Final Research Report

Rapid Pavement Construction Tools, Materials and Methods

by

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16. ABSTRACT

To address the need to deliver cost-effective projects while minimizing traffic impacts, the Washington State Department of Transportation (WSDOT) desires to improve their knowledge, awareness and retention of rapid pavement construction tools, materials and methods. This project discusses the implementation, use and experience of using the following items related to rapid pavement construction: CA4PRS (Construction Alternatives for Pavement Rehabilitation Strategies), portland cement concrete (PCC) pavement panel replacement, polymer concrete and traffic closure windows. CA4PRS is a Microsoft Access-based software program for predicting construction productivity for highway rehabilitation/reconstruction. It was tested in two case studies and has proved capable of providing meaningful scheduling and productivity inputs into early project planning. Panel replacement techniques and polymer concrete construction are reviewed (including contractor interviews) in an effort to document past successes and failures as well as key decision points when making future project decisions. Finally, a review of traffic closure windows for rapid construction is presented.

17. KEY WORDS

Rapid construction, portland cement concrete, polyester concrete, panel replacement, traffic closure windows, construction, pavement

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1 Introduction

In 2004, the Washington State Department of Transportation (WSDOT) calculated that approximately 1,600 lane-miles of concrete pavement on the state's roadway network were at least 20 years old (WSDOT Highways Capital Program, 2004). Although many of these pavements continue to provide safe and reliable service, WSDOT determined that 600 lane-miles of concrete pavement should be replaced over the next ten years (WSDOT Highways Capital Program, 2004). Pavements that require the most immediate attention include the most heavily utilized and relied upon routes such as Interstate 5, Interstate 90, Interstate 405 and other primary state highways. These major roadways commonly provide transportation for over 100,000 vehicles on a daily basis (WSDOT Annual Traffic Report, 2005). New roadway project proposals involving these heavily utilized corridors not only require construction planning, but mitigation and control of construction-related traffic impacts to roadway users.

To address the need to deliver cost-effective projects while minimizing traffic impacts, WSDOT has begun to use rapid construction techniques. Rapid construction refers to a method of designing and building roadway projects using fast-paced construction operations and more aggressive scheduling in order to reduce roadway user impacts. As traffic volumes throughout the state continue to rise, the importance and relevance of rapid construction will likely increase in-step. This report describes five rapid construction tools or methods available to WSDOT: (1) Constructability Analysis for Pavement Rehabilitation Strategies (CA4PRS) (2) Rapid PCC Panel Replacement (3) Polymer Concrete (4) Traffic Closure Windows and (5) a Rapid Construction Cost Management and Contract Development Guide.

1.1 CA4PRS

CA4PRS is a productivity estimation tool developed to aid in evaluating and choosing between highway pavement construction alternatives (Ibbs and Lee, 2005). This relatively new software tool was developed at the University of California at Berkeley in cooperation with the California Department of Transportation (Caltrans). While

California has successfully employed CA4PRS, WSDOT has yet to implement use of this estimation tool. This report will provide a brief description of CA4PRS, a description of how it was successfully used on two Caltrans projects, followed by an analysis of the implementation and applicability of the program to different levels of planning and design on Washington State roadway projects.

1.2 Rapid Panel Replacement

Rapid panel replacement is a valuable construction method that quickly and efficiently replaces failed concrete panels. On several rapid panel replacement contracts, WSDOT has successfully maintained traffic flows along busy routes while making essential panel repairs to improve the lifespan of older concrete pavements. This report details productivity and scheduling information useful to designers in delivering complete and cost-effective contracts for panel replacement.

1.3 Polymer Concrete

Highway bridges are essential components of the roadway network that link roads and communities over obstacles such as busy streets, rail road tracks and waterways. Because bridges are vital components of the transportation network, closing bridges for maintenance, repair and overlay can often result in severe impacts to traffic flow. WSDOT has the option to use fast-setting polymer concrete overlays when rapid construction is needed. Polymer concrete is not a new construction material, but has not seen widespread use throughout Washington State. WSDOT has limited the future use of the 3/8 inch thick epoxy and methyl methacrylate polymer overlays on bridges due to poor past performance. Over the last several years, WSDOT has gained further experience with the ¾ inch thick Polyester polymer concrete on bridges. This report provides an introduction to polymer concrete as well as a discussion of material limitations, costs and issues encountered by WSDOT in its use.

1.4 Traffic Closure Windows

Construction closure windows are often imposed on contractors to control the timing and duration of traffic lane closures. Reduced or shortened closure windows require the use of rapid construction methods and an increased dedication of contractor resources, which, in turn, increases construction costs. The use of rapid construction techniques requires balancing the increased costs of rapid construction with the benefits of reduced traffic impacts. This report includes an analysis that defines the relationship between the added cost of rapid construction versus the benefits of shorter lane closures and provides cost to benefit calculations to aid decision makers.

