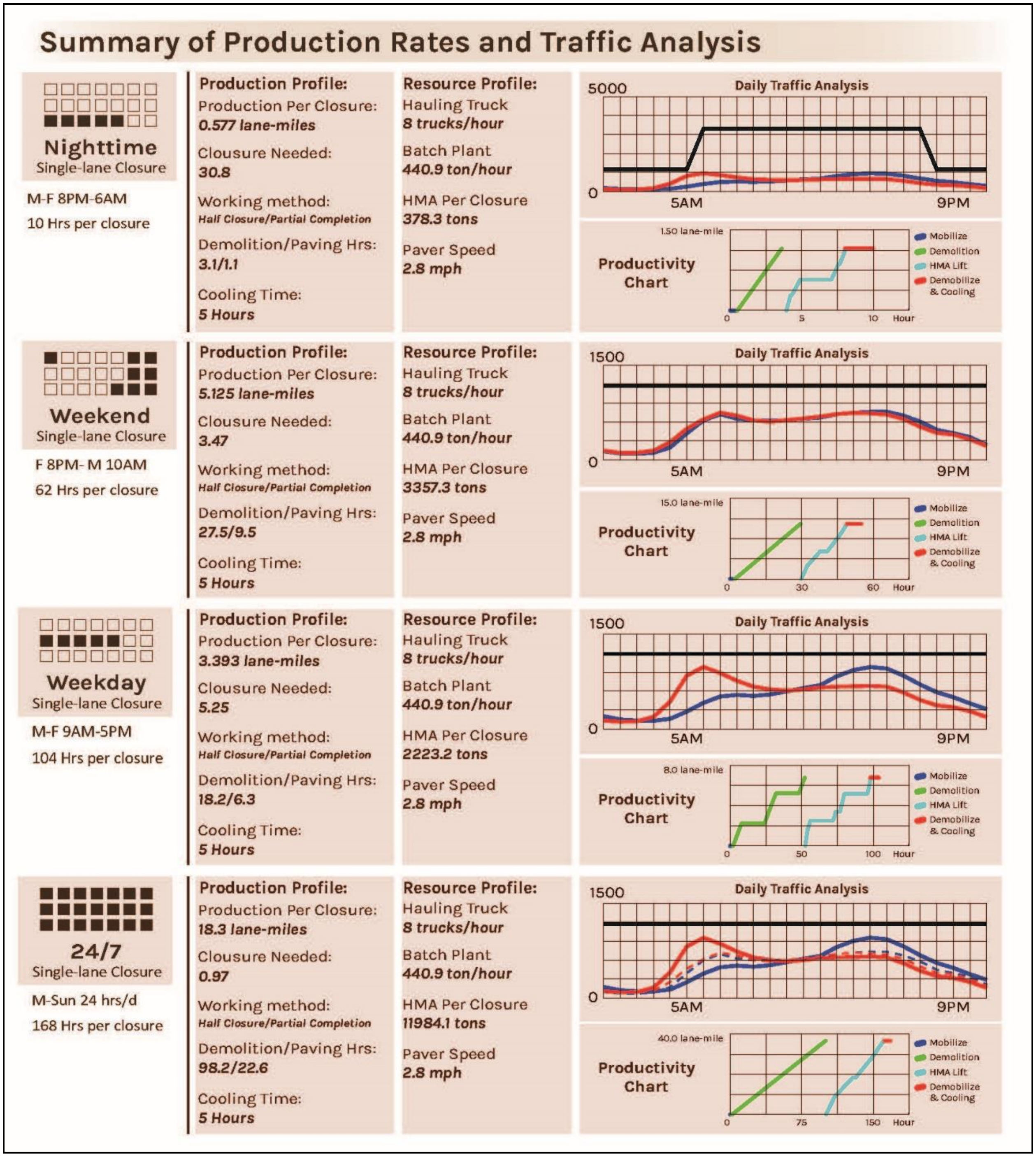


Figure 59. IH 45 Traffic Analysis Page 6.

IH 45 (BRYAN) SUMMARY

The following is a summary of the pavement recommendations assuming that the proposed geometry allows for reuse of the existing pavement:

- Mainlane.
    - Use the existing ML pavement as subbase for new concrete pavement and remove permeable friction course (PFC) surface.
  - Treat or reconstruct flexible shoulders to support detoured traffic and provide the CTB subbase for the concrete pavement.
- Frontage road.
  - From SH 75 to SH 30, the pavement is structurally sound; consider placing a new riding surface.
  - Reconstruct/rehabilitate the FRs from the SH 75/FM 1791 intersection north.
  - In areas with shallow water tables, consider adding a detail with an underdrain system. This detail can be similar to the drains used behind retaining walls and the drain used on US 290 close to Chappel Hill (about 2005), which had a similar shallow water table condition.
- All types.
  - Ensure that all hot-mix pavement surfaces have an asphalt performance grade binder of PG 76-22 and a surface aggregate class (SAC) of A.

The potential savings to the project is $12,300,000 and 140 working days (assuming overlap), which would be 10 months' impact to the traveling public for ML work. Additional savings in cost and time can be found by retaining the structurally sound FR pavement.

CHAPTER 6. SH 6 IN THE BRYAN DISTRICT

SH 6 PROJECT DATA

The current ADT is over 90,000. This section is a four-lane divided freeway with one-way FRs. The location map is shown in Figure 60. This section is a four-lane divided freeway with one-way FRs. The roadbeds are divided into sections based on pavement structural changes. The pavement and LiDAR analysis sections are noted on the map in Figure 61. Figure 62 depicts a picture of the section.

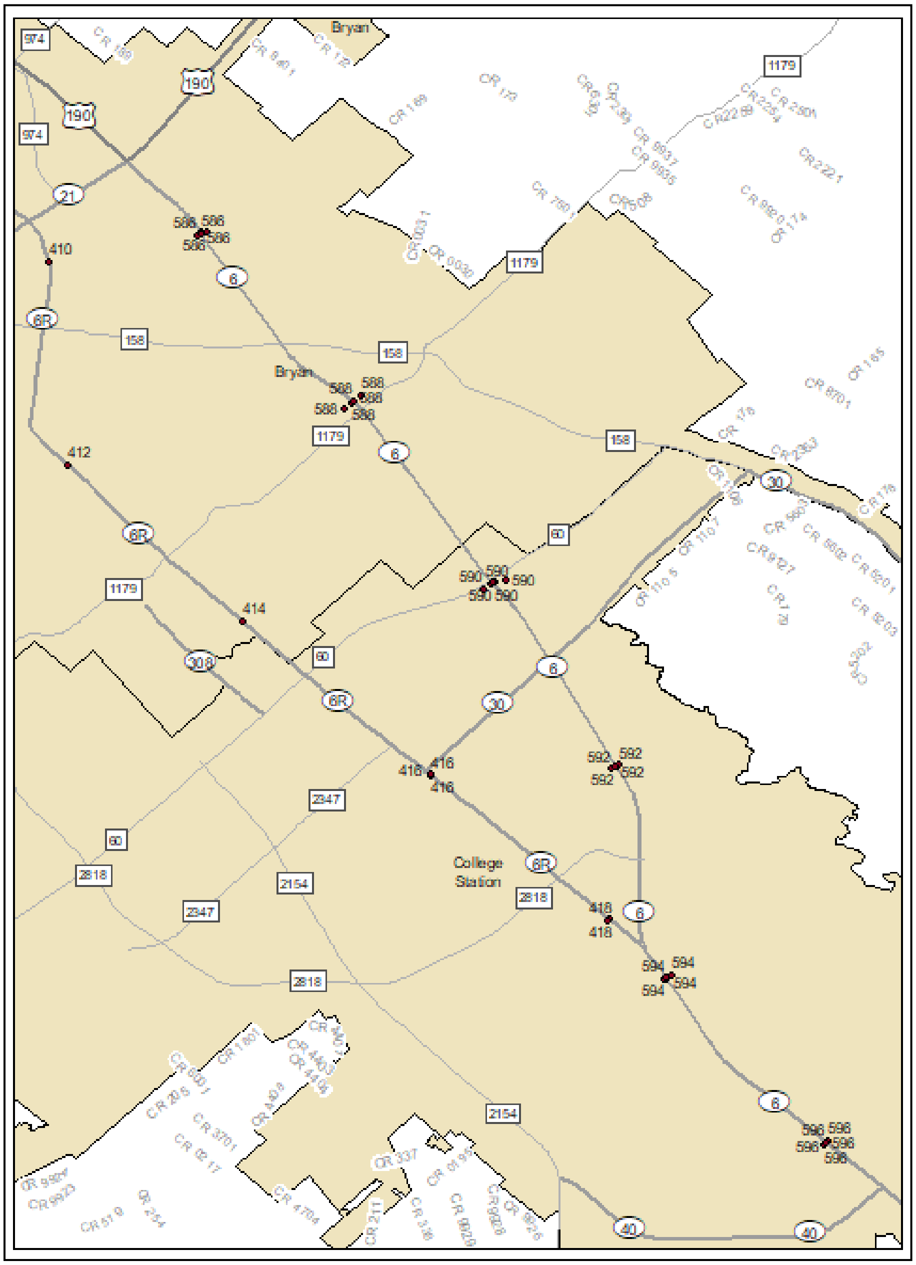


Figure 60. SH 6 Map.

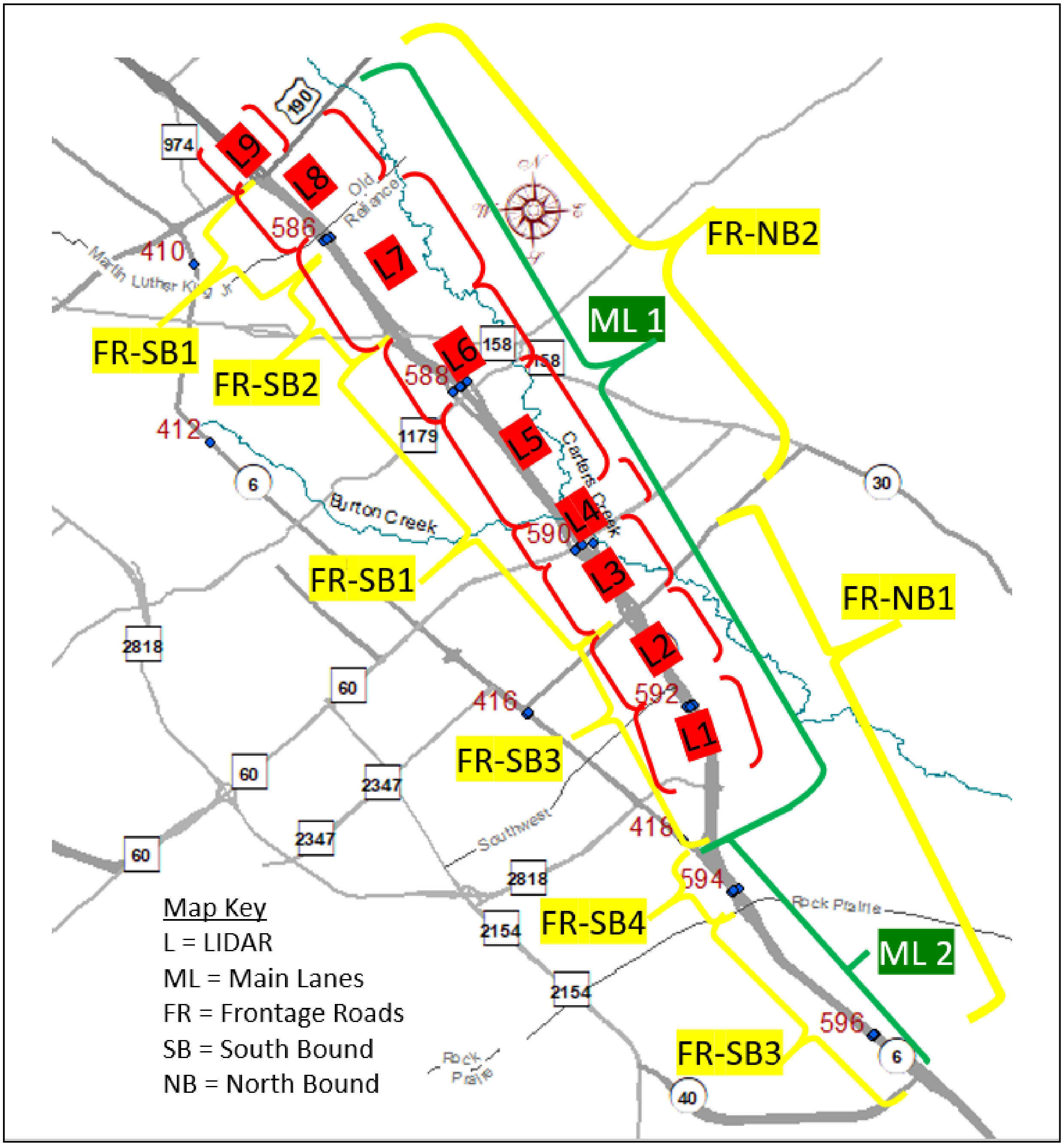


Figure 61. SH 6 Pavement Change Map.

Figure 62. SH 6 Southbound between FM 60 and SH 30.

