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EVALUATION OF CONSTRUCTION STRATEGIES FOR PCC PAVEMENT REHABILITATION PROJECTS

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16. ABSTRACT

This study investigated project management level solutions to optimizing resources, minimizing costs (including user costs) and time for PCC pavement rehabilitation projects. This study extensively evaluated the applicability of the Construction Analysis for Pavement Rehabilitation Strategies (CA4PRS) software program as a potential solution to achieve the goal. The usability of the CA4PRS was assessed by conducting knowledge inventory surveys at GDOT and ODOT as well as conducting four case studies. The pre and post knowledge inventory surveys indicated that there was a general understanding that the CA4PRS could be used as an excellent tool to help decision makers effectively plan PCC pavement rehabilitation projects. The four case studies indicated that, in addition to using the CA4PRS, there should be further efforts in order to develop an effective construction plan for a PCC pavement rehabilitation project. Some major recommendations are a) ODOT/GDOT must put efforts to collect CA4PRS input data and develop a database for reliable analysis using the CA4PRS, b) ODOT/GOT also need to use the CPM scheduling method and the CA4PRS together because the current CA4PRS considers only six major activities in project scheduling, c) A simulation program such as the Cyclone program can be used to determine the optimal number of resources of major activities. Based on the findings of this study, this project has designed an improved planning procedure to find the most efficient project phasing and closure scenario for PCC pavement rehabilitation projects. The procedure involves a quantitative analysis on every potential project execution scenario using the CA4PRS, the CPM method and a simulation tool.

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SI (METRIC) CONVERSION FACTORS

Approximate Conversions to SI Units					Approximate Conversions from SI Units				
Symbol	When you know	Multiply by	To Find	Symbol	Symbol	When you know	Multiply by	To Find	Symbol
		LENGTH					**LENGTH**		
in	inches	25.40	millimeters	mm	mm	millimeters	0.0394	inches	in
ft	feet	0.3048	meters	m	m	meters	3.281	feet	ft
yd	yards	0.9144	meters	m	m	meters	1.094	yards	yd
mi	miles	1.609	kilometers	km	km	kilometers	0.6214	miles	mi
		AREA					**AREA**		
in^2	square inches	645.2	square millimeters	mm	mm^2	square millimeters	0.00155	square inches	in^2
ft^2	square feet	0.0929	square meters	m^2	m^2	square meters	10.764	square feet	ft^2
yd^2	square yards	0.8361	square meters	m^2	m^2	square meters	1.196	square yards	yd^2
ac	acres	0.4047	hectares	ha	ha	hectares	2.471	acres	ac
mi^2	square miles	2.590	square kilometers	km^2	km^2	square kilometers	0.3861	square miles	mi^2
		VOLUME					**VOLUME**		
fl oz	fluid ounces	29.57	milliliters	mL	mL	milliliters	0.0338	fluid ounces	fl oz
gal	gallons	3.785	liters	L	L	liters	0.2642	gallons	gal
ft^3	cubic feet	0.0283	cubic meters	m^3	m^3	cubic meters	35.315	cubic feet	ft^3
yd^3	cubic yards	0.7645	cubic meters	m^3	m^3	cubic meters	1.308	cubic yards	yd^3
		MASS					**MASS**		
oz	ounces	28.35	grams	g	g	grams	0.0353	ounces	oz
lb	pounds	0.4536	kilograms	kg	kg	kilograms	2.205	pounds	lb
T	short tons (2000 lb)	0.907	megagrams	Mg	Mg	megagrams	1.1023	short tons (2000 lb)	T
		TEMPERATURE (exact)					**TEMPERATURE (exact)**		
°F	degrees Fahrenheit	(°F-32)/1.8	degrees Celsius	°C	°C	degrees Celsius	9/5+32	degrees Fahrenheit	°F
		FORCE and PRESSURE or STRESS					**FORCE and PRESSURE or STRESS**		
lbf	poundforce	4.448	Newtons	N	N	Newtons	0.2248	poundforce	lbf
lbf/in^2	poundforce per square inch	6.895	kilopascals	kPa	kPa	kilopascals	0.1450	poundforce per square inch	lbf/in^2

EVALUATION OF CONSTRUCTION STRATEGIES FOR PCC PAVEMENT REHABILIATION PROJECTS

Final Report

September 2010

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EXECUTIVE SUMMARY

Most highways in the United States were built during the 1960s and 1970s and have exceeded their design lives. Most transportation departments have turned their focal activities from the expansion of the highway system to maintaining, preserving, and rehabilitating the existing road network. With increasing needs of pavement maintenance projects, there is a need for better management strategies for these high demand projects in the nation.

This study investigated project management level solutions to optimizing resources, minimizing costs (including user costs), and reducing time for Portland Cement Concrete (PCC) pavement rehabilitation projects. This study extensively evaluated the applicability of the Construction Analysis for Pavement Rehabilitation Strategies (CA4PRS) [22] software program as a potential solution to achieve the goal. The usability of the CA4PRS was assessed by conducting knowledge inventory surveys at GDOT and ODOT as well as conducting four case studies (I-35 and I-40 projects in Oklahoma, I-75 and I-20 projects in Georgia).

The pre- and post-knowledge inventory surveys indicated that the CA4PRS could be used as an excellent tool to help decision makers effectively plan PCC pavement rehabilitation projects. Four case studies indicated that CA4PRS would be able to forecast project duration with a high level of accuracy for routine rehabilitation projects. However, in addition to using the CA4PRS, there should be further efforts in order to develop effective construction plans for various types of PCC pavement rehabilitation projects due to some practical shortcomings of the CA4PRS.

The output of the CA4PRS is highly dependent upon the input information, which includes resource profile information, mobilization/demobilization durations, lead/lag times and construction windows. However, there is currently no standard data collection system available for these input data in ODOT/GDOT. Some necessary improvements for the CA4PRS include a) a function to quantify the effect of queuing of resources in the input information, b) a resource utilization and allocation table for better resource management by contractors and c) a function to calculate the optimum number of resources required to maximize the production rate.

The following recommendations have been made for ODOT/GDOT to develop an effective construction planning for PCC pavement rehabilitation projects; a) ODOT/GDOT must put efforts to collect CA4PRS input data and develop a database for reliable analysis using the CA4PRS, b) ODOT/GOT need to use both the Critical Path Method (CPM) scheduling method and CA4PRS because the current CA4PRS only considers six major activities in project scheduling. The effects of other activities on project schedule must be studied with the CPM method, c) a simulation program such as the Cyclone program [29] can be used to determine the optimal number of resources of major activities. The input data for the resource profile tab in the CA4PRS can be generated using a simulation program.

Based on the findings of this study, this project has designed an improved planning procedure to find the most efficient project phasing and closure scenario for PCC pavement rehabilitation projects. The procedure involves a quantitative analysis on every potential project execution scenario using the CA4PRS, the Cyclone simulation tool, and the CPM method.

CHAPTER I
INTRODUCTION

1.1 OVERVIEW

The American Society of Civil Engineers (ASCE) estimates that $2.2 trillion is needed over a five-year period to bring the nation's infrastructure to a good condition (grade B) [1]. Among the infrastructure systems that need capital investment, America's road condition has been graded D. On the other hand, the current spending level of $70.3 billion per year for highway capital improvements is well below the estimated $186 billion needed annually. Poor road conditions cost motorists $67 billion a year in repairs and operating costs, $78.2 billion a year in traffic wasted time costs, and 14,000 Americans their lives [1]. Pavement conditions data in Oklahoma is also alarming. An estimated 40% of Oklahoma's major roads are rated in poor or mediocre condition [1]. Driving on roads in need of repair costs Oklahoma motorists $969 million a year in extra vehicle repairs and operating costs [2].

Most highways in the United States were built during the 1960s and 1970s and have exceeded their design lives. Most transportation departments have turned their focal activities from the expansion of the highway system to maintaining, preserving, and rehabilitating the existing road network. With increasing needs of pavement maintenance projects, there is a need for better management strategies for these high demand projects in the nation.

Unlike new road construction, preservation/rehabilitation projects interrupt the flow of existing traffic in the road networks. Depending on the type of interruption the road may be closed fully or partially which causes delays and extra fuel consumption. This problem is maximized when the project is inside an urban network with high average daily traffic (ADT). Because of these unique features of preservation/rehabilitation projects, design and implementation of the projects are complicated, since the increase of project duration may cost road users times, and safety. Therefore, transportation departments need to recognize the impacts of preservation/rehabilitation activities in the planning stage before construction activities. This allows for appropriate cost-effective mitigation strategies to be developed and implemented prior to delays occurring [3].

Designing a preservation/rehabilitation project is a critical process for which different conflicting objectives should be fulfilled. There must be an effective process which assesses all the possible scenarios and solutions for specific situations in order to find the best fitted answer to the question of improving the efficiency of projects. This cannot happen without a robust planning and staging system in the departments of transportation. This system should be able to develop the most optimum preservation/rehabilitation solution by comparing different possible scenarios.

When considering pavement rehabilitation strategies for roads, concrete may be excluded as an option due to its effects on constructability and staging. This limitation may be overcome with the awareness of methods that have proven successful elsewhere, with the potential of implementing them. In a recent Transportation Research Board report, potential research in the application of information technology to the design and construction of highways has been identified as a key opportunity for administrators, engineers, and practitioners in their quest for improving construction delivery [4].

In order to address the planning issues of preservation/rehabilitation projects the Federal Highway Administration (FHWA) updated federal regulations governing safety and mobility in work zones: Rule 23 Part 630 Subpart J on September 9, 2004 [5]. The regulation requires the implementation of project-level procedures to assess and manage the impacts of highway construction projects. For each project, the regulation calls for development, as part of the Plans Specifications and Estimates (PS&E), of a Traffic Management Plan which considers tools for reducing traffic delay caused by construction.

Therefore, there is a need to study successful planning and staging methods and analyze their applications to pavement preservation/rehabilitation projects. Implementing these staging and planning strategies will assist transportation departments to develop a construction planning scenario which has the least negative impact to the traveling public.

1.2 RESEARCH OBJECTIVES

This study aims to develop construction planning and staging methods that can be implemented in future Portland Cement Concrete (PCC) pavement rehabilitation projects. It seeks to find project management level solutions to optimizing resources, minimizing costs (including user costs) and time for PCC pavement rehabilitation projects by investigating the applicability of the Construction Analysis for Pavement Rehabilitation Strategies (CA4PRS) computer model for pavement reconstruction projects. This study is a collaborative work between Oklahoma State University and Georgia Institute of Technology.

The objectives of this study are:

- To identify current construction staging and planning procedures of the Oklahoma (ODOT) and the Georgia (GDOT) department of transportation.
- To evaluate current staging and planning procedures by studying case projects in Oklahoma and in Georgia.
- To compare the scheduling methods used by the ODOT and the GDOT and the techniques built in CA4PRS.
- To develop construction planning and staging methods that can be implemented in future PCC pavement rehabilitation projects in Oklahoma and Georgia.

1.3 RESEARCH METHODOLOGY

Figure 1.1 shows the relationship between objectives and research tasks. The following research tasks are performed to accomplish the research objectives.

Literature Review

A comprehensive literature review is performed regarding the planning issues of PCC pavement rehabilitation projects and staging and planning procedures.

Study the Planning Procedure of ODOT/GDOT

The current procedure of ODOT/GDOT in planning PCC pavement rehabilitation projects is analyzed and the responsibilities of different departments are explained.

Interview with ODOT/GDOT Engineers and Contractors

The most valuable information regarding PCC pavement rehabilitation projects can be acquired from ODOT/GDOT engineers and contractors. This step consists of interviews with ODOT/GDOT engineers, consultants, and contractors in order to assess the current practices of planning and construction of PCC pavement rehabilitation projects.

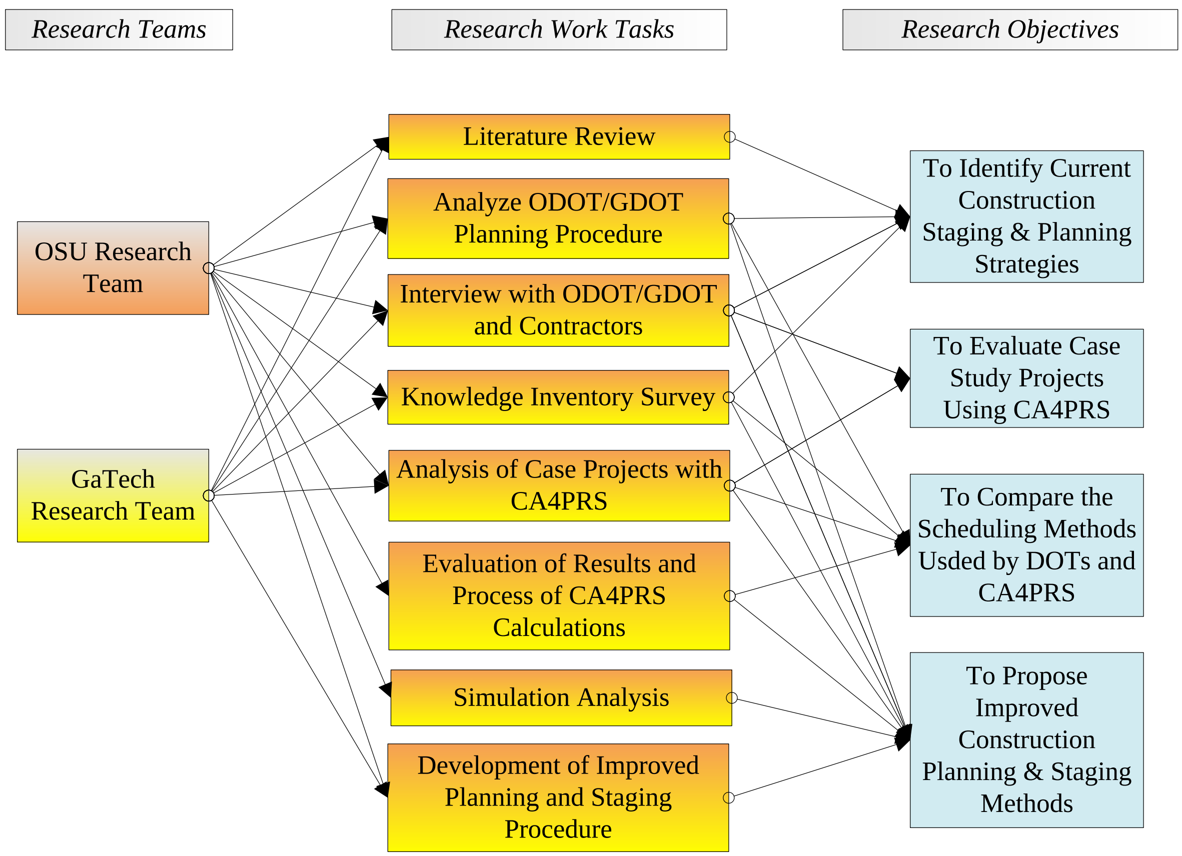


Figure 1.1 Research Objectives and Research Work Tasks

Knowledge Inventory Survey

The potential usability of CA4PRS in ODOT/GDOT is evaluated by conducting a survey before and after CA4PRS workshops.

Case Studies

Two major rehabilitation projects in ODOT and two major rehabilitation projects in GDOT are studied as case study projects. Construction data such as resource constraints and scheduling aspects are collected by visiting the project sites. A computer software program, developed by Dr. Eul-Bum Lee at the University of California at Berkeley, is utilized to perform scheduling and traffic analysis. Currently, Caltrans uses this software to determine schedule, cost, and traffic of concrete pavement rehabilitation projects during the design stage [6].

Comparison Study

After conducting the case studies, the results of the CA4PRS analysis are compared with ODOT and GDOT construction plans. Then the potential areas of improvement in the current planning and staging procedures are identified.

Evaluation of CA4PRS Calculations

The process of CA4PRS calculations is explained and the key input data is identified and studied in more details. A simulation model is developed to improve construction resource analysis in C4PRS.

Recommendations

A set of recommendations is developed for ODOT/GDOT to improve the efficiency of current planning procedures.

1.4 ORGANIZATION OF THE REPORT

This report starts with a literature review in the second Chapter. The CA4PRS scheduling procedure is explained by using an example project in the third chapter. In the fourth chapter, the current planning and design procedures of ODOT and GDOT are discussed. In the fifth chapter, the survey analysis is discussed and case projects are analyzed with CA4PRS. Chapter six discusses the planning procedures for pavement rehabilitation projects. Chapter seven summarizes the findings of the project.

CHAPTER II
LITERATURE REVIEW

This chapter summerizes prior studies on work zone management, closure scenarios, rehabiliation costs, and work zone simulation tools, which are critical components in developing construction and phasing plans for pavement rehabilitation projects.

2.1 WORK ZONE MANAGEMENT

Work zone is an area in which one or more lanes of a road are closed to the traffic for construction purposes and the capacity of road decreases accordingly. This makes backups and queues in the work zone which needs to be managed to have the least impact to the traveling public. In this section, two work zone management approaches are discussed.

Work zone management strategies are used to minimize traffic delays, improve mobility, maintain or improve motorist and worker safety, complete roadwork in a timely manner, and maintain access for businesses and residents [7]. Various work zone management strategies can be described as below [7]:

a) Temporary traffic control (TTC): i) Control strategies, ii) Traffic control devices and iii) Project coordination, contracting and innovative construction strategies,
b) Public information (PI): i) Public awareness strategies and ii) Motorist information strategies,
c) Transportation operations (TO): i) Demand management strategis, ii) Corridor/network management (traffic operations) strategies, iii) Work zone safety management strategies and iv) Traffic/incident management and information strategies.

Appendix A presents various work zone management strategies by category.

Chu et al. [8] studied the effects of automated work zone information system (AWIS) on traffic safety and diversions. AWIS consists of traffic data collecting devices to monitor traffic conditions, changeable message signs to display traffic information, and a server computer to calculate estimated travel times in the designed algorithm [9]. AWIS updates travelers with real-time information on the highway. AWIS may be implemented at a work zone to notify approaching motorists of changing traffic conditions, such as slowdowns or backups. The purpose of AWIS in rehabilitation projects is to make the work zone a safer area for motorists and to reduce traffic demand to make queue and backups as minimum as possible. The methodology of studying safety effects was the measure of effectiveness which is the number of collision accidents. A survey was performed on the passengers who had diverted their route. It showed that 78% of motorists diverted to avoid the traffic, 99% of them saw messages and 78% of who saw the messages changed their route. Also 63% of the motorists believed that messages were useful for taking alternative routes. They concluded that AWIS has effect on traffic smoothness and helps to increase safety. It also helps the motorists to take better decisions for diverting and choosing other routes.

Work zone intelligent transportation system (WZITS) is the application of state of the art technology to provide real time traffic information which can be used to improve transportation system operations. WZITSs often take the form of mobile, portable traffic monitoring and management to provide information to motorists to help with route choice, provide advance warning of slowed or stopped traffic, and ease overall frustration due to not knowing what to expect [10]. These systems usually integrate portable changeable message signs and speed sensors with a central control system that automatically determines appropriate messages that are based on current traffic condition. WZITSs are prompted as a way to improve safety and reduce congestion at a work zone location where traffic management centers do not exist. Traffic management center is the hub of communication resources where the operators are able to detect and assist in the handling of traffic [11].

Fontaine [11] has suggested some guidelines in his study for transportation agencies to decide whether WZITS is appropriate for the site or not. Before an agency chooses to install a WZITS at a work zone, the agency should reasonably expect that the system will improve operations or safety at the site. The most basic prerequisite for installing WZITS is that congestion be present at the site for at least some part of the day. If no congestion occurs at the site, the WZITS will not display any messages and will not produce any benefits. A WZITS probably will be most effective when the length of queue, and travel time through the work zone are variable from day to day. It should be used on long term construction or maintenance projects because the system is expensive and it takes considerable amount of time to be installed and configured. If no alternate route exists, the WZITS may not provide significant benefits. In these cases, drivers will be aware of the time to travel through the work zone, but they will have no options for reducing trip time. Operational tests in Maryland, Iowa, Kentucky, Nebraska, Illinois and Ohio indicates no documented proof of the operational or safety impact of WZITSs. The reasons are attributed to technological problems of early systems, unsuitable sites for application of WZITSs system and lack of attention of research team to collecting operational measures of effectiveness. Additional deployments are needed to determine the potential impact of these systems and to define conditions in which the WZITS may provide a benefit at a work zone. The study reported that work zone management techniques are necessary to decrease traffic delays and increase safety. However, these techniques are more effective in urban highways since traffic demand reduction is dependent on availability of alternative routes. There is no clear evidence to show that using WZITSs compensate its application costs by reducing queue length, delay or by increasing safety yet. This study shows there is still lack of a unique and standard procedure for using WZITSs in the rehabilitation projects.

Lee et al. [12] conducted a case study on the I-15 rehabilitation project. This project was on I-15 in Devore, California, where about 9 lane-km of deteriorated truck lanes were rebuilt during two (one for each direction) 9-day periods using extended one-roadbed full-closures, the counterflow traffic system, and continuous (24h per day until completed) construction operations. The goal of the case study was to use AWIS and public outreach using the Internet in order to measure the effects on traffic demand through the construction work zone (CWZ), and to evaluate road user cost savings accordingly. Caltrans required more traffic demand reduction than the standard value in Highway Capacity Manual (nominal 10% traffic reduction). Therefore, Caltrans implemented a proactive public outreach program to encourage more road user "no shows", travel pattern changes and diversions to detours [12].

The measurement of CWZ traffic impact showed that the average daily traffic for I-15 SB decreased by 19%, and the ADT for I-15 NB decreased by 16% during weekday closures [12].

This traffic reduction caused the weekday peak-hour traffic delay through the CWZ to be reduced from 90 to 50min. The traffic flow on the neighboring freeways before, during and after construction shows about 13% increase in ADT because of traffic that detoured from I-15 [12].

A benefit-cost analysis of AWIS indicated $3.6 million saving compared to the 10% traffic reduction calculated by the highway capacity manual. Three surveys of passengers before, during and after the project showed that after performing AWIS, the percentage of passengers who changed their route increased from 19% to 32%. It also showed a change in public opinion about the extended continuous closures. In the initial survey, the public showed a great deal of reluctance about the extended closures, with 56% of the survey respondents preferring weekend or night time closures rather than extended continuous closures. In the final survey, however the support for extended continuous closures rose to %70. This can be related to the fact that a successful work zone traffic management may change public perceptions of non-traditional rehabilitation scenarios such as extended closures [12].

The cost of using work zone management systems can be negligible compared to the savings on road user costs. Since different locations have different characteristics such as ADT, number of diversion routes, and behavior of passengers, the work zone management needs to be designed based on the specific needs of each project.

2.2 CLOSURE SCENARIOS

A closure scenario defines the duration and type of road closure and is developed based on the construction schedule, traffic impacts, and agency cost. The four major cloure scenarios are 72-hr weekday, 55-hr weekend, one roadbed continous (24 hr per day, seven days per week), and 10-hr nighttime.

Hancher and Taylor [13] conducted a survey of three different groups, including state departments of transportation (DOTs), selected Kentucky highway contractors, and the Kentucky Transportation Cabinet (KyTC) resident engineers to evaluate various night time construction issues and asked survey groups to rate the issues according to their importance and relevance. Based on this survey, night work's effect on cost is negative but it has helped to reduce the project duration. Also, the authors confirmed that the main reason for using night work was high daytime traffic levels. The critical factors in closure scenario selection are traffic-related parameters, construction-related parameters, social parameters, economic parameters, environmental parameters, cabinet issues, and legal issues. For more details regarding the factors affecting night time construction please see Appendix B. Finally, one can grade each item based on each specific site condition and a group of experts can weigh each item and evaluate and decide whether or not the project is a good candidate for night time construction. This study was based on a survey of different DOTs and did not perform any analysis to compare the productivity of nighttime closure scenarios [14].

Dunston et al. [13] compared nighttime closure scenario and weekend closure scenario in terms of production rate and quality. The authors concluded the overall level of quality for the weekend closure overlay was good with respect to smoothness, to density gradation, and to cyclic segregation. Also compared to historical data for in-place density and gradation from the Washington State DOT, the quality of the project was decidedly better than the average. Weekend closure yielded a higher production rate than only night time closure. Also, the survey of selected State Highway Agencies showed the partial nigh time closure was still the most popular strategy for minimizing highway reconstruction impacts to the public. On the other hand, weekend closure had more impact on public compared to night time closure but because of higher production rate its duration tends to be shorter.

Lee et al. [15] performed extensive research on improving pavement rehabilitation performance and production rate. They compared the weekend closure window with continuous closure. The continuous closure and continuous operation enables the crack seat overlay (CSOL) project to be finished 15% faster than weekend-only projects. Also full-depth Asphalt Concrete (AC) replacement project is finished 10% faster. However, continuous closure and continuous operation may not be realistic for many projects because of weekday traffic interruptions as well as additional costs, noise problems for nearby residents, and logistics [15].

Lee et al. [15] compared construction production rates of 7-h and 10-h night time closure scenario with 55-hr weekend closure for I-10 project. They concluded that in terms of the number of slabs replaced per hour, the 55-hr weekend closure was 54% more productive than the average nighttime closure. Concrete delivery and discharge at the site were constraining factors. Traffic volumes through the construction were reduced by 30-60% compared to the peak traffic during typical weekends. The percentage of traffic diverted to other routes doubled during the 55-h weekend closure during the daylight hours, while it was approximately 5% more than normal during the nighttime hours [15].

The research studies indicate the traditional nighttime closure scenario is not always the best decision for PCC pavement rehabilitation projects. Innovative closure scenarios like weekend closure and continuous closure have shown to be more productive than traditional strategies. One of the negative aspects of daytime closure scenarios isconstruction during the peak hours of traffic. This can be compensated by higher production rates during daytime closure scenarios.

2.3 REHABILITATION COSTS

One of the main factors which DOTs and contractors pay special attention to is the cost of PCC pavement rehabilitation projects. Compared to the importance of this issue, research studies are limited and more studies need to be performed to fill the gaps. The following is a summary of important findings on this topic.

The costs of pavement rehabilitation projects are divided into two main categories; direct costs and indirect costs. Direct cost is the agency cost which consists of construction cost plus traffic handling cost, while indirect cost is the road user costs such as delays made to the public because of rehabilitation works. Daniels et al. [16] defines road user cost as the estimated daily cost to the traveling public resulting from the construction work being performed. The cost primarily refers to lost time caused by any number of conditions including: a) Detours and rerouting that add to travel time, b) Reduced roadway capacity that slows travel speed and increases travel time, and c) Delay in the opening of a new or improved facility that prevents users from gaining travel time benefits.

Beg et al. [17] performed a study to develop a life cycle cost analysis (LCCA) procedure of evaluating different pavement types for Texas DOT to find the most economical type of pavement by considering both the agency and road user costs. As the result of this study, TxPTS (Texas Pavement Type Selection) was developed as a computer program to evaluate candidate strategies for pavement projects. This study focused on finding a suitable procedure for comparing different pavement strategies and types in order to find the most economical one while emphasizing that economic evaluations have limitations. Several sources, including the national and Texas surveys conducted for this research, substantiated that although an economic analysis provides a dependable framework for evaluating candidate strategies, the final selection is often affected by considerations that are not explicitly evaluated in such analyses [17].

Another program which supports the application of LCCA is RealCost which was developed by the Federal Highway Administration (FHWA). The software calculates life-cycle values for both agency and user costs associated with construction and rehabilitation. While RealCost compares two alternatives at a time, it is designed to give the pavement engineer the ability to compare an unlimited number of alternatives.

Lee et al. [18] performed a cost analysis for I-15 reconstruction project which compared the total cost of different closure scenarios by calculating agency and road user costs. In addition, the productivity issues together with construction work zone delays and some other qualitative factors were addressed in order to identify the most economical scenario. The CA4PRS was used as the scheduling computer program to calculate the duration of the project for each closure scenario. A demand-capacity analysis was performed to calculate the road user cost. One-time continuous closure emerged to be the most economical closure scenario but 72-h weekday closure was finally chosen as the best closure scenario since one time continuous closure was expected to create an unacceptable level of delay. Also, this study focused on incentive/disincentive calculations which were based mainly on road user cost derived from the traffic analysis [18].

In addition to the agency cost, traffic handling cost, and road user cost, every rehabilitation project has social cost which is related to the impact on the businesses. Closures or traffic demand reductions reduce the number of traveling public significantly. For businesses dependent on highway traffic, the rehabilitation projects can potentially disrupt the flow of customers by making closures or detours. De Solminihac and Harrison (1993) studied the effects of highway rehabilitation on businesses by two approaches. The first included analyzing historical sales data of the businesses located in the area of the construction activities. In the second approach, they interviewed the owners of businesses located along the road being rehabilitated. They concluded that road construction can clearly affect sales of businesses. This study shows that highway agencies can adopt a range of policies, from construction techniques to closely working with adjoining businesses, to mitigate these effects. In order to find the most economical strategy in pavement rehabilitation projects, there should be a method to convert this business impact to social cost. However, this study fell short of developing a method to quantify the effect of closures on businesses [19].

2.4 SIMULATION TOOLS FOR WORK ZONE ANALYSIS

The increasing demand of existing pavement restoration/rehabilitation has created the need for highway agencies to understand and manage the intensity of construction work zone impacts. The results from analyzing work zone impacts can help an agency improve decision-making as well as its overall understanding of the many considerations affecting work zone decisions: mobility, financial, environmental, safety and user costs. Simulation tools for work zone analysis can support the efforts of agencies to conduct work zone analysis [20].

According to the FHWA [21], work zone impacts assessment is the process of understanding the safety and mobility impacts of a road construction/maintenance/rehabilitation project. This constitutes: a) Assessing the likely work zone impacts and developing appropriate work zone transportation management plans (TMPs) during project development and delivery, b) Monitoring the actual impacts of the project and making adjustments to the TMP (if necessary) during project implementation, and c) Conducting performance assessment to track performance, document lessons learned, and identify trends towards overall improvement of work zone policies, procedures, and practices.

Factors that influence the level of impacts caused by a work zone include traffic conditions and characteristics, project characteristics, geographic/physical features, and aspects of the surrounding area (e.g., alternate routes, nearby businesses). The assessment process may involve a high-level, qualitative review of these factors for some projects, and a detailed quantitative analysis using modeling and/or simulation tools for other projects [21].

There are several tools specific to work zone analysis. They include QuickZone, QUEWA-98, and CA4PRS. The following section briefly discusses these programs.

QuickZone is a work zone delay estimation model developed by FHWA Research, Development, and Technology (RD&T) program. QuickZone can help enable the consideration of the work zone impacts of alternate work zone design and mitigation strategies. QuickZone provides analysis options to estimate work zone delays and user costs for different demand patterns and for temporal (seasonal, weekly, daily) and spatial variations of work zone configurations. It can quantify corridor delay resulting from capacity decreases in work zones, identify the impact on delay of alternative construction phasing plans, and support tradeoff analyses between construction costs and delay costs. It can assess the impact of delay mitigation strategies, such as alternate routing, signal re-timing, lane widening, and ramp metering. In addition to estimating work zone delays and user costs, QuickZone also provides a sketch-planning analysis of travel behavioral changes in response to work zones. QuickZone also supports the calculation of work-completion incentives. The software therefore helps highway agencies better phase and stage their construction and maintenance activities [21].

QUEWZ-98 is a microcomputer analysis tool for planning and scheduling freeway work zone lane closures. It analyzes traffic conditions on a freeway segment with and without a lane closure in place and provides estimates of the additional road user costs and of the queuing resulting from a work zone lane closure. The road user costs calculated include travel time, vehicle operating costs, and excess emissions.

Construction Analysis for Pavement Rehabilitation Strategies (CA4PRS) is a computer model intended to estimate the maximum amount (distance) of highway that can be rehabilitated or reconstructed within various closure frames. This model integrates pavement, construction, and traffic related decision-making by balancing numerous constraints such as scheduling interfaces, pavement materials and design, contractor logistics and resources, and traffic operations. When combined with a traffic model, the CA4PRS software can help determine which pavement structures and rehabilitation strategies maximize on-schedule construction production without creating unacceptable traffic delays [22].