2 Construction Analysis for Pavement Rehabilitation Strategies – CA4PRS

As pavements throughout the Washington State highway network approach the end of their service lives, WSDOT is faced with the major task of pavement reconstruction on high volume corridors. The traffic impacts caused by construction activities can be managed with extensive planning and a thorough analysis of multiple construction alternatives. The process of alternative evaluation and selection is heavily dependent upon construction productivity and potential traffic impacts. In order to evaluate and develop construction alternatives for paving projects, WSDOT design engineers need to quickly and efficiently develop realistic productivity estimates. One viable tool available to WSDOT engineers for analyzing construction alternatives is CA4PRS, a simulation model that estimates the number of lane miles a contractor may reconstruct within a specified construction closure window given equipment and scheduling constraints. CA4PRS has been developed and evaluated in California and is intended to aid public transportation agencies in evaluating construction alternatives by providing information about construction productivity, associated construction costs and traffic operations (Ibbs and Lee, 2005). This section describes CA4PRS, the program's major features and provides an analysis of CA4PRS applicability through two WSDOT case studies. The first case study examines CA4PRS's ability to generate productivity estimates that correspond to observed construction productivity on a completed WSDOT project. The second case study summarizes the benefits of CA4PRS productivity estimates observed during the development of a WSDOT construction alternative analysis report. Both of these case studies include PCC pavement reconstruction on a new hot mix asphalt (HMA) base. CA4PRS also has the capability to generate estimates for HMA paving and reconstruction, however, CA4PRS usage on WSDOT HMA projects is outside the scope of this report.

2.1 CA4PRS Background

2.1.1 CA4PRS Origins

The development and validation of the original version of the CA4PRS program was sponsored by the California Department of Transportation (Caltrans). Caltrans is currently facing the problem of reconstructing portions of its state highway network through major urban California corridors. To efficiently construct a project with minimal user delay, Caltrans has implemented a design policy of rapid construction (Lee et al., 2001). Relatively few resources exist to design the complex construction operations, planning and traffic management required for rapid pavement rehabilitation in heavily developed and trafficked urban corridors (Lee et al., 2001). For the purpose of determining how public road agencies can efficiently and reliably implement rapid construction designs, Caltrans implemented a demonstration and data collection project on a segment of I-10 in Pomona, California. On this project, the contractor successfully reconstructed 2.8 lane-kilometers of concrete pavement during one 55-hour weekend closure. From this demonstration project, the observed traffic management and productivity rates aided in the identification of which specific construction activities represented significant constraints throughout the construction process (Lee et al., 2001). The detailed traffic management, productivity rates and constraints to construction information contributed to the development of the first version of CA4PRS.

After the I-10 project, Caltrans implemented information and data collection for a second highway reconstruction project on I-710 in Long Beach California (Ibbs and Lee, 2005). The I-710 project involved rebuilding 26.3 lane-kilometers of HMA pavement using eight, 55-hour weekend construction closures. Incorporating construction output from this project into CA4PRS enabled the software to provide estimates for two new HMA rehabilitation strategies: (1) full–depth asphalt concrete replacement (FDAC) and (2) crack and seat asphalt overlay (CSOL). On this project, CA4PRS successfully predicted production rates within approximately five percent of the actual production rates achieved by the contractor (Ibbs and Lee, 2005).

Following the I-710 project, construction researchers collected information from another concrete rehabilitation project in Devore, San Bernardino County, California. This project which rebuilt 17 lane-kilometers of pavement on I-15 was accomplished using eight 72-hour continuous lane closures. The information gathered during this project further validated CA4PRS productivity estimation capabilities and also demonstrated the efficiency gains associated with longer continuous closures compared to more frequent and shorter closure windows (Ibbs and Lee, 2005).

2.1.2 CA4PRS Development History

The University of California Pavement Research Center used the information provided by the demonstration projects to develop, calibrate and test the first versions of CA4PRS. Caltrans and the State Pavement Technology Consortium (SPTC), a collection of state Departments of Transportation (DOTs) from California, Minnesota, Texas, and Washington, provided funding for the development of CA4PRS. CA4PRS version 1.5a and has been used for all analyses discussed within this report.

Detailed descriptions of the program inputs and operating definitions are provided in referenced program documentation material and will not be discussed in this paper. Although program inputs are not discussed, the following sections provide CA4PRS analysis method and construction sequencing definition descriptions for further program operational clarification.

2.2 CA4PRS Analysis Methods: Deterministic and Probabilistic Estimation

CA4PRS productivity estimates can be produced from two types of analysis methods: deterministic and probabilistic. Deterministic calculations hold the scheduling and resource inputs constant during productivity calculation. In contrast, probabilistic analysis can treat most input parameters as variables that change according to an assigned probability distribution function. When generating a probabilistic estimate, users have the option of applying one of nine different probability distribution functions to most of the input parameters. After the assignment of input parameters and probability distribution functions, CA4PRS performs a Monte Carlo simulation to produce a probabilistic productivity estimate. If input distribution information is known or can be confidently assumed, probabilistic estimation should be used because it produces the most probable number of lane miles to be paved and a more comprehensive analysis (Ibbs and Lee, 2005). Probabilistic analysis is more difficult to use because it requires information about how the input parameters can vary. Both probabilistic and deterministic analyses produce an estimate of contractor productivity, but provide different output information. The following discussion describes the output information generated by each analysis method.

2.2.1 Deterministic Outputs

A deterministic analysis report has three sections:

1. Analysis summary
2. Construction schedule
3. Linear production chart

The analysis summary contains a description of the project scheduling and resource inputs, as well as the analysis options and the productivity estimate results. Typical examples of deterministic output reports can be seen in Appendix E. As part of the deterministic analysis summary, CA4PRS calculates and reports the demolition, new base and PCC paving quantities for the project. This material quantity calculation is not provided in the probabilistic analysis summary. Within the second component of a deterministic report, an approximate schedule outlines the estimated start, completion, and duration times for demolition, base paving and surface course paving construction activities. The final component of a deterministic report is a linear scheduling chart that depicts construction activity progress through the construction closure window. This scheduling figure is helpful for comparing construction productivity rates and understanding construction activity sequencing.