The existing typical sections for the MLs and the FR are shown in Figure 63 through Figure 65. The section from US 190 to BS6-R has been overlaid with approximately 1.5-inch type D and 1-inch PFC mixes because the typical section was drawn in the 1990 PS&E. Several sections of the FR have full-depth hot mix, approximately 12 inches thick.

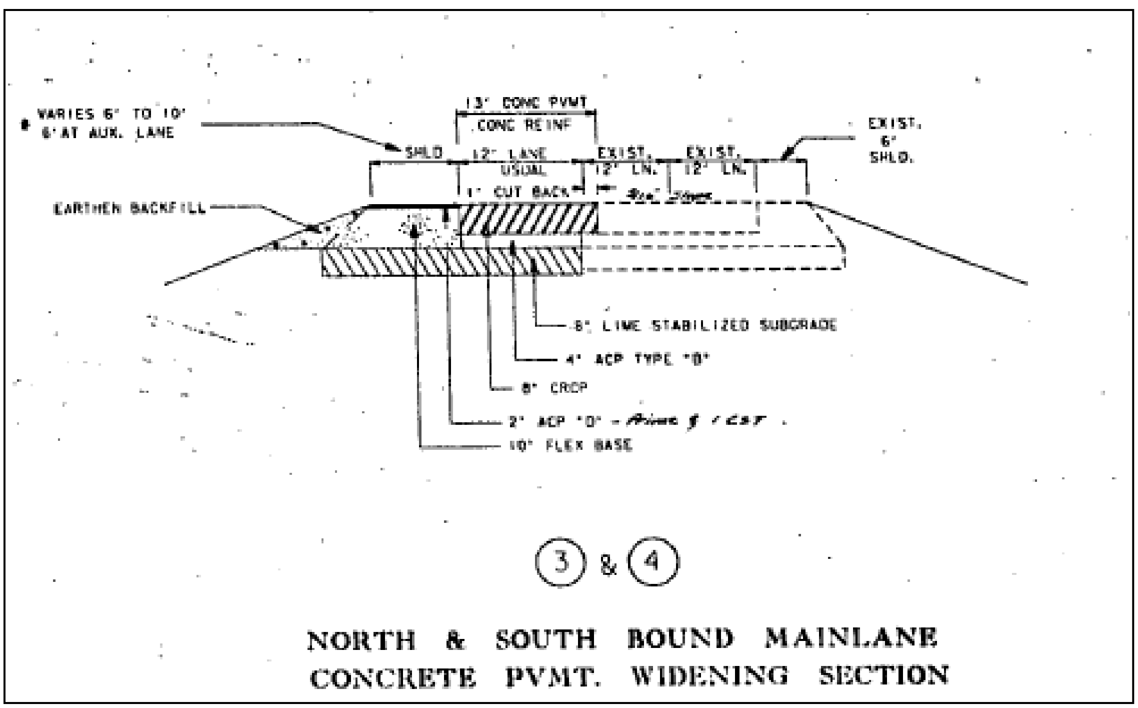


Figure 63. SH 6 Mainlane Typical Sections (1990) from US 190 to BS6-R.

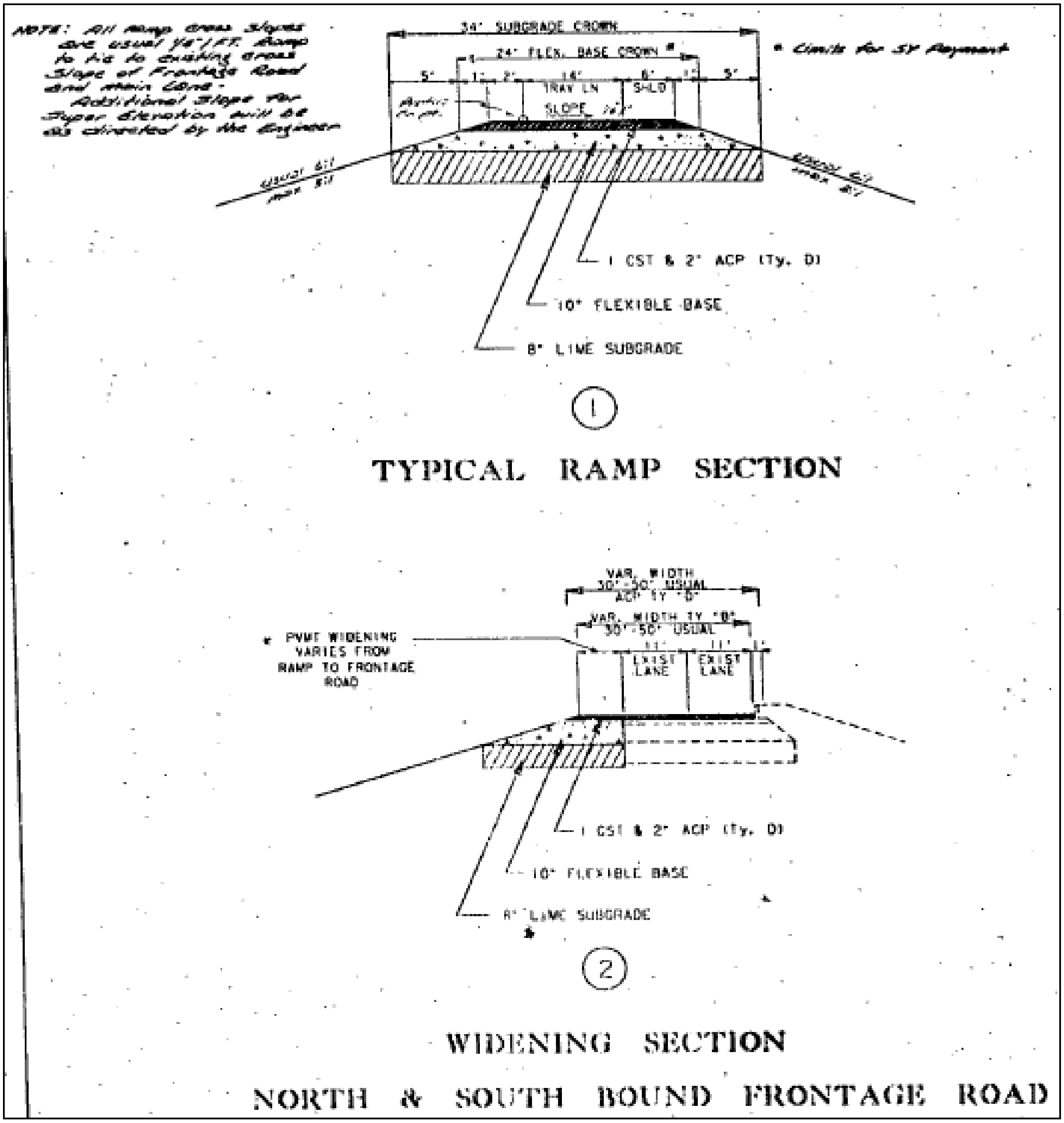


Figure 64. SH 6 Typical Sections—Ramp and Frontage Road (1990).

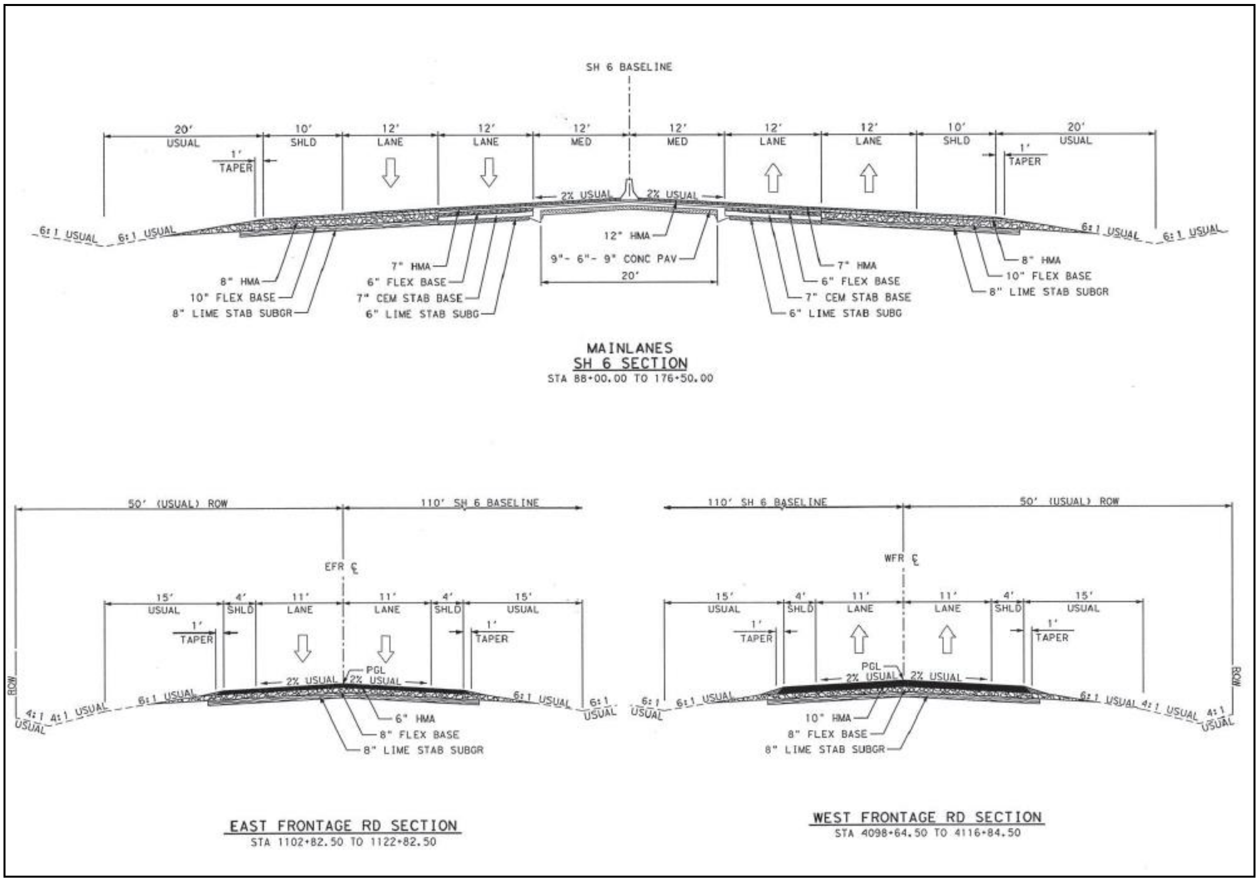


Figure 65. SH 6 Typical Sections from Approximately BS6-R to SH 40.

Traffic data were not provided. For the pavement analysis, the traffic data in Table 18 were used. All pavement designs should be verified with the official traffic data once they are received from TPP. The data are broken out based on roadbeds. A 70 percent correction factor is applied to the 20-year ESALs for the FPS 21 inputs, based on the *Pavement Manual*, Chapter 5, Table 5-2: Lane Distribution Adjustments. No adjustments are made for the TXCRCP-ME program because it adjusts internally based on the number of lanes. The locations are described as southbound (SB), northbound (NB), ML, and FR.

Table 18. Estimated Traffic Data.

					WIM History			
	Project Information				Flexible		Rigid	
Location	Initial ADT (2019)	Final ADT (2039)	% Truck	Design Period	T_f	Cumulative 18k ESALs (Adj 18k ESALs)	T_f	Cumulative 18k 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 Prairie Road								
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 Prairie Road 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 Prairie Road								
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 Prairie Road 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

SH 6 PAVEMENT EVALUATION

The following testing was performed:

- GPR data were collected on the ML and FR on all through lanes.
- FWD was collected in the outside lane of the FR throughout the project and the outside lane and outside shoulder of the ML from BS6-R to SH 40.
- TPAD data were collected on the outside lane of the ML from BS6-R to SH 21.
- Pavement cores were taken on the SB FR from SH 21 to FM 158.
- LiDAR data were collected throughout the project.

The ML 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 66 shows an example of an area with a large spike in data corresponding to a transverse crack.