Table 2.1 Work Zone Simulation Analysis Software Comparison [23]

	CA4PRS	**QuickZone**	**QUEWZ**
Data Assembly Time (hr)	1 to 2	2 to 6	2-Jan
Data Input Time (hr)	1	1.5 to 2.5	1
Data Analysis Time (min)	<1	<1	<1
Major Inputs		Lane Geometry Hourly Volume	Lane Geometry Hourly Volume
Major Outputs	Max Possible Rehab. Length (mi)	Queue Length (mi)	Queue Length (mi)
Minimum Length work zone	X		
Maximization of work zone productivity	X	X	
Optimal construction staging	X	X	X
Maximum tolerable traffic delay		X	X
Optimal work zone season		X	
Nighttime work zones	X	X	X
Crash frequency			
Minimal user cost rehabilitation strategy	X	X	X
Construction window lane closure tactic	X		X
Material selection: curing time for concrete or cooling time for asphalt	X		
Pavement cross section: thickness of new concrete or asphalt	X		
Contractor's logistical resource: location, capacity, and numbers of rehabilitation equipment available	X		
Scheduling interface: mobilization/demobilization, traffic control time, and activity lead-lag time relationships and buffer sizes	X		
Quantify corridor delay results from capacity decreasing work zones		X	X
Identify delay impacts of alternative project phasing plans		X	X
Support tradeoff analysis between construction costs and delay costs	X	X	
Examine the impacts of construction staging by location along mainline, time-of-day (peak vs. off-peak), and seasonal (summer vs. winter)		X	
Asses travel demand and measures and other delay mitigation strategies		X	X
Help establish work completion incentives	X	X	

Collura et al. [23] have compared and evaluated QUEWZ, QuickZone, and CA4PRS by performing case studies. They conclude that QUEWZ and QuickZone were able to provide reasonable queue estimates on interstate highways comparable to observations made in the field. Table 2.1 shows a comparison of the work zone analysis software programs evaluated in this study. It can be inferred from this table that CA4PRS has lower traffic analysis capabilities compared to QuickZone and QUEWZ but scheduling and resource management capabilities can only be performed by CA4PRS. They have also reported some difficulties in collecting required data for CA4PRS analysis. This is because the type of data required for CA4PRS analysis is typically obtainable from the paving contractor than from transportation engineers. It has been suggested by the authors that CA4PRS be evaluated by analyzing large-scale rehabilitation projects using more accurate information with the aid of paving contractors.

CHAPTER III
CA4PRS

In this chapter, the details of CA4PRS procedures and calculations are discussed. The logic behind the numbers calculated by the software is discussed to assist in getting a better sense of the input data needed to run the program. This will help departments of transportation, contractors, and individuals to use more precise input data and increase the accuracy of CA4PRS calculations.

3.1 OVERALL PROCEDURE OF CA4PRS

A schematic procedure used in CA4PRS to calculate the production rate of a closure can be seen in Figure 3.1. The program receives the production rate of activities in the unit of m^3/hr as resource information. Then by combining it with the section profile information, the production rates for each activity are converted to km/hr. Finally by using the lead/lag times, construction window settings, and mobilization and demobilization information, it calculates the effective closure duration and production rate of the rehabilitation in km/closure. Consequently, the production rate of each activity, section profile information, lead/lag times, mobilization/demobilization durations, and construction windows directly affect the production rate of the closure. Unlike the section profile information and construction window settings which can be clearly determined and input into the program, the production rate of each activity, lead/lag times, and mobilization/demobilization information are not available and need to be estimated. Since this input information significantly affects the output results, it is considered the most critical input information in CA4PRS.

3.2 DATA ENTRY PROCESS

The major steps in the solution process for PCC reconstruction project scheduling analysis using CA4PRS are described below [22]. CA4PRS determines the effective duration available for major rehabilitation operations after the mobilization and demobilization durations are accounted for within the construction window (See Figure 3.1).

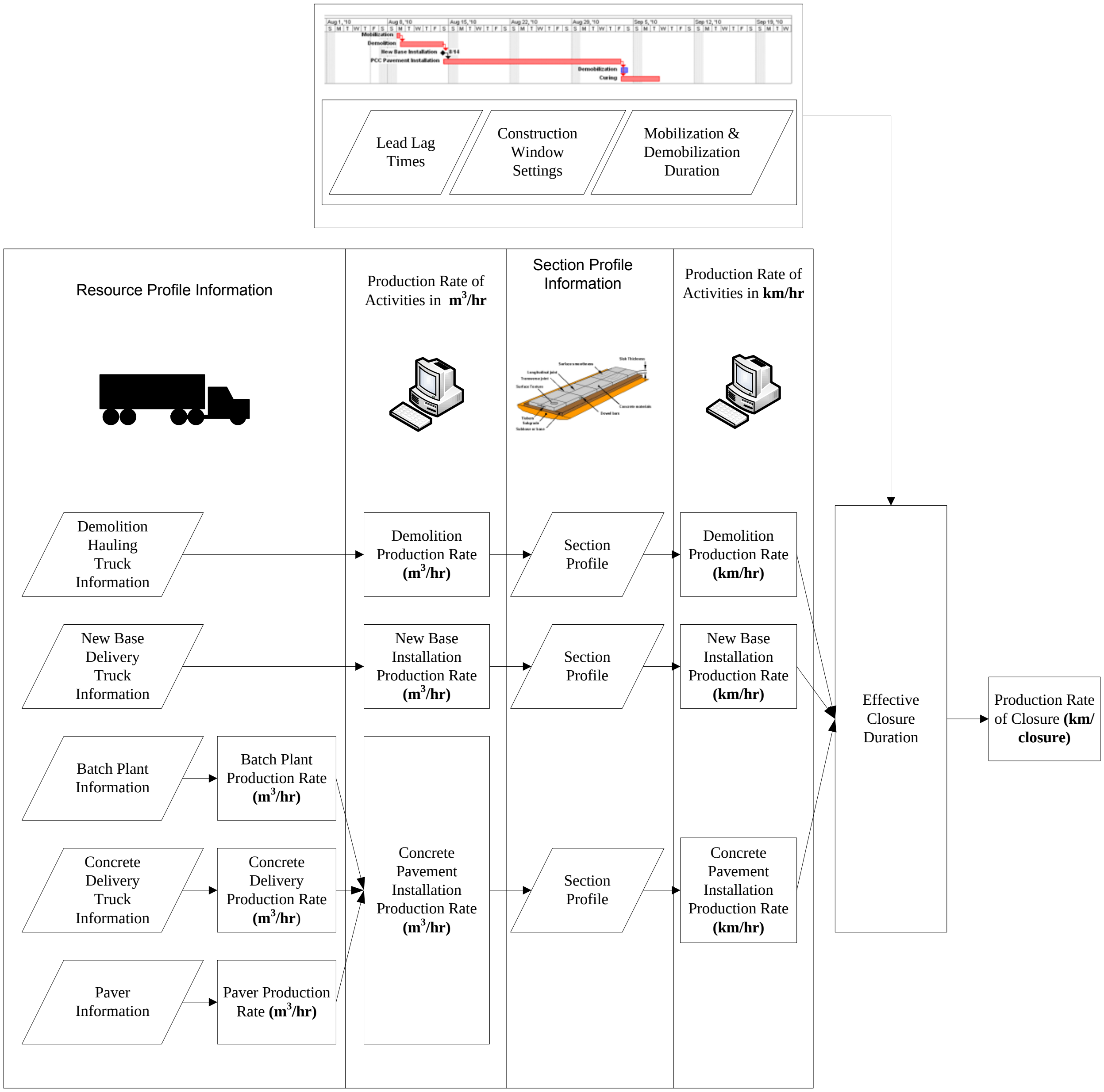


Figure 3.1 Overall Procedure of CA4PRS

Based on the selected construction method (concurrent or sequential), CA4PRS identifies the groups of concurrent activities. Then by using the production rates, the critical activity within each group is found.

The scheduling input data are investigated step by step by showing their input slots in the CA4PRS screens. CA4PRS uses four major input tabs with the names of Project Details, Activity Constraints, Resource Profile, and Schedule Analysis.

3.2.1 Project Details

General information about the project is entered into the project details tab. This information includes a description about the project, name of the analyst, date of analysis, route name, begin km point (mile point), end km point (mile point), objective/scope, location, and project notes. Figure 3.2 shows a screenshot of this input information window.

Objective/Scope

The total scope of rehabilitation in terms of lane-km or lane-miles is entered in Objective/Scope section (Item # 1, Figure 3.2). This is the only information in the project details tab that will be used for the schedule analysis.

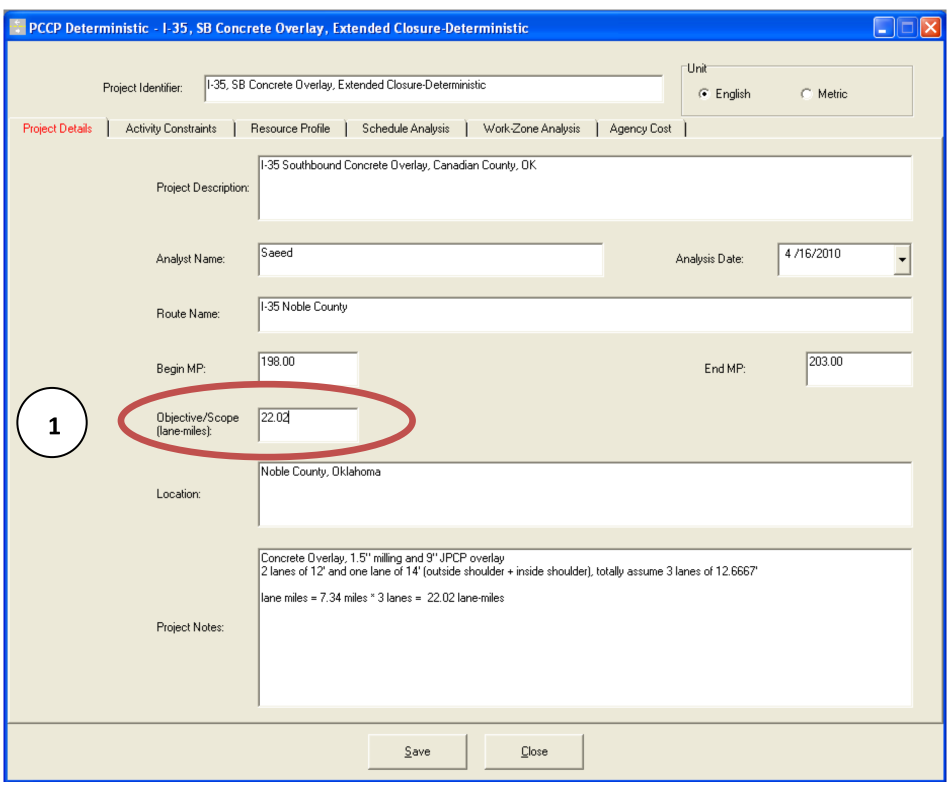


Figure 3.2 Project Details Window

3.2.2 Activity Constraints

In this tab, the construction windows settings, durations of mobilization and demobilization, and the lead/lag times between activities are identified. Figure 3.3 shows a screenshot of this input information window.

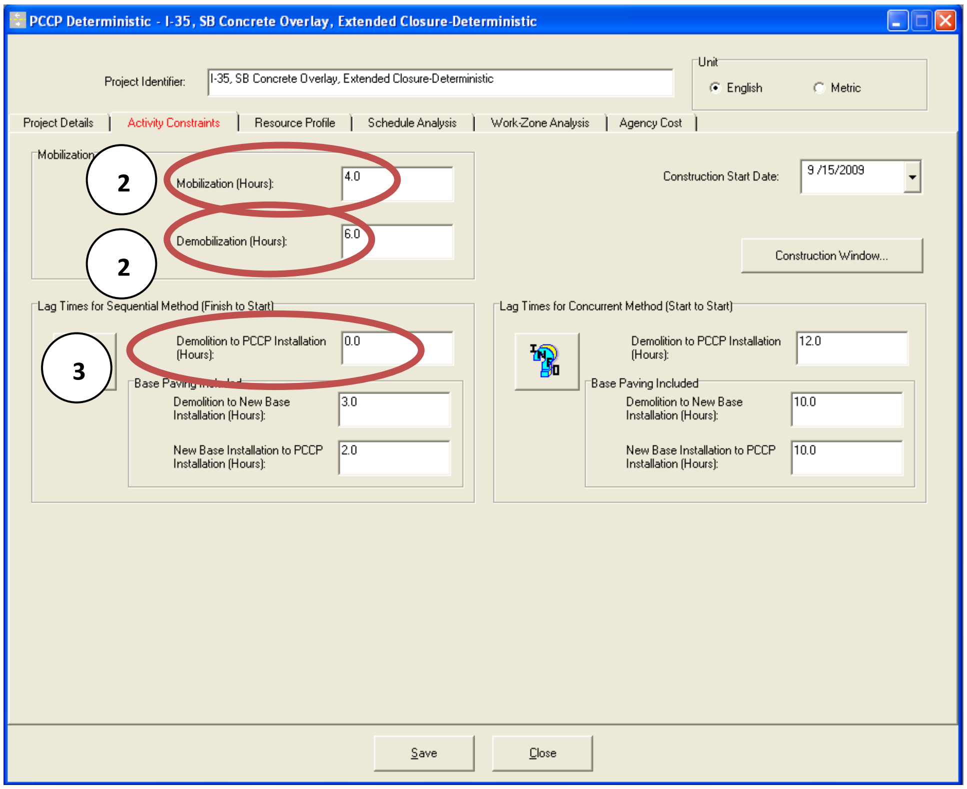


Figure 3.3 Activity Constraints Window

Mobilization & Demobilization

The mobilization and demobilization hours are entered in this section (Item # 2, Figure 3.3). Mobilization is the duration it takes until the major rehabilitation operations start and demobilization is the duration from the time the rehabilitation operations end until the end of the closure. The traffic closure is the main activity during the mobilization, and traffic opening and time allocated for concrete curing are the main activities during the demobilization.

Lag Times for Sequential Method (Finish to Start)

In this section the lag times between the main activities are entered in hours (Item # 3, Figure 3.3). Lag time represents a delay between the finish of the predecessor activity and the start of the successor activity. The three main activities modeled in CA4PRS scheduling are demolition, new base installation, and PCC pavement installation.

Construction Window Settings

Four construction windows or closure scenarios have been designed in the program as follow (Item #4, Figure 3.4):

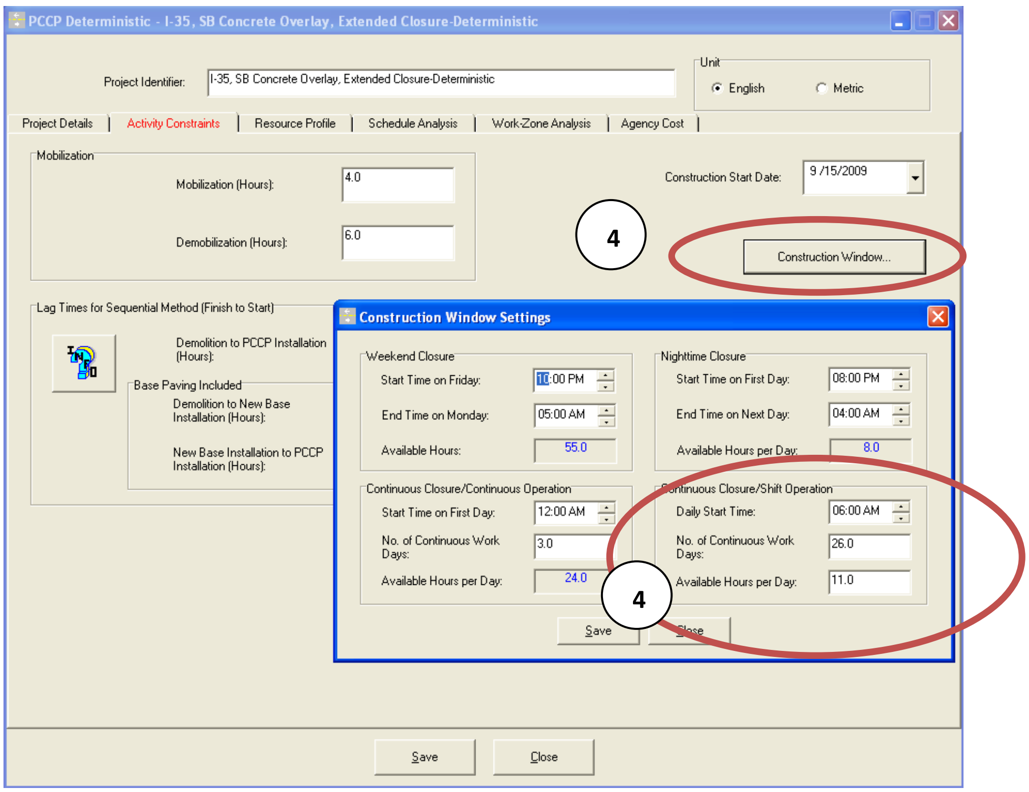


Figure 3.4 Construction Windows Settings

a) Weekend closure

In weekend closure construction window, one direction of the road is closed to traffic from Friday night to Monday morning. Caltrans set the weekend closure time of 55-hr (Friday 10:00 p.m. to the following Monday 5:00 a.m.). The traffic on the other direction of road is a counterflow traffic. The main advantage of this scenario is minimal traffic interruption during the weekdays. The disadvantages of this construction window are repeated mobilization and demobilization, curing time requirements, and higher labor costs on weekends.

b) Nighttime closure

Nighttime closure is the traditional closure scenario. The main advantage of this construction window is less interruption to traffic. The disadvantages of this closure are limited construction time, higher labor costs, and less production rates.

c) Continuous closure

This construction window keeps traffic off the newly constructed lanes until the paving has been finished by contractor. Continuous closures could serve as an alternative strategy because it will reduce the total time required to finish the rehabilitation project. The major advantages of continuous closures are the ability to maximize working hours by minimizing repeated mobilization/demobilization. Based on the number of operation shifts, continuous closure has two options: a) Continuous closure, continuous operation (3 shifts), and b) Continuous closure, daytime operation (1 or 2 shifts).

The disadvantages of continuous closure, continuous operation includes the disadvantages of night time operations and high labor and equipment costs. These disadvantages can be reduced by using continuous closure, daytime operation which eliminates the disadvantages of construction operations at night.

3.2.3 Resource Profile

The detailed information about the capacity of resources and production rates of the major rehabilitation activities are entered in this tab. Figure 3.5 shows a screenshot of this input information window.

Demolition Hauling Truck

In this section information about the demolition hauling trucks is entered (Item #5, Figure 3.5). It includes Rated Capacity in kg, trucks per hour per team, packing efficiency, number of team, and team efficiency. Packing efficiency is the efficiency of loose hauling volume compared to the solid volume of demolished pavement, depending on the type of demolition methods. Team efficiency decreases by any chance of interference loss. All the information in this part is utilized to calculate the production rate of demolition activity in unit of volume per unit of time.

Base Delivery Truck

In this section the capacity of base delivery trucks, number of trucks per hour, and packing efficiency are entered (Item #6, Figure 3.5). This information is utilized to calculate the production rate of demolition activity in unit of volume per unit of time.

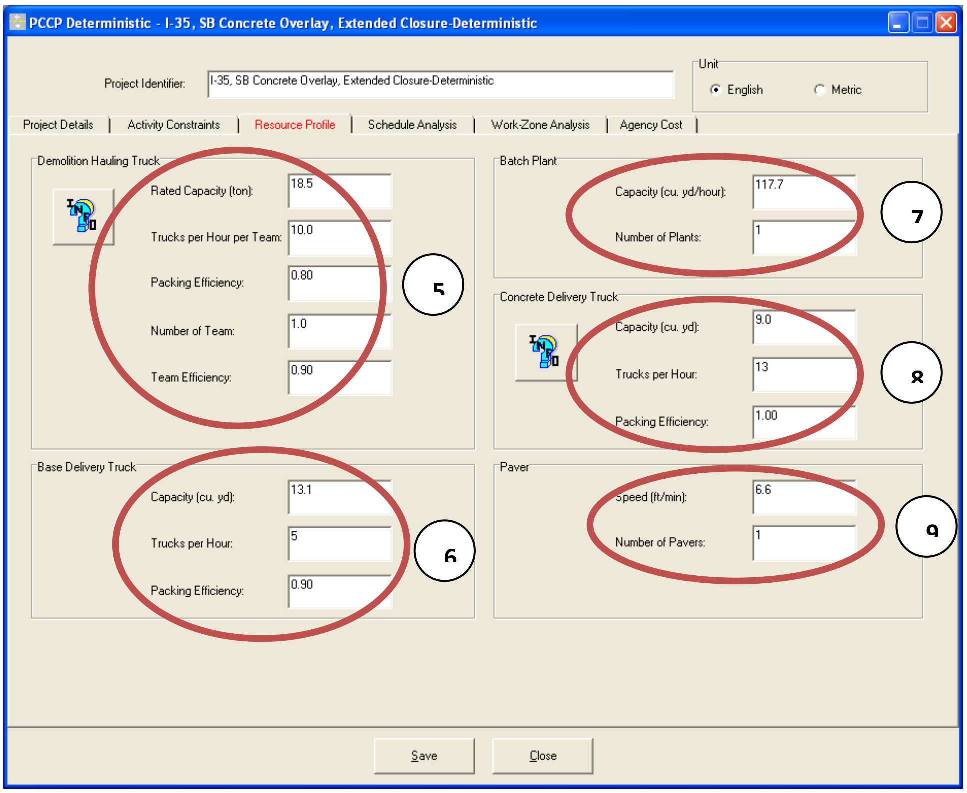


Figure 3.5 Resource Profile Information Window

Batch Plant

In this section the production rate of concrete production is entered (Item #7, Figure 3.5). By using this information the program compares the production rate of batch plant with production rate of concrete delivery to find the constraining resource and critical activity.

Concrete Delivery Truck

In this section the information about concrete delivery trucks is entered which is utilized to calculate the production rate of concrete pouring activity (Item #8, Figure 3.5). It includes capacity of trucks, number of trucks per hour, and packing efficiency.

Paver

For paver information the user needs to enter speed of paving machine and number of pavers (Item #9, Figure 3.5). This information is needed for calculating the production rate of paving machine.

3.2.4 Schedule Analysis

In this tab, construction window, section profile, lane width, curing time, and working method are identified. Figure 3.6 shows a screenshot of the input information window.

Construction Window

In this section a specific construction window that is to be analyzed is selected (Item #10, Figure 3.6). The detailed timing of the four main construction windows has already been set in construction windows settings. A user is also able to check more than one construction window which will enable them to compare the results of analysis with different construction windows. A screenshot of schedule analysis tab in the program can be seen in Figure 3.6.

Section Profile

The section profile of rehabilitation is defined in this input (Item #11, Figure 3.6). The user may either check the standard section profiles available or define a new section by inputting thicknesses of PCCP and Treated Base. Also it should be specified whether the rehabilitation activity changes roadway elevation or not. By utilizing this information, the program is able to calculate the demolition volume needed for the rehabilitation activity. Like the construction window section more than one section profile can be entered for analysis and the program generates the results for all the combinations.

Lane Width

Lane width is the width of the rehabilitation activity which is utilized to calculate the required demolition, new base, and concrete volumes (Item #12, Figure 3.6).

Curing Time

Curing Time is measured from after placement of concrete to opening construction to traffic. The user can either select one of the times available in the program or define another curing time based on the type of concrete being used for rehabilitation activity (Item #13, Figure 3.6).

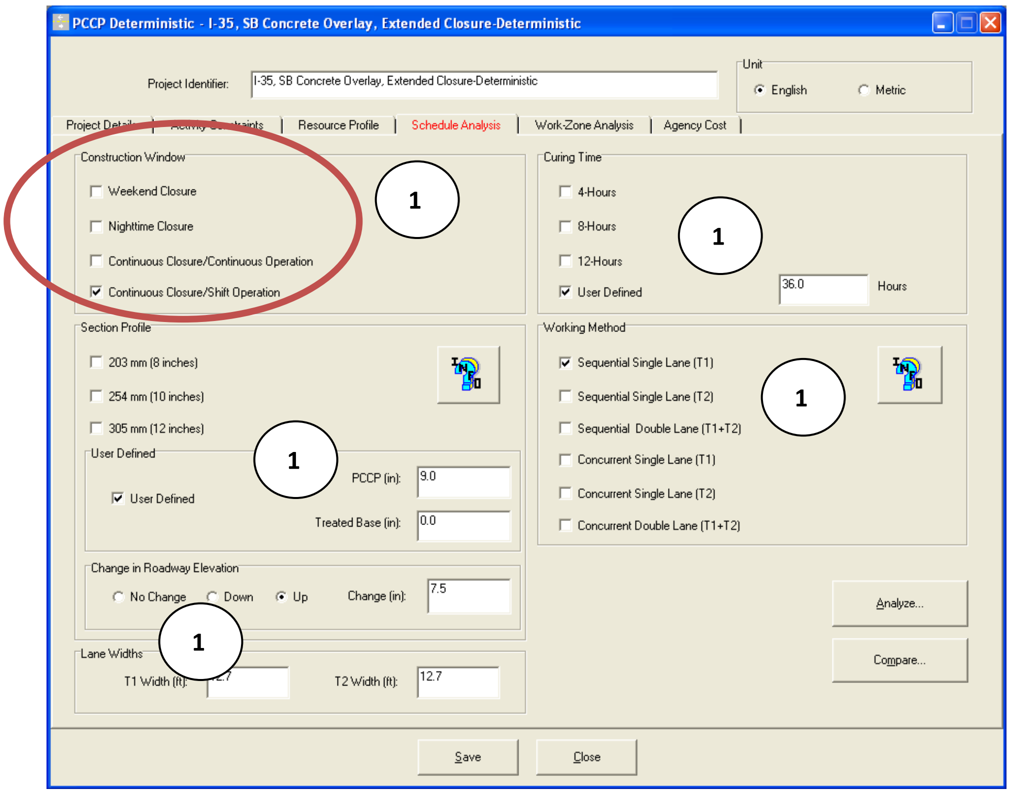


Figure 3.6 Schedule Analysis Window

Working Method

Any of the six working methods as a combination of Sequential or Concurrent and Single or Double lane rehabilitation, can be included in the comparison analysis. Figure 3.7 shows different lane closure tactics provided by the program.

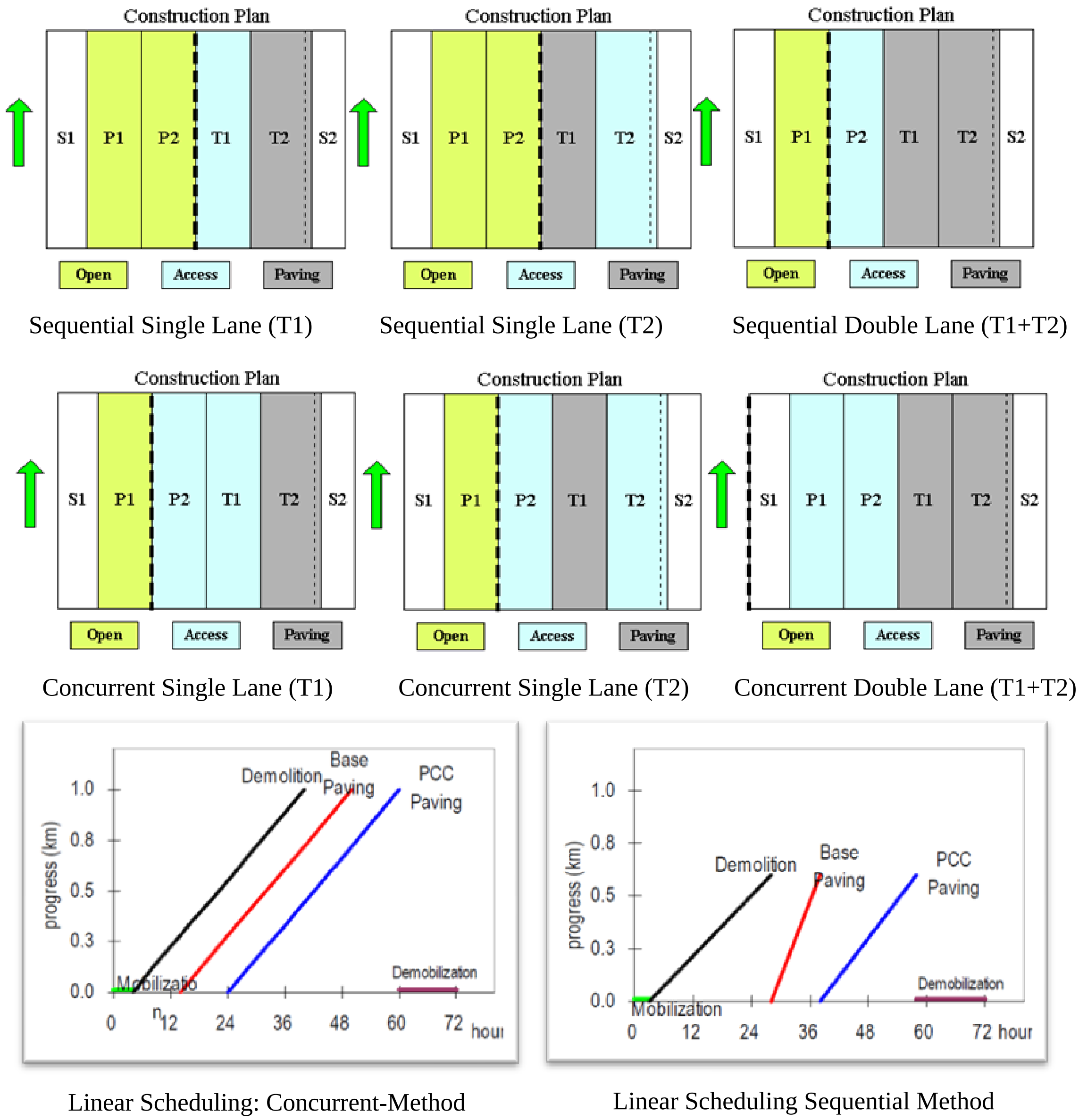


Figure 3.7 Lane closure schemes and progress of Linear Scheduling [22]

In the sequential method one lane is allocated to equipment access, therefore there should be a finish-start relationship between activities. In the concurrent method there are two access lanes in the work zone therefore the demolition, base paving, and PCC paving can be performed concurrently.

Once all the input information is entered, the program analyzes the data and calculates the production rate of each closure scenario. The production rate of the closure would be the length of the road (in lane-km) that can be rehabilitated during a construction window.

3.3 ANALYSIS OF AN EXAMPLE PROJECT

A PCC pavement rehabilitation project in I-35, Noble County, OK is used as an example. The results of hand calculations are compared with the output data generated by CA4PRS. In this project the existing pavement is milled about 3.81 cm (1.5 in) and new PCC pavement is poured which increases the level of pavement by 19.05 cm (7.5 in) (see Figure 3.8). The project consists of three lanes with the width of 3.86 m (12.67 ft) and the length of 11.81 km (7.34 mi). Consequently the total scope of the project would be 35.44 lane-km (22.02 lane-miles). Figure 3.8 shows the pavement section before and after the rehabilitation.

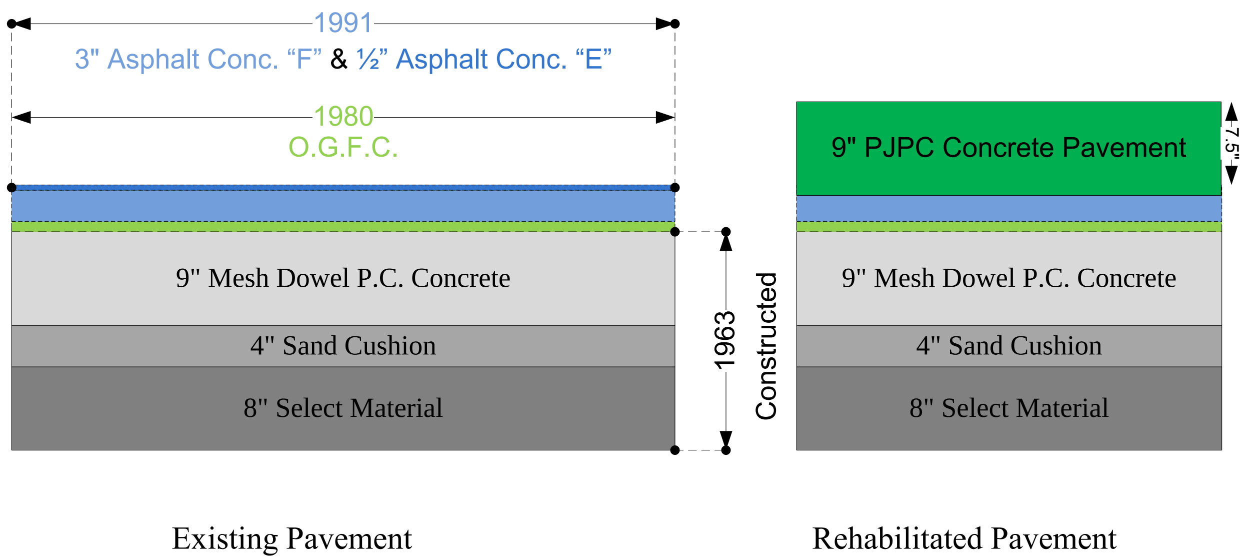


Figure 3.8 Profile of the example project (I-35)

The first step in calculating the production rate of closure scenario is to find the effective duration available for major rehabilitation operations. The major rehabilitation operations available in the program are: a) Demolition, b) New Base Installation, and c) PCC Pavement Installation.