2.2.2 Probabilistic Outputs

A probabilistic CA4PRS report can be divided into four sections:

1. Analysis summary

2. Input parameter distribution summary
3. Production distribution chart
4. Input parameter sensitivity chart

The analysis summary of a probabilistic CA4PRS report is similar to the analysis summary of a deterministic report. Both analysis reports provide a summary of the input parameter resource and scheduling profiles, the analysis options and the analysis results. Typical examples of probabilistic output reports can be seen in Appendix E.

The second section of the probabilistic report contains detailed information about each probabilistic input parameter. The probabilistic input parameter summary depicts a mean, standard deviation, maximum, minimum and three value ranges according to the 68, 87 and 95 percent confidence intervals for each probabilistic input parameter.

The third section contains a graph that shows the distribution of the estimated maximum possible paving distances. During a Monte Carlo simulation, CA4PRS calculates a maximum paving distance for all simulation iterations. The productivity estimate for each iteration can be different as the simulation values for input parameters will change according to assigned probability distribution functions. The production distribution graph shows the relative frequency of occurrence for the maximum paving lengths calculated during the Monte Carlo simulation (Figure 1). This chart depicts a mean maximum paving distance, as well as the estimated range of maximum paving distances. By producing a range of probable paving lengths, the probabilistic CA4PRS estimate yields a more comprehensive picture of probable construction scenarios. Design engineers and project management can use the probability associated with achieving a maximum paving length to determine the construction risks associated with different project closure windows.

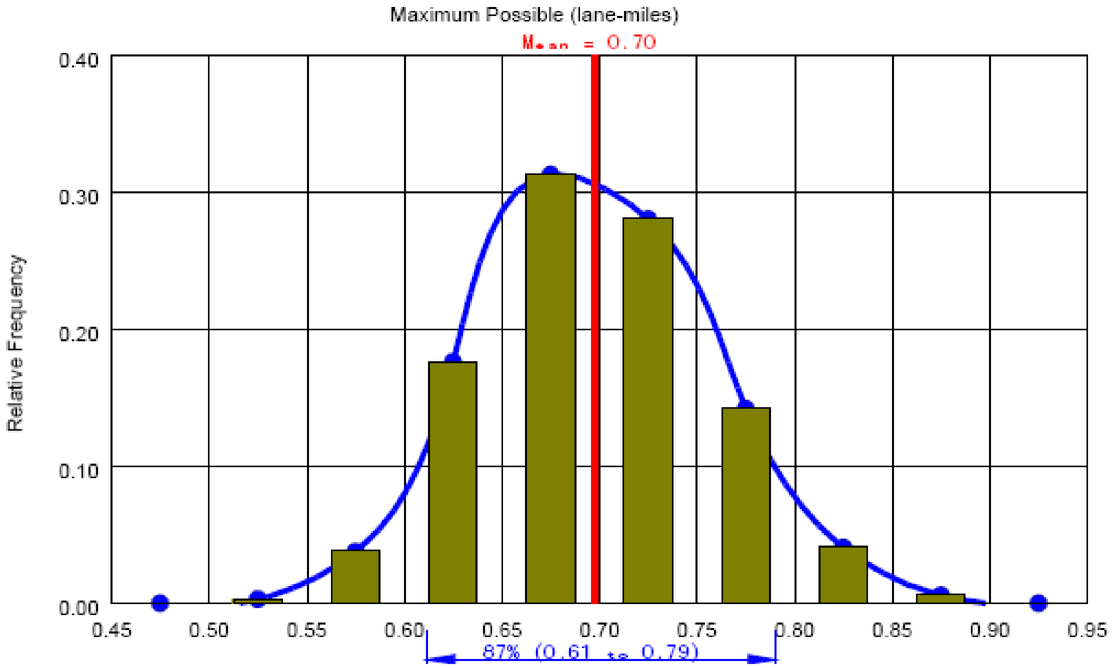

Figure 1 – Production distribution chart.

The fourth section of a probabilistic CA4PRS analysis is a sensitivity chart which uses a Spearman rank correlation coefficient to depict the relationship between CA4PRS input parameters and construction productivity. A Spearman's rank correlation coefficient describes the relationship between two variables based at an ordinal level using ranking. By using a rank statistic, variables do not need to be assigned relationship distributions (Weisstein, 2002). CA4PRS input parameter sensitivity charts depict variable correlation with a horizontal bar (Figure 2). The larger the bar, the larger the rank correlation coefficient and the greater the impact the input parameter has on construction productivity. Positive values indicate a positive relationship whereas negative values show a negative impact. In a positive relationship, construction productivity will increase if the input parameter value increases. In a negative relationship, construction productivity will decrease with larger input parameter values. The input parameters with the strongest relationship to productivity will be displayed at the top of the graph. Designers and construction personnel can use this relationship information to carefully manage the inputs that have the greatest impact upon construction productivity. A more thorough analysis of correlation and the Spearman coefficient is provided in Appendix J.