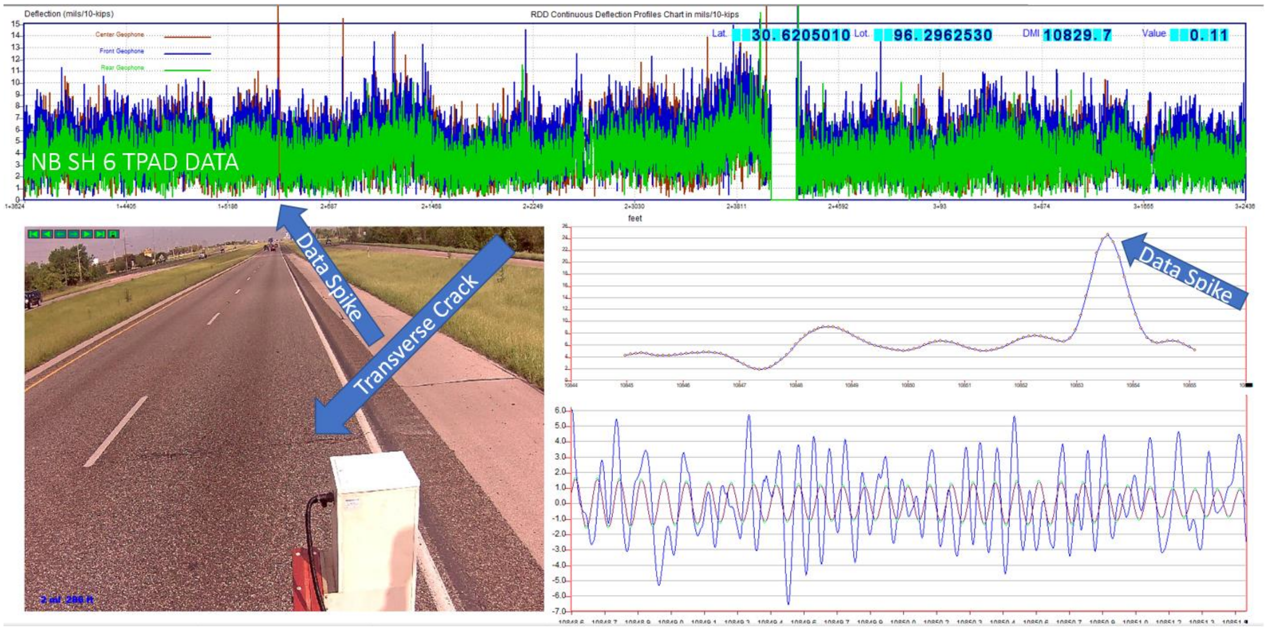


Figure 66. TPAD Data Example on SH 6.

FR 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 19 is a summary of the FWD results. Figure 67 shows the locations of the repairs and cores. All lanes need repairs in these sections based on the similar patterns in the GPR. Figure 68 shows GPR examples.

Table 19. FWD Testing Summary.

<table>
<tr><td rowspan="2">ML 2: ~ BS6-R to SH 40</td><td colspan="2">SB Outside Lane (OL)</td><td colspan="2">SB Outside Shoulder (OS)</td><td colspan="2">NBOL</td><td colspan="2">NBOS</td></tr>
<tr><td>Thickness (in)</td><td>Mod (ksi)</td><td>Thickness (in)</td><td>Mod (ksi)</td><td>Thickness (in)</td><td>Mod (ksi)</td><td>Thickness (in)</td><td>Mod (ksi)</td></tr>
<tr><td>Pavement:</td><td>8.00</td><td>1060</td><td>8.00</td><td>1580</td><td>8.00</td><td>1258</td><td>8.00</td><td>1085</td></tr>
<tr><td>Base:</td><td>10.00</td><td>724</td><td>10.00</td><td>163</td><td>10.00</td><td>611</td><td>10.00</td><td>229</td></tr>
<tr><td>Subgrade:</td><td>111.57</td><td>17.3</td><td>104.55</td><td>12.8</td><td>99.25</td><td>15.7</td><td>113.04</td><td>14.7</td></tr>
<tr><td>Sections:</td><td colspan="2">SB 1</td><td colspan="2">SB 2</td><td colspan="2">SB 3</td><td colspan="2">SB 4</td></tr>
<tr><td rowspan="2">SB FR</td><td colspan="2">SBFR SH 30 to SH 21</td><td colspan="2">SBFR-Water Locust to FM 158</td><td colspan="2">SBFR SH 30 to SH 40</td><td colspan="2">SBFR Tx AVE to Rock PR.</td></tr>
<tr><td>Thickness (in)</td><td>Mod (ksi)</td><td>Thickness (in)</td><td>Mod (ksi)</td><td>Thickness (in)</td><td>Mod (ksi)</td><td>Thickness (in)</td><td>Mod (ksi)</td></tr>
<tr><td>Pavement:</td><td>12.00</td><td>943</td><td>5.00</td><td>763</td><td>8.00</td><td>1245</td><td>2.00</td><td>708</td></tr>
<tr><td>Base:</td><td></td><td></td><td>6.00</td><td>103</td><td>8.00</td><td>136</td><td>10.00</td><td>1143</td></tr>
<tr><td>Subbase:</td><td></td><td></td><td>6.00</td><td>2000</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Subgrade:</td><td>125.55</td><td>9.3</td><td>111.5</td><td>10.2</td><td>111.31</td><td>10</td><td>284.38</td><td>21.9</td></tr>
<tr><td>Sections:</td><td colspan="2">NB 1</td><td colspan="2">NB 2</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">NB FR</td><td colspan="2">NBFR SH 40 to SH 30</td><td colspan="2">NBFR SH 30 to SH 21</td><td colspan="4" rowspan="6">Notes: Pavement Manual, Ch 5 for dense-graded mixes recommends:
Combined HMA thickness (T):
≤ 4 in. use 500 ksi
4.0 in. < T ≤ 8 in. use 650 ksi and
≥ 8 in. use 850 ksi
— Will use default design values if field tested values are greater. Used DCP results for SB2 base.</td></tr>
<tr><td>Thickness (in)</td><td>Mod (ksi)</td><td>Thickness (in)</td><td>Mod (ksi)</td></tr>
<tr><td>Pavement:</td><td>8.00</td><td>1750</td><td>12.00</td><td>1623</td></tr>
<tr><td>Base:</td><td>10.00</td><td>58</td><td></td><td></td></tr>
<tr><td>Subbase:</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Subgrade:</td><td>284.38</td><td>10.9</td><td>111.31</td><td>7.1</td></tr>
</table>

Figure 67. SH 6 Southbound Frontage Road Repair Area and Core Map.

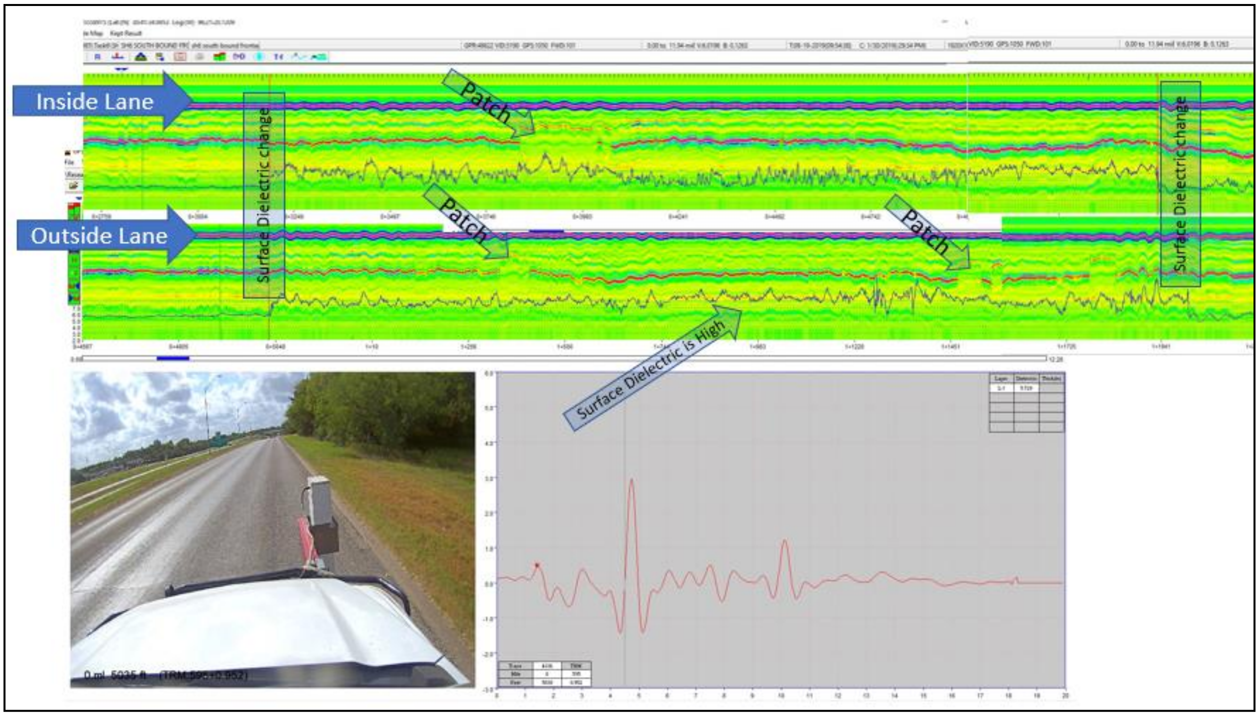


Figure 68. SH 6 Southbound Frontage Road Ground-Penetrating Radar in Repair Area 1.

Since the majority of the existing pavement is in good condition, it is recommended that it be used in all locations that the geometry will allow. This process will save in removal time and cost. 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. This is approximately 533,867 sy, which would cost $6,571,900 for removal and 241 working days. At an average of 13 working days per month, this process would have 19 months' impact on the traveling public. The replacement subbase construction cost would be $26,903,800, for a total potential savings on the MLs of $33,475,700.

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

Retaining all structurally sound existing pavement would result in 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 20 through Table 32 contain the proposed pavement work and estimate of cost normalized to a cost per square yard of pavement. Table 20 and Table 21 are a summary of the estimated cost of all alternatives considered for the ML and FR pavement options, respectively. Table 22 through Table 32 have the cost broken down by pavement layer and work for each option considered.

Table 20. Summary of Mainlane Pavement Repair Options on SH 6.

Keep Existing Pavement Options (ML)		$/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. CTB 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. CTB plant mixed is preferred.
	Removal Cost	$ –		
New Construction Options (MLs)		**$/sy**	**$/sy**	**Notes**
Flexible Pavement Section: ML1&2—Perpetual Pavement	Pavement New	$ 101.35	$140.38	Reconstruct with perpetual pavement (removal for ML1 and ML2 are approx. the same cost, ML1 is shown above).
	Removal Cost	$ 12.31		
	Year 15 PM Work (NPV)	$ 26.73		Total thickness of pavement structures are 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 (NPV)	$ 8.52		

Table 21. Summary of Frontage Road Pavement Repair Options on SH 6.

Options (FR)		$/sy	$/sy	Notes
Flexible Pavement FR Section: SB2, SB3 & NB1—Overlay	Pavement	$ 15.66	$ 15.66	2" overlay with underseal.
	Removal	$		
Flexible Pavement FR Section: SB1, SB4 & NB2—Mill & Inlay	Pavement	$ 15.66	$ 18.06	No additional structure is required. Replace surface layer.
	Removal	$ 2.40		
Flexible Pavement FR Section: SB1—Full-Depth HMA Repair	Pavement	$ 77.51	$ 90.71	Can match profile.
	Removal	$ 13.20		
	Year 15 PM Work (NPV)	$ 20.38	$ 11.09	LCCA for full-depth HMA FR section.
Flexible Pavement FR Section: SB1 Repairs—FDR	Pavement	$ 54.35	$ 54.35	Raises profile 7". Does not remove problem material (not a good option).
	Removal	$ –		
Rigid Pavement Section: FR	Pavement	$ 90.52	$ 6.24	Concrete pavement for frontage roads (assumed top 6" could be milled for RAP).
	Removal	$ 15.72		
	Year 15 PM Work (NPV)	$ 6.69	$ 12.93	LCCA for concrete FR section.

Table 22. Mainlane 1 Rigid Pavement Overlay on SH 6.

Rigid Pavement Section ML1: Keep Existing						
Layer Description	**Depth (in)**	**Item**	**Materials**		**$/sy**	**$/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 23. Mainlane 1, Rigid Pavement Widening on SH 6.

Rigid Pavement Section ML1: Widening						
Layer Description	**Depth (in)**	**Item**	**Materials**	**Stabilizer (%)**	**$/sy**	**$/CY**
Concrete	14	346	CRCP		$ 78.40	$201.60
Subbase	1.5	3076	DG- D		$ 7.21	$165.53
Prime		310	Prime		$ 0.65	
Treated Base	6	276	Plant Mix CTB		$ 15.06	$ 90.36
Subgrade Treatment	8	275	Road Mix CTS	2	$ 3.32	$ 14.93
		260	Road Mix LTS	2	$ 3.34	$ 15.01
	29.5	TOTAL			$ 107.97	$/sy
Comments:	Widen to match existing pavement layers. CTB 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 24. Mainlane 2 Overlay on SH 6.

Flexible Pavement Section: ML2—Overlay						
Layer Description	**Depth (in)**	**Item**	**Materials**		**$/sy**	**$/CY for FPS**
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:	Shoulder pavement is weaker than lane, requires a 3-inch overlay. This is still less expensive than reconstructing the shoulder since the ML needs 1.5-inch overlay. Milling is for removal of PFC.					

Table 25. Mainlane 2 Widening on SH 6.

	Flexible Pavement Section: ML2—Widening					
Layer Description	**Depth (in)**	**Item**	**Materials**	**Stabilizer (%)**	**$/sy**	**$/CY for FPS**
Hot Mix	1.5	346	SMA-D		$ 10.48	$244.08
	9.5	3077	SP-B		$ 46.66	$175.63
Underseal		316	SC-AC w/PGR 4		$ 1.79	
Prime		310	Prime		$ 0.65	
Treat Existing or Existing + New Material	10	276	Plant Mix CTB		$ 25.10	$ 90.36
Subgrade Treatment	8	275	Road Mix CTS	2	$ 3.32	$ 14.93
		260	Road Mix LTS	2	$ 3.34	$ 15.01
	19.0	New Pavement TOTAL			$ 91.33	$/sy
		Removal Cost			$ –	$/sy
Comments:	Widen to match existing pavement layers. CTB plant mixed is preferred due to mixing issues at the longitudinal construction joint.					