The effective time for the main operations is calculated by deducting the working duration from Mobilization, Lag time between demolition and PCCP installation, and Demobilization/Curing durations. Curing activity can continue during demobilization, therefore Demobilization/Curing duration is the duration of either Demobilization or Curing whichever is longer. Mobilization and demobilization hours have been assumed to be 4 & 6 hr respectively. Also as mentioned in step 3 the lag time between demolition and PCCP installation has been assumed to be zero. In addition curing time has been assumed to be 36 hr. This means that 40 hr (4h+0h+36h) needs to be deducted from the total closure duration to obtain effective duration.

Total closure duration is 26 days or 624 hr (26 days * 24 hr/day). The working duration is calculated by the information provided in construction window settings. Below equation shows how the total work duration is calculated.

*Working Duration = No. of Continuous Working Days * Available Hours per Day* *(Eq. 3.1)*

In this example the working duration would be 286 hr (26 Days * 11 hr). Also the effective duration would be 246 hr (286 hr – 40 hr).

There are three main activities available in CA4PRS and because there is not any new base installation in this example project, there would be only two main activities. With the existing information the shape of linear scheduling diagram can be estimated as in Figure 3.9. The diagram starts from time zero to 624 hr. The mobilization is in the beginning of the project with the duration of 4 hr. The curing happens at the end of the project with the duration of 36 hr. There only remain two main activities in this example which are shown in green and red lines. PCCP installation which is in red starts right after the end of demolition activity. The sequential working method has been chosen for this project. Therefore, there is a relationship of finish to start between demolition and PCCP installation. Since the contractor only works one shift of 11 hr during a day the activity lines are not straight lines in order to reflect the durations that project is not in operation. The slopes of the line represent the production rates of the operations.

The production rates of demolition and PCCP installation activities can be figured out from the resource profile information tab of CA4PRS. The production rate of demolition activity can be calculated by using the demolition hauling truck information. The production rate is calculated by Equation 3.2.:

*Production rate of Demolition = (Truck Capacity) * (Number of Trucks per Hour per Team) * (Packing Efficiency) * (Number of Team) * (Team Efficiency)* *(Eq. 3.2)*

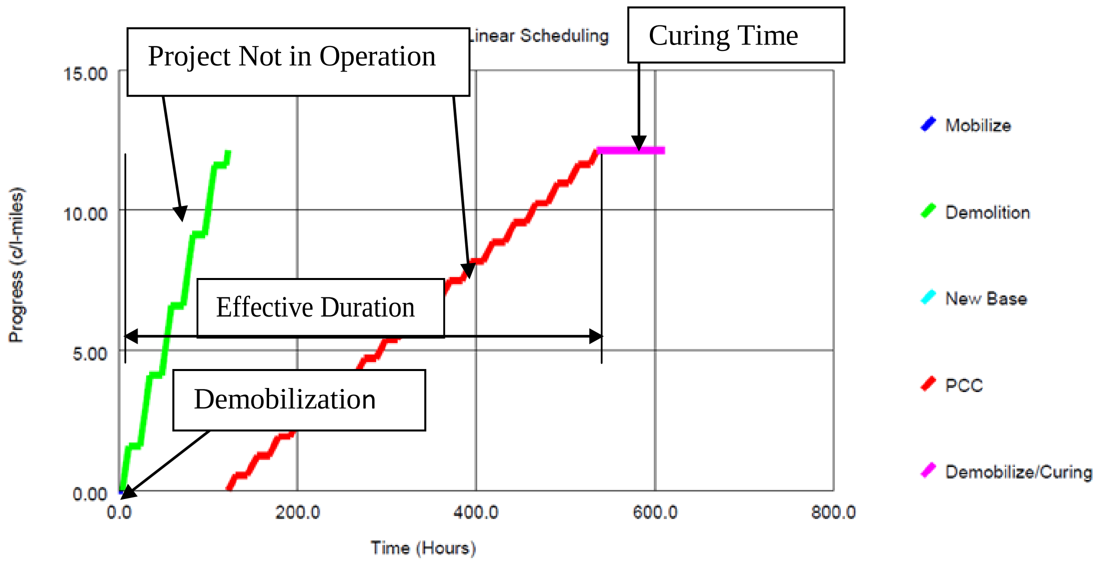


Figure 3.9 Estimated Linear Scheduling Diagram of the rehabilitation project

By using the equation 3.2, the production rate of demolition activity would be 120,810 kg (133.2 ton) per hr. Considering the CA4PRS assumption of the unit weight of 2,240 kg/m^3 (1.89 ton/yd^3) the production rate of 53.879 m^3/ hr (70.476 yd^3/hr) is calculated for demolition activity.

The production rate of concrete pouring activity can be calculated by the following equation:

*Production rate of Paving = (Truck Capacity) * (Number of Trucks per Hour) * (Packing Efficiency)* *(E.q. 3.3)*

By plugging into the above equation, the production rate of concrete pavement installation would be 89.45 m^3/ hr (117 yd^3/hr).

In order to calculate the production rates in lane-km per hour the profile section of demolition and concrete pavement installation need to be taken into account. According to the section profile information the demolition activity includes milling 38.1 mm (1.5 in) of the existing pavement with the width of 3.86 m (12.67 ft). Consequently the volume of demolition would be 135 m^3 (309.76 yd^3) per 1 km (1 mi) of the road. By dividing the production rate of 53.879 m^3/hr (70.476 yd^3/hr) by the volume of demolition, the production rate of demolition activity would be 0.366 lane-km/hr (0.2275 lane-mile/hr).

According to the section profile information, the thickness of new PCCP is 228.6 mm (9 in) with the width of 3.86 m (12.67 ft). Consequently the volume of PCCP would be 882.40 m^3 (1858 yd^3) per 1 km (1 mi) of the road. By dividing the production rate of 89.45 m^3/hr (117 yd^3/hr) by the volume of pavement installation, the production rate of concrete pavement installation would be 0.101 lane-km/hr (0.063 lane-mi/hr). Then, the production rate of concrete delivery is compared with the production rate of batch-plant and production rate of paver. The lowest production rate would be selected as the production rate of concrete pavement installation. It is assumed that the batch plant is able to support the production rate of 89.98 m^3/hr (117.7 yd^3/hr) and paver is able to support the production rate of 106.55 m^3/hr (139.37 yd^3/hr). Therefore concrete delivery with the production rate of 89.45 m^3/hr (117 yd^3/hr) is the controlling activity in PCCP installation.

In this stage, the durations should be divided between these two activities in a way that both activities progress the same during the closure period. In other words, longer duration needs to be allocated to the activity with lower production rate in order for both activities to have the same progress. By knowing that the total effective duration is equal to 246 hr and the progress of demolition and concrete pavement installation are the same, the following equations are generated:

$$\begin{cases} T1 + T2 = 246 \\ 0.336 * T1 = 0.101 * T2 \end{cases} \quad \text{(Eq. 3.4)}$$

where, T1 = The effective duration of demolition in closure window, T2 = The effective duration of concrete pavement installation in closure window.

After solving these equations, the amounts of T1 and T2 would be: T1 = 53.3, T2 = 192.7, therefore, the production rate of the closure would be:

*Production rate of Closure = 0.366 lane-km/hr (0.2275 lane-mile/hr) * 53.3 hr = 0.101 lane-km/hr (0.063 lane-mile/hr) * 192.7 hr = 19.52 lane-km/closure (12.13 lane-mile/closure)*

Now by knowing the total scope of the project which is 35.43 lane-km (22.02 lane-miles), the total number of closures required to finish this project would be:

Total number of closures needed = (Scope (lane-km)) / (Production rate of closure ((Lane-km)/Closure)) *(E.q. 3.5)*

By plugging the production rate of closure and scope of project into the above equation the total number of closures would be 1.82. This means that 1.82 closures are needed to complete this rehabilitation project. Thus, the project takes 47.32 working days (1.82 closures * 26 working days/closure) to be finished.

Figure 3.10 shows the final Linear Scheduling Diagram of the project. Four activities of Mobilization, Demolition, PCC Pavement Installation, and Demobilization/Curing are shown in the diagram.

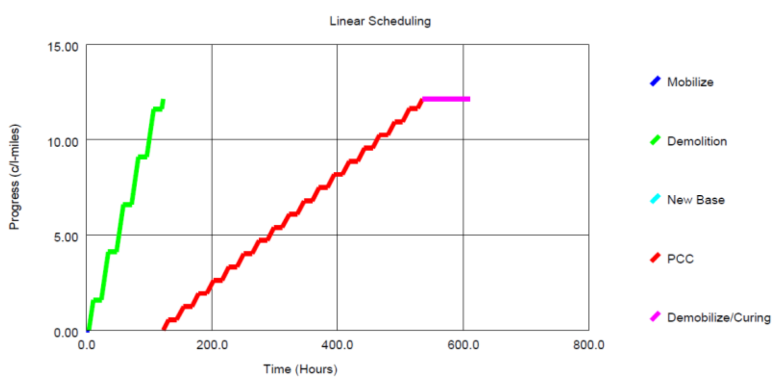


Figure 3.10 Linear Scheduling Diagram

CHAPTER IV
CURRENT PLANNING, DESIGN, AND BIDDING PROCEDURE OF ODOT & GDOT

This chapter discusses the current planning, design, and bidding procedure of ODOT & of GDOT. It summarizes the procedure from the long term development of the National Highway System to the short term construction plans which specify the priority and the type of projects needed to keep state highway systems in an acceptable condition. The main goal of this chapter is to identify the areas in the current procedure that needs to be improved or modified for efficient planning and staging of PCC pavement rehabilitation projects. In addition, by studying the current project scheduling and cost estimating techniques, the potential areas that ODOT & GDOT are able to get advantage of CA4PRS are recognized.

4.1 PLANNING, DESIGN, AND BIDDING PROCEDURE OF ODOT

The current ODOT procedure for planning, designing, staging, and letting of rehabilitation projects is indicated in the process chart in Figure 4.1. The detailed process chart is available in Appendix C.

ODOT performs two major planning studies, Needs Study & Sufficiency Rating Report and Construction Work Plan (CWP), to determine the situation of roadways and plan the projects needed to improve the road condition of Oklahoma. The *Needs Study & Sufficiency Rating Report* is published every two years in ODOT with following objectives [24]:

a. Assess the physical and operational conditions of the State Highway System

b. Estimate the cost to bring the Highway System up to minimum design standards

c. Estimate future state and federal funding available for highway improvements, and

d. Determine the adequacy of funding

The development of CWP begins with Field Division Engineers and is guided by their knowledge of the transportation needs and priorities in their respective Divisions. They work to maintain an understanding of the conditions of the roads and bridges in their areas of responsibility. In addition, other key Department Divisions collect and analyze transportation data factoring the following general characteristics as applicable; surface condition, bridge condition, geometrics (vertical and horizontal alignment), average annual daily traffic (AADT), percentage of truck traffic, accident history, local, regional and national traffic patterns, and capacity.

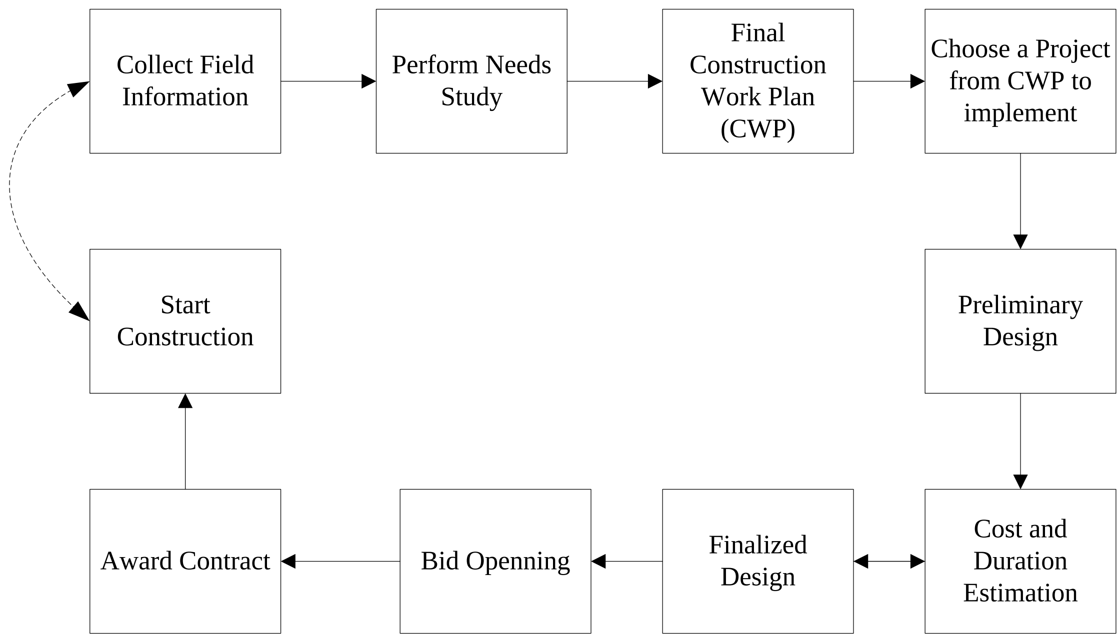


Figure 4.1 Process chart for current ODOT procedure

After the final capacity and conditions assessments and coordinating with Division's Transportation Commissioner, Field Division Engineers review and validate the scheduled CWP projects and formulate a group of new projects to be added in accordance with the projected funding availability.

Then the Planning & Research Division provides an opportunity for the public to participate and review the CWP. The results of this public involvement and the planning documents are provided to Field Division Engineers for their consideration as the Work Plan develops.

The Project Management Division works directly with and assists the Field Division Engineers in the development of their respective Division's CWP and in the subsequent daily management of the project development activities. New projects proposed by the Field Division Engineers are validated by Project Management Division and preliminary scope, schedule and budget is calculated. Concurrently, the scope, schedule and budget of projects previously existed in the CWP are re-validated.

As more detailed information about projects reveals, Project Management Division facilitates necessary modifications to the scope, schedule and budgets of approved CWP projects. The validation process is through project team meetings with the participation of appropriate preconstruction and operations Divisions.

The Director and Chief Engineer, in concert with the Director of Engineering, Director of Operations, Director of Capital Programs and Information Management, Director of Finance and Administration, the Programs Division, the Project Management Division and the Field Division Engineers work to fiscally constrain and balance the CWP in accordance with the percentage requirements of the different Federal funding categories. At all points of time during balancing CWP, project priorities of Field Division Engineers and Transportation Commissioners are highly taken into consideration.

The CWP is under review and revalidation by Programs Division, Project Management Division, Field Division and Central Office Divisions in order to make it as efficient as possible. This is called CWP Management Process. The time span of CWP is 8 years which can be categorized based on the level of flexibility available. Figure 4.2 shows the schematic of CWP Management Process.

According to the characteristics of CWP indicated in Figure 4.2 and the comparison shown in Table 4.1 it can be inferred that there would be more flexibility in the plan for projects in the transition year or in the extended program zone than projects in the current year. This is because there is no detailed information about these projects and estimations are not accurate and will change once the level of information increases. According to this plan, projects in nonflexible area cannot be easily modified in terms of Scope/Schedule/Budget.

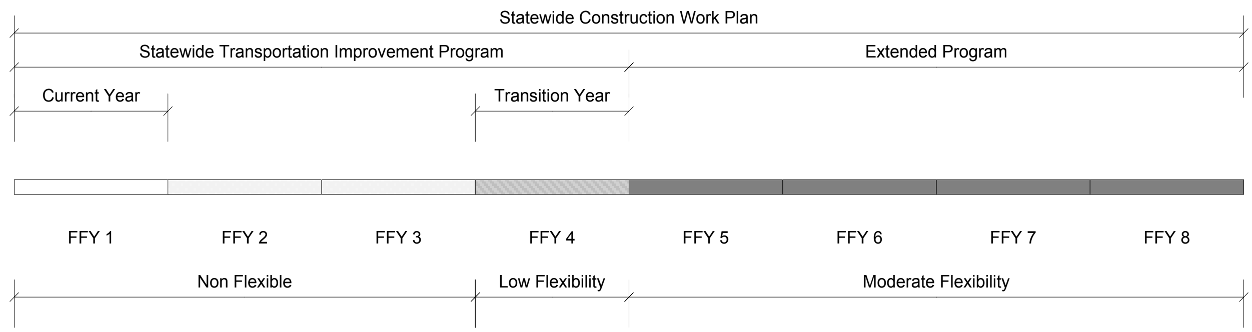


Figure 4.2 CWP Management Process [25]

After finalizing the CWP which is done yearly from July to August, the projects go through the design process based on their priorities. Projects are prioritized based on their bid dates so projects with closer letting date have higher priority. Based on the size and complexity of the projects, they are either designed in-house by ODOT or awarded to a consultant through a bid process. Usually the assistant director of Design Division, Chief Engineer, Roadway Division manager, Bridge Division manager and other responsible persons in ODOT will decide whether to choose the option of in-house design or let the project to a consultant. If a project is awarded to a consultant, the consultant would prepare the design and ODOT design related divisions need to approve it. Typically because most rehabilitation projects are routine projects, they are usually designed in-house. Project engineer who is assigned to each project is responsible for ensuring that the design is going through the right departments at the right time and coordinate the meetings and communications needed to finalize the design.

Value engineering is not common for the PCC pavement rehabilitation projects and is usually skipped in the design process. For the projects that need the Value Engineering process, Office Chief Engineer is in charge of doing so before the design is finalized. Once the design is finalized, it is submitted to the Office Engineer Division to make the bid documents for letting the project.

Table 4.1 Comparison between different levels of flexibility in CWP

	Non Flexible	**Low Flexibility**	**Moderate Flexibility**
Scope/Schedule/Budget of projects can be modified	No	Yes	Yes
Possibility of Unscheduled Project Inclusion	No	No	Yes
Possibility of Extended Program Projects Inclusion	Yes	Yes	N/A
Must Remain Balanced	Yes	Yes	Yes
Only modified through formal Program Revision Process	Yes	No	No
Yearly Evaluation of Plan	Yes	Yes	Yes
Any Project Can be Advanced for Inclusion	No	No	Yes

The Office Engineer Division is responsible for preparing the bid documents, letting the project and holding the bid. The first step is prequalifying the contractors who are willing to participate in the bid. Then they convert the plans to proposals which consist of contract items (i.e. pay items for bid) and contract provisions which include contract time, incentives/disincentives, permits, specifications, etc. The Office Engineer Division works along with Chief Engineer and Field Division Engineers to calculate the contract time and incentives/disincentives.

Then, the bid is advertised to the public and then qualified contractors and those who have purchased the bid documents participate in the pre-bid conference. Contractors are given a chance to ask questions and share their concerns with the Office Engineer Division and other contractors at the pre-bid meeting. It helps contractors to build up their understanding about the project in order to determine more accurate estimates for the bid. The main advantage of pre-bid conference is a quick review about the scope of the project in order to address the ambiguities in the designs. This will point out the problems existing in the designs and provide an opportunity for ODOT to revise the plans before the project is let for the bid. All the plan and proposal revisions are done in coordination with the Chief Engineer and Field Division Engineers.

For scheduling purposes, the critical path method (CPM) network is utilized. The production rates are based on the experience, available equipment and resources. Contract time calculated by ODOT is provided to contractors before opening the bid therefore contractors are aware of the maximum time allowed for each project.

In order to make sure that the project is not taking longer than a reasonable time, ODOT calculates the logical contract time according to the best of their knowledge and experience. In this stage, no specific scheduling tool is used by ODOT and CPM calculations are usually performed by hand.

Once the plan and proposals are finalized and confirmed by ODOT the bid is opened. Based on the type of the contract and inclusion of incentives/disincentives, different methods are used to rank contractors in the bid analysis stage. As a rule of thumb, ± 5-10% deviation from what ODOT has estimated as the contract price would be acceptable. Once the contractors are ranked based on the proposed price and duration, ODOT awards the project to the contractor with the best offer.

Once the bid analysis is finalized, the execution of contract starts. In this stage contract is prepared based on the approved bid and contractor is informed of the bonding requirements. The executed contract is submitted to ODOT Construction Division and they send the work order to the contractor to start the work. Also Field Divisions are informed in order to start tracking and supervising the construction activities.

As can be inferred from the current ODOT procedure, project cost and time estimations are used in a series of steps from the inception stage of a project to the time when the project is awarded to the contractor. In addition, both ODOT and contractor use the CPM network for scheduling and the unit price method for cost estimations.

4.1.1 A+B Contracts

An A+B contract is a cost-plus-time method that ODOT has begun to use for some rehabilitation projects. The efficiency of this type of contract depends upon accurate estimation of time, agency cost, and social cost of rehabilitation projects. CA4PRS is a potentially strong tool that can contribute to project scheduling and user cost estimations. Therefore, the A+B contracts and their procedure in ODOT are explained briefly in this section.

A is the sum of the unit prices bid multiplied by the unit quantities as reflected in the bid proposal. B is the product of the unit of time bid to achieve substantial completion of the project multiplied by the incentive/disincentive rate specified in the bid proposal. Incentive rate is the rate assigned for each unit of time for construction of the project. An incentive will be earned for the time the project is substantially complete prior to the expiration of the time bid, B Bid, not to exceed the maximum time specified in the bid proposal. Disincentive rate is usually a rate equal to incentive rate that will be assessed for the time in excess of the B Bid, required to achieve substantial completion. Time is included as one of the factors in awarding the bids. Due to the fact that inconvenience to the public and user cost is directly affected by the duration of rehabilitation projects, it is vital for transportation agencies to make sure that project is accomplished within the minimum duration. A+B contracts help transportation agencies to ensure competition over the duration as well as price which encourage contractors to use project acceleration methods.

The ODOT procedure for A+B contracts is specifying a cap for the duration of rehabilitation projects. For instance, if ODOT calculates the duration cap of 300 calendar days for a bid, then contractors have to propose a duration of up to 300 calendar days for this project otherwise their proposal will be rejected. If the winner's proposal is 275 calendar days then the contractor is eligible to receive incentives based on the number of days they finish ahead of schedule. There is always a cap for the amount of incentives which is usually 5% of the total contract price in ODOT. For example if we assume the incentive rate is $5,000 per day and contractor has finished the project in 230 days then the total incentive would be 45 days multiplied by $5,000 per day, which is $225,000. But if total contract price is $4,000,000 then the amount of incentives is limited to $4,000,000 x 5%, which is equal to $200,000. In other words, the contractor reaches to the maximum incentive amount ($200,000) if they finish the project 40 days earlier than contract time. Unlike incentives, disincentive does not have any cap and contractor will be charged the penalty for all the days that they are delivering the project later than the contract time.

4.1.2 Road User Cost Calculations

Road user cost is the indirect cost incurred to travelling public in rehabilitation projects. It is one of the main factors in determining incentive/disincentive amount in A+B contracts. In addition, estimating road user cost is essential in finding the optimal pavement rehabilitation scenario. In this section, the current ODOT procedure for calculating road user costs were evaluated.

The Traffic Engineering Division has developed a spreadsheet program which calculates the user cost due to road closure and delays. This division uses the program for two main purposes: a) Calculating the hourly length of queue made by the work zone, b) Calculating the cost of delay made to the public because of the speed limit reduction and the user cost incurred by the detour.

4.2 CURRENT PLANNING, DESIGN, AND BIDDING PROCEDURE OF GDOT

4.2.1 Project programming and scheduling

During the project planning stage, the transportation department monitors the existing transportation systems and in cooperation with local agencies and planning organizations, proposes improvements for possible inclusion in the work program of the GDOT. Any office of the department, commissioner, deputy commissioner, chief engineer and division directors may identify projects for inclusion in the work program. The project Nomination Review Committee (PNRC) evaluates the final projects submitted by the offices/sponsor for action.

The offices/sponsors provide the project's cost estimates for construction, right-of-way and utilities in addition to a basis and justification for the cost estimates. This justification provides the Project Manager with an idea of the environmental scope, information to prioritize projects, and guidance to prevent programming errors. All this information is used to provide an estimation of the scope and ultimately a plan for a better design.

Based on the information provided by the Project Manager, the office of planning programs develops the project's Phase I preliminary engineering. The priority in which a project is placed depends on factors such as project prioritization process scoring, benefit to cost ratio and prior knowledge of a project.

4.2.2 Schedule development

A project schedule has to comply with the Plan Development Process (PDP) and also with the programmed fiscal years for the authorization of funds. Within 10 days, the Program Control Administrator assigns the project to an office and the office assigns a Project Manager within 20 days. The State Scheduling Engineer submits a schedule to the Program Control Administrator. The State Scheduling Engineer will notify the Program Control Administrator, the Project Manager, Design Office, the Office of Bridge Design, Office of Environmental Services, Office of Right-of-way, and any other office with work activities in the schedule that the schedule is ready for review.

Once each calendar month, the Schedule Review Committee reviews the schedules submitted to the Office of Program Control. The Schedule Review Committee may recommend approval of a schedule with modifications or rejection of a schedule. The State Scheduling Engineer reviews the committee's recommendations and forwards them to the Chief Engineer and Director of Planning for approval, disapproval, or modification.

4.2.3 Concept Stage

With the schedules finalized for all the projects, the concept stage is carried out. The concept stage addresses the need and purpose of the programmed project after traffic and operational studies, accident analysis, determination of project deficiencies, planning requirements, environmental screening, study of alternatives, permit requirements, social and economical considerations, impacts, and benefit to cost analysis. Furthermore, the concept stage is performed to produce a higher quality and more detailed concept for all major projects by better organizing the resources, identifying the core team and specialty team members, establishing lines of communication and responsibilities among team members, better understanding of the project corridor, understanding the environmental scope, identifying information that is available, reviewing the project schedule and providing transition between the planning and design. In this stage, a need and purpose statement is provided by the office of planning in order to identify and describe the proposed actions, describe the problems, for the basis of the alternatives discussion, and assist with the identification of reasonable alternatives and the selection of the preferred alternative. Additionally, the concept development includes an analysis of the benefit to cost ratio for the project in order to help the department in determining whether the benefits from the proposed design equal or exceed the project cost. It is also used to determine the priority of the project in the Regional Transportation Plan.

The pavement type selection process also takes place in the concept stage since this early pavement determination helps build up an accurate cost estimate. During this process, the most effective pavement type is determined for a specific project by comparing alternative pavement types. The Office of Materials and Research (OMR) assists in the process by supplying Life Cycle Cost Analysis (LCCA) Reports to the Project Manager. The Project Manager is responsible for providing draft concept layout and typical section, old plans typical section, project traffic diagrams, existing overpass bridge vertical clearance, and expected profile changes.

The Project Manager reviews the right-of-way, utility, and construction costs of the project once each year and updates any significant cost increase or decrease. The revised estimate is forwarded to the Office of Engineering Services and then forwarded to the Office of Program Control for review and to the Chief Engineer for approval. Afterwards, the Office of Financial Management (OFM) updates the project cost estimate annually upon approval of the Chief Engineer. A Value Engineering (VE) study is performed for all projects having an anticipated cost of $10 million or more, including inflation and engineering cost and contingencies. The VE studies are accomplished during the early stages of preliminary plan development in order to include any significant cost savings in the project design.

4.2.4 Preliminary Design

The preliminary design phase starts with the approval of the project's Concept Report. After the approval, the preliminary construction and right-of-way planning begin. The environmental and preliminary design activities that took place during the concept stage are incorporated in the preliminary plans. Preliminary design and coordination activities include but are not limited to preliminary pavement design, traffic analysis, geometric design, driveway profiles, and drainage design among others (see Preliminary Plan Development Process, Appendix D). After the preliminary design is completed, a constructability review is performed by GDOT. The constructability review is conducted after Concept Report approval during the preliminary design phase, near 30% plan completion.

4.2.5 Constructability Review in Preliminary Design

The GDOT established a constructability review process (see Appendices D & E), which is a process that uses construction personnel with extensive construction knowledge early in the design stages of projects to ensure that the projects are buildable, cost-effective, biddable and maintainable. This process ensures direct communication between designers, construction personnel, suppliers, and contractors during the design phase. Additionally, this process improves the quality of GDOT's construction bid by making sure projects can be constructed with current practices, plans, and specifications. It also ensures that all contractors can prepare a competitive bid, projects can be maintained over the life cycle, and there is an increased involvement of experienced construction personnel during the planning and development phase (see Appendix D).

This review process prevents costly plan changes during construction, familiarizes the construction team members with the project, opens lines of communication, continues the team work process, and distributes ownership to the project. If the Value Engineering study significantly revises the concept, cost, or scope of the project, the Project Manager has to submit a revised Project Concept report and cost estimate for approval.

4.2.6 Final Design

During the final design phase, the right-of-way plans for the project are completed, the permits needed for the project are pursued, and the final construction plans are begun. The changes made to the construction plans and environmental analysis are submitted to the Office of Environmental Services for reevaluation of the environmental documents. The Project Manager informs all the parties of any significant changes to the plans that may affect their area of responsibility.

The Project Manager sends updated base plan sheets or electronic files to the Utility Engineer. This updated information contains the existing utility information, preliminary drainage and control plans, stage construction plans, cross sections, roadway profiles, and construction limits as set following the Preliminary Review. The District Utilities Office and the Project Manager review the second submission relocation plans and the utility adjustment schedules to ensure that provisions are made to account for relocations that may affect project construction. The Project Manager sends the base plan sheets to the Utility Engineer as soon as the existing utility information has been plotted and the project's footprint is verified. The second submission of utility plans contain the in-progress drainage plans, approved bridge and retaining wall layouts, and the location of strain poles, traffic signals and overhead signs.

The Project Manager prepares proposed pavement designs for review and approval (see Appendix F). For instance, if a rigid (concrete) pavement design is proposed for a project, the Project Manager requests the designs from the Office of Material and Research. For all the pavement designs in the Final Design stage, the up-to-date traffic data is utilized. The GDOT Pavement Design Manual provides guidance and procedure on pavement type selection, Life Cycle Cost Analysis (LCCA), and pavement design and approval for minor and major projects. Pavement design submittals from District Design offices are sent to the State Pavement Engineer for review and approval. The GDOT Pavement Design Manual includes a pavement design submittal checklist for the supporting items and documents required as part of the submittal package.

4.2.7 Final Field Plan Review (FFPR)

The FFPR is requested when construction plans, checked quantities, and special provisions are finalized. The Project Manager submits a letter of request for a FFPR to the Office of Engineering Services with the set of construction plans and special provisions. The Project Manager is responsible for revising plans and submitting the final documents to the Office of Construction Bidding Administration. When all comments have been addressed, the Project Manager submits the completed final plans, special provisions, electronic earthwork files, soil reports, required information for the notice of intent, and the Designer's Checklist to the Office of Construction Bidding Administration. Then contractors submit the bid proposals to the Office of Construction Bidding Administration. After the letting, the apparent low bid is awarded.

4.2.8 Construction

At the construction stage, the contractor begins to perform the tasks detailed in the contract. The contractor is responsible for constructing the work as detailed in the contract documents while the GDOT team, led by the Project Manager, is responsible for ensuring that the terms of the construction contract and the changes are fulfilled. GDOT monitors, manages, and documents the contractor's activities to ensure compliance with the plans, proposal, and specifications. After project completion, GDOT design and construction processes are reviewed and discussed by design personnel. During this phase, constructability issues of a completed project are examined in order to increase effectiveness and efficiency. These issues may have affected the completion time, design and construction costs, environmental concerns, and work zone safety.

4.3 AREAS TO IMPROVE IN CURRENT PRACTICES

The current ODOT/GDOT planning procedures indicate that the only criteria considered for treatment type selection is the condition of pavement. The effects of rehabilitation design on production rate are not taken into consideration. This is critical especially when a high traffic urban network is reconstructed because it is important to minimize the inconvenience to the travelling public. Another issue in the current planning procedure is that ODOT & GDOT do not evaluate all the possible closure scenarios in order to select the most optimal one for the project. Different closure scenarios (nighttime, weekend, and continuous) have different impacts on the traveling public and produce different production rates in the rehabilitation projects. All the possible closure scenarios must be studied and the one that minimizes the user cost and maximizes the production rate should be selected. According to the ODOT/GDOT procedures, only one scenario is selected which is based on the experience and expertise of the engineers. Although ODOT/GDOT may end up with selecting the optimal scenario; the procedure is highly dependent on the experience and expertise of DOT engineers, which may provide wrong results especially in complicated projects where there are several possible closure scenarios.

The current planning procedures lack the comparison of different rehabilitation and closure scenarios. For each scenario, the impacts on the traveling public needs to be evaluated and if it was acceptable, the solution can be studied in term of schedule and if it was approved, the cost needs to be estimated and confirmed. In each step, if a scenario is not acceptable, the scenario can be deleted and other scenarios may be studied by performing further analysis.