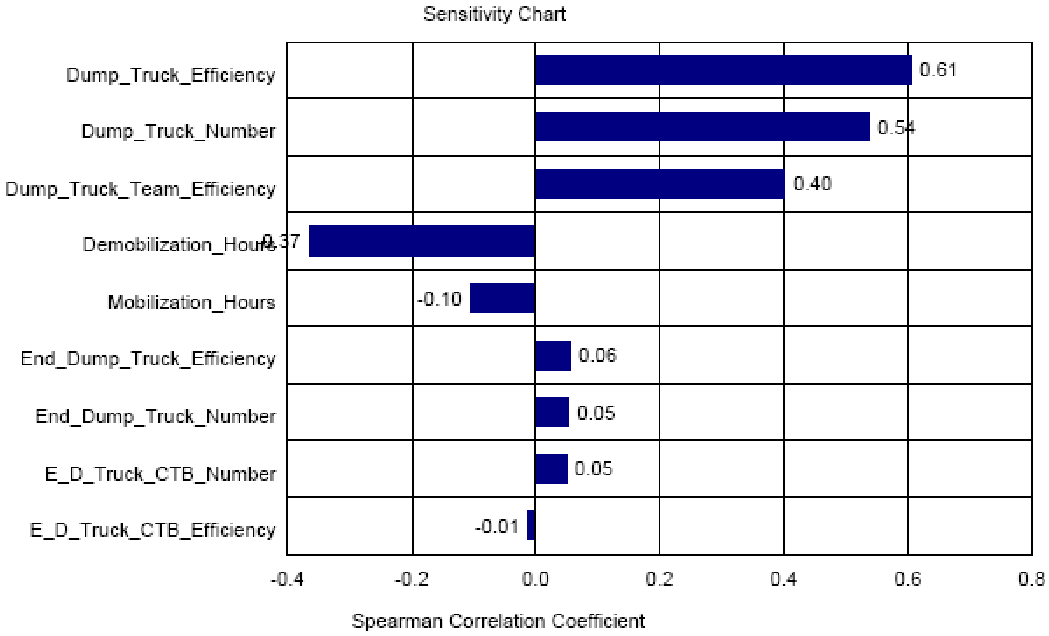

Figure 2 - A typical sensitivity chart produced for a probabilistic analysis.

2.3 Concurrent and Sequential Operations

In order to generate a CA4PRS estimate, users must specify the use of either concurrent or sequential construction operations. Concurrent operations assume that demolition, base paving and surface course paving can progress at the same time. Each activity has a lag time, which is the amount of time specified to elapse before the next construction activity can begin. For instance, on the I-15 Devore Project, the contractor used a lag time of 15 hours between demolition and new base installation during the continuous 72-hour weekday closures (Lee, 2000). CA4PRS models this sequencing with a demolition-to-base lag time input parameter of 15. During concurrent operations demolition, base paving and surface paving are depicted as progressing at the same rate on the linear productivity chart, as shown in Figure 3. CA4PRS assumes a contractor can only use concurrent construction operations when two adjacent access lanes are available. The assumption is that with an additional lane a contractor will have enough truck access to work on two construction activities (Figure 4) without them interfering with each other's access.

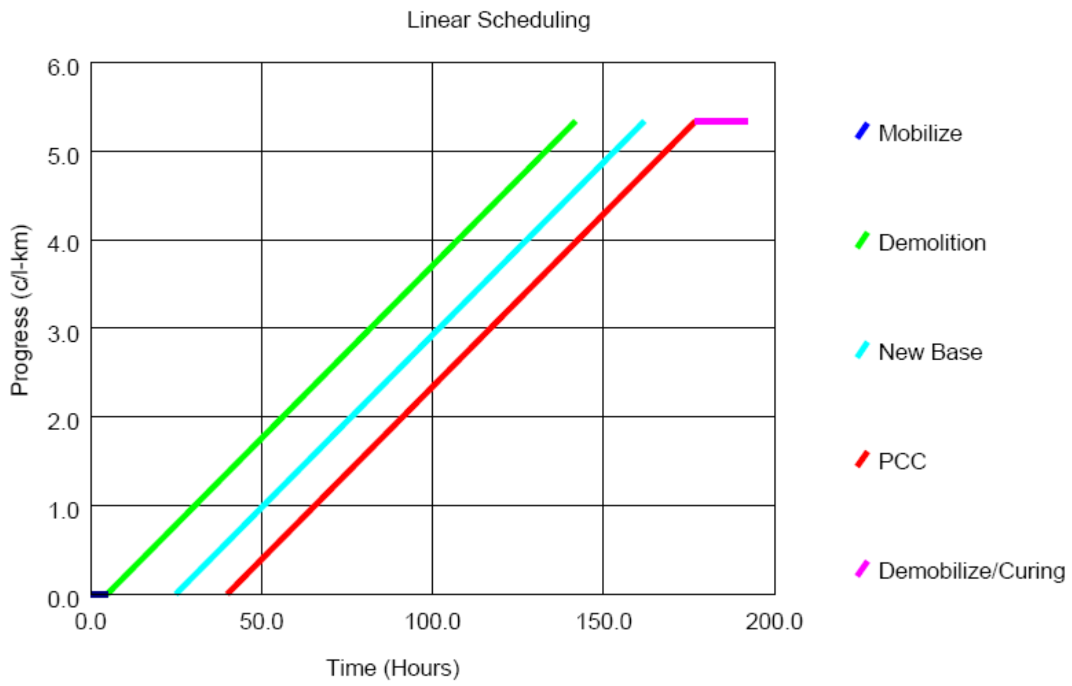

Figure 3 - Concurrent operations production chart from the I-15 Devore continuous closure.