Table 26. Mill and Inlay of Frontage Road Southbound 1, Southbound 4, and Northbound 2 on SH 6.

Flexible Pavement Frontage Road Section: SB1, SB4 & NB2—Mill & Inlay						
Layer Description	**Depth (in)**	**Item**	**Materials**		**$/sy**	**$/CY for FPS**
Hot Mix	2	346	SMA-D		$ 13.87	$244.08
Removal	2	354	Mill		$ 2.40	$ 43.20
Underseal		316	SC-AC w/PGR 4		$ 1.79	
		New Pavement TOTAL			$ 15.66	$/sy
		Removal Cost			$ 2.40	$/sy
Comments:	No additional structure is required. Replace surface layer.					

Table 27. Overlay of Frontage Road Southbound 2, Southbound 3, and Northbound 1 on SH 6.

Flexible Pavement Frontage Road Section: SB2, SB3 & NB1—Overlay						
Layer Description	**Depth (in)**	**Item**	**Materials**	**Stabilizer (%)**	**$/sy**	**$/CY for FPS**
Hot Mix	2	346	SMA-D		$ 13.87	$244.08
Underseal		316	SC-AC w/PGR 4		$ 1.79	
	2	New Pavement TOTAL			$ 15.66	$/sy
		Removal Cost			$ –	$/sy
Comments:	2-inch overlay with underseal.					

Table 28. Repairs of Frontage Road Southbound 1 on SH 6.

Flexible Pavement Frontage Road Section: SB1 Repairs—FDR						
Layer Description	**Depth (in)**	**Item**	**Materials**	**Stabilizer (%)**	**$/sy**	**$/CY for FPS**
Hot Mix	2	346	SMA D		$ 13.87	$ 244.08
	5	3077	SP B		$ 24.70	$ 175.63
Underseal		316	SC-AC w/PGR 4		$ 1.79	
Treat Existing or Existing+New Material	12	SS	Road Mix w/Foam	2.4	$ 9.71	$ 29.14
	12	275	Road Mix w/Cement	1	$ 4.28	$ 12.84
	19.0	New Pavement TOTAL			$ 54.35	$/sy
		Removal Cost			$ –	$/sy
Comments:	Raises profile 7 inches.					

Table 29. Full-Depth Hot-Mix Asphalt Repairs of Frontage Road Southbound 1.

Flexible Pavement Frontage Road Section: SB1—Full Depth HMA Repair						
Layer Description	**Depth (in)**	**Item**	**Materials**	**Stabilizer (%)**	**$/sy**	**$/CY for FPS**
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-AC w/PGR 4		$ 1.79	
Subgrade Treatment	8	260	Road Mix LTSS	4	$ 4.43	$ 19.95
	8.0	New Pavement TOTAL			$ 77.51	$/sy
		Removal Cost			$ 13.20	$/sy
Comments:	Can match profile.					

Table 30. Frontage Road Rigid Pavement Design.

Rigid Pavement Section: Frontage Roads						
Layer Description	**Depth (in)**	**Item**	**Materials**	**Stabilizer (%)**	**$/sy**	**$/CY**
Concrete	11	346	CRCP		$ 61.60	$ 201.60
Subbase (Hot Mix)	1.5	3076	DG- D		$ 7.21	$ 165.53
Treated Base	6	276	Plant Mix CTB		$ 15.06	$ 90.36
Subgrade Treatment	8	275	Road Mix CTS	2	$ 3.32	$ 14.93
		260	Road Mix LTS	2	$ 3.34	$ 15.01
Removal	6	354	Mill		$ 7.20	$ 43.20
Removal	12	105	Remove Flexible Pavement		$ 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 RAP).					

Table 31. Mainlane Perpetual Pavement.

Flexible Pavement Section: ML1&2—Perpetual Pavement						
Layer Description	**Depth (in)**	**Item**	**Materials**	**Stabilizer (%)**	**$/sy**	**$/CY for FPS**
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 Concrete Pavement		$ 5.27	$ –
Removal	4	105	Remove Flexible Pavement		$ 2.84	$ 25.56
Underseal		316	SC-AC w/PGR 4		$ 1.79	
Prime		310	Prime		$ 0.65	
Flex Base	6	247	Flexible Base		$ 11.34	$ 68.04
Subgrade Treatment	8	275	Road Mix CTS	2	$ 3.32	$ 14.93
		260	Road Mix LTS	2	$ 3.34	$ 15.01
	29.5	New Pavement TOTAL			$ 101.35	$/sy
		Removal Cost			$ 12.31	$/sy
Comments:		Reconstruct with perpetual pavement (removal for ML1 and ML2 are approximately the same cost, ML1 is shown above).				
ML1&2—Perpetual Pavement YR 15 PM work						
	Depth (in)	**Item**	**Materials**	**Stabilizer (%)**	**$/sy**	**$/CY for FPS**
	1.5	346	SMA-D		$ 10.48	$ 244.08
	1	3077	SP Lv		$ 5.23	$ 177.21
	1.5	354	Mill		$ 1.80	$ 43.20
		316	SC-AC w/PGR 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 (NPV)			$ 27.96	**$/sy**
		Net Present Value			$141.61	**$/sy**
Comments:		Replace surface at year 15.				

Table 32. Mainlane New Rigid Pavement.

Rigid Pavement Section: New Construction						
Layer Description	**Depth (in)**	**Item**	**Materials**	**Stabilizer (%)**	**$/sy**	**$/CY**
Concrete	14	346	CRCP		$ 78.40	$ 201.60
Subbase (Hot Mix)	1.5	3076	DG-D		$ 7.21	$ 165.53
Prime		310	Prime		$ 0.65	
Treated Base	6	276	Plant Mix CTB		$ 15.06	$ 90.36
Subgrade Treatment	8	275	Road Mix CTS	2	$ 3.32	$ 14.93
		260	Road Mix LTS	2	$ 3.34	$ 15.01
Removal	3.5	354	Mill		$ 4.20	$ 43.20
Removal	8	104	Remove Concrete Pavement		$ 5.27	$ –
Removal	4	105	Remove Flexible Pavement		$ 2.84	$ 25.56
	29.5	New Pavement TOTAL			$ 107.97	$/sy
		Removal Cost			$ 12.31	$/sy
Comments:		Concrete Pavement for FR				

Rigid Pavement Section: PM Work					
Depth (in)	Item	Materials	Repair (%)	$/sy	$/CY
14	346	CRCP 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 (NPV)			$ 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 69 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.

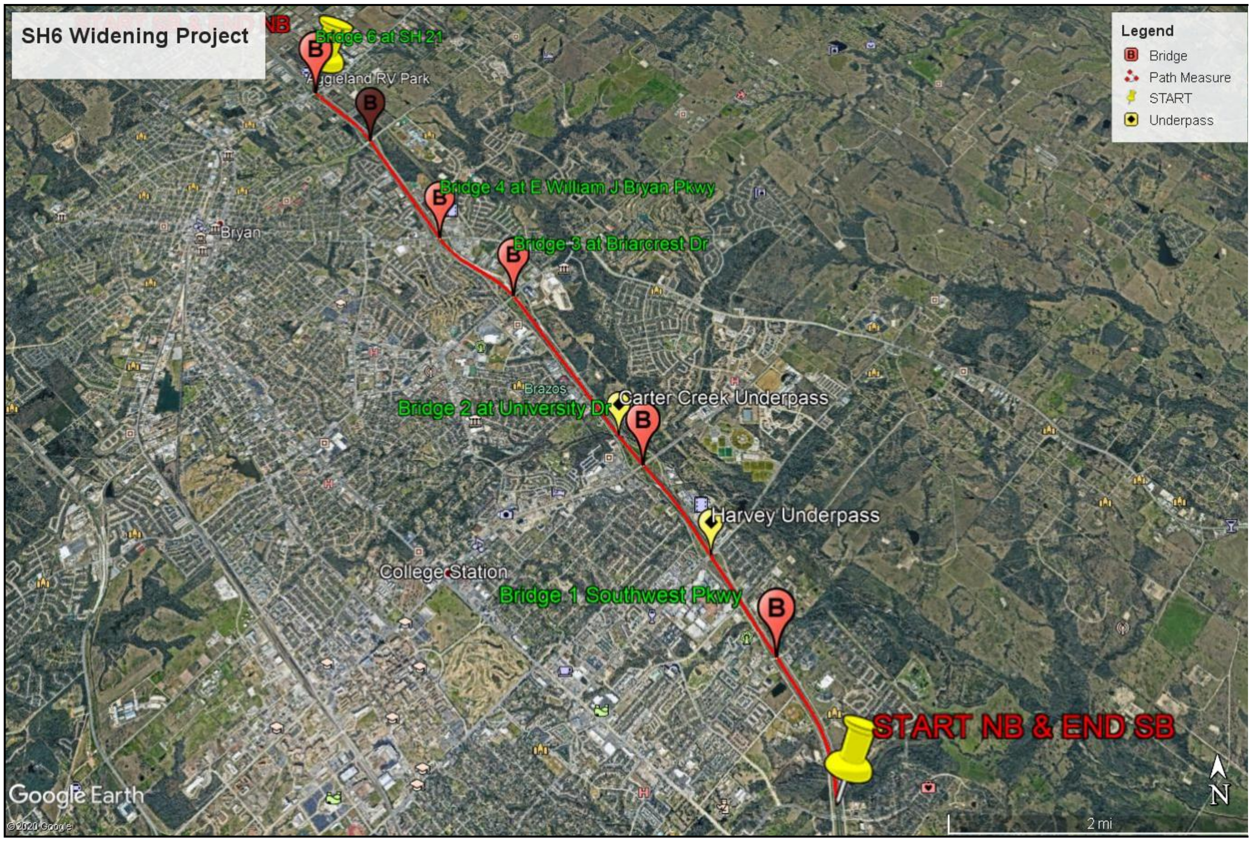


Figure 69. Aerial Picture Showing the SH 6 Widening Project.

The TxDOT *Roadway Design Manual* [16]was used as a reference to guide the geometric analysis. The design criteria recommend a 16-ft surface median or a 76-ft depressed median with inner shoulders. However, minimum median widths are 4 ft for a surface median and 48 ft for a depressed median with inner shoulders. Recommended desirable inside or outside shoulder width is 10 ft. The design criteria also note a minimum recommended inside shoulder width of 4 ft for a depressed median, while the minimum recommended outside shoulder width is 8 ft.

The analysis used nine logical subsections. These analysis sections are:

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

The mobile LiDAR unit used for this data collection provides transverse strings (i.e., cross sections) on approximately 10inch increments. Summarizing these data into useful information presents a challenge. Using the nine analysis segments, the researchers created Table 33 to summarize the existing condition and the future condition when widening to the inside with a 12-ft lane and a 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 33 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 Martin Luther King overpass. Within this area, the average median width exceeds 48 ft, though some isolated 1,000-ft sections have averages between 45 ft and 48 ft. However, these widths do not violate the design criteria because the measurements in Table 33 are from edge-of-pavement to end-of-pavement, and when including the inside shoulders (i.e., 4 ft on each roadbed), the required median width is achieved. Furthermore, Table 33 shows that after widening to the inside, the new front slopes along SH 6 will remain flatter than 4(H):1(V) and mostly remain flatter than 5(H):1(V).