CHAPTER V
SURVEYS AND CASE STUDIES

This chapter provides survey analysis results regarding the usability of CA4PRS in ODOT and GDOT. Then two PCC pavement rehabilitation projects in Oklahoma (I-35 & I-40) and two PCC pavement rehabilitation project in Georgia (I-75 & I-20) are analyzed using the CA4PRS. Scheduling and user cost estimation are the main focus of the case studies. In addition, the constructability issues that affected the production rates of rehabilitation activities are discussed in details.

5.1 POTENTIAL USABILITY OF CA4PRS

The CA4PRS is a tool designed to estimate the maximum probable length that can be rehabilitated given the various project constraints [6, 26]. The tool evaluates "what-if" scenarios with respect to rehabilitation by comparing input variables such as construction window, lane closure tactics, material constraints, pavement cross section, and scheduling interfaces among others [6, 27, 28]. Additionally, it quantifies road user costs during construction in order to help planners, designers and engineers determine which pavement materials and rehabilitation strategies maximize production without creating unacceptable traffic delays [15, 26, 28]. The results of this systematic and planning tool are useful for transportation agencies to calculate concrete pavement construction productivities for various construction strategies and traffic management scenarios. Additionally, it is possible to determine the typical process of pavement rehabilitation from a constructability point of view by identifying the major constraints limiting the production capability of rehabilitation.

A pre and post knowledge inventory survey was conducted to capture software usability from potential users on the training session for using CA4PRS. The pre and post knowledge inventory survey included the following topics covered by 19 items (see Table 5.1); i) General knowledge of the program (Items 1 and 2); (ii) Applicability to GDOT/ODOT operations (Items 3, 4, 19); iii) Potential for improvement of process (Items 5,6,7,8,9,10,14,18); iv) Availability of information (Items 11,12,13,15); and v) Usability of the program (Items 16,17). Each item was provided in the form of statement and the subjects were asked to score the level of agreement based on a 5-point Likert scale (1=strongly disagree, 2= disagree, 3=not sure, 4=agree, 5=strongly agree). Once the pre and post inventory survey for Oklahoma and Georgia were completed, descriptive statistics and statistical analysis were performed.

Table 5.1 Items of the Knowledge Inventory Survey

Item	Statement
1	CA4PRS is a scheduling and traffic analysis tool
2	CA4PRS is used to select the most economical strategies for highway rehabilitation given various project constraints
3	CA4PRS will allow GDOT/ODOT to comply with FHWA Rule 23 CFR Part 630 Subpart J
4	The use of CA4PRS will allow GDOT/ODOT to improve safety in work zones
5	The use of CA4PRS will improve constructability of GDOT's/ODOT's new roadway projects
6	The use of CA4PRS will improve constructability of GDOT's/ODOT's roadway rehabilitation projects
7	CA4PRS is applicable for asphalt pavement construction and/or rehabilitation in GA/OK
8	CA4PRS is applicable for Jointed Plane Concrete Pavement (JPCP) construction and/or rehabilitation in Georgia/Oklahoma
9	CA4PRS is applicable for Continuously Reinforced Concrete Pavement (CRCP) construction and/or rehabilitation in Georgia/Oklahoma
10	CA4PRS is applicable to the way lane closures are implemented in GA/OK
11	GDOT/ODOT has readily available information regarding mobilization and demobilization durations.
12	GDOT/ODOT has readily available schedule logic relationship information (for example, finish-to-start) for paving activities
13	GDOT/ODOT has readily available contractor resource information (number of trucks, capacity of batch plants, speed and number of paving machines, etc.)
14	CA4PRS is a useful tool for analysis of staging alternatives in GA/OK
15	GDOT/ODOT has the necessary data to make use of CA4PRS without substantial changes to current practices.
16	I feel that I can learn to use CA4PRS on my own.
17	I feel that I will be more productive in my job by using CA4PRS
18	CA4PRS can improve communication between the various project participants at GDOT/ODOT
19	CA4PRS can easily be integrated into the current GDOT/ODOT project development process

5.1.1 Pre and Post Knowledge Inventory Survey in ODOT

Descriptive statistics of the data for Oklahoma are provided in Appendix G. The results of the pre and post knowledge inventory survey can be seen in Figure 5.1. The highest mean in the pre-demonstration survey was for items 1, 6, and 11. The highest mean in the post-demonstration survey was for item 1 (=4.50). The lowest mean for the pre-demonstration survey was for item 13 and item 15. These results indicate that the survey respondents feel that ODOT does not have the contractor's data to input to the software. Additionally, the respondents think that ODOT needs to make substantial changes to the actual process of pavement rehabilitation in order to utilize the CA4PRS.

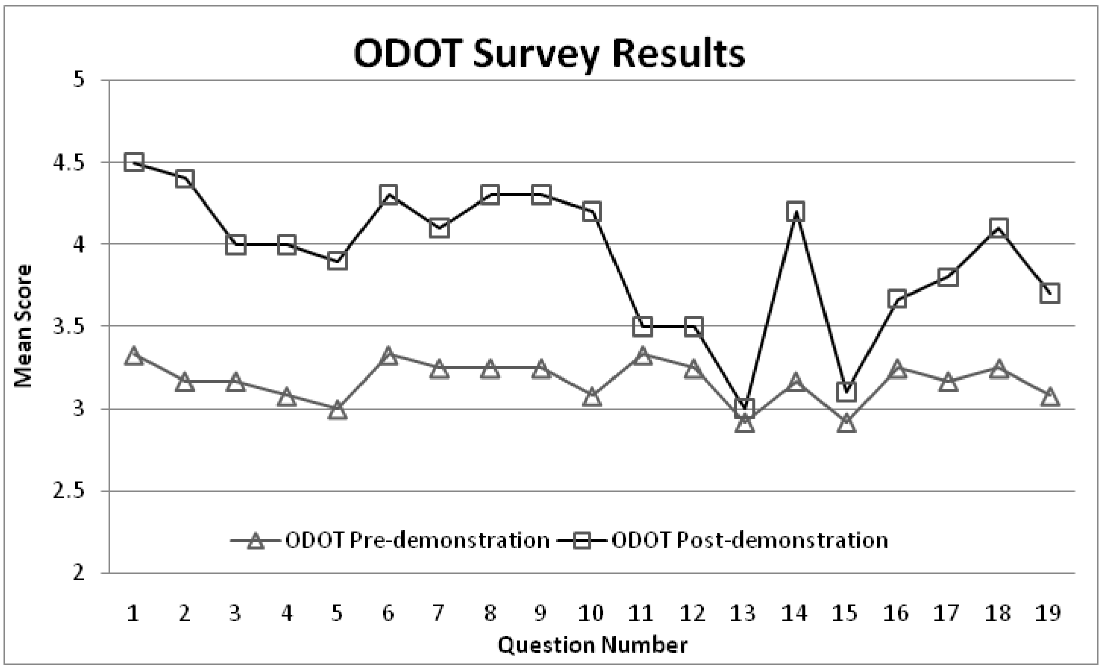


Figure 5.1 Survey Results of ODOT Workshop

There was a general increase (approximately 27%) in the understanding of the participants about the general knowledge of the CA4PRS software. As for the applicability of the CA4PRS to ODOT operations, there was a general increase (approximately 20%) in the level of agreement. There was a general increase (range from 20.73% to 26.59%) in the level of agreement of participants with the idea that CA4PRS could improve ODOT's current practices. Furthermore, there was a little increase in the level of agreement (range from 2.78% to 7.14%) on the direct availability of necessary data for CA4PRS implementation.

5.1.2 Pre and Post Knowledge Inventory Survey in GDOT

Descriptive statistics of the data for Georgia are provided in Appendix H. The results of the pre and post knowledge inventory survey can be seen in Figure 5.2. The highest mean in the pre-demonstration survey was for item 14 *(=3.43*) indicating that potential users feel that CA4PRS is a useful tool that compares different alternatives. The highest mean in the post-demonstration survey was for item 1 *(=4.31).* This result indicates that potential users changed their perceptions after the training session. Most of them expected that the CA4PRS is a tool for the analysis of scheduling and traffic. The lowest mean for the pre-demonstration survey and for the post-demonstration survey was for item 12: *(=2.90, =3.07).* This result indicates that before and after the training session potential users feel that GDOT does not have the schedule information on paving rehabilitation activities.

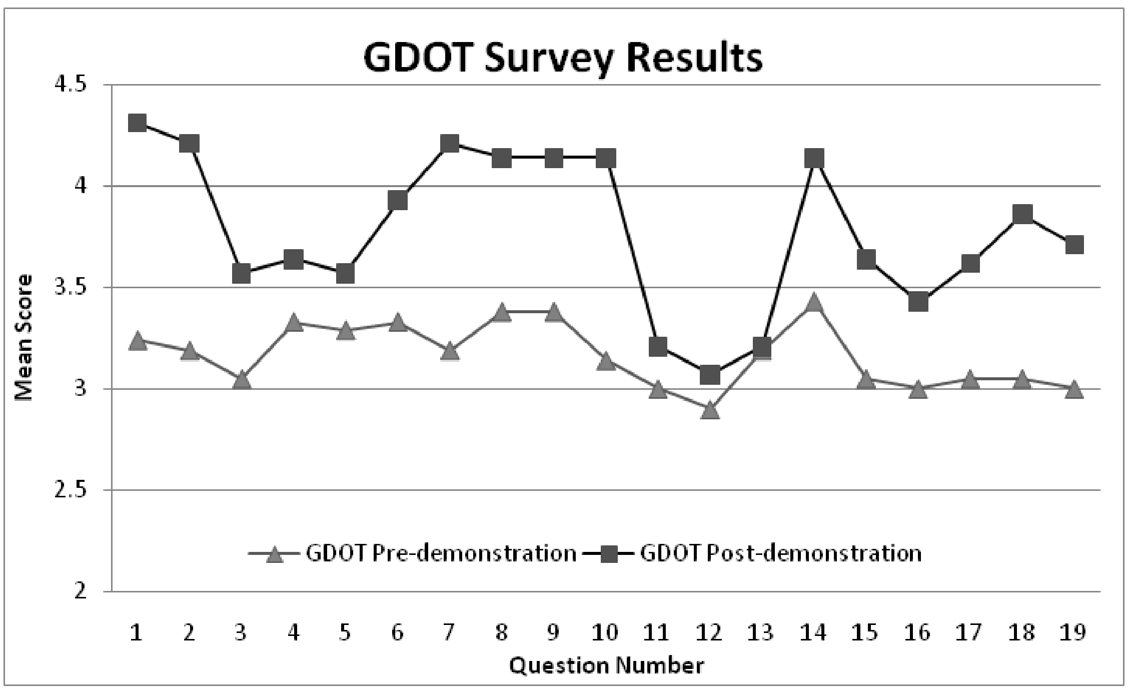


Figure 5.2 Survey Results of GDOT Workshop

There was a general increase (approximately 24%) in the understanding of the participants about the general knowledge of the CA4PRS software. As for the applicability of the CA4PRS to GDOT operations, there was a general increase (approximately 24%) in the level of agreement. However, there was a small increase in the level of agreement (0.74%) on the direct integration of CA4PRS into the current process. There was some increase (range from 12.5% to 21%) in the level of agreement of participants with the idea that the CA4PRS could improve GDOT's current practices. Furthermore, there was an increase in the level of agreement (range from 8.5% to 15.7%) regarding the direct availability of necessary data for CA4PRS implementation. Finally, there was a small change (6.67% to 8.0%) in the level of agreement from participants about the required effort to learn the CA4PRS program. This could have resulted from the short format of the training session.

5.1.3 Interpretation of the Results

As can be seen in Figure 5.1 & 5.2, pre- and post-demonstration surveys indicate major differences in the questions about general knowledge of the program (Items 1 and 2) and potential for improvement of process (Items 5, 6, 7, 8, 9, 10, 14, 18). The improvement in the general knowledge of the program can be related to the demonstration program itself which has given the participants a better understanding of how the program works. The increase in the potential for improvement indicates that both GDOT and ODOT participants agree that the features available in the program are able to improve existing procedures and are applicable for rehabilitation projects.

Also the least amount of difference between pre and post demonstration survey results is obtained for items 11, 12, and 13. These are the questions related to the availability of information to run the CA4PRS. Although the level of agreement to these questions have increased after the demonstration but it shows the least level of change compared to other questions. This means that the survey participants have been consistent with their perception that both GDOT and ODOT do not have the readily available input information to run the CA4PRS.

5.2 CASE STUDIES

After assessing the applicability of the CA4PRS, two implementation studies on each state were investigated. Information that was collected included background of the project, general pavement design information, contractual information, field operations and staging, resources, and constructability and safety issues. The main source of data for the case studies was based on regular meetings with GDOT, ODOT, and contractor engineers. Moreover, the site visits and monitoring construction activities helped the research team to gather the input data for CA4PRS more accurately.

5.2.1 I-35, Noble County, Oklahoma

Project Overview

The I-35 is a north-south interstate highway with the length of 378 km (235 mi) in Oklahoma. It passes through many of the state's major cities including Ardmore, Norman, Oklahoma City, Edmond, and Guthrie. There are two lanes in the north direction and two lanes in the south direction. The case study project is a PCC pavement rehabilitation project located in Noble County, Oklahoma with the length of 8.96 km (5.57 mi). The project starts approximately from the mile post of 197 and ends in the mile post of 204. The location of the project along I-35 is indicated in Figure 5.3. This section of the highway was constructed in 1963 with 22.86 cm (9 in) of Mesh Dowel PCC over 10.16 cm (4 in) of sand cushion and 20.32 cm (8 in) of select material as base and sub-base. During 1980 it was overlaid by a layer of Open Graded Friction Course (O.G.F.C). Eleven years later in 1991, 7.62 cm (3 in) of Asphalt Concrete Type "F" and 1.27 cm (½ in) of Asphalt Concrete Type "E" was installed on top of the existing pavement.

Contractual Features

The contract type was A+B contract with the "A" amount of $13.1 million and the B amount of 275 calendar days. The amount of incentives/disincentives assigned to this project was $7,500 per day with the maximum incentive of 90 days. The project started on August 2009 and finished on May 2010 and the actual duration was 275 calendar days. In other words the contractor has finished the project on time without being eligible to receive incentives or pay disincentives.

Figure 5.3 I-35 Project Location

Project Issues

The main issues observed in this project are related to the weather and traffic. The weather issues include moisture, rain, ice rain, freezing temperature and storms like tornado which has stopped the project for 45 calendar days. Also the traffic situation has been critical during national holidays such as Christmas and Thanksgiving days. Based on the interviews with the resident engineer, the traffic in the work zone has experienced a delay of around 1.5 hr during the major holidays. The other traffic issue has been related to the vehicles that are pulled off into the median. Due to having only one lane open to traffic in each direction the traffic had to be stopped for a while to rescue the vehicles.

Unique Features

In order to model the I-35 project with the CA4PRS, the project was divided into seven different traffic phases (see Figure 5.4); i) Move traffic in NB to inside lane and construct temporary shoulder. The temporary shoulder is constructed with concrete pavement with the width of 1.83 m (6 ft) and thickness of 19.05 cm (7-1/2 in). The length of this section is 6.24 km (3.88 mi); ii) Shift traffic in both directions to outside lane and construct crossovers. There are two crossovers; one is located in the south and the other is located in the north of the work zone with the length of 190.5 m (625 ft), width of 15.24 m (50 ft), and length of 160 m (525 ft), width of 15.24 m (50 ft) respectively; iii) Shift traffic from Southbound onto Northbound and construct unbounded overlay and full depth reconstruction on Southbound.

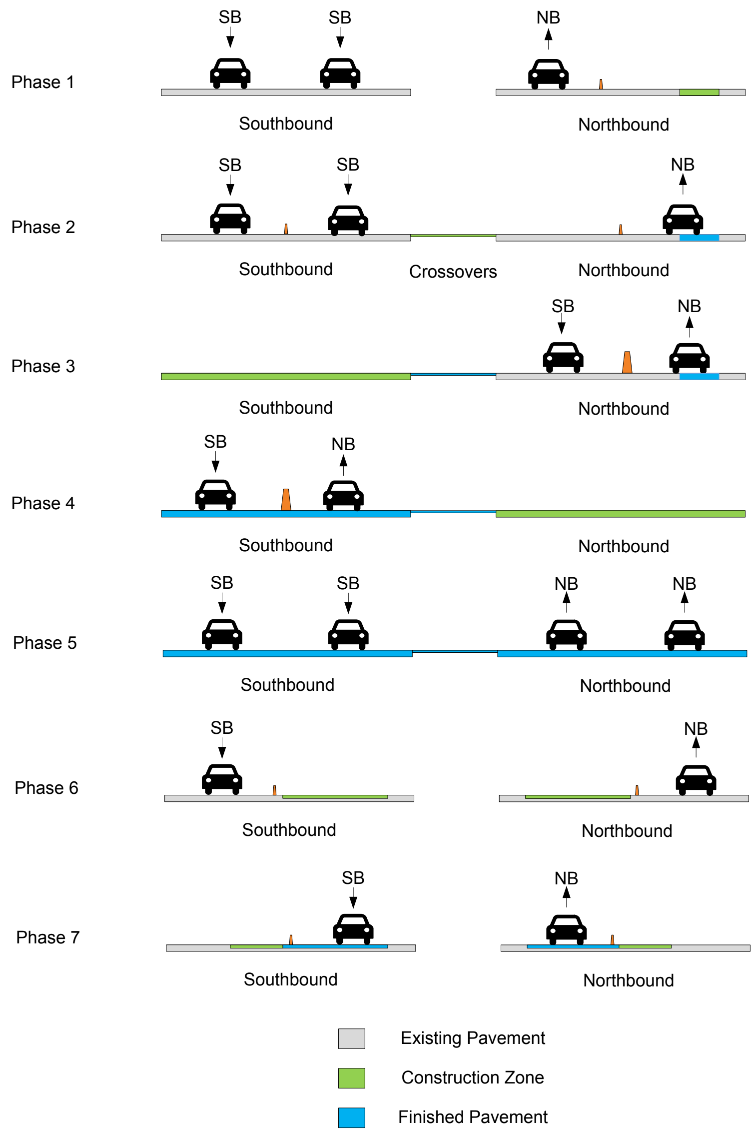


Figure 5.4 I-35 Traffic phases

In the unbounded overlay sections, 3.81 cm (1.5-in) of the existing pavement is milled and 22.86 cm (9-in) of Dowel Jointed PCC pavement is overlaid. The total length of this section is 5.94 km (3.69 mi). The full depth reconstruction sections consist of 29.21 cm (11.5-in) of Dowel Jointed PCC pavement over 33.02 cm (13-in) of base with the total length of 1.42 km (0.88 mi). Including the inside and outside shoulders there are two lanes with the length of 3.66 m (12 ft) and one lane (10' outside shoulder + 4' inside shoulder) with the length of 4.27 m (14 ft) that need to be reconstructed; iv) Shift traffic from Northbound onto Southbound and construct unbounded overlay and full depth on Northbound; v) Open lanes for both directions; vi) Shift traffic in both directions to outside lane and mill and overlay the inside lane in the north end of project; vii) Shift traffic in both directions to inside lane and mill and overlay the outside lane in north end of project.

Continuous closure shift operation was chosen as the only possible option for this project. Working method is Sequential Single lane since there were always one lane under construction and one lane being used as construction access. Therefore paving and demolition activities could not be performed concurrently since each of them needed one single access lane which was not available in this project. The rehabilitation activity consisted of concrete overlaying of two 3.66 m (12 ft) lanes, one 1.22 m (4 ft) inside shoulder and one 3.05 m (10 ft) outside shoulder in South Bound and North Bound of I-35. In order to facilitate the analysis, it was assumed that the project consisted of three lanes with the width of 3.86 m (12.67 ft).

CA4PRS Analysis Results

The input information and the output of the CA4PRS analysis is summarized in Tables 5.2, 5.3, and 5.4. There are also some activities which were not included in the CA4PRS analysis and these activities are indicated as Other Activities in the tables. Some of those activities include strip topsoil on edge, seal joints, guardrail widening, temporary strip, setting barrier wall, erosion control, and cable barrier. The durations of these activities have been estimated to be 38 working days. The total duration of the project is the summation of durations calculated in Table 5.4 because all the major activities were performed sequentially. Hence, the project duration is estimated to be 194 working days. Considering 15% expansion factor suggested by the developer of the CA4PRS, the final suggested duration for this project would be 230 working days.

This project has been scheduled and finished by the contractor in 200 working days (275 calendar days). In other words, the contractor has finished the project 30 working days earlier than what was estimated by CA4PRS. It can be inferred from the analysis results that the actual productivity of the project was higher than CA4PRS calculations. This might be attributed to the fact that resource profile information used for analysis is based on the interviews with the contractor and ODOT resident engineers and it may be different from the real resource profile used by the contractor. Since the production rates are directly related to the resource profile information, it would be necessary to evaluate the information in order to come up with standard input information for ODOT to use in future projects.

Table 5.2 I-35 CA4PRS Input Information

Resource Description	Capacity characteristics	Phase 1	Phase 3&4, Section 1	Phase 3&4, Section 2	Phase 6&7
Demolition Hauling Truck	Rated capacity	16,780 kg (18.5 ton)	16,780 kg (18.5 ton)	16,780 kg (18.5 ton)	-
	Trucks per hour per team	6	10	10	-
	Efficiency	0.7	0.8	0.6	-
	Number of teams	1	1	1	-
	Team efficiency	0.9	0.9	0.9	-
Base Delivery Truck	Rated capacity	0 m^3	0 m^3	0 m^3	-
	Trucks per hour	0	0	0	-
	Efficiency	-	-	-	-
Batch Plant	Capacity	89.98 m^3/h (117.7 yd^3/hr)	89.98 m^3/h (117.7 yd^3/hr)	89.98 m^3/h (117.7 yd^3/hr)	272,100 kg/h (300 ton/hour)
	Number of plants	1	1	1	1
Concrete Delivery Truck	Rated capacity	6.88 m^3 (9 yd^3)	6.88 m^3 (9 yd^3)	6.88 m^3 (9 yd^3)	-
	Trucks per hour	6	13	13	-
	Efficiency	1	1	1	-
Paver	Speed	2.01 m/min (6.6 ft/min)	2.01 m/min (6.6 ft/min)	2.01 m/min (6.6 ft/min)	29 km/h (18 mph)
	Number of pavers	1	1	1	1
Milling and Hauling	Number of Teams	-	-	-	1
	Team efficiency	-	-	-	0.95
Milling Machine	Machine Class	-	-	-	Medium
	Material Type	-	-	-	AC - Medium
	Efficiency Factor for Downtimes	-	-	-	0.7
Hauling Truck	Rated Capacity (kg)	-	-	-	16,780
	Trucks per hour per team	-	-	-	11
	Packing Efficiency	-	-	-	0.75
HMA Delivery Truck	Rated Capacity (kg)	-	-	-	18,140
	Trucks per Hour	-	-	-	10
	Packing Efficiency	-	-	-	0.9

Table 5.3 I-35 Input information for user cost analysis (I-35 Project)

Input Information	Value
Passenger Car ($/hr)	12
Commercial Truck ($/hr)	28
Percent Truck (%)	37
AADT	19,530

Table 5.4 I-35 Estimated project duration with CA4PRS

Phase	Description	Duration (working days)	User cost ($)
1	NB temporary shoulder	15	51,108
2	Pave crossovers	5	14,720
3&4, Section 1	SB & NB Concrete overlays	47	176,736
3&4, Section 2	SB & NB full depth reconstruction	85	498,027
6&7	Mill and overlay	4	23,552
8	Other activities	38	322,869
Total		**194**	**1,087,012**

5.2.2 I-40, Canadian County, Oklahoma

Project Overview

The I-40 is a major west-east interstate highway in the United States. This interstate highway covers 533 km (331 mi) in Oklahoma passing through many cities and towns of Oklahoma such as El Reno, Oklahoma City, Shawnee, and Roland. The location of the project along I-40 is shown in Figure 5.5.

This case study project is rehabilitation and widening of 11.89 km (7.31 mi) of Interstate 40 in Canadian County, Oklahoma. Location of project is from mile marker 125 to mile marker 136. The existing road is two lanes in each direction with Jointed Portland Cement Concrete (JPCC) pavement and asphalt shoulders. The reconstruction scope includes 8.53 m (28 ft) widening of existing roadway and bridge repair along with resurfacing of the existing pavement.

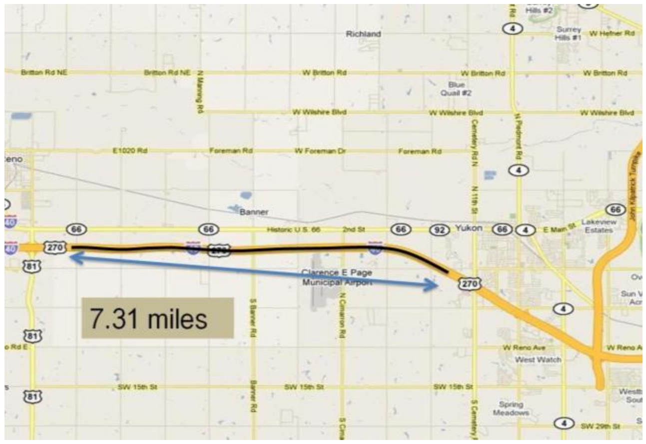


Figure 5.5 Location of Project along with I-40

Contractual Features

The contract is A+B with the contract time of 830 calendar days. The contract price or "A" is around $59,000,000. The maximum days allowed or "B" bid for substantial completion of the project is 800 calendar days. The incentive/disincentive rate of this project is $15,000 per day and the maximum number of days for which incentive will be paid is 150 days. The contractor has planned to finish the project in 617 calendar days. In case the contractor substantially completes the project within the scheduled time they would be eligible to receive the maximum incentive with the amount of $2,250,000. In addition the liquidated damage of $2,000 per day has been considered after the expiration of the contract time. The liquidated damages are calculated by quantifying inconvenience to the public, added cost of engineering and supervision, and other extra expenditures of public funds due to the contractor's failure to complete the work on time. In order to restrict the lane closures during the construction, the Lane Rental Fees for lane closures has also been considered in the contract in order to avoid contractors from closing the lanes during the time that the highway is under heavy traffic. Table 5.5 shows the Lane Rental Fees considered for this project. As can be seen in the table there would be a lane rental of $30,000 per hour from 6 a.m. to 9 p.m. during the weekdays and 12 pm to 9 pm during the weekends. Contractor would be able to close the lanes during the other time spans for free as long as they keep one lane open in each direction at all times.

Project Issues

The main issues observed in this project are related to the severe weather condition and changes in the design. The weather issue includes winter storms that have delayed the project for 15 days. The design issue is related to the substantial changes in the rehabilitation method and closure scenario during the contract bidding process. Thus, the final designs and closure scenarios are different from the designs available in the bid packages. Changing the closure scenario from partial closure to full closure and using counter-flow traffic without updating the design package has made ODOT redesign some parts of the project during the construction. This difference between the design package and what the contractor actually performed on the job site has been the source of number of construction issues.

Table 5.5 Lane Rental Fees (per lane per hour)

Time	Monday thru Friday	Saturday	Sunday
12 a.m. - 6 a.m.	$0	$0	$0
6 a.m. - 9 a.m.	$30,000	$0	$0
9 a.m. - 12 p.m.	$30,000	$0	$0
12 p.m. - 6 p.m.	$30,000	$30,000	$30,000
6 p.m. - 9 p.m.	$30,000	$30,000	$0
9 p.m. - 12 a.m.	$0	$0	$0

Unique Features

This project is considered one of the major reconstruction/rehabilitation projects in Oklahoma in terms of scope, cost, and inconvenience to the public. During the interviews with the contractor and resident engineers, it was found that the contractor has proposed a change in the design and closure scenario, which have enabled them to propose a shorter duration with lower price during the bid process. Since the major part of the existing pavement has acceptable condition, the contractor proposed to use the existing pavement as the base of the new pavement. The full depth rehabilitation was replaced with concrete overlay which saved considerable amount of cost and time in the project. Also the closure technique was changed from the partial closure to full closure with counter-flow traffic because this could provide the contractor with more access area for construction. More access area increases the productivity by providing the trucks and crews with more mobility. In addition, it assists in increasing the safety by separating the construction crews from the traffic.

The closure scenario can be seen in Figure 5.6. In phase one, EB outside lane is closed to traffic during night and the 3.05 m (10 ft) shoulder is removed and reconstructed with 20.32 cm (8 in) concrete. In phase two, the EB widening with the width of 8.53 m (28 ft) and 24.13 cm (9.5 in) of Dowel Jointed PCC pavement, 10.16 cm (4 in) of Cement Treated Base, 15.24 cm (6 in) of Aggregate Base, and 20.32 cm (8 in) of Lime Treated Base is constructed. Then in phase three, the two lane WB traffic is moved to EB creating counter flow traffic in EB and reconstruction and widening is started in WB. This phase is a combination of concrete overlay with the thickness of 24.13 cm (9.5 in), patching, and 8.53 m (28 ft) widening. In phase four, both WB and EB traffic are moved to WB and rehabilitation is performed in EB.

As can be seen in Figure 5.6, by combining the rehabilitation project with highway widening, ODOT kept two lanes open to traffic during all the phases except for phase one which is constructed during night. This technique has reduced the amount of user cost significantly.

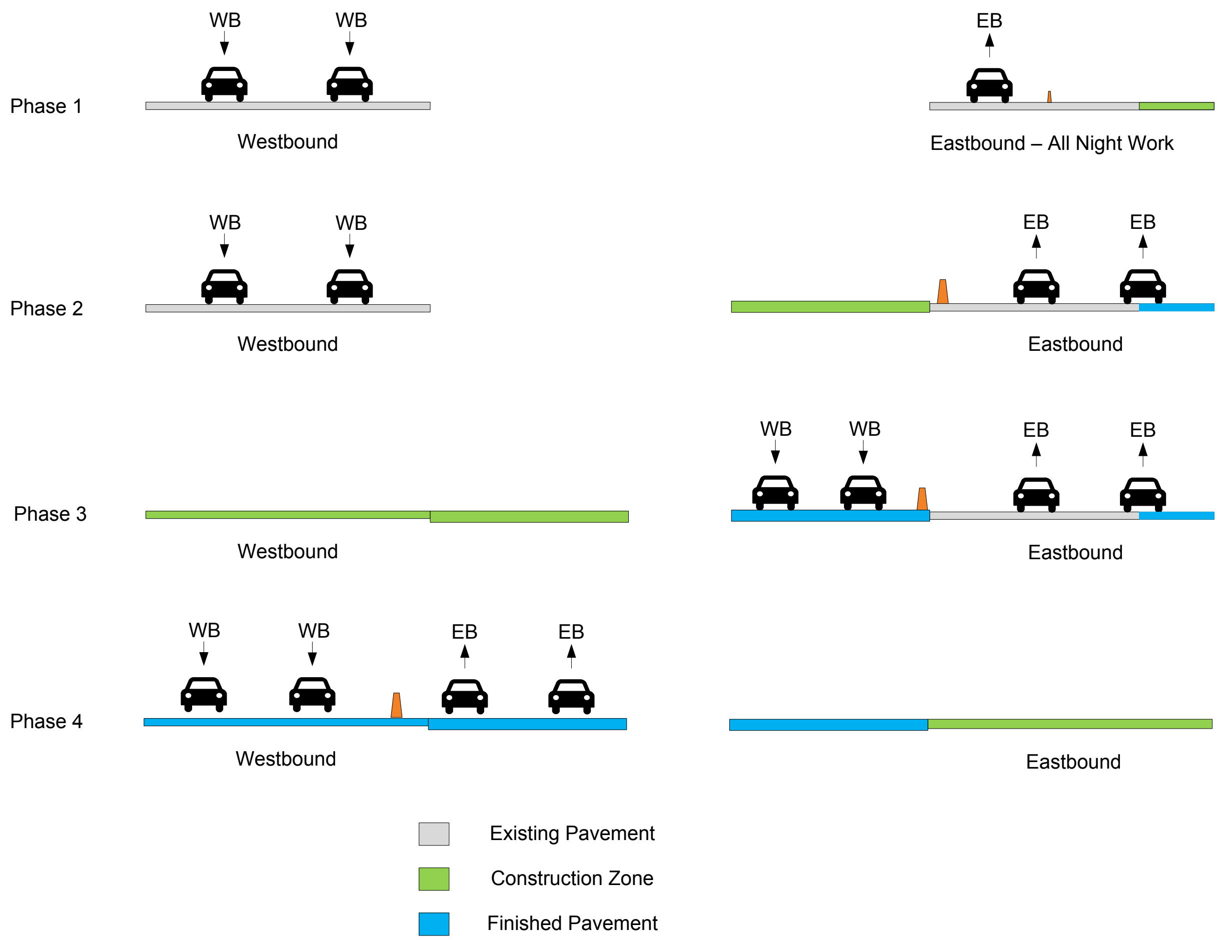


Figure 5.6 Closure scenario of I-40 project

CA4PRS Analysis Results

Although some activities could be modeled by the CA4PRS, simulating the whole project was not possible. This was due to the fact that the project includes bridge rehabilitation, pavement rehabilitation, safety improvement, and adding lanes. The CA4PRS has no function to model these activities in the program.