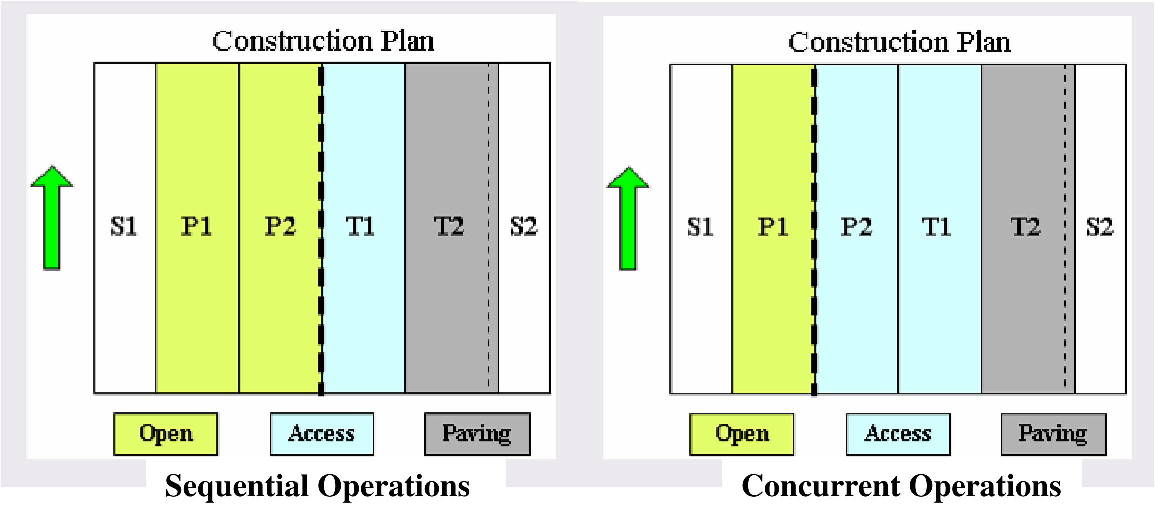

Figure 4 - Truck access for concurrent and sequential construction operations.

In contrast, sequential operations assume one access lane for all construction (Figure 4), which limits the ability of trucks and equipment to move and operate in the work zone (Lee et al., 2001). This limitation on material movement is modeled by requiring demolition to progress to completion before PCC paving can begin (Figure 5). New base paving can progress concurrently with demolition and is modeled as finishing at the same time as demolition finishes. If input parameters remain constant, sequential operations will typical generate lower productivity rates in comparison to concurrent operations due to reduced construction access. For both types of operations, construction sequencing can be defined as either single-lane or double-lane. These two definitions provide for construction of either a single lane or two adjacent lanes simultaneously.

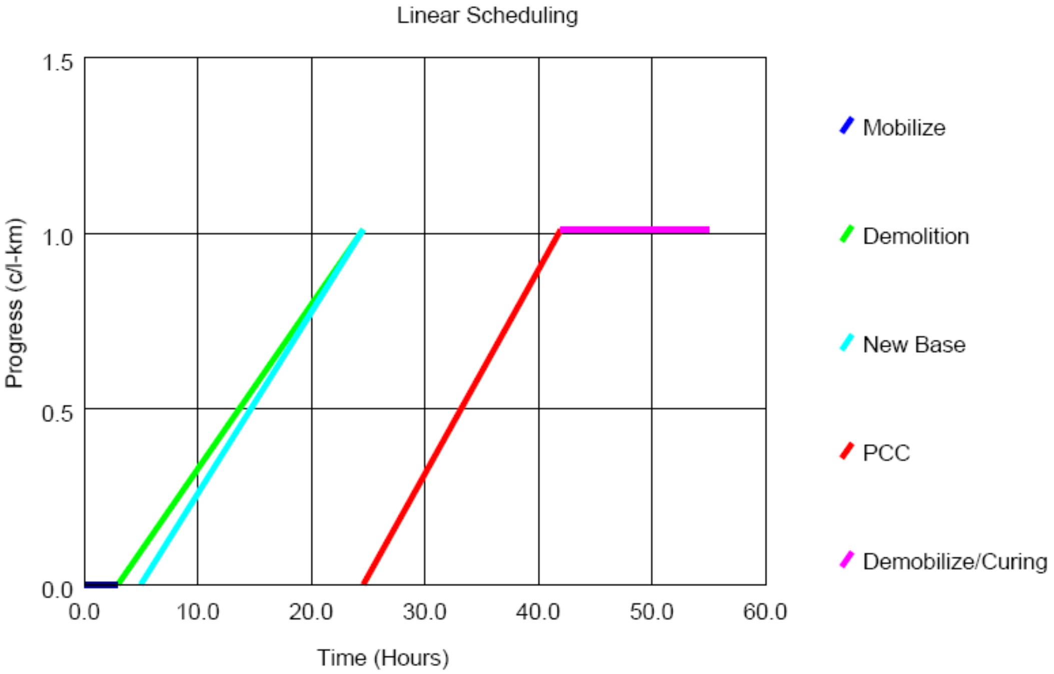

Figure 5 - Sequential productivity chart from the I-15 Devore weekend closure.

2.4 CA4PRS Benefits

CA4PRS is a tool that can aid project decision-making by:

1. Analyzing construction productivity and traffic impacts between project alternatives
2. Identifying the limiting resources for a construction operation
3. Verifying contractor submitted schedules

The following discussion provides a summary of these main program benefits.

2.4.1 Alternative Evaluation

CA4PRS provides a means of evaluating and comparing paving productivity, construction logistics and construction traffic closure requirements between different construction alternatives. Construction alternatives analysis is a complicated procedure that requires DOT personnel to evaluate issues such as construction costs, paving productivity and traffic impacts for project construction alternatives. CA4PRS facilitates this evaluation process during early planning by rapidly producing productivity estimates and project durations for user-specified construction closures and contractor resources. The productivity and estimation information provided by CA4PRS can then be integrated with macro and microscopic traffic simulation models to determine the best construction alternative (Ibbs and Lee, 2005). Incorporating traffic models with productivity estimates provides users with a means of weighing construction costs, construction logistics and traffic impacts that best meets agency goals during project planning.