Approximately 1,000 ft north of the Martin Luther King 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 33. Existing and Future Median Widths and 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	1000	67.49	14.67	14.04	53.49	8.75	7.18	Depressed Median
439.318	743.813	1000	63.26	13.38	11.16	49.26	7.09	5.42	Depressed Median
744.118	1048.61	1000	65.82	14.23	10.42	51.82	7.89	4.93	Depressed Median
1048.92	1353.41	1000	63.32	12.18	12.72	49.32	6.04	6.64	Depressed Median
1353.72	1658.21	1000	59.21	12.92	11.94	45.21	6.53	5.31	Depressed Median
1658.52	1835.91	583	62.13	11.51	11.32	48.13	6.15	5.41	Depressed Median
SEC_2_SW_PKWY_TO_HARVEY_RD									
1857.55	2162.05	1000	61.71	12.49	12.38	47.71	6.5	6.01	Depressed Median
2162.35	2466.85	1000	64.33	11.15	10.09	50.33	5.97	5	Depressed Median
2467.15	2771.65	1000	61.34	13.73	10.34	47.35	7.42	4.44	Depressed Median
2771.95	3076.45	1000	61.03	10.97	11.47	47.03	5.24	5.63	Depressed Median
3076.75	3220.92	474	61.48	17.36	12.86	47.63	9.54	6.26	Depressed Median
SEC_3_HARVEY_RD_TO_UNIV_BLVD									
3281.88	3586.38	1000	61.52	12.03	12.05	47.49	6.78	5.69	Depressed Median
3586.68	3891.18	1000	63.14	11.69	11.7	49.14	6.41	5.81	Depressed Median
3891.48	4195.98	1000	61.56	10.71	12.48	47.58	5.38	6.42	Depressed Median
4196.28	4500.78	1000	61.76	10.02	10.97	47.76	5.11	5.87	Depressed Median
4501.08	4660.49	524	62.16	10.23	12.37	48.16	5.15	6.69	Depressed Median
SEC_4_UNIV_BLVD_TO_CARTER_CK									
4674.21	4978.7	1000	62.89	8.93	11.13	47.33	4.49	5.62	Depressed Median
4979.01	5139.94	529	62.15	11.25	12.71	51.26	6.27	7.14	Depressed Median
SEC_5_CARTER_CK_TO_BRCREST_DR									
5187.8	5492.29	1000	62.84	11.66	14.94	48.84	5.15	8.2	Depressed Median
5492.6	5797.09	1000	61.92	9.99	10.96	47.92	5.16	5.58	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
5797.4	6101.89	1000	60.87	11.98	12.36	46.87	5.81	6.06	Depressed Median
6102.2	6406.69	1000	59.43	9.68	9.98	45.43	4.56	5.1	Depressed Median
6407	6711.49	1000	65.42	9.76	11.7	51.42	4.75	6.7	Depressed Median
6711.8	7016.29	1000	65.53	10.7	11.77	51.53	5.39	6.52	Depressed Median
7016.6	7321.09	1000	62.94	10.59	11	48.95	5.18	5.77	Depressed Median
7321.4	7625.89	1000	58.97	11.95	11.26	44.97	6.04	5.59	Depressed Median
7626.2	7680.45	179	61.29	14.4	11.99	47.29	7.11	6.35	Depressed Median
SEC_6_BRCREST_DR_TO_WJ_BRYAN									
7692.95	7997.44	1000	63.51	12.64	13.93	49.51	5.91	7.5	Depressed Median
7997.75	8302.24	1000	65.91	10.99	10.18	51.91	5.86	5.4	Depressed Median
8302.55	8607.04	1000	64.07	9.26	12.62	50.07	4.41	7.05	Depressed Median
8607.35	8911.84	1000	61.73	10.96	13.09	47.73	5.51	6.95	Depressed Median
8912.15	9109.35	648	61.75	12.65	12.58	47.75	6.66	6.22	Depressed Median
SEC_7_WJ_BRYAN_TO_MLK_RD									
9129.78	9434.27	1000	64.11	11.14	11.72	50.11	5.81	6.19	Depressed Median
9434.58	9739.07	1000	63.32	11.04	11.97	49.32	5.57	6.26	Depressed Median
9739.38	10043.9	1000	62.21	10.07	12.11	48.21	4.89	6.47	Depressed Median
10044.2	10348.7	1000	62.51	10.14	12.34	48.51	4.78	6.81	Depressed Median
10349	10653.5	1000	63.43	10.14	13.66	49.43	4.39	7.62	Depressed Median
10653.8	10958.3	1000	63.23	8.86	10.62	49.23	4.33	5.89	Depressed Median
10958.6	11182.9	737	64.08	11.95	13.33	50.08	6.04	7.09	Depressed Median
SEC_8_MLK_RD_TO_SH21_HW									
11215.2	11519.7	1000	56.06	9.89	10.98	42.06	4.35	5.26	Depressed Median
11520	11824.5	1000	40.5	9.57	11.34	26.53	2.56	3.72	Surfaced Median
11824.8	12129.3	1000	38.62	10.62	10.96	24.67	2.51	3.18	Surfaced Median
12129.6	12434.1	1000	37.25	12.48	11.64	23.26	2.61	3.04	Surfaced Median
12434.4	12487.1	174	36.31	12.56	12.55	22.37	2.24	2.99	Surfaced Median
SEC_9_AFTER_SH21_HW									
12510.3	12517.6	25	34.84	11.52	13.73	21.92	1.83	3.25	Surfaced Median
12517.9	12517.9	1	32	10.7	12.51	18	0.56	2.53	Surfaced Median

With six overpasses flying over SH 6 and SH 6 having two bridges within the analysis area, widening presents concerns for the impact on the structures. Using mobile LiDAR data, the researchers measured the horizontal clearance to the bridge columns for overpasses. Additionally, the widths of the bridges along SH 6 were also measured. Table 34 summarizes these measurements. Table 34 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 Martin Luther King Street 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 34 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 34. Details of Overpasses and Bridges on 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	—	—
Harvey Road Underpass	—	—	42.3	42.3
University Drive Overpass	30.84	30.84	—	—
Carter Creek Bridge	—	—	42.61	42.48
Briarcrest Drive Overpass	30.51	31.5	—	—
William J. Bryan Parkway Overpass	30.51	31.17	—	—
Martin Luther King Street Overpass	29.2	30.51	—	—
SH 21 Overpass	15.42	16.73	—	—

Note: — means not applicable.

Additional plots for each analysis segment are shown in the Appendix of this report.

SH 6 TRAFFIC CONTROL STRATEGIES

The MLs on SH 6 from US 190 to BS6-R is an 8.5-mi section with a proposed 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 MLs 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 70 through Figure 82 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 70. 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 71. SH 6 CA4PRS Summary Page 2.

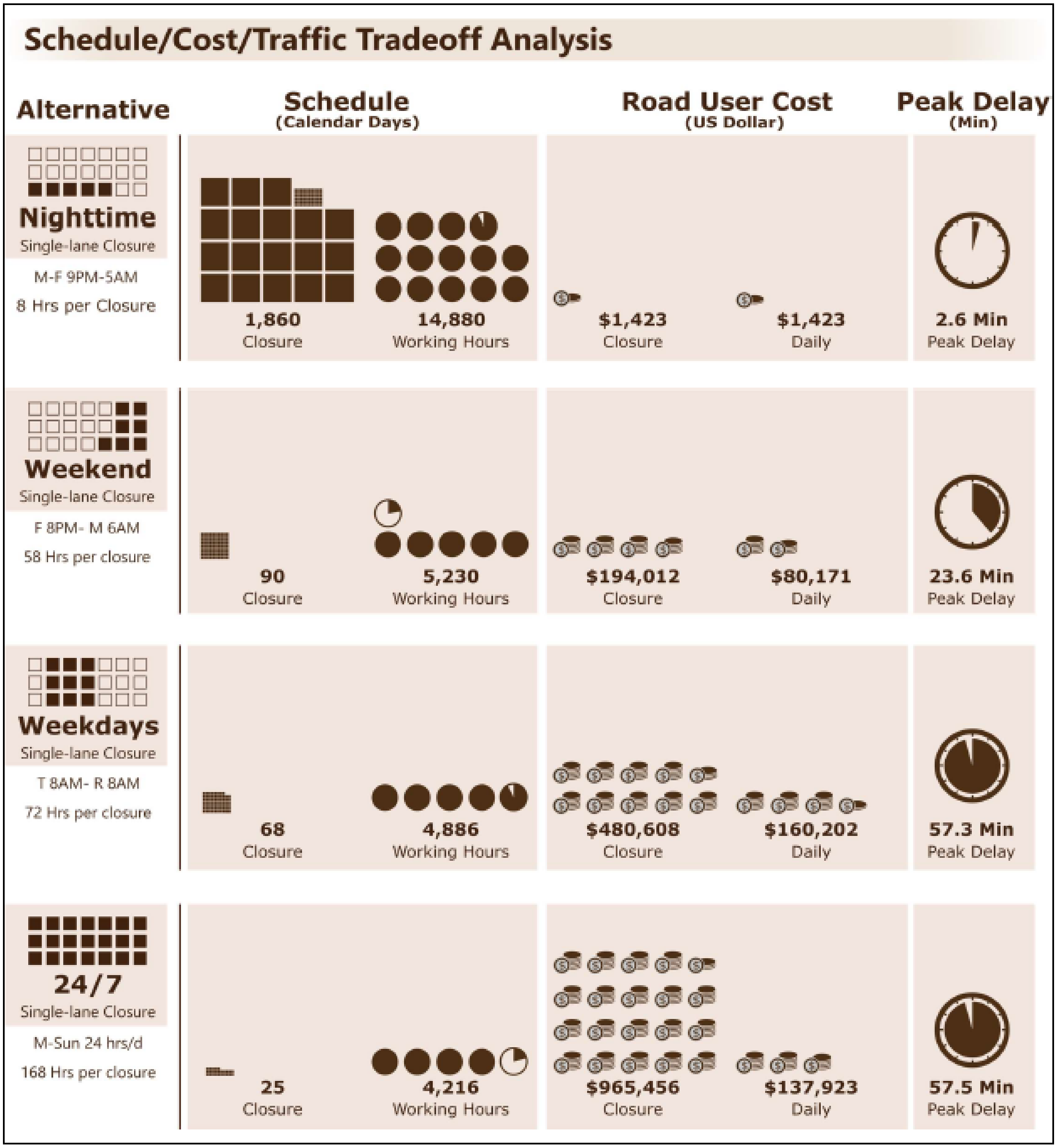


Figure 72. SH 6 CA4PRS Summary Page 3.

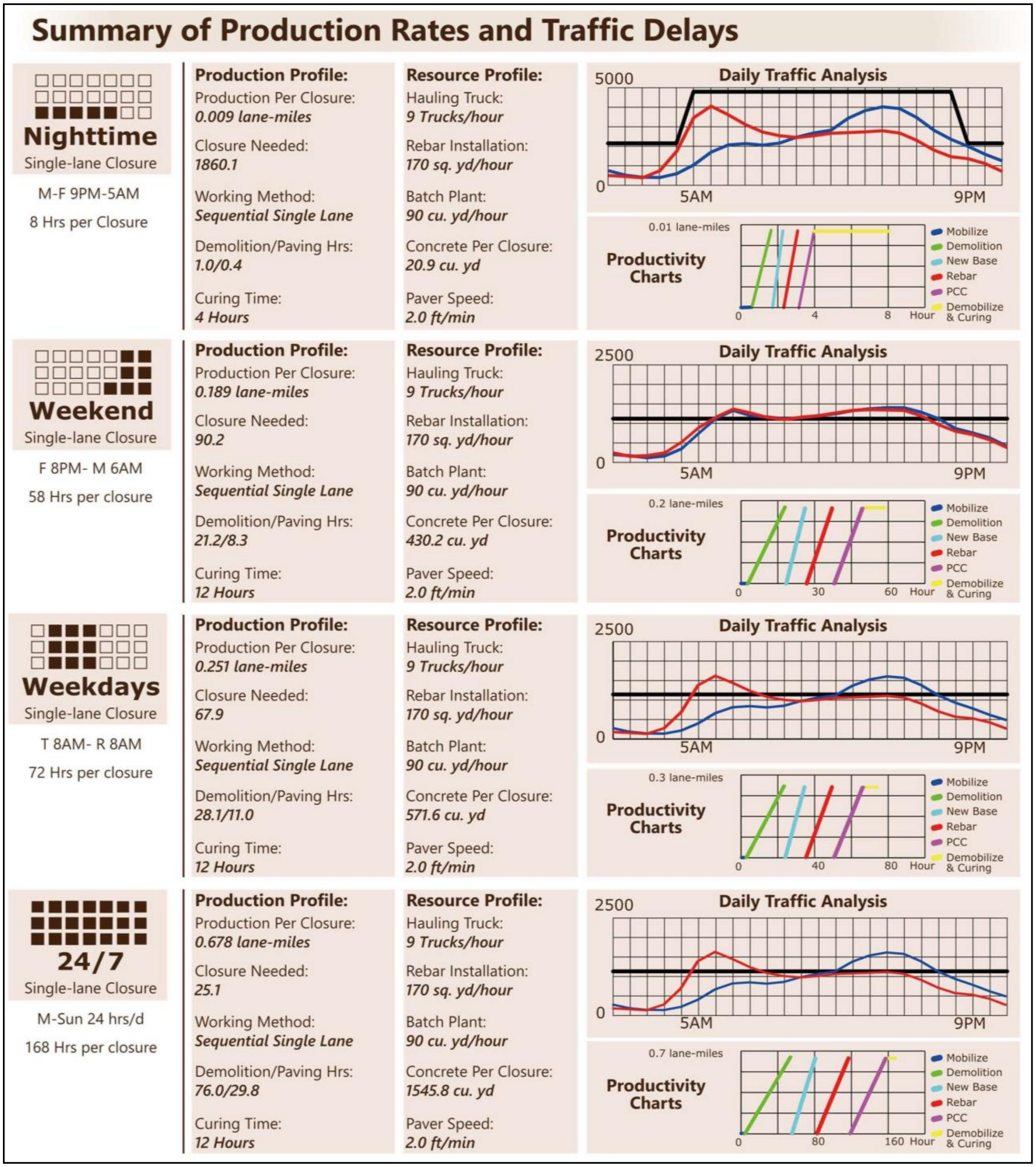


Figure 73. SH 6 CA4PRS Summary Page 4.

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 74. SH 6 CA4PRS Summary Page 5.