The user cost analysis was performed by the Work-Zone Analysis module in the CA4PRS. Since the Scheduling Analysis could not be performed by the CA4PRS, the durations used for user cost analysis were based on the contractor's schedule. The costs of passenger cars and commercial trucks were assumed to be $16.31/hr and $24.93/hr respectively.

Table 5.7 shows the user cost analysis of I-40 project based on the input information from Table 5.6. The project consists of four major phases and user cost has been calculated for each phase separately. Furthermore the traffic demand has been checked with the traffic capacity of the road in order to identify the time spans that queue is developed and check the accuracy of lane rental schedule as shown in Table 5.5. The hourly traffic graph of phase 1 during the weekend is shown in Figure 5.7. Phase 1 is performed during the night therefore from 6 a.m. to 9 p.m. Two lanes would be open to EB traffic otherwise the contractor is charged $30,000/hr for lane rental. The hourly traffic graph shows that both EB lanes should be open to traffic from 6 a.m. to 9 p.m. otherwise a maximum delay of 125 min can occur. This supports the decision of ODOT in restricting the lane closures from 6 a.m. to 9 p.m.

The traffic analysis of phase one during Saturdays can be seen in Figure 5.8. As can be seen in the lane rental fee table (Table 5.7), the contractor is charged if they close a lane from 12 p.m. to 9 p.m. But the results of traffic analysis show that the traffic demand is more than capacity from 6 a.m. to 12 p.m. By comparing the traffic analysis results with the lane rental fee table it can be inferred that ODOT should have restricted lane closure on Saturdays from 6 a.m. to 9 p.m. not 12 p.m. to 9 p.m. In other phases, since two lanes are open to traffic all the time the traffic demand is always less than traffic capacity therefore no queue is developed in the roadway and user cost is only related to speed restrictions in the work zone.

Table 5.6 Input information for user cost analysis (I-40 project)

Input Information	Value
Passenger Car ($/hr)	12
Commercial Truck ($/hr)	28
Percent Truck (%)	37
AADT	39,500

The amount of lane rental fee per hour is also calculated by the CA4PRS. In case the contractor closes one lane in each direction the amount of user cost per hour would be around $27,000/hr. This result supports the lane rental fee assumed by ODOT for the I-40 project which is $30,000/hr.

Table 5.7 User cost analysis for I-40 project

	Duration	User Cost	Queue
Phase 1	50	$528,958.00	Saturdays 6 a.m. - 12 p.m.
Phase 2	200	$1,589,221.00	-
Phase 3	200	$3,178,443.00	-
Phase 4	100	$1,589,221.00	-
Total		**$6,885,843.00**	

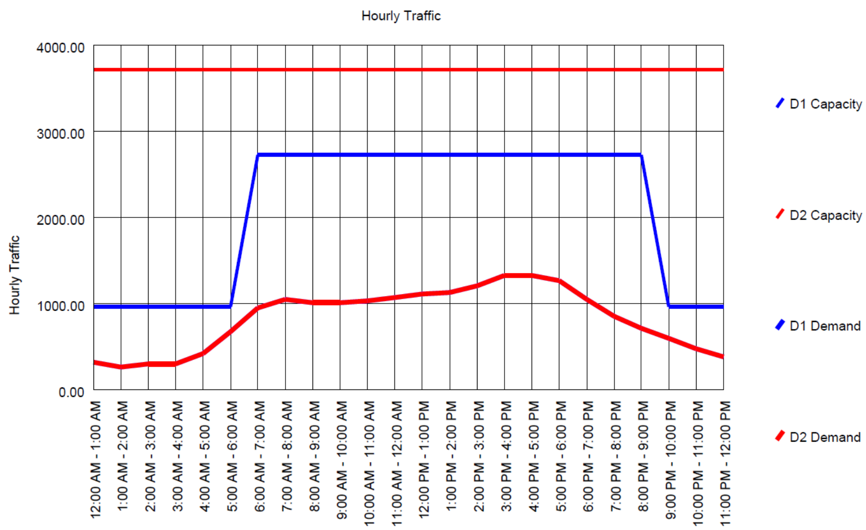


Figure 5.7 Hourly Traffic Graph, I-40 project, Phase 1 during weekdays

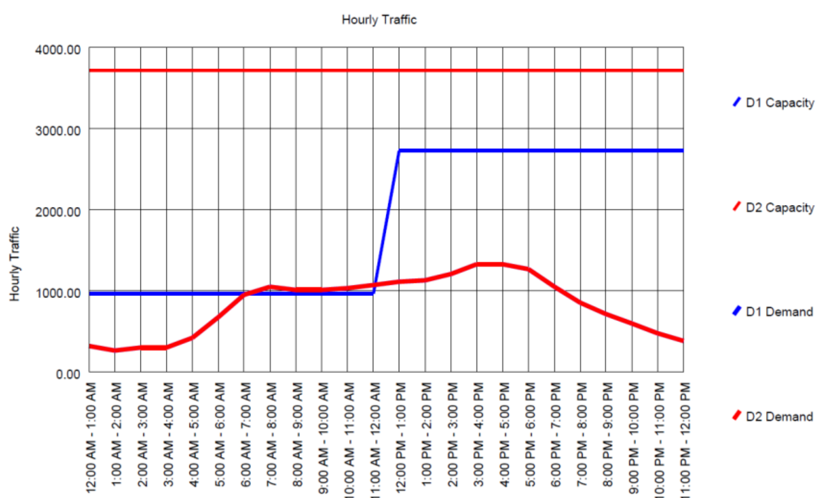


Figure 5.8 Hourly Traffic Graph, I-40 project, Phase 1 on Saturdays

During the traffic analysis of the I-40 project, it was identified that hourly traffic demand information is not available in ODOT. The traffic analysis performed for the I-40 project is based on the assumptions made by the CA4PRS which may be different from the actual data. Therefore, ODOT needs to develop the hourly traffic demand data for the road network of Oklahoma in order to calculate road user costs more accurately.

5.2.3 I-75, Georgia

Project Overview

The I-75 project is a 14.48 km (9 mi or 95 lane-miles) PCC rehabilitation project located between Glade Road in Bartow County, GA and Barrett Parkway in Cobb County, GA as shown in Figure 5.9. The rehabilitation design included 3.66 m (12 ft) Continuously Reinforced Concrete (CRC) being added onto the existing pavement. It was originally designed as asphalt mill and inlay project, but was changed in a fast-track manner to a deep mill and PCC inlay project when GDOT's Office of Materials discovered a deficient "deep" layer of asphalt. The project was let in March 2006 at a cost of $80,000,000. The Notice to Proceed was given on April 2006. The original project proposal contained provisions for counter-flow traffic control utilizing 32 weekends for construction operations, but a Value Engineering (VE) proposal resulted in an agreement between the contractor and GDOT to eliminate the counter-flow method of Maintenance of Traffic (M.O.T). Among the reasons cited by the contractor for the elimination of counter-flow were the following: ability to perform the work utilizing only single lane closures thus eliminating all double lane closures, and ability to eliminate weekend only counterflow as M.O.T. method. These changes would result in a total contract cost savings of $2.3 million. The first concrete pour of the project occurred in March 2007.

Pavement Design and Construction Information

The traffic flow in the project area included 235,000 vehicles per day (VPD) with 15% trucks. Concrete quantities for the project required 547,663 m^2 (655,000 yd^2) of PCC. The project also required 6 major traffic switches with 4 zones of differing lane closure restrictions and extended holiday shut downs (6 weeks from Thanksgiving day to New Year's day). The project required 100% grinding on all completed PCC Pavement.

Figure 5.9 I-75 Project Location

The section characteristics of the existing pavement included a 431.8 mm (17 in) asphalt layer in the main line with 254 mm (10 in) asphalt shoulders. The rehabilitation design included 304.8 mm (12 in) of concrete slabs over a 76.2 mm (3 in) asphalt layer (minimum after milling) for the travel lanes and the outside shoulder. For the inside shoulders, the design called for 304.8 mm (12 in) of concrete over a 76.2 mm (3 in) asphalt layer over 304.8 mm (12 in) Graded Aggregate Base (GAB) for a total cross-section of 685.8 mm (27 in). The project was divided into 4 zones for the purposes of staging due to the closure restriction included in section 150.11 of the special conditions (see Appendix I). A typical cross section of the I-75 Project is shown in Appendix J.

The pavement design for the project required three mix designs. A Class 1 mix design with a 20 MPa (3000 psi) compressive strength requirement at 28 days was required for mainline shoulders and Lane 3, a Class 3 mix design with a 20 MPa (3000 psi) compressive strength requirement at 28 days was required for ramps, and a High Early Strength (HES) mix with a 18 MPa (2500 psi) compressive strength requirement at 24 hr and a 25 MPa (3500 psi) compressive strength requirement at 72 hr was required for ramps, Lanes 1, and 2 (weekend work). Since the reconstructions of the ramps required them to be completely closed to traffic, it was required that the work be completed during the allowed 72-hr weekend construction window.

Incentive and Penalty Provisions

The project contract has some important restrictions that influenced the contractors planning for the project. Table 5.8 shows important requirements and their associated penalty or reward. The project was divided into 4 zones for the purposes of staging due to the closure restriction included in section 150.11 of the Special Conditions as shown in Appendix I.

Table 5.8 I-75 Project Disincentives and Incentives

Requirement	Reward or Penalty
Failure to reopen all lanes at times specified	$10,000 per hour
Counterflow weekends used beyond the 32 allowed	$250,000 per weekend
Failure to reopen ramps	$10,000 per calendar day
Failure to complete all work by April 30, 2009	$500,000 lump sum + $10,000 per day
Complete project 100 days earlier than 4/30/09	$1,000,000 bonus

Closure and Constructability Issues

The I-75 Project personnel provided the research team with information related to constructability issues faced during the various phases of the project. The following is a summary of the issues discussed during the interviews with project personnel.

Phase 1 Issues

Constructability issues during this phase were mainly related to limited work area. According to the contractor, this was due to the required width of 3.05 m (10 ft) for the completed travel lanes, the constraints caused by the presence of guardrails, and steep slopes in various areas with no possibility of widening to provide for more work area. In addition to work area related issues, truck egress/ingress from the work zone was an issue during construction. During the initial phase, trucks were required to enter the work zone from the travel lanes and, once concrete unloading was completed, were required to enter the traffic flow at an increased speed or “dive” into traffic (Figure 5.10). Other issues included shoulder duct bank and manhole conflicts, first phase learning curve, and the 48 hr healed shoulder requirement, which resulted in additional work if progress was not achieved at a satisfactory rate.

Figure 5.10 Work area issues in Phase 1

Phase 2 Issues

During the second phase, truck ingress/egress continued to present problems for the safety of workers, truck drivers, and the traveling public. In addition, this situation would also result in additional costs of idle crew time when delay of material delivery occurred. The contractor's solution to the problem was a change of paving equipment to a Gomaco 2600 Placer/Spreader (Figure 5.11). The change in equipment eliminated the problems with truck egress, provided a better-finished product, and allowed the contractor to achieve better production with less traffic exposure.

Figure 5.11 Gomaco 2600 Placer/Spreader as solution to work area issues

Phase 3 Issues

Phase 3 issue included limited weekday work for crews, since most of the work during this phase was scheduled for weekends. It consisted of two runs of continuous drill and dowel operations vs. none in Phase 2. Also moving traffic to the HES concrete on Monday mornings, winter weather, and material/fuel cost escalations were the main issues faced during phase 3 of project, among others.

General Project Challenges

In addition to the construction phase-specific challenges, the contractor discussed other challenges faced during construction on the I-75 Project. Some of those challenges were related to high speed traffic, intoxicated drivers at late hours, driver frustration caused by long traffic delays, high volume of heavy vehicle traffic, the "rubber-necking" phenomenon caused by construction operations, and accidents in the work zone, among others. Some of the solutions that were implemented to address these issues included; reduced speed limit from 105 kph (65 mph) to 88.5 kph (55 mph), increase in work zone police patrols, and an accelerated construction schedule.

In addition to traffic-related challenges, construction operation challenges included; night paving operations, proximity to traffic, hot temperature paving, sufficient existing asphalt base under travel lanes, and damaged concrete. For the issue of paving in hot weather, the contractor used a 3,785 liters (10,000 gallon) chilled water tank and a sprinkler system on aggregate stockpiles to control the moisture content and temperature of aggregates during days of excessively hot weather. In addition to this measure, the contractor also changed the fasteners for the dowel baskets from 6.35 cm (2.5 in) Hilti clips to 30.5 cm (12 in) pins. Another strategy used by the contractor when temperatures were elevated was to schedule night paving when feasible.

Damaged concrete was another challenge that the contractor contended with during the project. Figure 5.12 shows an example of a damaged section of pavement. This situation required the contractor make repairs that were not part of the original contract and ensure that the structural integrity of the pavement was not affected by the damage.

When a section did not have sufficient existing asphalt base under travel lanes (as shown in Figure 5.13), the contractor was required to do additional work based on the following excerpt from the contract documents. "In the event that the milled surface leaves less than 50.8 mm (2 in) of asphalt, the contractor shall mill/excavate an additional amount such that a minimum of 76.2 mm (3 in) of 19 mm (3/4 in) asphaltic concrete is provided as a suitable base for the 30.48 cm (12 in) of concrete." (General Contract Requirements, Construction Detail. See Appendix I).

Figure 5.12 Damaged concrete pavement

Figure 5.13 Insufficient asphalt base under travel lanes

Given this situation, the contractor performed exploratory preliminary core drilling and conducted pre-planning with milling and asphalt paving subcontractors prior to paving operations in order to be prepared in the event that the requirements for asphalt base were not met.

CA4PRS Analysis Results

The working methods that the program provides define the number of lanes that will be closed for equipment access and paving. The actual project involved an existing three lane road which would become a four lane road with widened shoulders. There was no option in the CA4PRS to model a multi-phase project that involved paving different lanes and closing different lanes at different points in time. Therefore, to model the I-75 project, a single lane closure was chosen since it was the closest scenario to what was happening. With this method there is always one lane under construction and one lane used as access for construction operations.

Another factor of the program is that it totals the working scope across an entire construction window, based on either continuous closure, weekend closure, or nighttime closure, but not a combination of options. As a consequence, the project was divided into 4 zones due to the closure restriction.

The project is modeled in the CA4PRS based on the stages defined previously. With the assumption of 26 working days per month and 8 working hr/day, and the sequential working method, the following results have been produced. Table 5.9 shows the resource profile information used for Zones 1 through 4. Resource utilization is available in Table 5.10.

The resource utilization sensitivity analysis done by the CA4PRS shows that demolition hauling trucks, base delivery trucks and concrete delivery trucks are the controlling resources in this operation (See Table 5.10). Also by comparing the allocated and utilized number of demolition hauling trucks, base delivery trucks and concrete delivery trucks, it can be inferred that all the allocated trucks are being utilized.

The production rate was different in each zone (see Table 5.11), but the overall production rate of the rehabilitation was calculated by finding the weighted production rate which is 1.13 lane-km (0.70 lane-miles) per closure. Total lane-km (lane-miles) of this project were 115.8 (72) and considering the production rate of 1.126 lane-km (0.70 lane-miles) per closure, the number of closures would be approximately 260 days.

Table 5.9 Resource Profile information used for analysis in Zone 1 through Zone 4

Resource Description	Capacity characteristics
Demolition Hauling Truck	Rated capacity: 18.14 Mg (20 ton)
	Trucks per hour per team: 10
	Efficiency: 0.60
	Number of teams: 2
	Team efficiency: 1.0
Base Delivery Truck	Rated capacity: 9.94 m^3 (13 yd^3)
	Trucks per hour: 10
	Efficiency: 0.90
Batch Plant	Capacity: 99.39 m^3/h (130 yd^3/hr)
	Number of plants: 1
Concrete Delivery Truck	Rated capacity: 6.88 m^3 (9 yd^3)
	Trucks per hour: 10
	Efficiency:0.90
Paver	Speed: 3.048 m/min (10 ft/min)
	Number of pavers: 1

Table 5.10 Resource utilization for Zone 1 through Zone 4

Resource	Allocated	Utilized
Demolition Hauling Truck (per hour per team)	10.0	10.0
Base Delivery Truck (per hour)	10.0	10.0
Batch Plant	99.39 m^3/h (130 yd^3/hr)	61.9 (81.0)
Concrete Delivery Truck (per hour)	10.0	10.0
Paver Speed	3.048 m/min (10 ft/min)	0.91 (3.0)

Table 5.11 I-75 Productivity Results for Zone 1 to Zone 4

Zone	Scope	Construction windows needed to meet objective	Closure production
1	22.526 lane-km (14 lane-miles)	21.23	1.062 lane-km (0.66 lane-miles)
2	22.526 lane-km (14 lane-miles)	19.46	1.158 lane-km (0.72 lane-miles)
3	35.14 lane-km (22 lane-miles)	33.36	1.062 lane-km (0.66 lane-miles)
4	35.14 lane-km (22 lane-miles)	28.78	1.222 lane-km (0.76 lane-miles)

5.2.4 I-20, Georgia

Project Overview

The section of I-20 rehabilitated on this project is a 38.62 km (24 mi) section located between State Route 61 and the Alabama state line in Carroll and Haralson Counties (Figure 5.14). The original pavement on this section was constructed in 1977-78 with a normal service life of 20 years prior to the first major maintenance activity. This section of I-20 was 8 years overdue for major maintenance activity. The total cost of the project is $85,000,000. The project involves total pavement replacement with CRC. Specifically, the outside shoulder was replaced with full-depth CRC, the inside shoulder was replaced with hot mix asphalt, and existing guardrails was upgraded to current standards. The project required 441,460 m^2 (528,000 yd^2) of CRC and 429,918,000 kg (474,000 tons) of GAB. The traffic volume in this section of I-20 is 49,500 VPD with 39% of trucks. The traffic control plan utilized counter-flow staging to maintain a minimum of two traffic lanes in each direction.

Figure 5.14 Location of I-20 Project

Pavement Design and Construction Information

The original pavement profile consisted of 279.4 mm (11 in) of Jointed Plain Concrete Pavement (JPCP) with dowel joints @ 6.09 m (20 ft) spacing; 25.4 mm (1 in) of asphaltic concrete; 127

mm (5 in) of graded aggregate base, and 228.6 mm (9 in) of selected borrow. The shoulders consisted of 152.4 to 279.4 mm (6 to 11 in) of Portland Cement Concrete Pavement (PCCP) over 228.6 mm (9 in) of selected borrow. The design for the rehabilitated pavement consisted of 304.8 cm (12 in) of CRC, 76.2 mm (3 in) of Superpave, 304.8 mm (12 in) of GAB, 76.2 mm (3 in) of Superpave for the travel lanes and outside shoulders. The inside shoulder design consisted of 76.2 mm (3 in) of Superpave, 127 mm (5 in) of Superpave, and 304.8 mm (12 in) of GAB. Figure 5.15 shows the typical section of the I-20 Project.

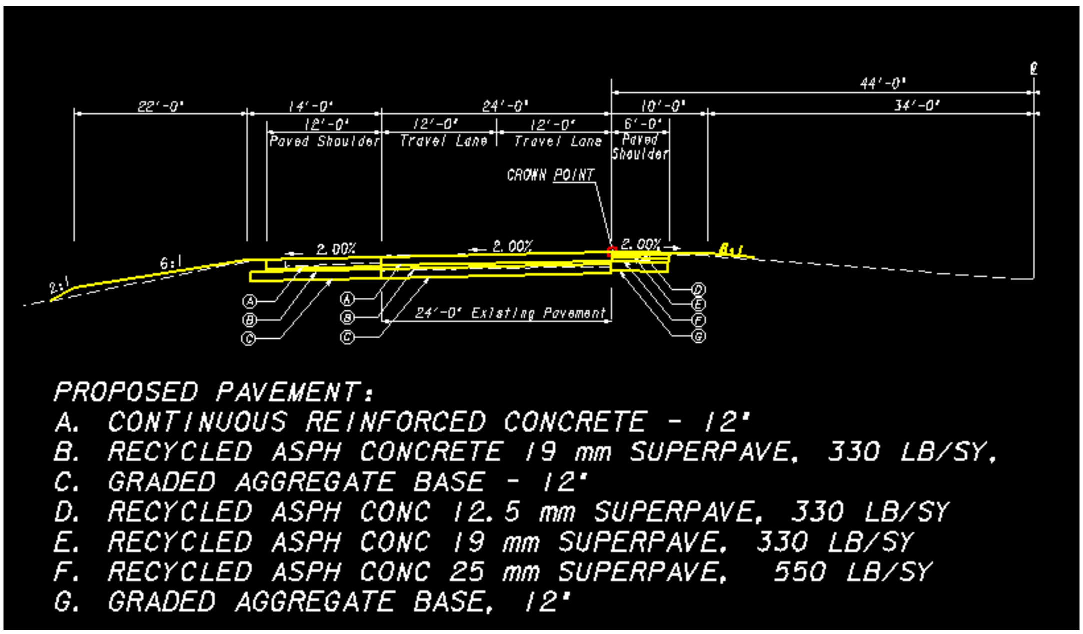


Figure 5.15 I-20 Project Typical Section

Incentive and Penalty Provisions

The contract indicated that failure to remove lane closures as specified will result in the Liquidated Damages at the rate of $10,000 per hour or portion of an hour, thereof. The I-20 Project contract did not include any incentive payment for early completion.

Closure and Constructability Issues

The following Restrictive Working Hours are shown in the Section 150.11 Special Provision for the I-20 Project:

Single Lane closures will be allowed:

9:00 p.m. Monday through 5:00 a.m. Tuesday
9:00 p.m. Tuesday through 5:00 a.m. Wednesday
9:00 p.m. Wednesday through 5:00 a.m. Thursday
9:00 p.m. Thursday through 5:00 a.m. Friday
9:00 p.m. Friday through 5:00 a.m. Monday

"Ramps may be closed at 9:00 p.m. Friday until 5:00 a.m. Monday. Only one exit and entrance ramp may be closed per occurrence. The ramp closure is limited to one per lane per interchange." In addition to lane closure restriction, no work was allowed on any State-recognized holiday, or adjacent weekend, as defined in Section 101.31 of the Georgia Standard Specifications and no work was allowed on the two weekends during the year that the NASCAR race was held at Talladega Super Speedway located in Talladega, Alabama.

The main constructability issues on the I-20 project were limited clearance at bridges (Figure 5.16), complexities in the coordination of traffic staging, and the requirement of maintaining two lanes of traffic in each direction. In addition, workspace limitation was an issue when signboards were present since it was necessary to relocate them at additional cost to the project. Another issue faced during construction was the damage to the 1.83 m (6 ft) outside shoulders during construction of adjacent lanes.

Figure 5.16 Issues with clearance on bridges

General Project Challenges

According to FHWA specifications, 2 lanes must be maintained open to traffic during the rehabilitation project. GDOT design team decided to use counter-flow staging for the project in order to comply with FHWA specifications. The benefits of counter-flow staging on this project included: additional workspace, meeting FHWA requirements, and work flow continuity. The main issues faced in this stage were concerns with safety in case of breakdowns and access for emergency responders. The solution to this situation was to provide emergency pullovers for every 4.827 km (3 mi).

The counter-flow staging used in the I-20 Project is illustrated in Figures 5.17 to 5.21. Stage 1 of the project consisted of construction of both inside asphalt shoulders and outside concrete shoulders (see Figure 5.17). For this stage, temporary striping was required.

The inside shoulders were built on weekends (Friday 9 p.m. to Monday 5 a.m.) utilizing lane closures. Construction of the 3.66 m (12 ft) outside shoulder occurred during the weekdays utilizing nighttime lane closures.

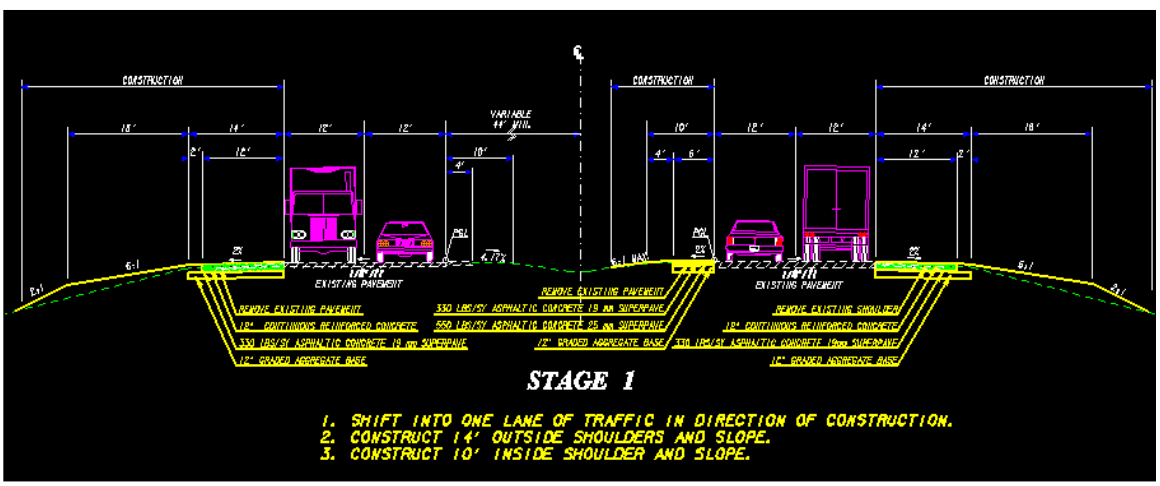


Figure 5.17 I-20 Stage 1

Stage 2 consisted of constructing the median crossovers for shifting one lane of westbound traffic to the eastbound lanes behind the barrier wall. The westbound 3.66 m (12 ft) outside lane was constructed while maintaining one lane of traffic on the newly constructed inside shoulder and the other one on the eastbound counter-flow lane (Figure 5.18).

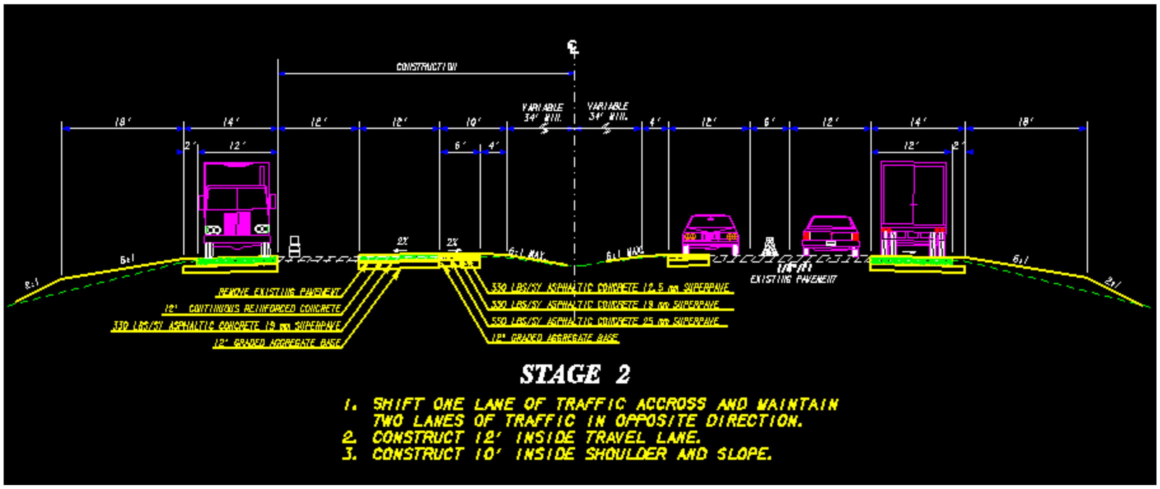


Figure 5.18 I-20 Stage 2

Stage 3 consisted of shifting one westbound lane of traffic to the new westbound inside travel lane and shoulder and constructing the westbound outside travel lane as shown in Figure 5.19.

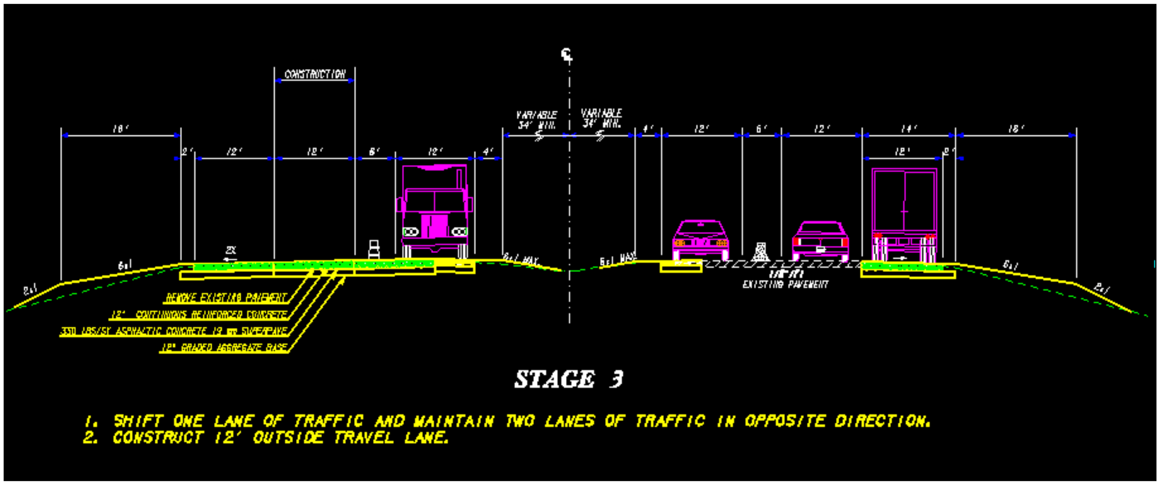


Figure 5.19 I-20 Stage 3

On Stage 4, the counter-flow lane was shifted to the westbound side of the Interstate, providing one lane of eastbound traffic separated from the two westbound lanes of traffic by the barrier wall (Figure 5.20). Then eastbound inside lane was constructed along with the final asphalt layers on the 1.83 m (6 ft) shoulder.

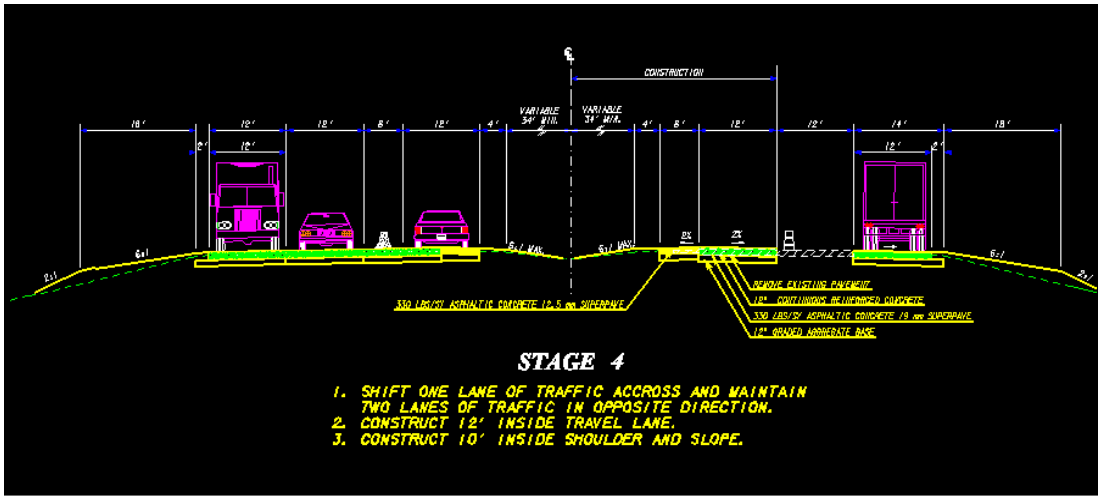


Figure 5.20 I-20 Stage 4

Stage 5 consisted of shifting one eastbound lane of traffic to the new eastbound inside lane and shoulder and constructing the eastbound outside travel lane (Figure 5.21). Finally, in Stage 6 normal traffic flow was restored.