2.4.2 Identification of Limiting Resources

Creating a productivity estimate requires inputting project-specific information for project scheduling and resources. In the process of using this information to produce an estimate, CA4PRS also identifies the constraining resources in the construction process. By identifying the factors that control productivity, project management can potentially take measure to improve resource management during contract development and potentially improve paving production.

2.4.3 Validation of Contractor Submitted Schedules

The paving contractor for any roadway rehabilitation or reconstruction project will develop a preliminary schedule prior to the start of construction. These early schedules will outline anticipated paving progress and construction productivity. CA4PRS estimates can aid both the contractor and the project owner by confirming the feasibility of anticipated construction schedules. On the I-710 project in Long Beach, California, CA4PRS was credited with providing beneficial information that aided the paving contractor in restructuring an overly optimistic schedule (Ibbs and Lee, 2005). For this project, CA4PRS predicted that a contractor would be able to complete 1.3 kilometers of crack and seat asphalt overlay (CSOL) and 0.4 kilometers of full–depth asphalt concrete replacement (FDAC) paving per closure window. In contrast, the contractor initially estimated that it would be feasible to complete 1.3 kilometers of CSOL and 0.8 kilometers of FDAC. Based upon the lower CA4PRS estimation output and the recommendation of researchers, the project contractor revised their construction plans. The final paving productivity recorded during construction was measured to be within 5 percent of the CA4PRS productivity estimates (Ibbs and Lee, 2005).

3 Current WSDOT Estimation Practices

This section describes the WSDOT productivity estimation and scheduling process in order to more accurately identify where CA4PRS estimates may be useful. The development of a WSDOT project schedule proceeds through approximately three stages of development and review before construction:

1. **Project Scoping Report**: Outlines work performed within a project and a starting budget
2. **Project Design Report**: Refines project scope by providing a more accurate schedule and budget in addition to construction and design logistics
3. **Plans, Specifications and Estimate** (PS&E): Contract Bid Documents
    a. 30 percent Submittal: beginning of detailed estimation for construction scheduling and sequencing
    b. 60 percent Submittal: refined estimate for construction scheduling and sequencing
    c. 90 percent Submittal: highly refined estimate for precise construction scheduling and sequencing
    d. 100 percent Submittal: complete estimate and construction schedule that anticipates how a contractor will build a project

3.1 Scoping Level Report

A scoping level report is a basic report generated for providing agency personnel with a general approximation of the work to be completed for a project. The report details if project work will consist of general safety improvements, lane widening, drainage improvements, pavement rehabilitation or other types of construction. At this level of project planning, state personnel make general decisions regarding issues such as paving material selection and the location of the project limits. The report also may contain a very general estimate of project cost. The intent of scoping level reports is to clarify and establish project objectives and scope. At this level of planning, productivity estimates and construction schedules are not typically necessary, but could provide beneficial decision making information. With default input parameters, CA4PRS could aid engineers in developing approximate productivity estimates and delivering more complete scoping level reports.

3.2 Design Report

The design report revises and builds upon the information contained in the scoping level report. Within this report, project designers use standard specifications and plans to refine the type and amount of work that will be covered by the contract. Towards the end of the design report process, planners may create an approximate or preliminary schedule (B. Dotson, personal interview, April 22, 2006). CA4PRS can be used to generate estimates at this phase of design and planning, but will probably be more beneficial further along in the design process when more information is known about contractor resources and job-specific productivity constraints.

3.3 Productivity Estimation for 30, 60, 90 and 100 Percent Submittals

After establishing project scope and creating a design report, engineers begin developing the contract documents referred to as the PS&E (Plans Specifications and Estimate). The PS&E documents specify what the contractor will build within a contract. The PS&E are dynamic and reviewed over four stages of increasing complexity: the 30, 60, 90 and 100 percent submittals. The following discussion describes the development of construction schedules and productivity estimates and the applicability of CA4PRS estimates for the 30, 60 and 90 percent submittals. The 100 percent submittal is not addressed in this section or in future program evaluation because it is assumed that the 90 and 100 percent submittals have similar, if not identical, schedules and productivity estimates.

3.3.1 30 Percent Submittal Estimation

During the development of the 30 percent submittal, state personnel commonly develop multiple construction alternatives in order to evaluate and compare the impacts and costs of each alternative. By weighing the impacts and costs associated with each alternative, project management can select the best project alternative according to their decision criteria. Preliminary construction schedules and productivity estimates are integral components of this alternative selection process. For each alternative, state personnel evaluate different issues such as construction sequencing, road closure requirements and the amount of equipment and personnel that would be required for construction. Developing accurate and reliable construction alternatives can be a resource intensive process, requiring both time and agency personnel with construction experience. At the 30 percent submittal level of design and planning, both state construction and design teams work together to plan how they believe a contractor will be able to implement the design within the constraints set by the project contract documents. Instead of looking at general material quantities and broad work zone constraints as in the scoping level report, planners consider how equipment will move and operate within the constraints set by the contract (B. Dotson, personal interview, April 22, 2006). If the plans outline an aggressive construction plan within a tight schedule, contractors will see greater risks in completing the work and will correspondingly adjust their bid price upwards. The estimates produced by CA4PRS appear to have significant potential for providing information useful for the planning and design decisions made at the PS&E 30 percent submittal level.