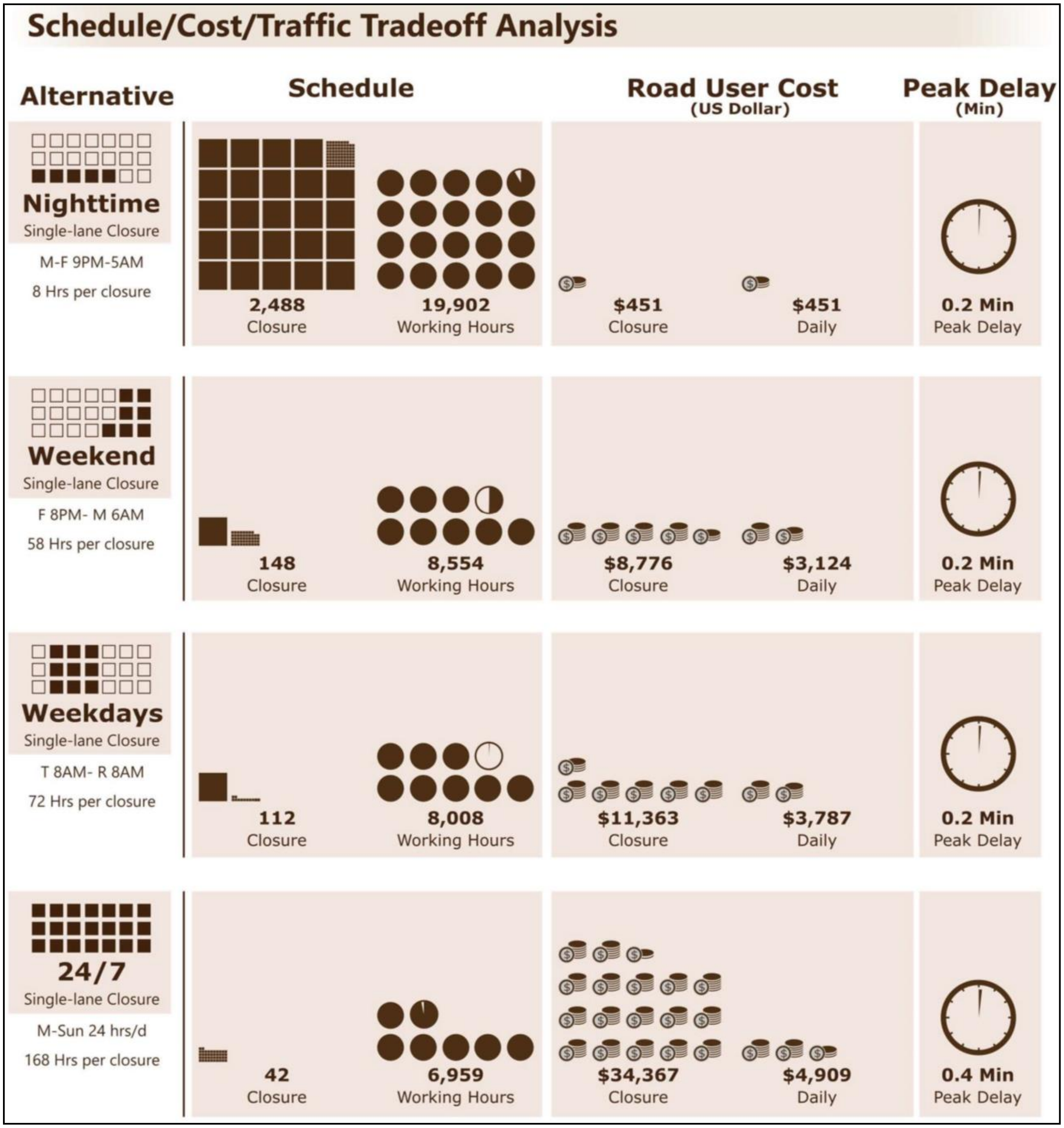


Figure 75. SH 6 CA4PRS Summary Page 6.

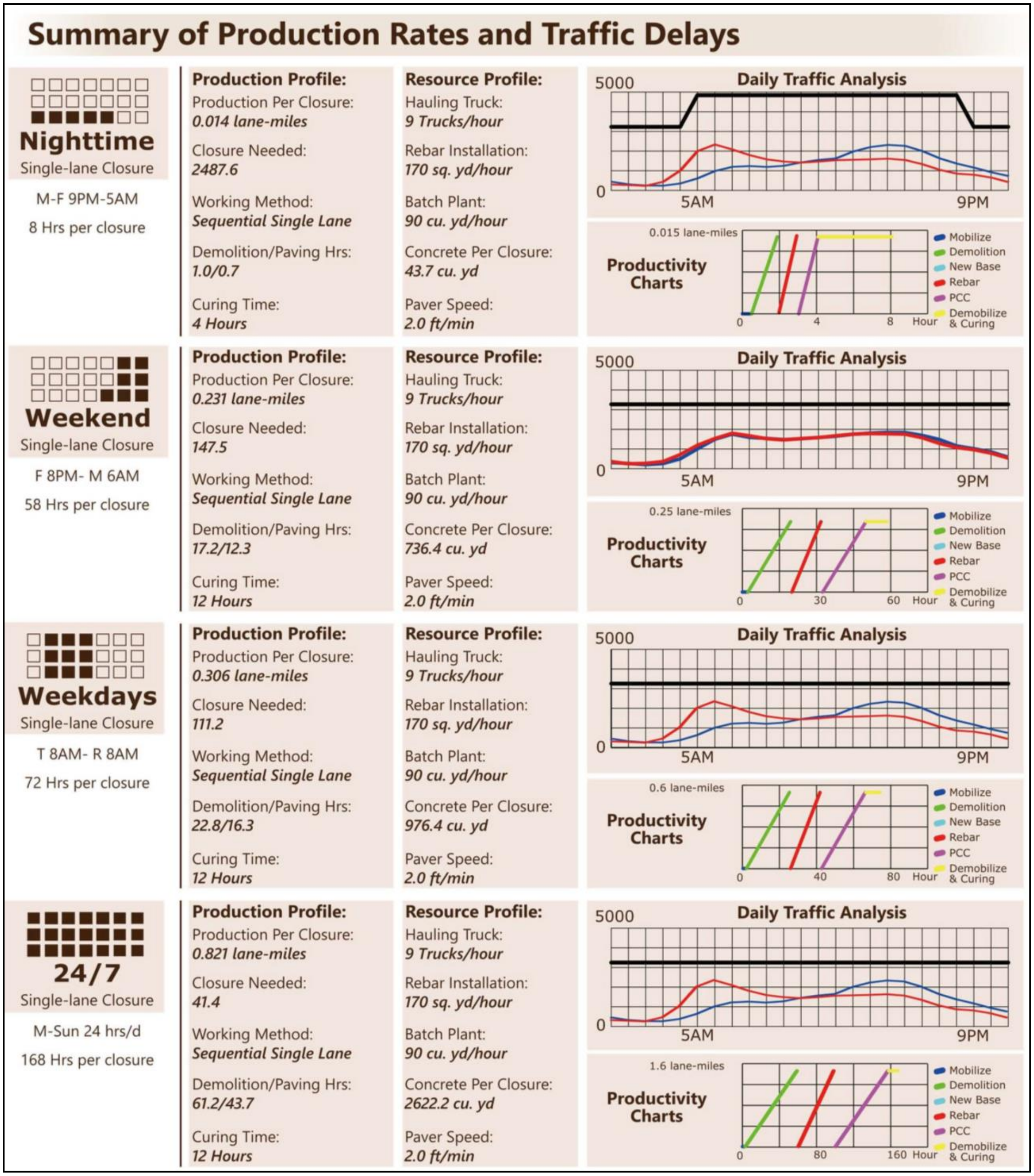


Figure 76. SH 6 CA4PRS Summary Page 7.

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 77. SH 6 CA4PRS Summary Page 8.

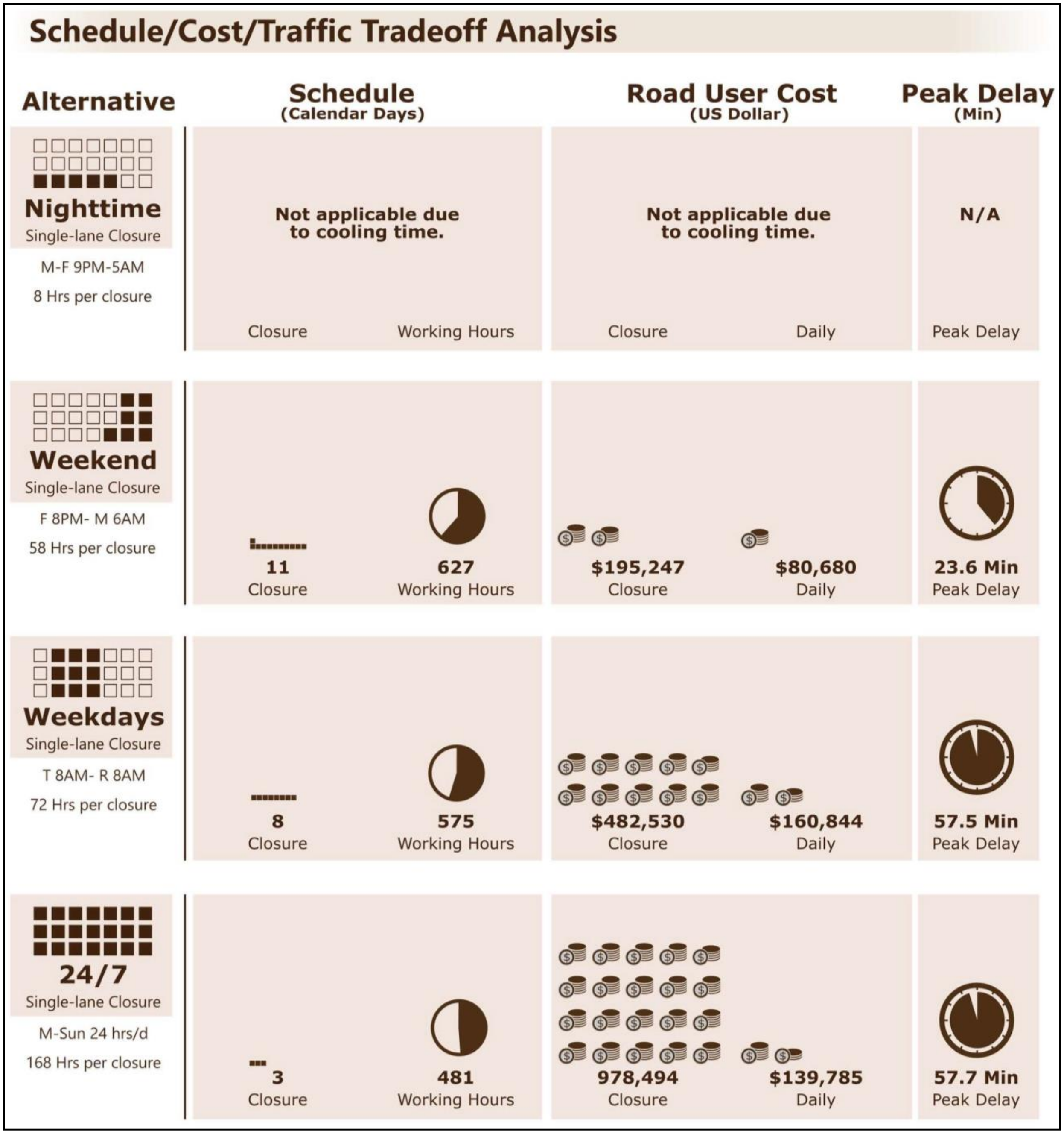


Figure 78. SH 6 CA4PRS Summary Page 9.

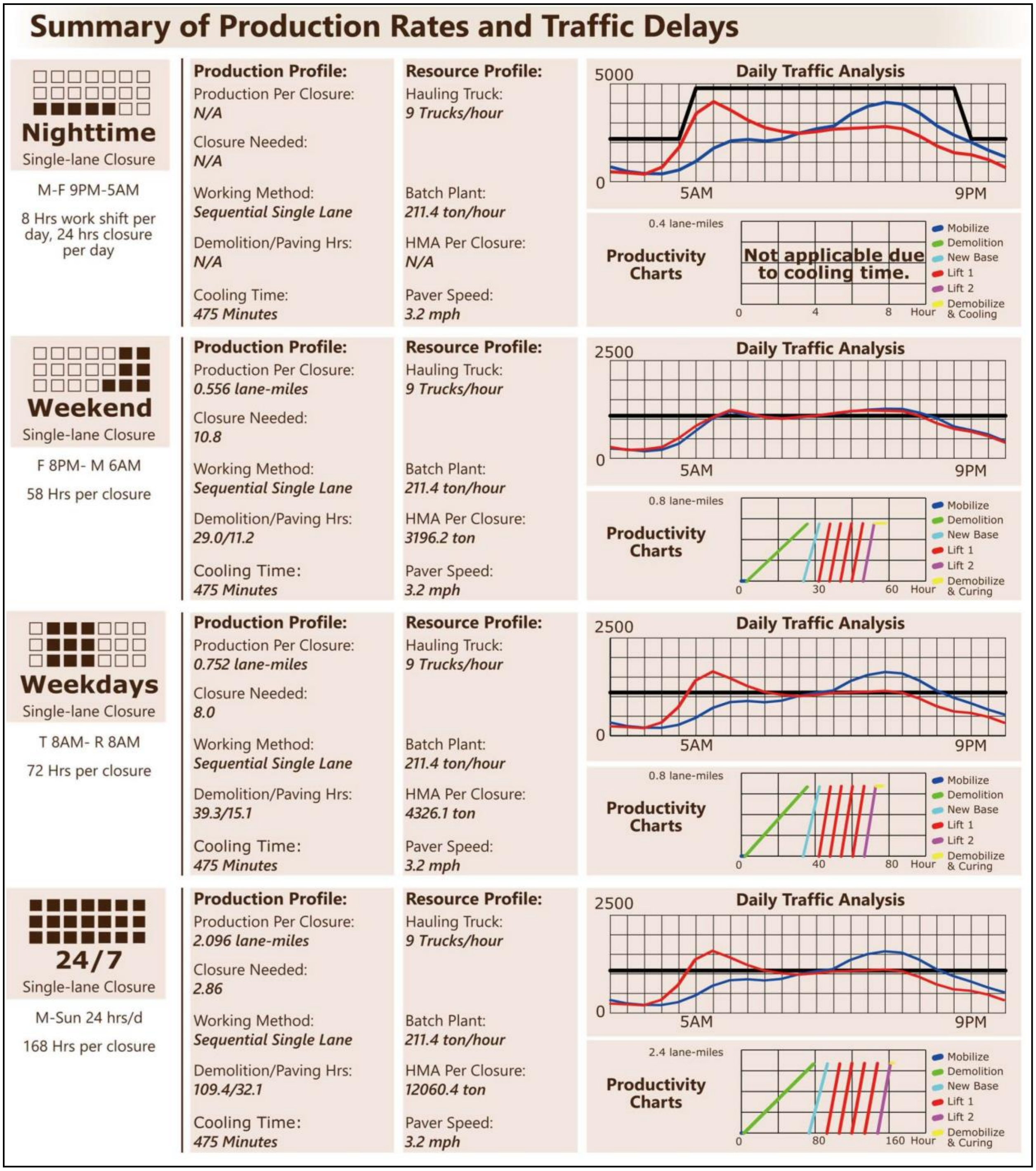


Figure 79. SH 6 CA4PRS Summary Page 10.