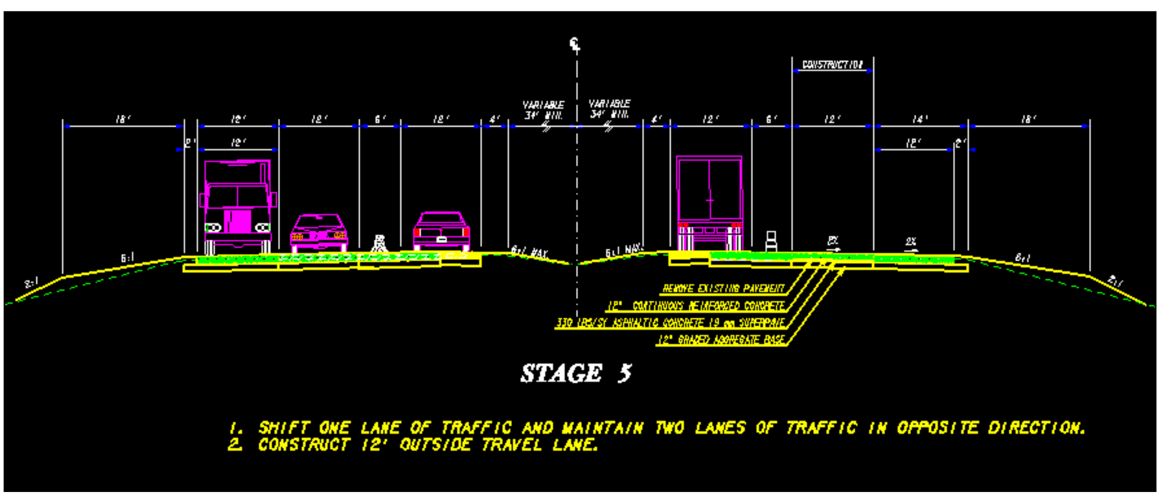


Figure 5.21 I-20 Stage 5

CA4PRS Analysis Results

The project is modeled in the CA4PRS based on the stages defined previously. With the assumption of 26 working days per month and 8 working hr/day, and the sequential working method, the following results have been produced. Since this project used the same working window throughout the project, it was possible to model the whole rehabilitation at once. The I-20 involved three phases of construction, with the first being a shoulder widening to serve as temporary access. There is no option to model this in the program, so we had to discard this phase rather than end up modeling the entire lane and skewing the results. Additionally, the project involved the construction of a concrete barrier, which is not an option provided in the CA4PRS and had to be discarded from the model. Table 5.12 shows the resource profile information used for the project. Resource utilization is available in Table 5.13.

Table 5.12 I-20 Resource Profile information used for analysis

Resource Description	Capacity characteristics
Demolition Hauling Truck	Rated capacity: 18.14 Mg (20 ton)
	Trucks per hour per team: 10
	Efficiency: 0.60
	Number of teams: 2
	Team efficiency: 1.0
Base Delivery Truck	Rated capacity: 9.94 m^3 (13 yd^3)
	Trucks per hour: 10
	Efficiency: 0.90
Rebar Installation	Production: 107.03 m^2 (140 sq. yd)
	Number of teams: 1
	Team efficiency: 0.90
Batch Plant	Capacity: 99.39 m^3 (130 yd^3/hr)
	Number of plants: 1
Concrete Delivery Truck	Rated capacity: 9 yd^3
	Trucks per hour: 10
	Efficiency:0.90
Paver	Speed: 3.05 m/min (10 ft/min)
	Number of pavers: 1

The resource utilization sensitivity analysis done by the CA4PRS shows that demolition hauling trucks, base delivery trucks, rebar production, and concrete delivery trucks are the controlling resources in this operation (See Table 5.13). Also by comparing the allocated and utilized number of demolition hauling trucks, base delivery trucks, rebar production, and concrete delivery trucks, it can be inferred that all the allocated trucks are being utilized.

Table 5.13 I-20 Resource utilization

Resource	Allocated	Utilized
Demolition Hauling Truck (per hour per team)	10.0	10.0
Base Delivery Truck (per hour)	10.0	10.0
Rebar Production	128 m^2/hr (140.0 sq. yd/hr)	128 (140.0)
Batch Plant	99.39 m^3 (130.0 yd^3/hr)	61.9 (81.0)
Concrete Delivery Truck (per hour)	10.0	10.0
Paver Speed	3.05 m/min (10.0 ft/min)	0.911 (3.0)

The project scope is a total pavement replacement with CRC of a 38.62 km (24 mi) section. Specifically, the outside shoulder was replaced with full-depth CRC, the inside shoulder with hot mix asphalt and existing guardrails was upgraded to current standards. In this case, the project was modeled as a JPCP overlay with partial milling of existing asphalt. This project involved three construction phases. One of the phases was a shoulder widening and the other was the construction of a concrete barrier.

The production rate was 2.82 lane-km per closure (1.75 lane-miles per closure) (see Table 5.14). Total lane-km (lane-miles) of this project were 154.46 (96) and considering the production rate of 2.82 lane-km per closure (1.75 lane-miles per closure), the number of closures was calculated which was approximately 54.8 weekend closures.

Table 5.14 I-20 Productivity Results

Zone	Scope	Construction windows needed to meet objective	Closure production
1	154.46 lane-km (96 lane-miles)	54.81	2.82 lane-km (1.75 lane-miles)

Since this project involved rebar reinforcing, an additional activity was added to the schedule with an additional lag time needed for that activity. The key element was the lag settings being set correctly to provide maximum efficiency of resource use and maximum production rate in each construction window. Additionally, in each construction window curing time was a major factor. Curing time took up a substantial portion of the window and provided no production during that period.

CHAPTER VI
IMPROVED PLANNING FOR PAVEMENT REHABILITATION PROJECTS

This chapter discusses some improvements that should be made in the CA4PRS algorithm in order to make it more efficient in addressing the current limitations of ODOT and GDOT planning procedures. These improvements include solutions for handling additional activities on PCC pavement rehabilitation projects and suggestions for standard resource profile information. In addition, a simulation analysis technique is developed to replace the current resource profile module of the CA4PRS in order to resolve the main difficulty in using the CA4PRS, which is the lack of precise resource profile input information. A new planning procedure which can replace the current ODOT & GDOT planning procedures is discussed at the end of this chapter.

6.1 EFFECTS OF ADDITIONAL ACTIVITIES ON PROJET SCHEDULE

CA4PRS only considers three major activities and three minor activities for PCC pavement rehabilitation scheduling analysis. The major activities are Demolition, New Base Installation, and PCC pavement installation. The minor activities are Mobilization, Demobilization, and Curing. While minor activities are always assumed to be sequentially related to other activities, major activities can be assumed to be either sequential or concurrent. Also the lead and lag times for finish to start (sequential) and start to start (concurrent) relationships can be entered by the user. The scheduling of the project is performed by a combination of the Critical Path Method (CPM) and the Linear Scheduling technique. In this section, the inclusion of additional activities and their effects on the scheduling of the project is elaborated.

Activities such as Traffic Control, Dirt Fill Crossovers, Pave Crossovers, Set Barrier Wall, Strip Topsoil on Edge, Seal Joints, Guardrail Widening, and Temporary Stripe are usually included in a rehabilitation project. The relationships between such activities may vary based on the situation of the project or the characteristics of the activity itself. These activities are not analyzed by the CA4PRS. Therefore, they are not considered in production rate calculations. In order to evaluate the effect of adding additional activities on the existing schedule provided by the CA4PRS, the

Microsoft Project was used in this study. The Gantt chart of this analysis is shown in Figure 6.1. The activities shown in red are on the Critical Path.

According to the analysis and assuming that project starts on August 09, 2010 the finish date is expected to be September 7, 2010 (duration: 29 days). Then the activity of "Pave Crossovers" is added to the project in order to study the possible effects of adding extra activities to the scheduling of the rehabilitation project. It is assumed that this activity is the predecessor of New Base Installation. Depending on the relationship and duration of this activity compared to the other activities in the project, three different schedules are generated. In the first case, it has been assumed that the activity of pave crossovers has a finish to start relationship with other activities. In the second case, the new activity has a start to start relationship with a demolition activity with longer duration. In the third case, the new activity and demolition activity has a start to start relationship but the new activity has a shorter duration.

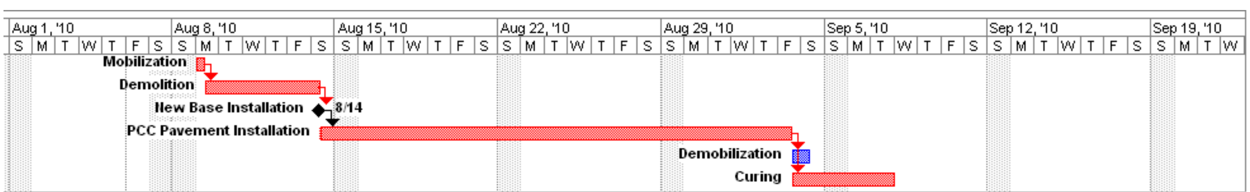


Figure 6.1 Gantt Chart of Rehabilitation Project

6.1.1 Case One

It is assumed that Pave Crossovers is performed sequentially after the Demolition. Therefore Demolition is assumed as a predecessor of Pave Crossovers and the duration of Pave Crossovers is assumed to be 66 working hours. The Gantt Chart of this situation is shown in Figure 6.2. Because the Pave Crossover is on the Critical Path, its duration is added to the duration of the project. In this situation, the project is expected to take 36 days.

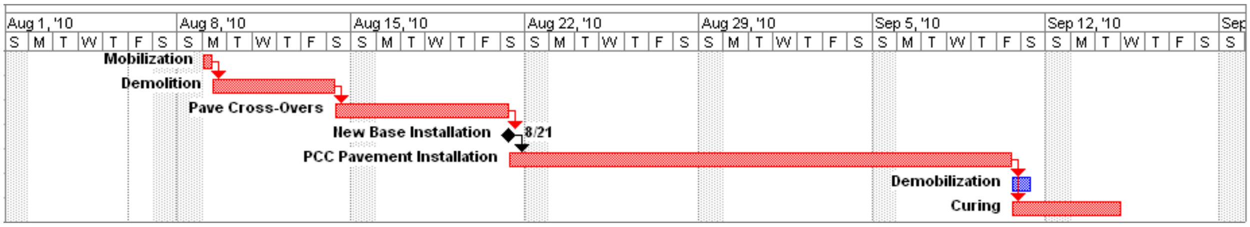


Figure 6.2 Gantt Chart of Rehabilitation Project Case 1

6.1.2 Case Two

It is assumed that Pave Crossover has a Start to Start relationship with demolition activity. Also it is assumed that both Pave Crossover and Demolition are predecessors of New Base Installation. In addition it is assumed that Pave Crossovers take 66 working hours to be finished. As can be seen in the Gantt chart shown in Figure 6.3 the Critical Path has changed. The new Critical Path does not include the Demolition activity and the new activity of Pave Crossovers is on the Critical Path. Therefore, the project duration is increased by the amount of difference between Demolition and Pave Crossover activities. Hence the expected duration of the project would be 31 days.

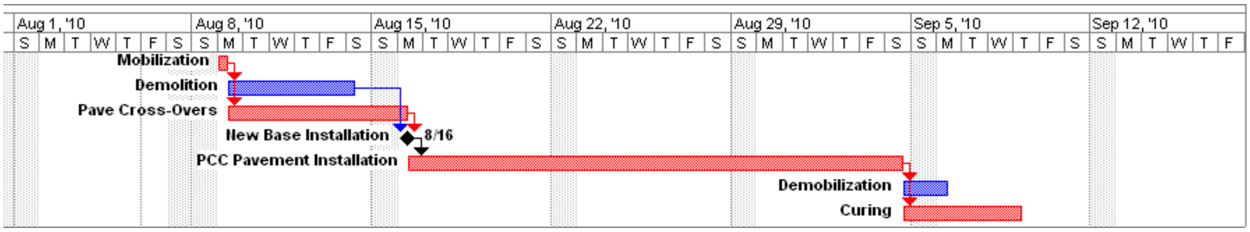


Figure 6.3 Gantt Chart of Rehabilitation Project Case 2

6.1.3 Case Three

In this case it is assumed that Pave Crossover has a Start to Start relationship with demolition activity. Also it is assumed that both Pave Crossover and Demolition are predecessors of New Base Installation. The difference between this case and case two is that the duration of the Pave Crossovers in this case has been assumed to be less than the duration of Demolition activity or 44 working hours. As can be seen in the Gantt Chart shown in Figure 6.4 the Critical Path does not change and the duration of project is the same as the CA4PRS analysis. According to the analysis the project is expected to take 29 days.

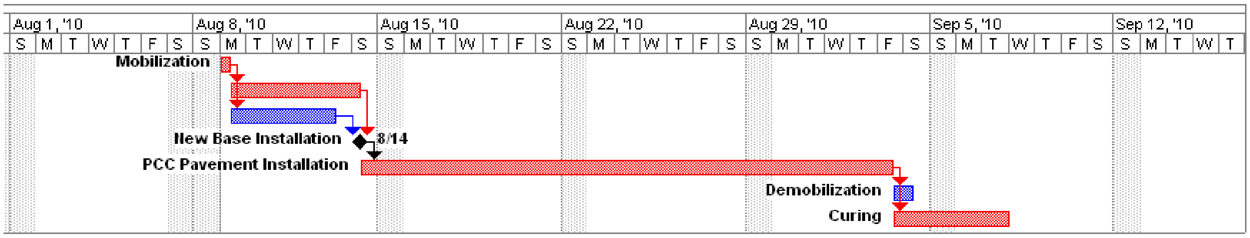


Figure 6.4 Gantt Chart of Rehabilitation Project Case 3

From three cases discussed above, adding one activity to the existing schedule may increase the duration of project by 6 days, 2 days or it may result in the same duration as the original schedule. These changes depend on the characteristic of the new activity and its relationship with existing activities.

There are many activities that are not included in the CA4PRS schedule and need to be considered separately for an accurate scheduling. Considering the fact that even adding one activity to the project could result in three different project durations, one can conclude that adding more activities to the project necessitate rescheduling the whole project. Hence, the CA4PRS may not come up with an accurate estimate of the project duration because it only considers 6 activities in the rehabilitation project. Furthermore, the CA4PRS is not able to substitute the need for scheduling rehabilitation projects with the CPM network method. Therefore, while the CA4PRS may be used for scheduling the projects in the inception phase, the departments of transportation are encouraged to reschedule the projects by using a network scheduling method in order to accurately plan the project.

6.2 RESOURCE PROFILE INFORMATION

In using the CA4PRS, the output information is highly dependent on the resource profile information. Although there is a guideline in the software manual which helps in choosing the right resource profile information, standard input information needs to be developed for rehabilitation projects in different states. This is due to the fact that this input data is highly dependent on both contractors' capabilities and characteristics of projects which are different in each state. For instance, the capabilities of roadway contractors working in California may be higher than the contractors working in Oklahoma or Georgia in terms of equipment efficiency, resource allocation, and production rates. Consequently, the production rates assumed in California may not be achievable in other states. A standard input data was developed based on analyzing the actual activity durations in the I-35 project in Oklahoma, visiting on the job sites, and measuring the production rates and number of the pieces of equipment for each activity.

Table 6.1 shows the suggested resource profile information. This study indicates that even in a single job and for a single contractor, the rates are not close to each other. For example, the number of base delivery trucks per hour changes from 2 to 20 and the number of concrete delivery trucks per hour changes from 5 to 22. Also Table 6.1 shows the minimum and maximum number of resources together with the average of these numbers and suggested amounts by the CA4PRS manual. This table can be used by ODOT as a starting point and needs to be frequently updated with collected project information from different site conditions and different contractors.

Table 6.1 Suggested Resource Profile Information

Resource Description	Suggested Input Data	Minimum Observed	Maximum Observed	Mean	CA4PRS Manual
Demolition Hauling Truck	Truck Capacity: 20.861 Mg (23 ton) Trucks per Hour per Team: 4-6 Efficiency: 0.45 Number of Teams: 1 Team Efficiency: 0.94	3	5	4	8 to 13
Base Delivery Truck	Truck Capac.: 6.116 m^3 (8 yd^3) Trucks per Hour: 6-8 Efficiency: 0.90	2	20	7	-
Batch Plant	Capacity: 152.9 m^3/h (200 yd^3/h) Number of Plants: 1				
Concrete Delivery Truck	Truck Capacity: 6.88 m^3 (9 yd^3) Trucks per Hour: 14-16 Efficiency: 1.0	5	22	14	9 to 16
Paver	Speed: 1.68 m/min (5.5 ft/min) Number of Pavers: 1				

6.3 SIMULATION OF PCC PAVEMENT REHABILITATION PROJECTS

The resource profile information that is entered in the CA4PRS is based on the number of trucks per hour. As inferred from the knowledge inventory survey results, the main disadvantage of using the resource profile information is that DOTs do not have access to this type of information. Typically, contractors manage the operation by allocating a specific number of resources to an activity rather than defining the required number of resources per hour.

6.3.1 Assessment of CA4PRS input information

Table 6.2 shows a sample of resource utilization table generated by the CA4PRS output. In this table the allocated resources show the CA4PRS input information and the utilized resources show the CA4PRS output. Based on the output information, the allocated concrete delivery trucks per hour is more than what is utilized and the allocated demolition hauling trucks and base delivery trucks are the same as what is used. Since demolition hauling trucks and base delivery trucks are the constraining resources, the demolition and base installation activities are considered the critical activities in the operation. Now in order to manage the number of resources, one should know how many trucks need to be added to or released from the operation to obtain an optimum level of operation. The CA4PRS does not provide any information to support this decision. The user may wrongly increase the number of trucks allocated to the operation with the hope of increasing the number of trucks per hour and accelerating the project while he/she only increases the operation costs of the project without adding to the production rate.

Table 6.2 Resource Utilization

Resource	**Allocated**	**Utilized**
Demolition Hauling Truck (per Hour per Team)	10	10
Base Delivery Truck (per Hour)	5	5
Batch Plant	91.74 m^3/h (120 yd^3/h)	91.74 (120)
Concrete Delivery Truck (per Hour)	20	16.7
Paver Speed	2.01 m/min (6.6 ft/min)	1.40 (4.6)

The number of resources used in the CA4PRS as input information does not mean the total number of resources allocated to an operation. Instead, the CA4PRS uses the number of trucks per hour as input information which is a production rate. For example, according to the resource utilization output shown in Table 6.2, 10 demolition hauling trucks are loaded per hour while it does not necessarily mean that the contractor uses 10 trucks for this operation. The contractor may need to allocate 20 trucks to the operation to obtain the production rate of 10 trucks per hour. In order for contractors to be able to use the CA4PRS more effectively, input and output resource profile information should be based on the number of resources instead of production rate of each activity. Considering the fact that the number of resources is related to the cost management of projects, contractors keep monitoring it on a daily basis. Therefore contractors are able to provide accurate input information while most contractors do not have the production rate information of different construction activities. In addition, the production rates of activities are also dependent on construction site characteristics which can be different from project to project. In order to use the number of resources in estimating the production rate in the CA4PRS, a simulation model needs to be developed to connect the number of resources to the production rate of activities.

Model Development

A simulation model of concrete delivery procedure is developed and analyzed by using CYCLONE (see Figure 6.5 & 6.6). CYCLONE stands for CYCLic Operations Network. It is a modeling technique that allows the graphical representation and simulation of discrete systems that deals with deterministic or stochastic variables. A construction process simulation using the CYCLONE methodology abstracts the reality into a graphical representation by dividing the process into discrete pieces or work task and by representing how these interact.

It is assumed that the duration and resource information is provided in Table 6.3. The maximum production rate after 30 cycles is 5.7 trucks per hour. This analysis indicates that although the trucks are able to dump concrete every 10 minutes which is equivalent to 6 trucks per hour, the maximum production rate of the system is 5.6 trucks per hour due to the adverse effect of Queuing systems. This type of analysis is not available in the CA4PRS.

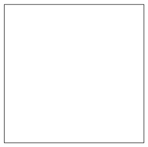
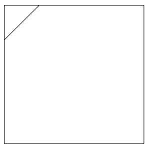
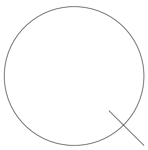
Modeling Element	Name of Element	Description of Modeling Element
	Normal	The normal work task modeling element, which is unconstrained in its starting logic and indicates active processing of (or by) resource entities.
	COMBI	The constrained work task modeling element, which is logically constrained in its starting logic, otherwise similar to the normal work task modeling element.
	Q NODE	The idle state of a resource entity symbolically representing a queuing up or waiting for use of passive state of resources.
	ARROW	The resource entity directional flow modeling element.

Figure 6.5 Basic Modeling Elements [29]

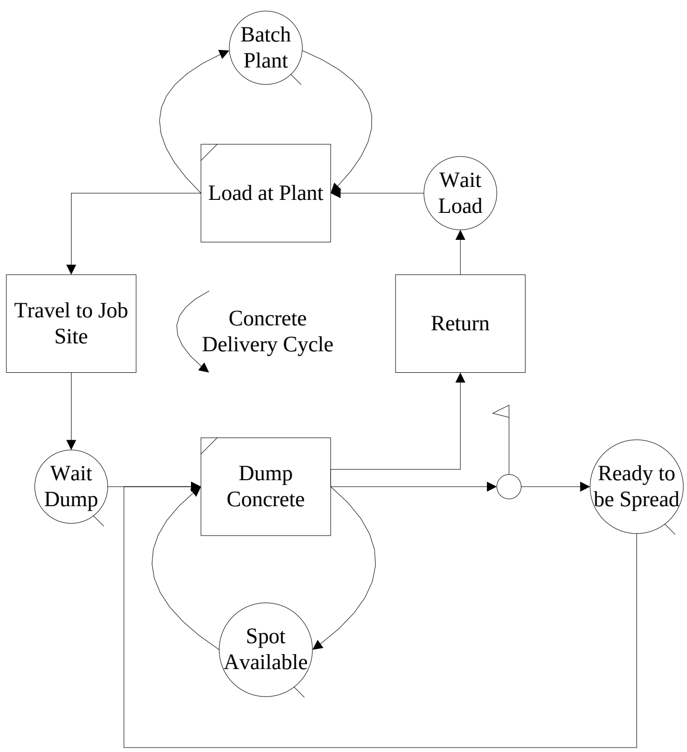


Figure 6.6 Model of Concrete Delivery Procedure

Table 6.3 Duration and resource information for Simulation Analysis

Tasks	Duration (min)	Resources	Numbers
Load at Plant	5	Batch Plant	1
Travel to Job Site	15	Trucks	10
Dump	10	Spot Available	1
Return	15		

Resource Optimization

Based on the sensitivity analysis performed by the CYCLONE diagram shown in Figure 6.7, the concrete delivery procedure reaches the maximum production rate by allocating 5 trucks to the operation. This means that the optimum number of trucks that can be allocated to this operation with the above mentioned assumptions is 5. During the CA4PRS analysis, the user is able to increase the number of trucks per hour without any limit while in the above analysis it is indicated that the system has a maximum production rate which cannot be raised by increasing the number of trucks.

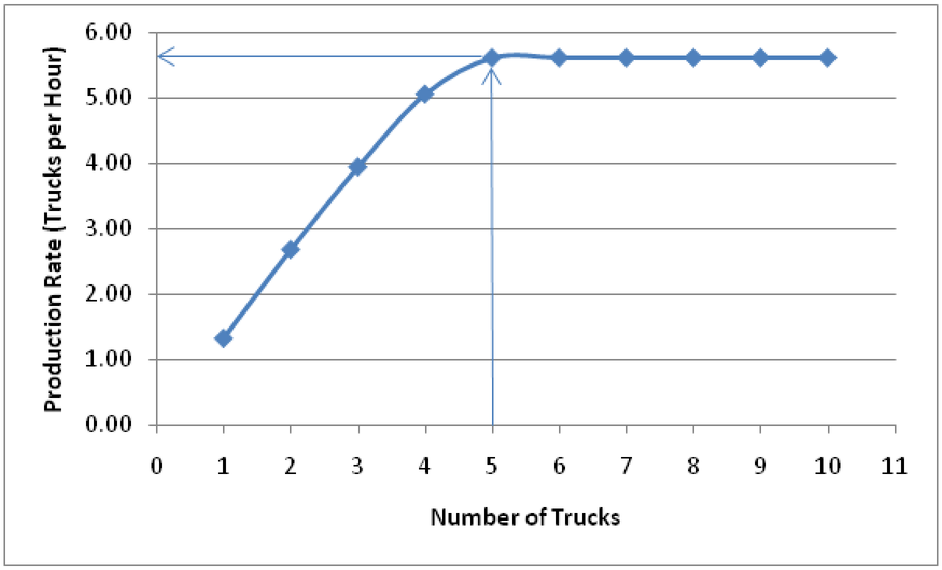


Figure 6.7 Sensitivity Analysis of the concrete delivery procedure

Figure 6.8 also indicates that the production rate of the system does not increase by increasing the values of the CA4PRS input variables or by increasing the total number of trucks. In this figure the maximum production rate and the optimum number of trucks have been calculated by using the Cyclone simulation analysis. The CA4PRS input value has been utilized to calculate the duration of Dump concrete activity in Figure 6.8.

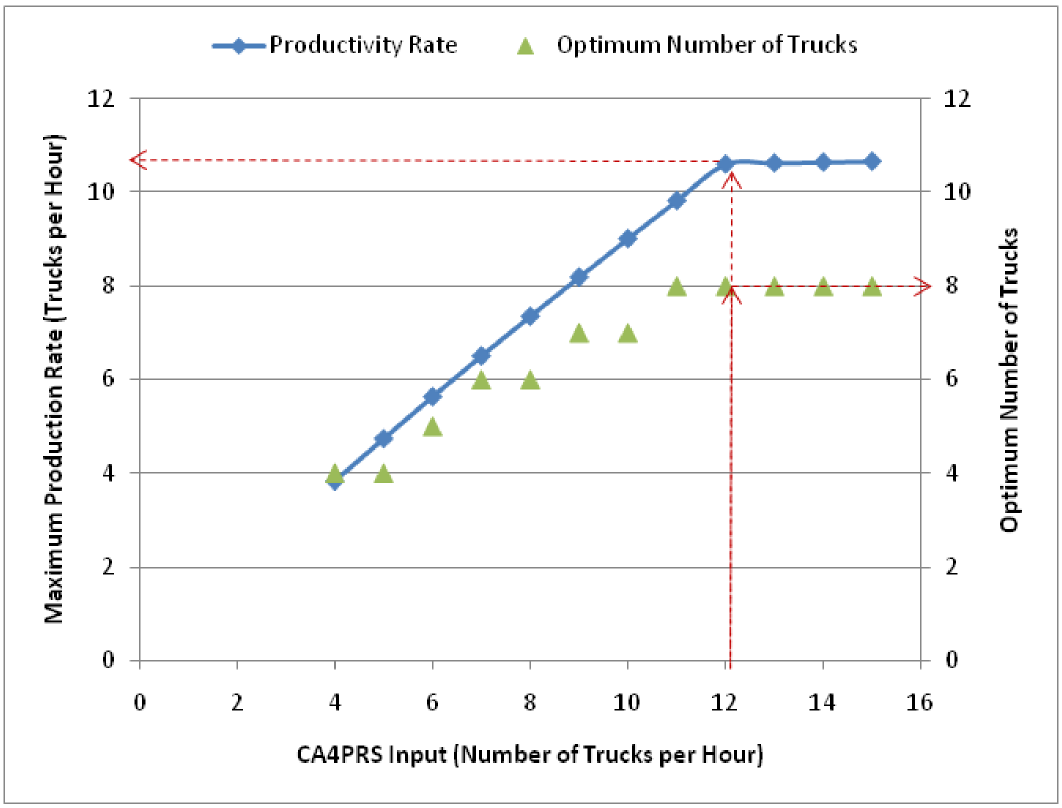


Figure 6.8 Sensitivity Analysis of the concrete delivery procedure

For instance, the CA4PRS input value of 12 means that every five minutes one truck is able to discharge concrete in the job site. In other words, the duration of Dump concrete activity in the Cyclone simulation analysis would be 5 minutes. To generate the data points in Figure 6.8, the maximum productivity of the system and the optimum number of trucks were calculated for different durations of the dump concrete activity. As can be seen in this figure, the maximum production rate of the system would be 10.59 trucks per hour for CA4PRS input value of 12 trucks per hour (dump concrete duration of 5 minutes). This shows that CA4PRS is overestimating the production rate by considering 12 trucks per hour as the production rate of the concrete pouring activity. Now by considering the CA4PRS input value of 15 trucks per hour (Dump concrete duration of 4 minutes), the maximum production rate of the system would be 10.59 trucks per hour again. It can be inferred that although the CA4PRS considers 15 trucks per hour as the production rate of the concrete pouring activity, the real production rate of the system would be 10.59 trucks per hour.

The results demonstrated in Figure 6.8 shows that the CA4PRS input values are different from the total number of trucks per hour. Even when 12 trucks per hour is used as the input value, the optimum number of trucks in the system would be 8, which means that the contractor only needs to allocate 8 trucks to this operation to achieve the production rate of 10.59 trucks per hour.

Effect of Distance from Batch-Plant

It is recommended that a contractor simulate the operation and analyze it separately for each project to find the right resource input information to run the CA4PRS. This is because the distance from the batch plant to the job site is different in each project and there may be different durations for dumping and loading at the plant based on different construction access areas, trucks, concrete delivery methods, and materials.

The effect of distance from the batch plant to the jobsite on the maximum production rate and the optimal number of trucks is shown in Figure 6.9. In this figure, the production rate and the optimal number of trucks are analyzed for different distances from the batch plant. The durations assumed for Travel to Job Site and Return has increased from 5 min to 45 min. The maximum production rate of the system declines when distance from the batch plant increases. In addition as the distance from the batch plant increases more trucks are needed for the system to reach to the maximum production rate.

For instance, when the distance from the batch plant is 5 minutes, the maximum production rate of the system would be 5.8 trucks per hour and the optimum number of trucks would be 3. When the distance from the batch plant increases to 45 minutes, 8 more trucks are needed in the system to reach to the maximum production rate. This means that a total of 11 trucks are needed and still the maximum production rate of the system would be 0.66 trucks per hour, which is less than the case with the distance of 5 minutes. So, no matter how many trucks are utilized in the system, the maximum production rate of the system declines as the distance from the batch plant increases.

The same situation exists for the demolition cycle and new base installation cycle. By performing the same analysis for these cycles, the maximum production rate and optimal number of trucks can be calculated. Then by comparing the total number of trucks with the optimum number of trucks, the contractor would be able to adjust the number of equipment allocated to each activity.

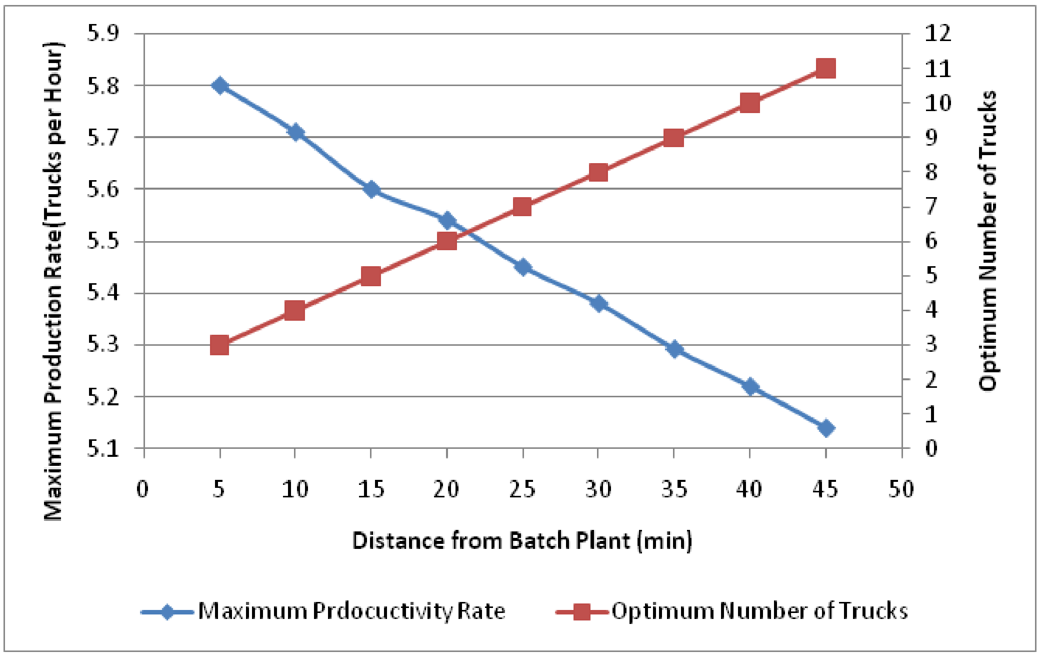


Figure 6.9 Effects of distance from batch plant on productivity

The shortcomings of the CA4PRS in resource management are: a) the input information is not available in GDOT & ODOT, b) the effect of queuing of resources is not considered in the input information, c) the resource utilization table provided by the CA4PRS output does not help the contractors in managing the number of resources needed to be allocated to a job, d) the optimum number of resources is not calculated by the CA4PRS. The research team suggests replacing the resource profile information tab in the CA4PRS with a simulation model which can provide more accurate and helpful information to the users.