3.3.2 60, 90 and 100 Percent Submittal Level Estimation

As project plans approach 60, 90 or 100 percent completion, estimators will have considered how additional factors such as grade-breaks, super elevations, material cure times, specific trucking routes, joint locations, anticipated weather conditions and city noise variances can impact construction productivity and scheduling. Depending upon the size and complexity of a project, development and review of construction plans for the 60 and 90 percent submittal levels can require several experienced personnel working several weeks up to several months (B. Dotson, personal interview, April 22, 2006). On the complex I-5 James to Olive Streets Pavement Rehabilitation project (referred to as the I-5 James to Olive Project) case study used in this report, two construction engineers collaborated with the design department for approximately two months (B. Dotson, personal interview, April 22, 2006). CA4PRS produces estimates based on three construction activities and cannot incorporate all of the complex productivity parameters that are considered at higher levels of estimation refinement. Because of the high level of detail incorporated in the 60 and 90 percent PS&E submittals, CA4PRS estimates at these estimation levels may require modification to address a wide range of potential productivity impacts and could potentially be more difficult to produce.

All of the information discussed above and in the preceding sections about WSDOT estimation techniques and procedures for each level of project information was collected during interviews with WSDOT Field Engineer Robert Dotson.

4 Case Study 1

Validation of CA4PRS Paving Productivity Rates on the I-5 James to Olive Project

In 2005, the WSDOT Northwest Region reconstructed about two lane-miles of portland cement concrete (PCC) pavement on Interstate 5 through downtown Seattle. Although CA4PRS was not used in WSDOT planning efforts, this case study compares CA4PRS productivity predictions with actual construction productivity data in an effort to:

1. Determine its applicability to such complex projects in Washington State and
2. Determine at what planning stage, if any, CA4PRS is best employed

This study first describes the project planning and execution as it occurred, followed by the project details, constraints and observed productivities. Finally, CA4PRS is used to model project productivity estimates using information at increasingly accurate levels of detail in an effort to ascertain its potential effectiveness at different stages of the planning and estimation process.

4.1 Project Background

Through downtown Seattle, Washington, Interstate 5 is a heavily used and essential transportation corridor for freight and regional travel. On an average weekday, this segment of I-5 serves well over 180,000 vehicles in each direction (WSDOT Annual Traffic Report, 2005). The original PCC was constructed in the 1960's. WSDOT later widened I-5 by adding additional lanes and ramps using HMA over unfinished PCC (Figure 6). Prior to the 2005 construction, potholes and cracks caused by heavy traffic had already necessitated several costly and disruptive repairs. By 2005, a combination of fatigued HMA and cracked PCC slabs led WSDOT to develop a long-lasting rehabilitation plan which would provide for safer and smoother driving conditions (Figure 7).