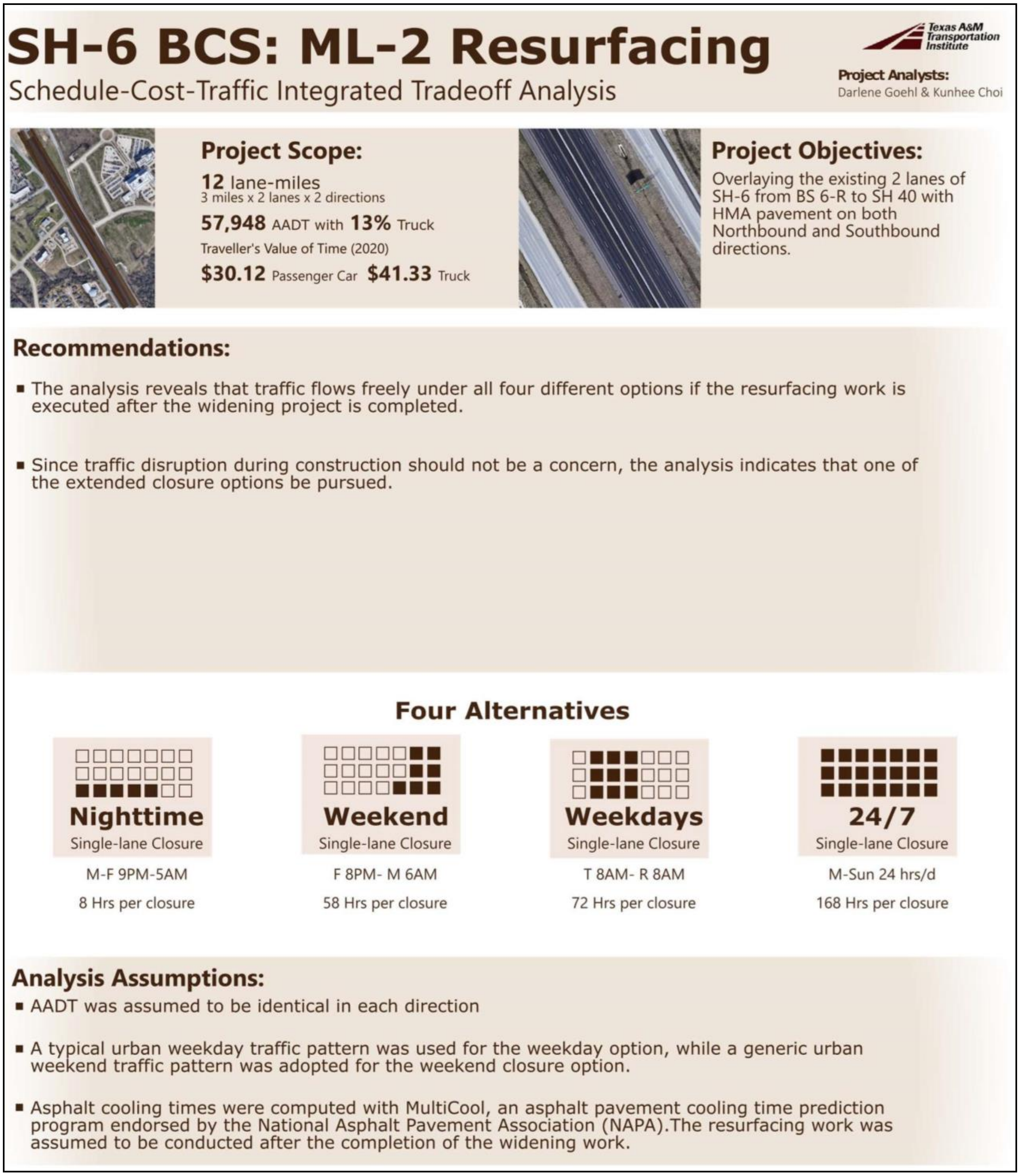


Figure 80. SH 6 CA4PRS Summary Page 11.

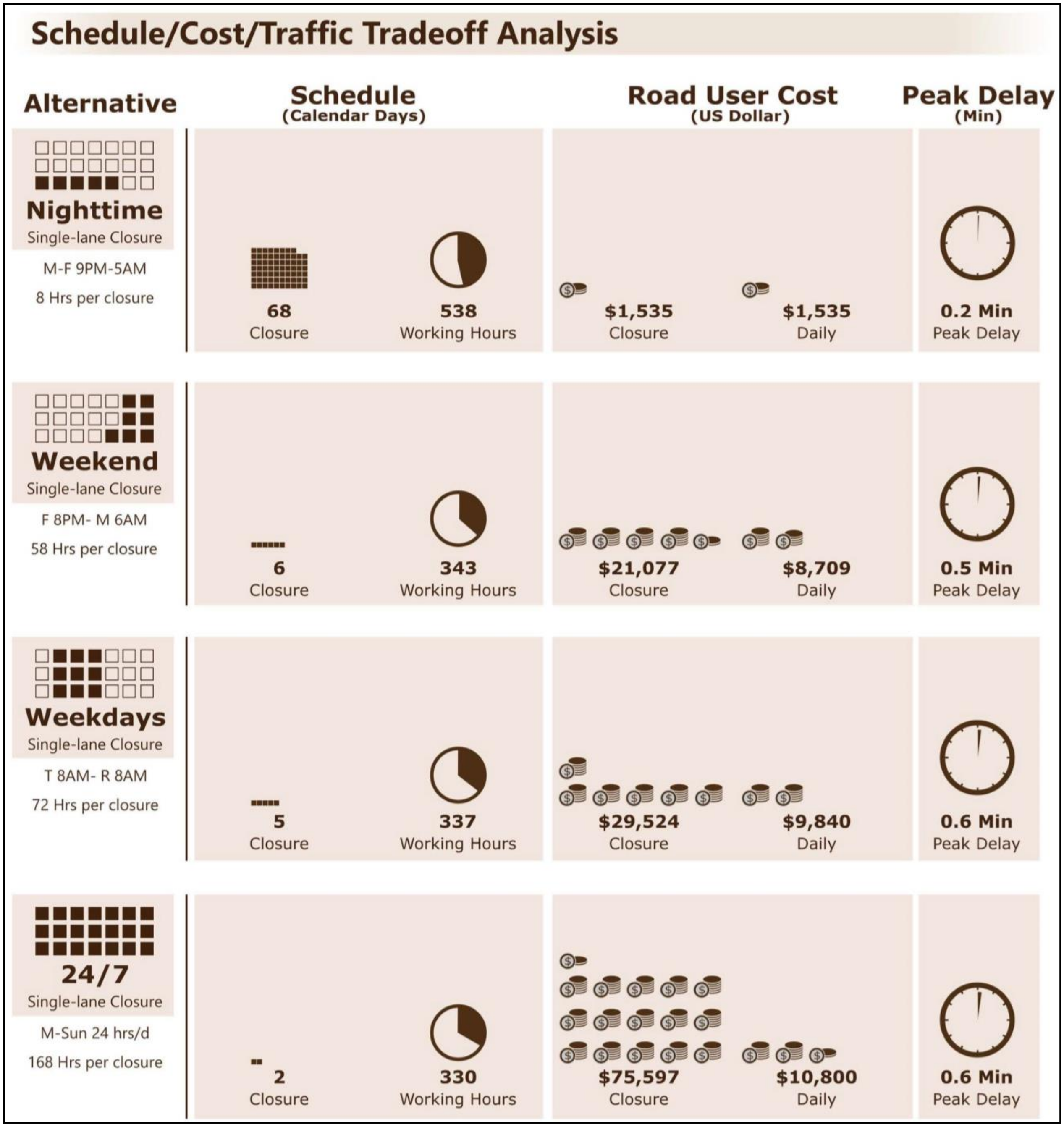


Figure 81. SH 6 CA4PRS Summary Page 12.

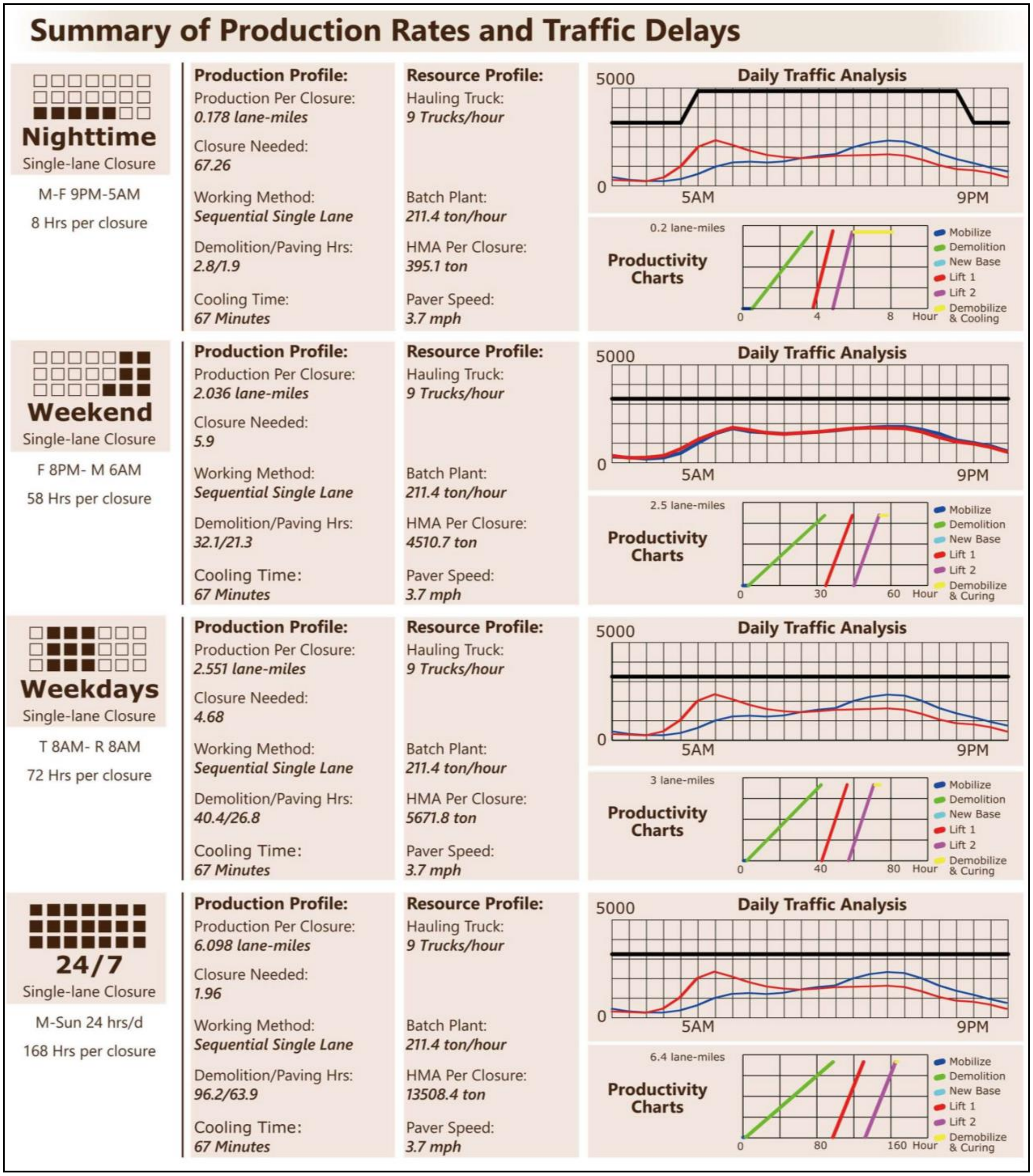


Figure 82. SH 6 CA4PRS Summary Page 13.