6.4 USER COST ANALYSIS of ODOT vs. CA4PRS

ODOT currently uses two spreadsheet programs to calculate the impacts of rehabilitation projects on the public. One of them is the ODOT Lane Rental Model which is used to calculate the lane rental schedule and fees (see Figure 6.10). The output of this spreadsheet software is the estimated length of queue during the 24 hr and average user cost per hour. The length of queue during 24 hr helps ODOT to restrict the lane closure during the hours that the length of queue is more than the acceptable level. On the other hand, the average user cost per hour provides a reasonable estimate for calculating the amount of lane rental fee.

The user can select the type of road in the ODOT Lane Rental Model from four different options as follow: a) Interstate Urban, b) Interstate Rural, c) Arterial Urban, d) Arterial Rural.

I-35 Noble County

ODOT Lane Rental Model
Version 4.0

Analysis Code (use code from table):	iu	
Direction (Inbound or Outbound):	inbound	
AADT (both directions)	110,000	
Percent Trucks:	5%	
Passenger car equivalents per truck:	3	– Enter the number of passenger cars equivalents per truck. The default is 2.
Passenger cars / day:	121,000	
Number of lanes (one direction):	3	
Free flow speed (mph):	70	
Basic lane capacity (pcphpl):	2400	
Baseline queue length limit (miles):	99	– Enter a large number (ex.: 99) to avoid limiting the queue length.
Lane Rental queue length limit (miles):	99	– Enter a large number (ex.: 99) to avoid limiting the queue length.
Confidence Level (%) - enter from 20-100	50	
Delay ($/hour) passenger car:	$10.00	
Fuel costs ($/gal):	$3.00	
Average # people per vehicle:	1.2	
Queue reset time:	0350	– Enter time with 4 digits (ex. 1510 = 3:10 PM). The default is 0350; only use 10-min. intervals.

Net Lane Rental Road User Costs
Portion of costs associated with the lane closure.

Analysis Codes	
IU	Interstate - Urban (ODOT)
IR	Interstate - Rural (ODOT)
AU	Arterial - Urban (ODOT)
AR	Arterial - Rural (ODOT)
UF	User Defined Factors
UV	User Defined Volumes

	Morning Peak 6am-9am	Daytime Non-Peak 9am-3pm	Evening Peak 3pm-6pm	Nighttime Non-Peak 6pm-12pm	Morning Peak 12pm-6am	Daily Summary 24 hr.
Total Cost of Delay ($):	0	0	44,038	41,843	0	85,882
# of Hrs. Lanes Closed:	0	0	3	6	6	4
Ave. Cost/Hr. Closed ($):	0	0	14,679	6,974	0	21,470
Ave. Cost/Hr. for Period ($):	0	0	11,010	3,804	0	3,578
Traffic Volume:	13,528	19,859	14,447	9,151	0	60,101
Max # of Cars in Queue:	0	0	2,607	1,554	0	2,607
Max Queue Length (mi.):	0.0	0.0	3.3	2.0	0.0	3.3

		Interstate – Urban								
Hour	# of Lanes Closed (1)	AADT Factor (K)	Direction Factor (D)	Volume (2)	Limiting Capacity	Max Cars in Queue (3)	Delay Cost (4)	Fuel Cost (4)	Total Cost (4)	Max Queue L. (mi.) (3)
Mid.-1am	0	0.01325	0.50	802	7,200	0	0	0	0	0.0
1am-2am	0	0.00725	0.50	439	7,200	0	0	0	0	0.0
2am-3am	0	0.00575	0.50	348	7,200	0	0	0	0	0.0
3am-4am	0	0.00475	0.50	287	7,200	0	0	0	0	0.0
4am-5am	0	0.00575	0.50	348	7,200	0	0	0	0	0.0
5am-6am	0	0.01475	0.50	892	7,200	0	0	0	0	0.0
6am-7am	0	0.03825	0.65	3,008	7,200	0	0	0	0	0.0
7am-8am	0	0.07675	0.65	6,036	7,200	0	0	0	0	0.0
8am-9am	0	0.05700	0.65	4,483	7,200	0	0	0	0	0.0
9am-10am	0	0.04850	0.50	2,934	7,200	0	0	0	0	0.0
10am-11am	0	0.05000	0.50	3,025	7,200	0	0	0	0	0.0
11am-Noon	0	0.05500	0.50	3,328	7,200	0	0	0	0	0.0
Noon-1pm	0	0.05775	0.50	3,494	7,200	0	0	0	0	0.0
1pm-2pm	0	0.05725	0.50	3,464	7,200	0	0	0	0	0.0
2pm-3pm	0	0.05975	0.50	3,615	7,200	0	0	0	0	0.0
3pm-4pm	1	0.07050	0.40	3,412	3,029	385	2,310	604	2,914	0.5
4pm-5pm	1	0.08425	0.40	4,078	3,029	1,436	10,926	1,991	12,917	1.8
5pm-6pm	1	0.08675	0.40	4,199	3,029	2,607	24,258	3,949	28,207	3.3
6pm-7pm	1	0.05700	0.40	2,759	3,029	2,562	29,670	4,435	34,105	3.2
7pm-8pm	0	0.04125	0.50	2,496	7,200	1,554	6,986	752	7,738	2.0
8pm-9pm	0	0.03500	0.50	2,118	7,200	0	0	0	0	0.0
9pm-10pm	0	0.03025	0.50	1,830	7,200	0	0	0	0	0.0
10pm-11pm	0	0.02575	0.50	1,558	7,200	0	0	0	0	0.0
11pm-Mid.	0	0.01900	0.50	1,150	7,200	0	0	0	0	0.0

Info. & Instructions | LR Input & Results | Raw LR RUC | Baseline RUC | LR Factors | Raw LR Calc. | Baseline Calc. | Version Histo

Figure 6.10 ODOT spreadsheet program used for user cost calculation

Once the road is selected, the hourly traffic distribution and hourly traffic capacity of the road is defined. Then by knowing the AADT and the closure hours the program calculates the hourly traffic demand of the road. By comparing traffic demand and capacity, the program calculates the delay cost and maximum queue length per hour. In this program the delay made by speed limit reduction in the work zone cannot be calculated. ODOT uses another spreadsheet to calculate the delay. While the output of ODOT lane Rental Model is only used to identify lane rental fees and schedule, the output of the second program is only used for calculating the amount of Incentive/Disincentive.

The Work-Zone Analysis module of the CA4PRS provides an analytical traffic analysis environment. It not only provides the user with the output of the above mentioned ODOT programs but also let users have a better control over the traffic capacity and demand adjustments (see Figure 6.11). There are four traffic groups defined in the CA4PRS which are a combination of Week Day or Weekend and Rural or Urban. The effects of difference in traffic distribution between weekdays and weekends are also accounted for in CA4PRS which is not the case in the ODOT procedure. By comparing CA4PRS analysis with ODOT results, it is realized that with the same hourly traffic demand distribution, the results are nearly the same except for the weekend analysis. This is due to the fact that ODOT assumes the same traffic distribution for weekend and weekdays.

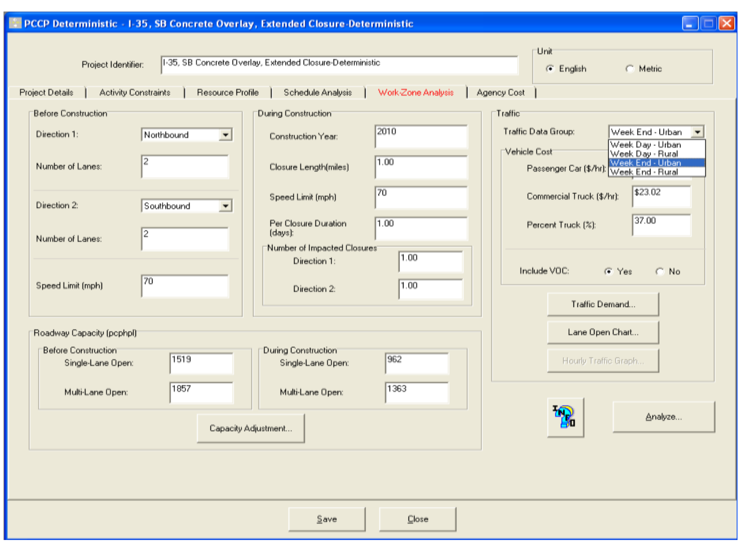


Figure 6.11 Work-Zone Analysis Module of CA4PRS

On the other hand, the traffic distributions used in CA4PRS analysis have not been specifically developed for the networks of Oklahoma. The hourly traffic distribution is different for each road depending on its location and the characteristics of its surrounding area. In order to perform an accurate traffic analysis, one needs to identify the accurate distribution of traffic. Therefore ODOT is recommended to start collecting hourly traffic information for the road network in Oklahoma in order to conduct more accurate traffic analysis in the future.

6.5 RECOMMENDED PRACTICE FOR ODOT/GDOT

Figure 6.12 shows the current ODOT/GDOT planning procedure. The existing procedure is dependent upon the experience and analysis of the ODOT/GDOT engineers. Based on the experience and the expert judgment, the scope of a project is decided and cost is estimated. Then the scheduling analysis is performed based on the experience from previous projects and the preliminary analysis. Finally, the traffic analysis is performed to obtain the user costs and delays to the public in order to calculate incentive/disincentive and lane rental fees. The main characteristic of this current planning procedure is that the cost, schedule, and traffic are decided based on DOT engineers' experience. Currently, there is no structured platform in place to compare any possible and potential scenarios in order to find the most optimum rehabilitation method in terms of cost, schedule, and traffic.

Figure 6.13 illustrates an improved planning procedure to find the most efficient project phasing and closure scenario. This procedure starts with one alternative and each alternative is evaluated in terms of schedule, traffic, and cost. In this procedure, the evaluation and analysis starts with the schedule of project and the alternative is rejected if the duration and closure production are not within the acceptable range. In case, the schedule of an alternative is acceptable, the user cost and delays made to the public are evaluated and finally the cost is analyzed and evaluated before an alternative is accepted. By following this procedure, all the possible rehabilitation alternatives can be evaluated and compared with each other until the DOT can find the most optimum scenario. Consequently, the main area that the CA4PRS would be able to improve the existing ODOT/GDOT procedure is an environment for ODOT/GDOT engineers to compare different designs and scenarios in order to identify the most optimum one.

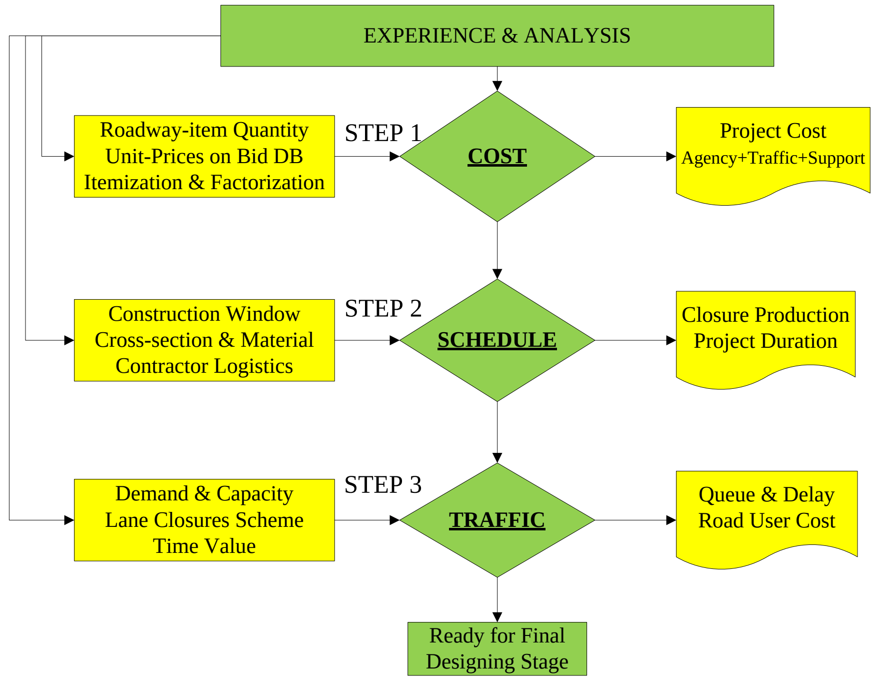


Figure 6.12 Current ODOT & GDOT Planning Procedure

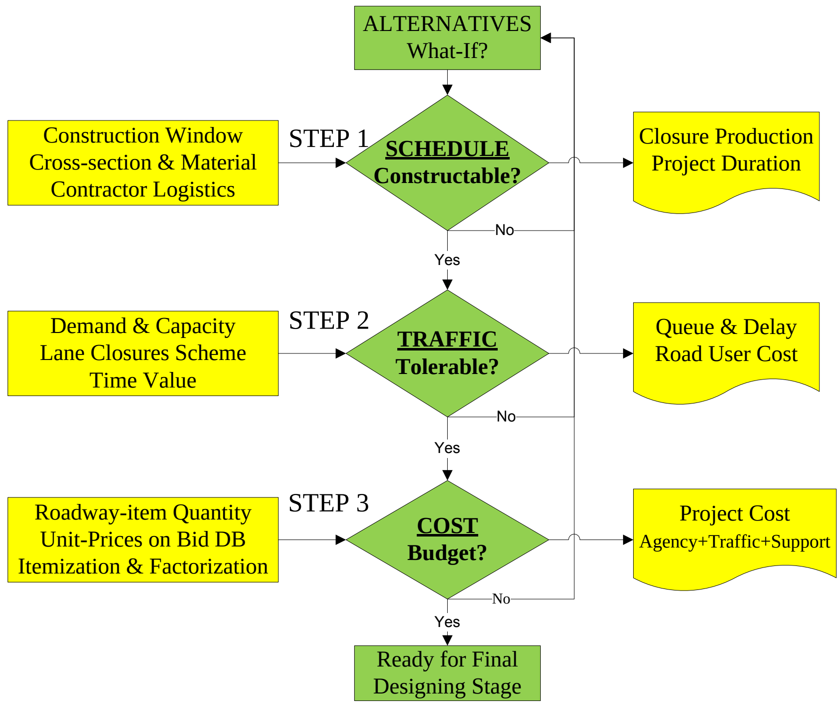


Figure 6.13 Suggested Procedure for Pavement Rehabilitation

The current method used by ODOT/GDOT in determining the contract time for PCC pavement rehabilitation projects is CPM. The scheduler breaks out the project into specific single activities and calculates the duration for each activity based on the production rates already available. These production rates have been calculated based on the historical data and expert opinions. The production rates that are used are constant numbers and are not affected by different resource profiles, rehabilitation scenarios, and construction windows. Once the duration for each activity is finalized, the CPM network is drawn and critical path is determined and total contract duration is calculated accordingly. The accuracy of the results is highly dependent upon the expertise, experience, and proficiency level of the scheduler who is performing the estimation. The contract time calculated by ODOT/GDOT in this stage is used as the maximum contract time for bid purposes. Although the CA4PRS cannot replace the CPM network calculations, the scheduler would be able to compare different rehabilitation scenarios using the CA4PRS and develop the CPM network for the most optimum scenario in terms of agency cost, schedule, and user cost.

In A+B contracts, the contract time estimation is critical. This is because ODOT/GDOT needs to accurately estimate the production rate of closures and potential time saving in order to calculate the incentive/disincentive amounts. By using the CA4PRS, ODOT/GDOT would be able to compare the production rates generated through different resource allocations and estimate the most optimal duration. The CA4PRS also helps ODOT/GDOT and contractors in estimating the additional number of resources that is needed to accelerate the project for a certain amount of time.

CHAPTER VII
CONCLUSIONS

This study investigated project management level solutions to optimizing resources, minimizing costs (including user costs) and time for PCC pavement rehabilitation projects. This study extensively evaluated the applicability of the CA4PRS computer software as a potential solution to achieve the goal.

The current ODOT/GDOT planning procedures indicated that the effects of pavement rehabilitation design on production rate are not seriously taken into consideration. Also, the current planning procedures do not evaluate all the possible closure scenarios in selecting the most optimum one for the project. Different closure scenarios (nighttime, weekend, and continuous closures) have different impacts on the traveling public and produce different production rates in the rehabilitation project. All the possible closure scenarios must be evaluated and the one that minimizes the user cost and maximizes the production rate should be selected.

The pre- and post-knowledge inventory survey indicates that there was a general increase in the understanding of the participants about the knowledge of the CA4PRS software. However, both groups of survey participants reported that GDOT and ODOT do not have the readily available input information to run the CA4PRS.

The four case studies on rehabilitation projects in Oklahoma and Georgia yielded mixed results. It was found on the I-35 project that the actual production rate of the project was higher than CA4PRS calculations, which may be attributed to the difference between actual and assumed resource profile information. The I-40 project could not be modeled completely with the CA4PRS because the project includes bridge rehabilitation, pavement rehabilitation, safety improvement, and adding lanes as there is no option to model these activities in the CA4PRS program. The traffic analysis of the I-40 project supports ODOT lane rental fees and schedules during the weekdays. During the traffic analysis of I-40 project, it was found that hourly traffic demand information is not available in ODOT. Even for a single road, hourly traffic demand information may change based on the season, national holidays, and etc. The traffic analysis performed for the I-40 project is based on the assumptions made by the CA4PRS which may be different from the real data. Therefore, it is recommended that ODOT needs to develop the hourly traffic demand data for the road network of Oklahoma in order to calculate road user costs more accurately.

On the I-75 project in Georgia, it was not clear how a multi-phase project could be modeled with the CA4PRS that involved paving different lanes and closing different lanes at different points in time. In the I-75 and I-20 projects, production rate was increased by adding in lag times. Lag times allowed some activities to start before the previous activities had finished. This feature of the CA4PRS lets the user keep activities at a maximum efficiency of resource use with some experimentation. Additionally, it helps identify which resources are constraints and which are exceeding the actual operation. Therefore, costs can be reduced by eliminating the resources that are not allocated in the process.

This research project has also identified some practical shortcomings of the CA4PRS software. The output of the CA4PRS is highly dependent upon the input information, which includes resource profile information, mobilization/demobilization durations, lead lag times and construction windows. However, most input information is not currently available in ODOT/GDOT. Other shortcomings of the CA4PRS include a) the effect of queuing of resources is not considered in the input information, b) the resource utilization table provided by the CA4PRS output does not help contractors in managing the number of resources needed to be allocated to a job, c) The optimum number of resources is not calculated by the CA4PRS.

In order to overcome these shortcomings, the following recommendations are made; a) ODOT/GDOT must put efforts to collect and develop a database for CA4PRS input data for reliable analysis using the CA4PRS, b) ODOT/GOT also need to use both the CPM scheduling method and the CA4PRS as the current CA4PRS only considers six activities in project scheduling and the effects of other activities on project schedule must be studied with the CPM method, c) A simulation program such as the Cyclone program can be used in determining the optimal number of resources of major activities and generating input data for the resource profile tab in the CA4PRS.

Based on the findings of this study, this project has designed an improved planning procedure to find the most efficient project phasing and closure scenario for PCC pavement rehabilitation projects. The procedure involves a quantitative analysis on every potential project execution scenario using the CA4PRS, simulation tool, and the CPM method. ODOT/GOT are also required to put efforts to collect and maintain necessary input data for reliable use of the CA4PRS.

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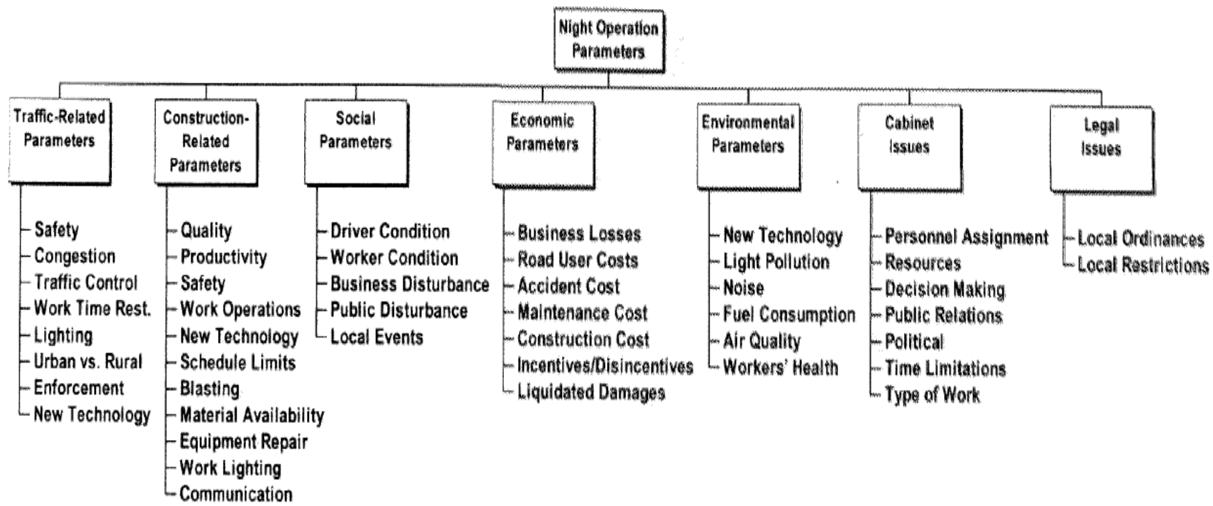
APPENDICES

APPENDIX A
WORK ZONE MANAGEMENT STRATEGIES BY CATEGORY

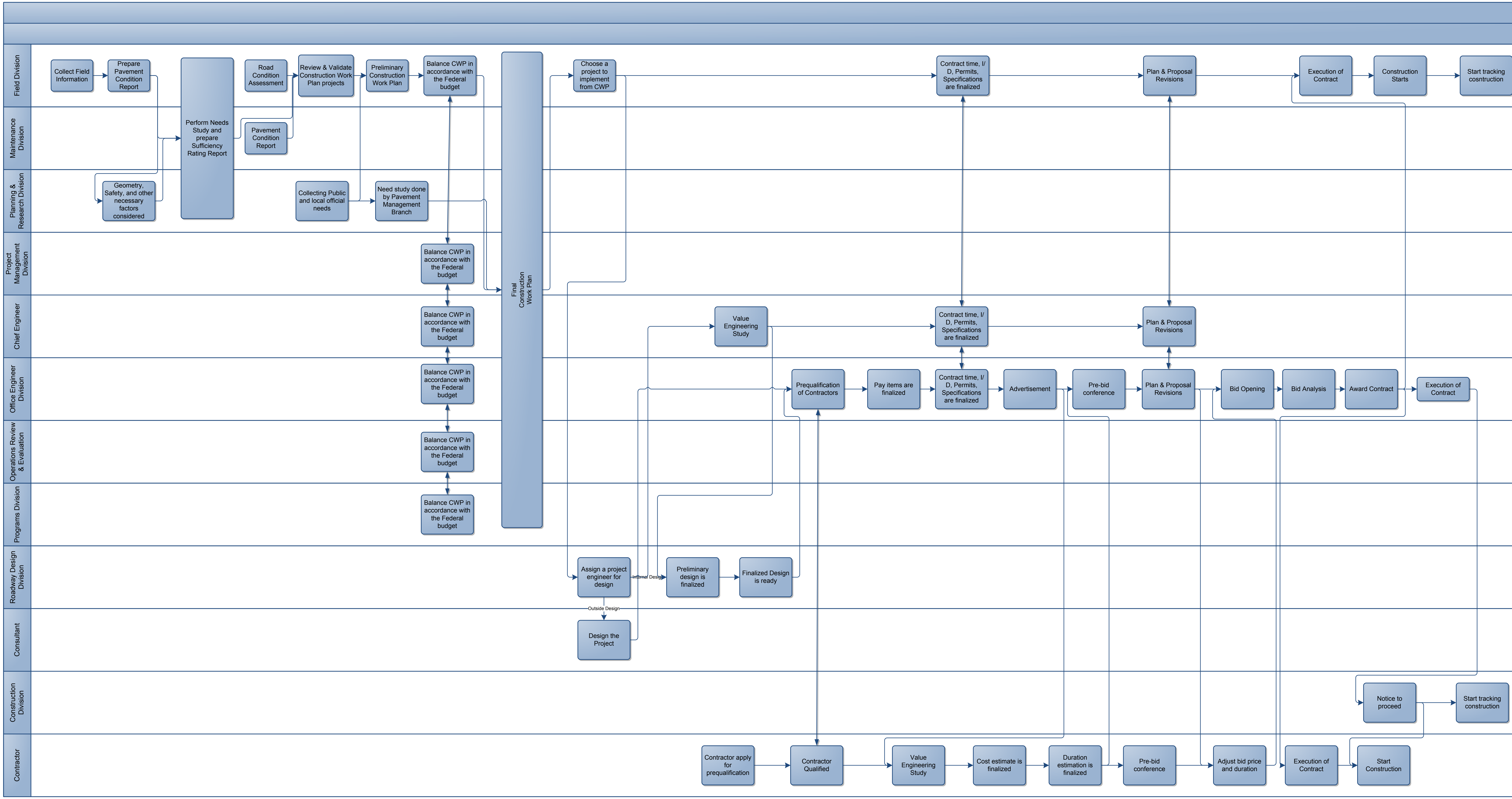
I. Temporary Traffic Control (TTC)			II. Public Information (PI)	
A. Control Strategies	B. Traffic Control Devices[2]	C. Project Coordination, Contracting and Innovative Construction Strategies	A. Public Awareness Strategies	B. Motorist Information Strategies
IA1 Construction phasing/staging	IB1 Temporary signs - Warning - Regulatory - Guide/information	IC1 Project coordination - Coordination with other projects - Utilities coordination - Right-of-way coordination - Coordination with other transportation infrastructure	IIA1 Brochures and mailers	IIB1 Traffic radio
IA2 Full roadway closures	IB2 Changeable message signs (CMS)	IC2 Contracting strategies - Design-build - A+B bidding - Incentive/disincentive clauses - Lane rental	IIA2 Press releases/media alerts	IIB2 Changeable message signs (CMS)
IA3 Lane shifts or closures - Reduced lane widths to maintain number of lanes (constriction) - Lane closures to provide worker safety - Reduced shoulder width to maintain number of lanes - Shoulder closures to provide worker safety - Lane shift to shoulder/median to maintain number of lanes	IB3 Arrow panels	IC3 Innovative construction techniques (precast members, rapid cure materials)	IIA3 Paid advertisements	IIB3 Temporary motorist information signs
IA4 One-lane, two-way operation	IB4 Channelizing devices		IIA4 Public information center	IIB4 Dynamic speed message sign
IA5 Two-way traffic on one side of divided facility (crossover)	IB5 Temporary pavement markings		IIA5 Telephone hotline	IIB5 Highway advisory radio (HAR)
IA6 Reversible lanes	IB6 Flaggers and uniformed traffic control officers		IIA6 Planned lane closure web site	IIB6 Extinguishable signs
IA7 Ramp closures/relocation	IB7 Temporary traffic signals		IIA7 Project web site	IIB7 Highway information network (web-based)
IA8 Freeway-to-freeway interchange closures	IB8 Lighting devices		IIA8 Public meetings/hearings	IIB8 511 traveler information systems (wireless, handhelds)
IA9 Night work			IIA9 Community task forces	IIB9 Freight travel information
IA10 Weekend work			IIA10 Coordination with media/schools/businesses/emergency services	IIB10 Transportation management center (TMC)
IA11 Work hour restrictions for peak travel			IIA11 Work zone education and safety campaigns	
IA12 Pedestrian/bicycle access improvements			IIA12 Work zone safety highway signs	
IA13 Business access improvements			IIA13 Rideshare promotions	
IA14 Off-site detours/use of alternate routes			IIA14 Visual information (videos, slides, presentations) for meetings and web	

III. Transportation Operations (TO)			
A. Demand Management Strategies	B. Corridor/Network Management Strategies	C. Work Zone Safety Management Strategies	D. Traffic/Incident Management and Enforcement Strategies
IIIA1 Transit service improvements	IIIB1 Signal timing/ coordination improvements	IIIC1 Speed limit reduction/variable speed limits	IIID1 ITS for traffic monitoring/ management
IIIA2 Transit incentives	IIIB2 Temporary traffic signals	IIIC2 Temporary traffic signals	IIID2 Transportation management center (TMC)
IIIA3 Shuttle services	IIIB3 Street/intersection improvements	IIIC3 Temporary traffic barrier	IIID3 Surveillance (Closed-Circuit Television [CCTV], loop detectors, lasers, probe vehicles)
IIIA4 Ridesharing/carpooling incentives	IIIB4 Bus turnouts	IIIC4 Movable traffic barrier systems	IIID4 Helicopter for aerial surveillance
IIIA5 Park-and-ride promotion	IIIB5 Turn restrictions	IIIC5 Crash-cushions	IIID5 Traffic screens
IIIA6 High-occupancy vehicle (HOV) lanes	IIIB6 Parking restrictions	IIIC6 Temporary rumble strips	IIID6 Call boxes
IIIA7 Toll/congestion pricing	IIIB7 Truck/heavy vehicle restrictions	IIIC7 Intrusion alarms	IIID7 Mile-post markers
IIIA8 Ramp metering	IIIB8 Separate truck lanes	IIIC8 Warning lights	IIID8 Tow/freeway service patrol
IIIA9 Parking supply management	IIIB9 Reversible lanes	IIIC9 Automated Flagger Assistance Devices (AFADs)	IIID9 Total station units
IIIA10 Variable work hours	IIIB10 Dynamic lane closure system	IIIC10 Project task force/ committee	IIID10 Photogrammetry
IIIA11 Telecommuting	IIIB11 Ramp metering	IIIC11 Construction safety supervisors/inspectors	IIID11 Coordination with media
	IIIB12 Temporary suspension of ramp metering	IIIC12 Road safety audits	IIID12 Local detour routes
	IIIB13 Ramp closures	IIIC13 TMP monitor/inspection team	IIID13 Contract support for incident management
	IIIB14 Railroad crossings controls	IIIC14 Team meetings	IIID14 Incident/emergency management coordinator
	IIIB15 Coordination with adjacent construction site(s)	IIIC15 Project on-site safety training	IIID15 Incident/emergency response plan
		IIIC16 Safety awards/incentives	IIID16 Dedicated (paid) police enforcement
		IIIC17 Windshield surveys	IIID17 Cooperative police enforcement
			IIID18 Automated enforcement
			IIID19 Increased penalties for work zone violations

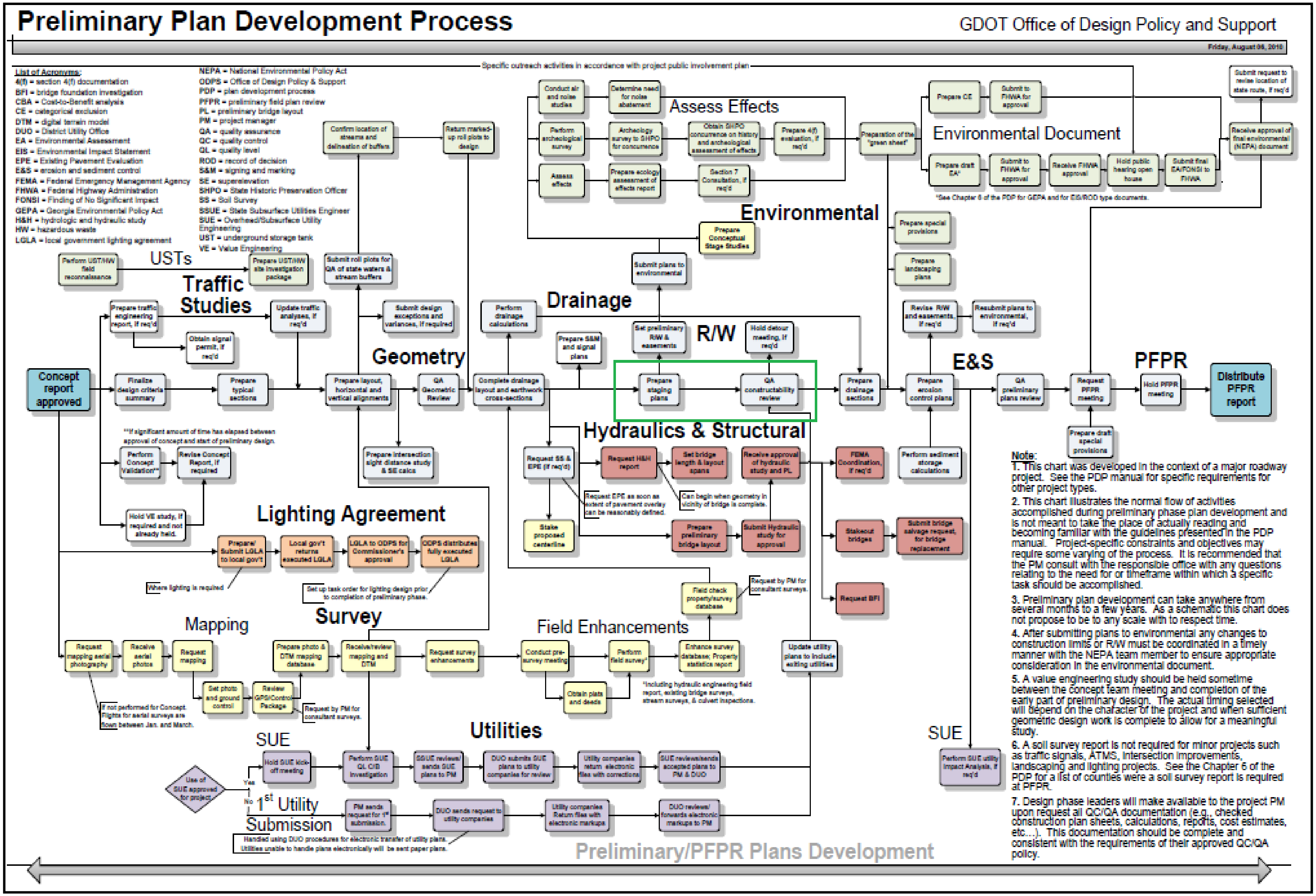
APPENDIX B
FACTORS AFFECTING NIGHTTIME CONSTRUCTION [14]