SH 6 SUMMARY

The following is a summary of the pavement recommendations assuming that the proposed geometry allows for reuse of the existing pavement (see Figure 83):

- Mainlane.
  - Use a rigid pavement section for any areas that need to be fully reconstructed.
  - From BS6-R to SH 40:
    - The existing pavement is in good structural condition; however, the shoulder requires an overlay. Overlay MLs and shoulders with 3 inches of hot mix and widen to match the existing structure.
    - Widen to the outside.
  - From BS6-R to SH 21:
    - Use the existing ML pavement as subbase for new concrete pavement.
      - This process will raise the profile approximately 13 inches, which would be a problem for vertical clearance of the overpasses.
    - Treat or reconstruct flexible shoulders to hold detoured traffic and to be used as CTB subbase for the new concrete pavement.
    - Widen to the inside.
- Frontage road.
  - Use a rigid pavement section for any areas that need to be fully reconstructed.
  - The FR pavement is also in good structural condition except for approximately 2 mi on the SB side from SH 21 to Water Locust Street.
    - For SB2, SB3, and NB1, overlay with 2 inches of hot mix.
    - For SB1, SB4, and NB2, mill and inlay the surface or overlay.
  - Reconstruct/rehabilitate the SB section from SH 21 to Water Locust Street (SB1 spot repairs).
- All types.
  - Ensure that all flexible surfaces are PG 76-22 with SAC A aggregate for both the ML and FRs.

The ML removal cost is estimated at $6,571,900. The replacement subbase construction cost would be $26,903,800, for a total potential savings on the ML of $33,475,700. This would also result in up to 19 months of time impact to the traveling public. Additional savings in cost and time can be found by retaining the structurally sound FR pavement and flexible ML pavement.

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.	$15.70/sy
FR-SB1, SB4 & NB2	No additional structure is required. Replace Surface Layer.	Match pavement section.	$18.10/sy
FR-SB1 Spot Repairs	FDR raises profile or Full Depth HMA (FDH) can match profile.	Widening cost will be similar to the FDH repair cost.	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).			

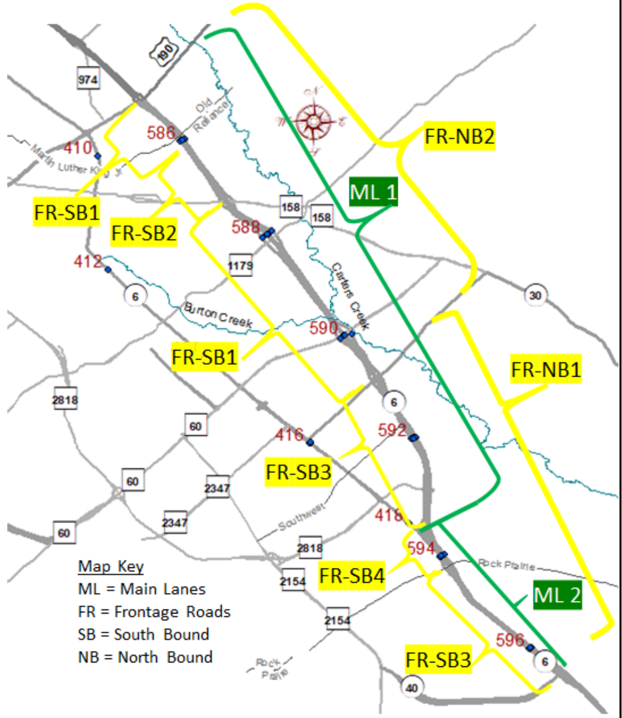


Figure 83. SH 6 Summary.

CHAPTER 7. IH 45 IN THE HOUSTON DISTRICT

This project showcases how CA4PRS can help the agency make critical decisions for urban projects with extremely high traffic volumes. The scope of the project was to reconstruct a critically deteriorated 1.5-mi section of IH 45 in Houston, Texas. The work zone impacted was one of the busiest highways in the United States, with an AADT of approximately 250,000, approximately 5 percent of which were heavy trucks.

The research team was tasked with evaluating the traffic impact and determining the appropriate workdays and daily I/D amount for four alternatives: nighttime, weekends, 24/7, and 24/7 with a quick-change movable barrier (QMB) system. The CA4PRS system was used to determine contract time, an effective and reliable B value for the A+B bidding, and daily road user costs.

Step 1 through 6 of CA4PRS were followed to analyze the schedule, road user costs, and peak traffic delays for each alternative. Based on the results (see Figure 84), TTI recommended nighttime construction because the other three options would cause intolerable traffic delays. The results also quantified and strongly supported the effectiveness of the QMB system for reducing traffic delays and road user costs in projects with high traffic volumes. If the agency's main goal was to minimize the public inconvenience by completing the project in the most expeditious manner possible, 24/7 construction with the QMB system would be recommended, with implementation taking place during a summer holiday break time. In this case, the benefit of using the QMB system outweighed the additional cost of deploying it.

Texas A&M Transportation Institute

Project Analyst: Darlene Goehl & KC Choi

IH-45 Project

Schedule/Cost/Traffic Integration Analysis

Project Scope:

2.625 lane-mile
1.5mi x 12'/12' for SB + 1.5mi x 9'/12' for NB

AADT = 248,000 with 5% Truck

Value of Time (2014 TTI report)
$21.73 passenger cars $31.71 trucks

Project Objectives:

Reconstruct a badly deteriorated 1.5-mile slot stitching section of north and southbound main lanes on the IH-45 corridor with 8″ full-depth CRCP.

Recommendation:

- Given the unprecedentedly high AADT, it is recommended that the ***nighttime*** strategy be adopted, as traffic delay on other three alternatives is intolerable.
- If the agency's main goal is to beat the clock in a viable way to minimize public inconvenience, ***24/7 around-the-clock operation with a dynamic lane configuration (#4)*** can be implemented during a summer holiday break. Further, it clearly shows that the additional cost of using a QMB* system is outweighed by the savings achieved from reduced road user delay costs, compared to 24/7 *alternative #3.*

*QMB: Quickchange Movable Barrier (QMB) system

Alternative	Schedule Comparison: Closure Hours	Schedule Comparison: Total Closure	Road User Cost ($Million): Daily RUC	Road User Cost ($Million): Closure RUC	Max. Peak Delay (Min): NB	Max. Peak Delay (Min): SB
Nighttime	1,096	137	0.3*	0.1**	5	46
Weekend	192	3.4	16.0	38	536	550
24/7	118	0.7	19.0	155	645	612
24/7 QMB	118	0.7	7.8	96	456	315

* 24 hours ** 8 hours

Figure 84. Best Use Case 3: Integrated Schedule–Cost–Traffic Analysis Highlights.

CHAPTER 8. CONCLUSIONS

Evaluating the existing pavement and roadway conditions is essential in the design for accelerated pavement construction.

NON-DESTRUCTIVE TESTING TOOLS AND TECHNIQUES

The goal of accelerated construction is to minimize construction zone impacts to the driving public. Current guidelines focus on high-profile projects for accelerating construction, but performing a pavement evaluation and design can lead to methods that accelerate construction for almost all projects. Following methods that develop a testing and sampling plan and then evaluating pavement design strategies can lead to routinely selecting pavement design strategies that are also fast to construct. TxDOT should implement these tools and techniques to assist with pavement evaluation and design for all pavement projects. In addition, TxDOT should continue to improve current practices and develop innovative tools and technologies.

TRAFFIC CONTROL

The survey responses indicate that there is not a formal process used within TxDOT to develop and review the construction schedule time determination developed for the PS&E. It is concerning that production values used in 1992 [17] are in many cases higher than those used in 2020 [4] to estimate working days; for example, hot mix in 1992 was estimated at 2,000 tons per day verses 1,250 tons per day in 2020. A formal process should be developed that includes development of construction time schedules and review. Additional training is needed to help designers develop realistic schedules that include an evaluation of the traffic control timing strategies.

FUTURE RESEARCH AND IMPLEMENTATION

TxDOT should investigate new and innovative tools and technologies for non-destructive pavement testing and evaluation; develop procedures to estimate construction schedules including traffic control strategies and improvements to scheduling software; and continue to develop practices and new innovative methods to assist with accelerating pavement construction.

Conducting training workshops based on the material developed in this study is recommended to help designers develop a testing and sampling program. In addition, TxDOT should develop training workshops to help designers evaluate the traffic control timing strategies and develop realistic schedules.

APPENDIX. VALUE OF RESEARCH

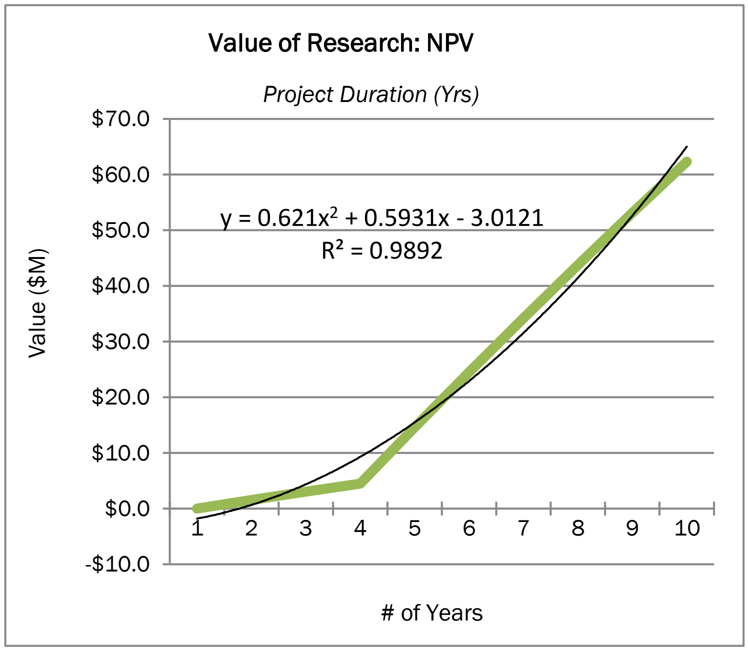
VALUE OF RESEARCH: QUALITATIVE VALUE

Benefit Area	Qualitative	Economic	Both	TxDOT	State	Both	Definition in Context to the Project Statement and Value
Level of Knowledge	X			X			This project will significantly increase TxDOT's understanding and knowledge of the use of NDT equipment and construction analysis software to identify time and construction scheduling cost savings.
Environmental Sustainability	X				X		Characterization of existing material helps increase possibility of recycling and a reduction in the need for new materials. Reduced delay times can positively affect air quality by reducing overall low-speed emissions from vehicles.
Expedited Project Delivery		X		X			Accelerate construction time and reduce project cost by using existing pavement structure.
Traffic and Congestion Reduction		X			X		Reduced construction time reduces exposure to work zones, and interim conditions will lead to fewer traffic impacts to the traveling public.
Reduced User Cost		X			X		Reduced construction time reduces exposure to work zones and interim conditions that can be a risk to the traveling public and TxDOT employees.
Reduced Construction, Operations, and Maintenance Cost		X			X		Accelerated projects using existing material compared to reconstruction using all new material will reduce construction cost. NDT evaluation will provide data to support pavement design strategies that reduce operation and maintenance costs.
Engineering Design Improvement			x			x	The methods developed to predict delay times based on pavement construction will help improve engineering design accuracy.
Safety			X			X	Reduce risks to the traveling public passing through the work zones and construction workers working in the work zones due to reduced construction exposure times.

VALUE OF RESEARCH: QUANTITATIVE VALUE

Agency:	TTI	**Project Budget**	$ 480,843
Project Duration (Yr)	3	**Exp. Value (per Yr)**	$ 11,304,286
Expected Value Duration (Yr)	10	**Discount Rate**	2%
Economic Value			
Total Savings:	$ 61,841,030	**Net Present Value (NPV):**	$ 62,321,873
Payback Period (Yr):	2.2	**Cost Benefit Ratio (CBR, $1 : $___):**	$ 130
		Return on Investment (ROI, $1 : __):	$ 150.13

Years	Expected Value
0	$0
1	$0
2	$1,614,898
3	$1,614,898
4	$1,614,898
5	$11,304,286
6	$11,304,286
7	$11,304,286
8	$11,304,286
9	$11,304,286
10	$11,304,286



Variable Justification

For FY18 to FY21 lettings, construction projects were filtered to remove RMC and PM type projects. For the remaining projects, the average barricade months was 14 with 17 working days/month: average construction cost of $8,100,000. Based on Item 4.6.2, the average project overhead is $34,898/month. The removal of the existing pavement is estimated at 2% of the construction cost, and the replacement of that material into the new pavement structure is estimated at 18% of the construction cost, for a total of $1,580,000. Assume year 2 through year 4 save a minimum of 1 month on demonstration projects (expect more, however; this is a conservative estimate) plus the pavement removal and replace costs is $1,614,898 per project. Year 5 to 10 save 1 month plus pavement removal and replace costs on 10% of the projects let (used 70 projects based on similar contracts currently under construction). Note: Regarding the ability to use existing pavement decrease removal time, the estimated removal is 1 (38' wide) roadbed mile/month. For the SH 6 case study, savings were estimated at up to $31,000,000 in pavement cost alone.

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