Night Operation Parameters
Traffic-Related Parameters
Construction-Related Parameters
Social Parameters
Economic Parameters
Environmental Parameters
Cabinet Issues
Legal Issues
Safety
Congestion
Traffic Control
Work Time Rest.
Lighting
Urban vs. Rural
Enforcement
New Technology
Quality
Productivity
Safety
Work Operations
New Technology
Schedule Limits
Blasting
Material Availability
Equipment Repair
Work Lighting
Communication
Driver Condition
Worker Condition
Business Disturbance
Public Disturbance
Local Events
Business Losses
Road User Costs
Accident Cost
Maintenance Cost
Construction Cost
Incentives/Disincentives
Liquidated Damages
New Technology
Light Pollution
Noise
Fuel Consumption
Air Quality
Workers' Health
Personnel Assignment
Resources
Decision Making
Public Relations
Political
Time Limitations
Type of Work
Local Ordinances
Local Restrictions

APPENDIX C
ODOT CURRENT PLANNING AND STAGING PROCEDURE


Field Division
Maintenance Division
Planning & Research Division
Project Management Division
Chief Engineer
Office Engineer Division
Operations Review & Evaluation
Programs Division
Roadway Design Division
Consultant
Construction Division
Contractor
Collect Field Information
Prepare Pavement Condition Report
Perform Needs Study and prepare Sufficiency Rating Report
Road Condition Assessment
Pavement Condition Report
Review & Validate Construction Work Plan projects
Preliminary Construction Work Plan
Balance CWP in accordance with the Federal budget
Geometry, Safety, and other necessary factors considered
Collecting Public and local official needs
Need study done by Pavement Management Branch
Final Construction Work Plan
Choose a project to implement from CWP
Contract time, I/D, Permits, Specifications are finalized
Plan & Proposal Revisions
Execution of Contract
Construction Starts
Start tracking cosntruction
Value Engineering Study
Prequalification of Contractors
Pay items are finalized
Advertisement
Pre-bid conference
Bid Opening
Bid Analysis
Award Contract
Assign a project engineer for design
Preliminary design is finalized
Finalized Design is ready
Outside Design
Design the Project
Notice to proceed
Start tracking construction
Contractor apply for prequalification
Contractor Qualified
Cost estimate is finalized
Duration estimation is finalized
Adjust bid price and duration
Start Construction

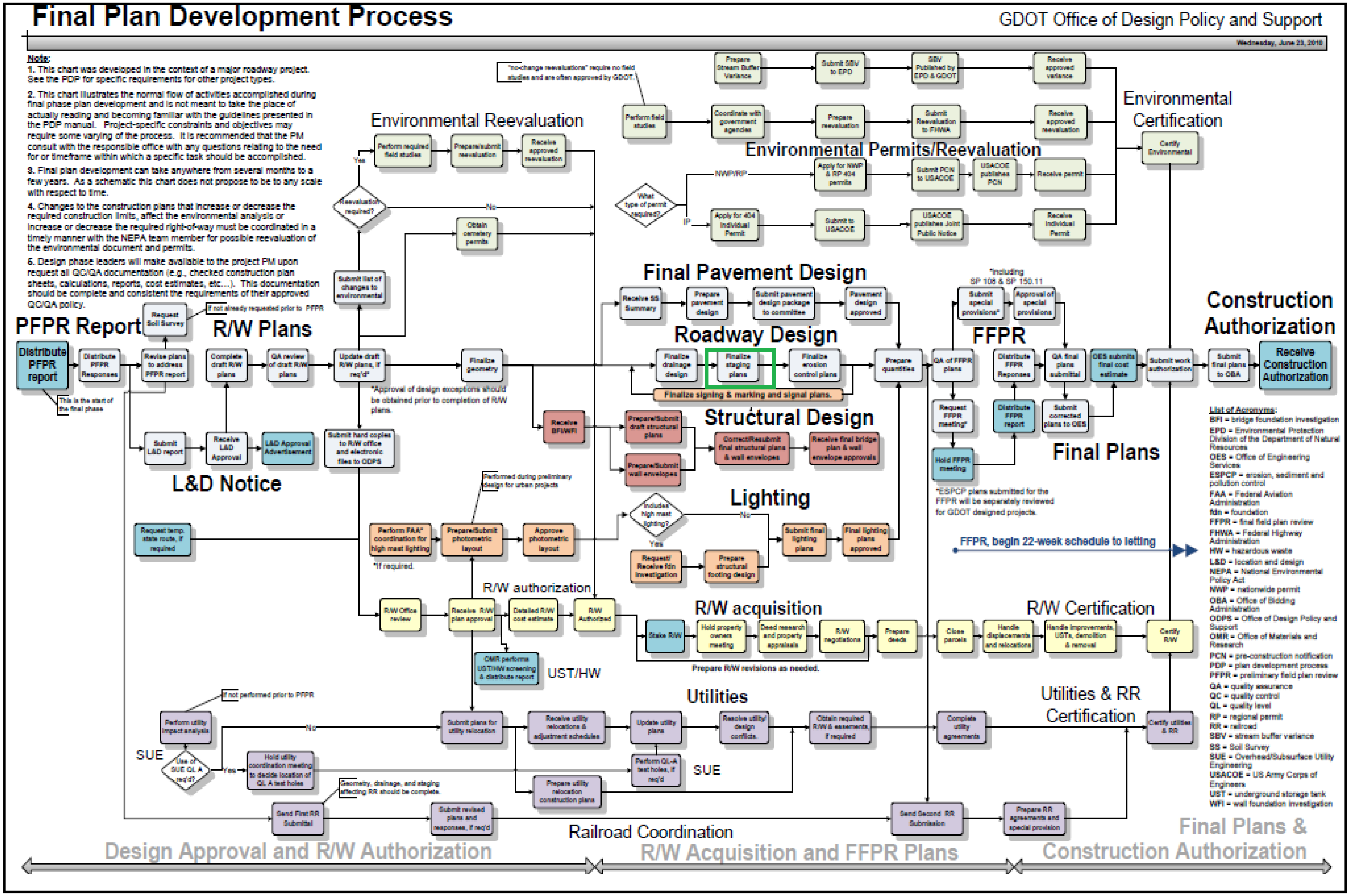
APPENDIX D
PRELIMINARY PLAN DEVELOPMENT PROCESS


Preliminary Plan Development Process
GDOT Office of Design Policy and Support
Friday, August 06, 2010
Specific outreach activities in accordance with project public involvement plan
List of Acronyms:
4(f) = section 4(f) documentation
BFI = bridge foundation investigation
CBA = Cost-to-Benefit analysis
CE = categorical exclusion
DTM = digital terrain model
DUO = District Utility Office
EA = Environmental Assessment
EIS = Environmental Impact Statement
EPE = Existing Pavement Evaluation
E&S = erosion and sediment control
FEMA = Federal Emergency Management Agency
FHWA = Federal Highway Administration
FONSI = Finding of No Significant Impact
GEPA = Georgia Environmental Policy Act
H&H = hydrologic and hydraulic study
HW = hazardous waste
LGLA = local government lighting agreement
NEPA = National Environmental Policy Act
ODPS = Office of Design Policy & Support
PDP = plan development process
PFPR = preliminary field plan review
PL = preliminary bridge layout
PM = project manager
QA = quality assurance
QC = quality control
QL = quality level
ROD = record of decision
S&M = signing and marking
SE = superelevation
SHPO = State Historic Preservation Officer
SS = Soil Survey
SSUE = State Subsurface Utilities Engineer
SUE = Overhead/Subsurface Utility Engineering
UST = underground storage tank
VE = Value Engineering
USTs
Traffic Studies
Geometry
Drainage
R/W
Assess Effects
Environmental
Environmental Document
Hydraulics & Structural
E&S
PFPR
Concept report approved
Distribute PFPR report
Lighting Agreement
Mapping
Survey
Field Enhancements
Utilities
SUE
1st Utility Submission
Preliminary/PFPR Plans Development
Note:
1. This chart was developed in the context of a major roadway project. See the PDP manual for specific requirements for other project types.
2. This chart illustrates the normal flow of activities accomplished during preliminary phase plan development and is not meant to take the place of actually reading and becoming familiar with the guidelines presented in the PDP manual. Project-specific constraints and objectives may require some varying of the process. It is recommended that the PM consult with the responsible office with any questions relating to the need for or timeframe within which a specific task should be accomplished.
3. Preliminary plan development can take anywhere from several months to a few years. As a schematic this chart does not propose to be to any scale with to respect time.
4. After submitting plans to environmental any changes to construction limits or R/W must be coordinated in a timely manner with the NEPA team member to ensure appropriate consideration in the environmental document.
5. A value engineering study should be held sometime between the concept team meeting and completion of the early part of preliminary design. The actual timing selected will depend on the character of the project and when sufficient geometric design work is complete to allow for a meaningful study.
6. A soil survey report is not required for minor projects such as traffic signals, ATMS, intersection improvements, landscaping and lighting projects. See the Chapter 6 of the PDP for a list of counties were a soil survey report is required at PFPR.
7. Design phase leaders will make available to the project PM upon request all QC/QA documentation (e.g., checked construction plan sheets, calculations, reports, cost estimates, etc…). This documentation should be complete and consistent with the requirements of their approved QC/QA policy.

APPENDIX E
CONSTRUCTABILITY REVIEW GUIDANCE TOOL

CONSTRUCTABILITY REVIEW GUIDANCE TOOL		
Project No.		
P.I. No.		
Route / Termini:		
County:		
A	SITE INVESTIGATION	COMMENT
1	Perform field investigation to ensure actual site conditions reflected in the plans and design.	
2	Perform utility investigation – overhead & underground conflicts, notify all utilities.	
3	Ensure proper lay down, stockpile, and staging areas are available.	
4	Ensure input from local government departments regarding development approvals and signed permits are	
5	Permit concerns such as SPDES, CORP, DNR, etc. are known.	
6	Consider project access requirements for contractor equipment and operations.	
B	EARTHWORK	COMMENT
1	Ensure earthwork volumes are economically balanced in each stage of construction whenever possible.	
2	Any visual evidence, or prior indication by past local area projects, that rock will be encountered within project.	
3	Temporary stream crossings considered when earthwork balances dictate hauling across a river or stream.	
C	BASES & PAVEMENT	COMMENT
1	Ensure profile grades have been established.	
2	Provide allowances for contractor equipment and operations in staged construction or when constructions	
3	Concrete base widening considered in lieu of asphalt base in urban areas where entrances and irregular areas	
4	Allowances have been made for equipment widths, track lines, string lines, etc. when lanes are paved in stages or	
5	For new construction there should be no staging concerns; hence construction staging should not be the basis for pavement type selection on such projects. Construction staging may be a factor for other projects.	
6	Ensure asphalt leveling quantities will be sufficiently calculated for staging phases.	
D	DRAINAGE	COMMENT
1	Consider temporary / permanent drainage systems and facilities during each stage of construction.	
2	Ensure erosion control has been provided for each stage or work.	
3	Impacts of future urban development has been considered in stormwater design.	
4	Temporary ditches and pipes are incorporated in each stage to allow runoff to occur.	
E	STRUCTURES – Bridges, Culverts and Retaining Walls	COMMENT
1	Ensure there is sufficient room between existing and new alignments for bridge construction.	
2	Make provisions for contractor access to the site (long beams, large cranes, etc…)	
3	Ensure bridge staging is coordinated with roadway staging.	
4	Vertical clearances have been considered.	
5	Final retaining wall elevations and staging plans are compatible.	
D	TRAFFIC CONTROL PLAN	COMMENT
1	All city and county road closures have been identified and approved.	
2	Ensure traffic control requirements are realistic for site conditions.	
3	Check all temporary lanes widths for adequacy.	
4	All lane closures are reasonable for traffic volumes and penalty for closure is provided for when required.	
5	Power source and overhead clearances are available for temporary/permanent lighting, flashing, barricades and	
6	Detours have been considered to avert delays.	
7	Traffic control study completed and compatible with staging plans. Incident plan developed and realistic.	
H	MAINTENANCE CONSIDERATIONS	COMMENT
1	Project specific concerns are addressed by GDOT District Maintenance Engineer.	
I	JOB SPECIAL PROVISIONS/PLANS	COMMENT
1	Typical sections are provided for all pavement/shoulder transition areas.	
2	Any conflicts between the special provisions, standard specs., and plans.	
3	Railroad involvement?	
4	Details as shown on the plans can be constructed using standard equipment and operating procedures.	
5	Temporary median crossovers have been considered on dual lane roadways to shorten haul times.	
6	All utility lines that cross the alignment have the vertical clearances required for earthmoving equipment to pass	
7	Existing billboards and signage conflicts considered.	
J	CONSTRUCTION STAGING	COMMENT
1	Construction staging will not require material to be hauled across/over the new pavement or provisions for x-over	
2	Existing pavement to be removed can be incorporated into staged in slopes or disposal sites available within the	
3	Work has been phased to minimize the number of stages.	
4	Coordinate structure and roadway staging.	
5	Private and commercial entrances accessible at all times on all stages.	
K	RIGHT OF WAY	COMMENT
1	Sufficient Right-of-Way available for all operations.	
2	Sufficient easements available for all operations.	
3	All buried UST's and environmental contamination sites have been investigated and disposal plans developed.	
4	Removal of all structures (houses, businesses, wells, etc.) in R/W Agreement are removed BEFORE construction.	
L	SCHEDULE	COMMENT
1	Working days and productions rates for work items are reasonable.	
2	Construction staging sequences checked for accuracy.	
3	Consideration has been given for seasonal / weather constraints.	
4	All regulatory permit restrictions such as working in a river or cutting trees have been clearly identified.	
5	Any local restrictions on working hours have been identified.	
6	Material submittal lead times are compatible with recommended project schedule.	
7	Is there need for detailed scheduling implementation?	

APPENDIX F
FINAL PLAN DEVELOPMENT PROCESS


Final Plan Development Process
GDOT Office of Design Policy and Support
Wednesday, June 23, 2010
Note:
1. This chart was developed in the context of a major roadway project. See the PDP for specific requirements for other project types.
2. This chart illustrates the normal flow of activities accomplished during final phase plan development and is not meant to take the place of actually reading and becoming familiar with the guidelines presented in the PDP manual. Project-specific constraints and objectives may require some varying of the process. It is recommended that the PM consult with the responsible office with any questions relating to the need for or timeframe within which a specific task should be accomplished.
3. Final plan development can take anywhere from several months to a few years. As a schematic this chart does not propose to be to any scale with respect to time.
4. Changes to the construction plans that increase or decrease the required construction limits, affect the environmental analysis or increase or decrease the required right-of-way must be coordinated in a timely manner with the NEPA team member for possible reevaluation of the environmental document and permits.
6. Design phase leaders will make available to the project PM upon request all QC/QA documentation (e.g., checked construction plan sheets, calculations, reports, cost estimates, etc…). This documentation should be complete and consistent the requirements of their approved QC/QA policy.
PFPR Report
Distribute PFPR report
This is the start of the final phase
Distribute PFPR Responses
Revise plans to address PFPR report
Request Soil Survey
If not already requested prior to PFPR
R/W Plans
Complete draft R/W plans
QA review of draft R/W plans
Update draft R/W plans, if req'd*
*Approval of design exceptions should be obtained prior to completion of R/W plans.
Submit hard copies to R/W office and electronic files to ODPS
L&D Notice
Submit L&D report
Receive L&D Approval
L&D Approval Advertisement
Environmental Reevaluation
Reevaluation required?
Yes
No
Perform required field studies
Prepare/submit reevaluation
Receive approved reevaluation
Submit list of changes to environmental
Obtain cemetery permits
"no-change reevaluations" require no field studies and are often approved by GDOT.
Environmental Permits/Reevaluation
Perform field studies
Prepare Stream Buffer Variance
Submit SBV to EPD
SBV Published by EPD & GDOT
Receive approved variance
Coordinate with government agencies
Prepare reevaluation
Submit Reevaluation to FHWA
Receive approved reevaluation
What type of permit required?
NWP/RP
IP
Apply for NWP & RP 404 permits
Submit PCN to USACOE
USACOE publishes PCN
Receive permit
Apply for 404 Individual Permit
Submit to USACOE
USACOE publishes Joint Public Notice
Receive Individual Permit
Environmental Certification
Certify Environmental
Finalize geometry
Final Pavement Design
Receive SS Summary
Prepare pavement design
Submit pavement design package to committee
Pavement design approved
Roadway Design
Finalize drainage design
Finalize staging plans
Finalize erosion control plans
Finalize signing & marking and signal plans.
Prepare quantities
Structural Design
Receive BFI/WFI
Prepare/Submit draft structural plans
Prepare/Submit wall envelopes
Correct/Resubmit final structural plans & wall envelopes
Receive final bridge plan & wall envelope approvals
Lighting
Request temp. state route, if required
Perform FAA* coordination for high mast lighting
*If required.
Prepare/Submit photometric layout
Performed during preliminary design for urban projects
Approve photometric layout
Includes high mast lighting?
Yes
No
Request/Receive fdn investigation
Prepare structural footing design
Submit final lighting plans
Final lighting plans approved
R/W authorization
R/W Office review
Receive R/W plan approval
Detailed R/W cost estimate
R/W Authorized
OMR performs UST/HW screening & distribute report
UST/HW
R/W acquisition
Stake R/W
Hold property owners meeting
Deed research and property appraisals
R/W negotiations
Prepare deeds
Close parcels
Prepare R/W revisions as needed.
R/W Certification
Handle displacements and relocations
Handle improvements, USTs, demolition & removal
Certify R/W
FFPR
*Including SP 108 & SP 150.11
Submit special provisions*
Approval of special provisions
QA of FFPR plans
Request FFPR meeting*
Hold FFPR meeting
Distribute FFPR Responses
Distribute FFPR report
QA final plans submittal
Submit corrected plans to OES
OES submits final cost estimate
*ESPCP plans submitted for the FFPR will be separately reviewed for GDOT designed projects.
Final Plans
FFPR, begin 22-week schedule to letting
Construction Authorization
Submit work authorization
Submit final plans to OBA
Receive Construction Authorization
Utilities
Perform utility impact analysis
If not performed prior to PFPR
SUE
Use of SUE QL A req'd?
Yes
No
Hold utility coordination meeting to decide location of QL A test holes
Submit plans for utility relocation
Receive utility relocations & adjustment schedules
Prepare utility relocation construction plans
Update utility plans
Perform QL-A test holes, if req'd
SUE
Resolve utility/design conflicts.
Obtain required R/W & easements, if required
Complete utility agreements
Utilities & RR Certification
Certify utilities & RR
Railroad Coordination
Send First RR Submittal
Geometry, drainage, and staging affecting RR should be complete.
Submit revised plans and responses, if req'd
Send Second RR Submission
Prepare RR agreements and special provision
List of Acronyms:
BFI = bridge foundation investigation
EPD = Environmental Protection Division of the Department of Natural Resources
OES = Office of Engineering Services
ESPCP = erosion, sediment and pollution control
FAA = Federal Aviation Administration
fdn = foundation
FFPR = final field plan review
FHWA = Federal Highway Administration
HW = hazardous waste
L&D = location and design
NEPA = National Environmental Policy Act
NWP = nationwide permit
OBA = Office of Bidding Administration
ODPS = Office of Design Policy and Support
OMR = Office of Materials and Research
PCN = pre-construction notification
PDP = plan development process
PFPR = preliminary field plan review
QA = quality assurance
QC = quality control
QL = quality level
RP = regional permit
RR = railroad
SBV = stream buffer variance
SS = Soil Survey
SUE = Overhead/Subsurface Utility Engineering
USACOE = US Army Corps of Engineers
UST = underground storage tank
WFI = wall foundation investigation
Design Approval and R/W Authorization
R/W Acquisition and FFPR Plans
Final Plans & Construction Authorization

APPENDIX G
PRE- AND POST-KNOWLEDGE INVENTORY SURVEY OF ODOT

	Pre-demonstration			Post-demonstration			Mean change	% Mean change
Item	min	max	mean	min	max	mean		
1	3	4	3.33	4	5	4.50	1.17	25.93
2	3	4	3.17	4	5	4.40	1.23	28.03
3	3	5	3.17	3	5	4.00	0.83	20.83
4	3	4	3.08	3	5	4.00	0.92	22.92
5	2	4	3.00	3	5	3.90	0.90	23.08
6	3	5	3.33	3	5	4.30	0.97	22.48
7	3	5	3.25	3	5	4.10	0.85	20.73
8	3	5	3.25	4	5	4.30	1.05	24.42
9	3	5	3.25	4	5	4.30	1.05	24.42
10	3	4	3.08	4	5	4.20	1.12	26.59
11	2	4	3.33	1	5	3.50	0.17	4.76
12	2	5	3.25	1	4	3.50	0.25	7.14
13	1	4	2.92	1	4	3.00	0.08	2.78
14	3	4	3.17	3	5	4.20	1.03	24.60
15	2	4	2.92	2	4	3.10	0.18	5.91
16	3	4	3.25	2	4	3.67	0.42	11.36
17	3	4	3.17	3	5	3.80	0.63	16.67
18	3	4	3.25	4	5	4.10	0.85	20.73
19	3	4	3.08	3	5	3.70	0.62	16.67

APPENDIX H
PRE- AND POST-KNOWLEDGE INVENTORY SURVEY OF GDOT

	Pre-demonstration			Post-demonstration			Mean change	% Mean change
Item	min	max	mean	min	max	mean		
1	2	5	3.24	4	5	4.31	1.07	24.83
2	2	4	3.19	4	5	4.21	1.02	24.29
3	3	4	3.05	2	5	3.57	1.02	24.29
4	3	4	3.33	2	5	3.64	1.00	24.14
5	3	4	3.29	2	5	3.57	0.81	20.99
6	3	4	3.33	2	5	3.93	0.71	19.23
7	2	4	3.19	4	5	4.21	0.76	18.39
8	3	4	3.38	2	5	4.14	0.76	18.39
9	3	4	3.38	3	5	4.14	0.71	17.24
10	3	5	3.14	3	5	4.14	0.60	16.34
11	2	4	3.00	2	5	3.21	0.57	15.70
12	2	3	2.90	2	5	3.07	0.60	15.15
13	2	4	3.19	1	5	3.21	0.52	14.67
14	3	4	3.43	2	5	4.14	0.43	12.50
15	3	4	3.05	3	5	3.64	0.31	8.50
16	2	4	3.00	2	5	3.43	0.29	8.00
17	3	4	3.05	3	4	3.62	0.21	6.67
18	3	4	3.05	2	5	3.86	0.17	5.43
19	3	3	3.00	3	5	3.71	0.02	0.74

APPENDIX I
I-75 LANE CLOSURE RESTRICTIONS

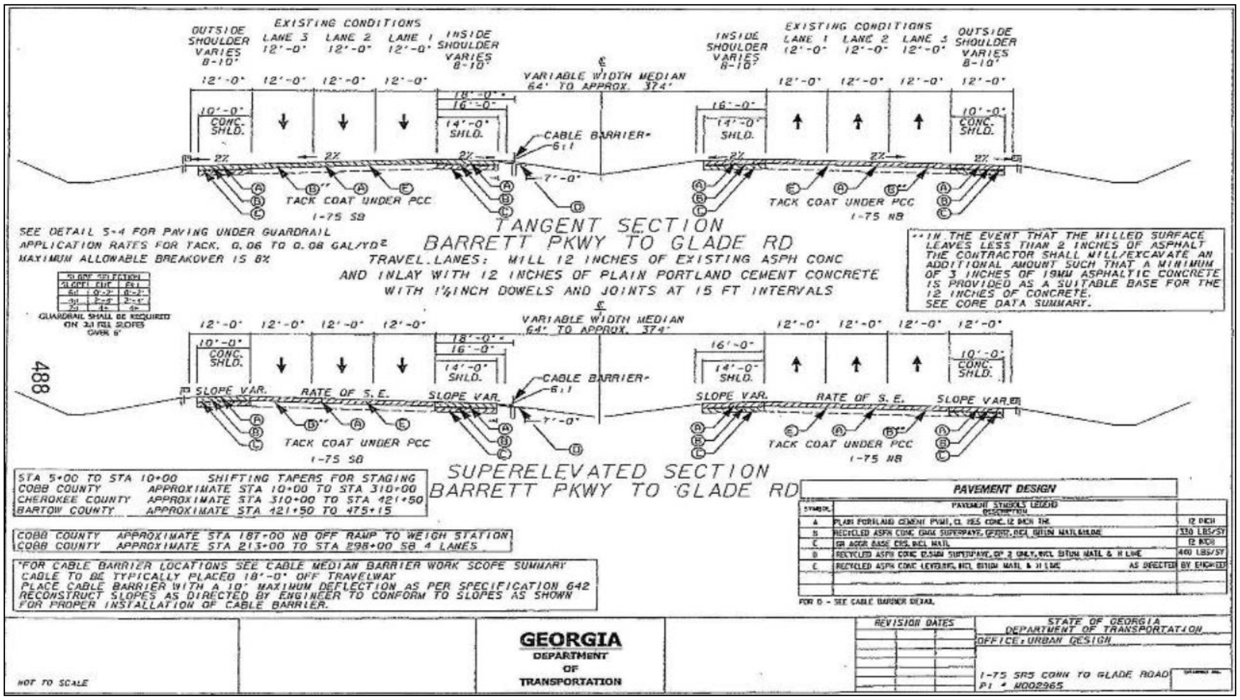
4 ZONES

150.11 SPECIAL CONDITIONS

A. Lane closures, detours, pacing of traffic, moving equipment or material and other activities shall not be allowed on I-75 except during the hours shown below. "Weekdays" shall be deemed to mean Monday through Thursday.

1. I-75 SOUTHBOUND FROM BARRETT PKWY TO WADE GREEN ROAD
   a) The following are the allowable times for Single Lane Closures:
      Weekdays 7:00 PM – 5:00 AM 10 hrs
      Friday 7:00 PM – Monday 5:00 AM 58 hrs
   b) The following are the allowable times for Double Lane Closures:
      Weekdays 11:00 PM – 5:00 AM
      Friday 8:00 PM – Saturday 8:00 AM
      Saturday 8:00 PM – Sunday 8:00 AM
      Sunday 8:00 PM – Monday 5:00 AM
2. I-75 NORTHBOUND FROM BARRETT PKWY TO WADE GREEN ROAD
   a) The following are the allowable times for Single Lane Closures:
      Weekdays 8:00 PM – 9:00 AM 13 hrs
      Friday 7:00 PM – Monday 9:00 AM 62 hrs
   b) The following are the allowable times for Double Lane Closures:
      Weekdays 12:00 MIDNIGHT – 6:00 AM
      Friday 9:00 PM – Saturday 9:00 AM
      Saturday 9:00 PM – Sunday 9:00 AM
      Sunday 8:00 PM – Monday 5:00 AM
3. I-75 SOUTHBOUND FROM WADE GREEN ROAD TO GLADE ROAD
   a) The following are the allowable times for Single Lane Closures:
      Weekdays 11:00 AM – 5:00 AM Next Day 18 hrs
      Friday 7:00 PM – Monday 5:00 AM 58 hrs
   b) The following are the allowable times for Double Lane Closures:
      Weekdays 10:00 PM – 5:00 AM
      Friday 8:00 PM – Saturday 10:00 AM
      Saturday 7:00 PM – Sunday 9:00 AM
      Sunday 7:00 PM – Monday 5:00 AM
4. I-75 NORTHBOUND FROM WADE GREEN ROAD TO GLADE ROAD
   a) The following are the allowable times for Single Lane Closures:
      18 hrs Weekdays 7:00 PM – 1PM Next Day except Friday-11AM
      65 hrs Friday 8:00 PM –1:00 PM Monday
   b) The following are the allowable times for Double Lane Closures:
      Weekdays 10:00 PM – 5:00 AM
      Friday 9:00 PM – Saturday 11:00 AM
      Saturday 9:00 PM – Sunday 11:00 AM
      Sunday 8:00 PM - Monday 5:00 AM

APPENDIX J
I-75 PROJECT TYPICAL SECTION


EXISTING CONDITIONS
OUTSIDE SHOULDER VARIES 8-10'
LANE 3 12'-0"
LANE 2 12'-0"
LANE 1 12'-0"
INSIDE SHOULDER VARIES 8-10'
VARIABLE WIDTH MEDIAN 64' TO APPROX. 374'
CABLE BARRIER*
TACK COAT UNDER PCC
I-75 SB
I-75 NB
TANGENT SECTION
BARRETT PKWY TO GLADE RD
SEE DETAIL 5-4 FOR PAVING UNDER GUARDRAIL
APPLICATION RATES FOR TACK, 0.06 TO 0.08 GAL/YD²
MAXIMUM ALLOWABLE BREAKOVER IS 8%
TRAVEL LANES: MILL 12 INCHES OF EXISTING ASPH CONC AND INLAY WITH 12 INCHES OF PLAIN PORTLAND CEMENT CONCRETE WITH 1½ INCH DOWELS AND JOINTS AT 15 FT INTERVALS
** IN THE EVENT THAT THE MILLED SURFACE LEAVES LESS THAN 2 INCHES OF ASPHALT THE CONTRACTOR SHALL MILL/EXCAVATE AN ADDITIONAL AMOUNT SUCH THAT A MINIMUM OF 3 INCHES OF 19MM ASPHALTIC CONCRETE IS PROVIDED AS A SUITABLE BASE FOR THE 12 INCHES OF CONCRETE. SEE CORE DATA SUMMARY.
GUARDRAIL SHALL BE REQUIRED ON 3:1 FILL SLOPES OVER 6'
488
SLOPE VAR.
RATE OF S.E.
SUPERELEVATED SECTION
BARRETT PKWY TO GLADE RD
STA 5+00 TO STA 10+00 SHIFTING TAPERS FOR STAGING
COBB COUNTY APPROXIMATE STA 10+00 TO STA 310+00
CHEROKEE COUNTY APPROXIMATE STA 310+00 TO STA 421+50
BARTOW COUNTY APPROXIMATE STA 421+50 TO 475+15
COBB COUNTY APPROXIMATE STA 187+00 NB OFF RAMP TO WEIGH STATION
COBB COUNTY APPROXIMATE STA 213+00 TO STA 298+00 SB 4 LANES
*FOR CABLE BARRIER LOCATIONS SEE CABLE MEDIAN BARRIER WORK SCOPE SUMMARY
CABLE TO BE TYPICALLY PLACED 18'-0" OFF TRAVELWAY
PLACE CABLE BARRIER WITH A 10' MAXIMUM DEFLECTION AS PER SPECIFICATION 642
RECONSTRUCT SLOPES AS DIRECTED BY ENGINEER TO CONFORM TO SLOPES AS SHOWN FOR PROPER INSTALLATION OF CABLE BARRIER.
PAVEMENT DESIGN
PAVEMENT SYMBOLS LEGEND
FOR D - SEE CABLE BARRIER DETAIL
NOT TO SCALE
GEORGIA DEPARTMENT OF TRANSPORTATION
REVISION DATES
STATE OF GEORGIA DEPARTMENT OF TRANSPORTATION
OFFICE: URBAN DESIGN
I-75 SR5 CONN TO GLADE ROAD
PI # M002965