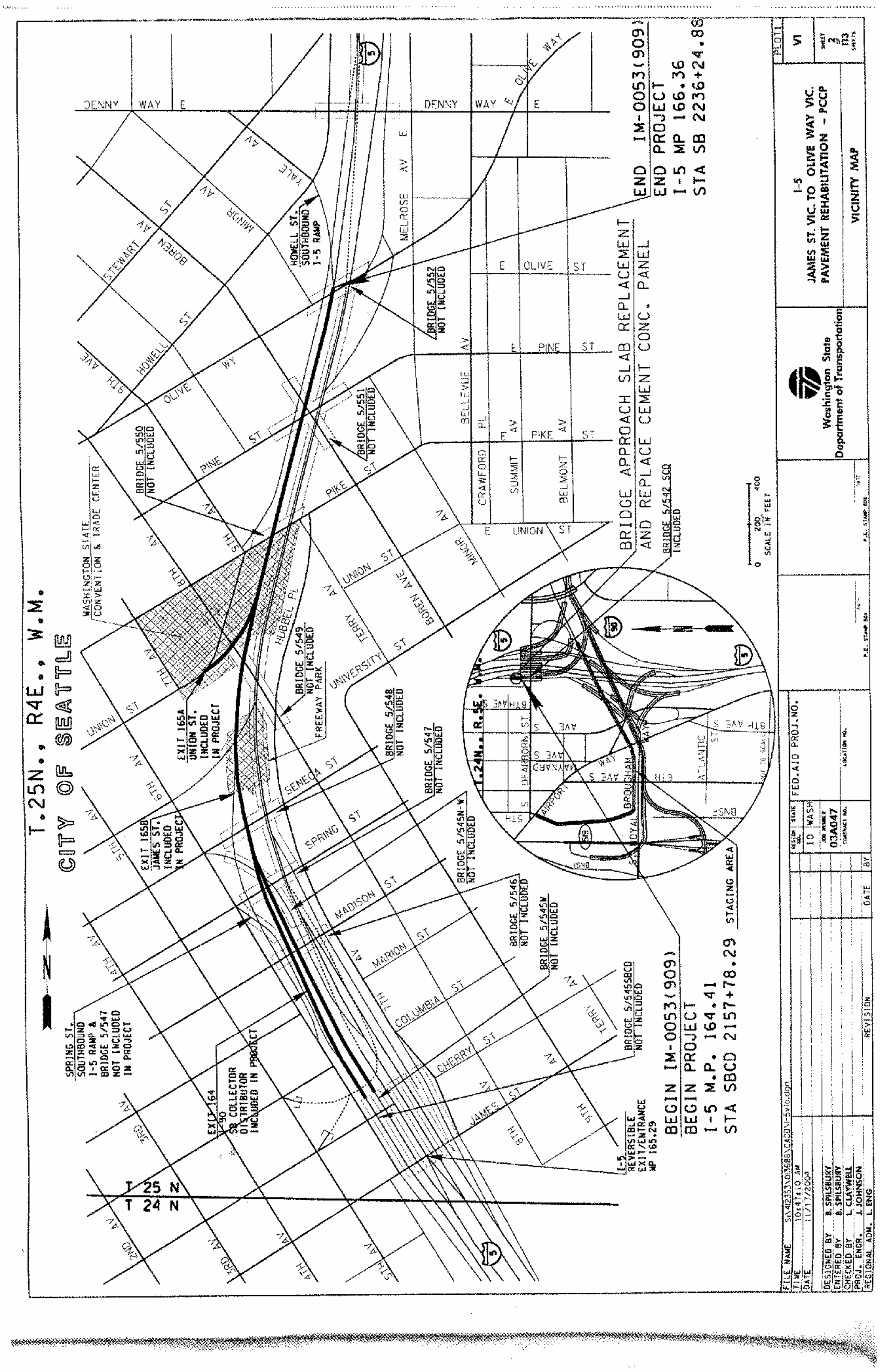

Figure 6 - I-5 James to Olive Vicinity Map

WSDOT faced an important decision regarding how to most efficiently replace this vital I-5 segment while minimizing negative impacts to the traveling public and not exceeding a project budget. The process of balancing construction costs and traffic impacts while negotiating constraints such as construction access, weather windows, event windows and heavy traffic patterns created a rehabilitation scenario that demanded accurate estimation of paving productivity.

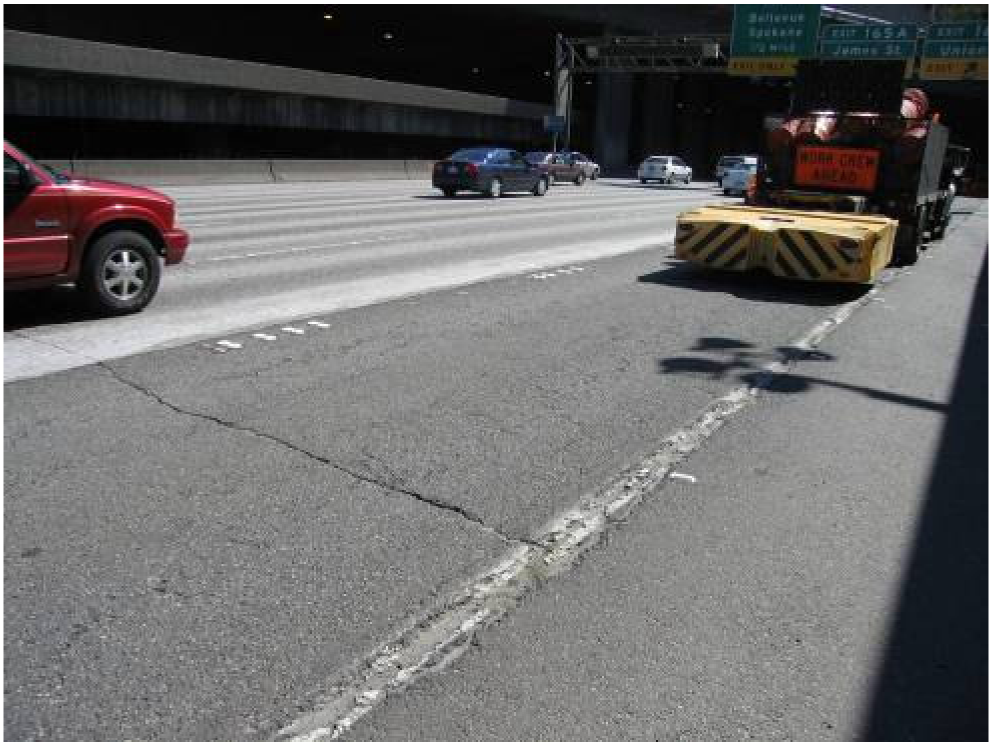

Figure 7 – Fatigue cracking and wear prior to project construction (Photo courtesy of WSDOT).

4.1.1 Project Scope

The scope included reconstruction of the outside lane, drop lane and off ramp segments of I-5 between Olive and James streets from I-5 Mile Post 164.41 to Mile Post 166.36 with new PCC pavement. Reconstructed roadway segments are contained within the project limits and are depicted on the vicinity map in Figure 6. WSDOT also used the traffic closures included in this project to pave the Union Street Exit under the convention center as well as for paving and bridge repairs further south at Dearborn Street. Four construction companies submitted bids for the project. WSDOT awarded the contract to the lowest bidder, Gary Merlino Construction Co., for a bid price of $3,948,000. The general contractor employed nine sub-contractors to complete the work. Appendix A contains bid tabs for this project.

WSDOT designed the contract so the entire project would be completed using four 55-hour weekend closures in April and May 2005. In an effort to reduce traffic impacts, WSDOT offered a $100,000 incentive for completing the work in three weekends. Weather and event considerations eventually resulted in construction taking place in the four weekend stages shown in Table 1.

Table 1 - I-5 James to Olive Project Construction Dates

Stage	Construction Dates
1	Friday April 22nd to Monday April 25th 2005
2	Friday June 17th to Monday June 20th 2005
3	Friday June 24th to Monday June 27th 2005
4	Friday July 15th to Monday July 18th 2005

The major project rehabilitation and paving quantities are summarized in Table 2

Table 2 - Project Material Removal And Paving Quantities

Construction Activity
Removal of nine inches of existing concrete pavement and worn HMA overlay
Removal of approximately seven inches of crushed surfacing base course
Removal of approximately 6,500 cy^3 of material from demolition activities
Placement of three inches HMA as new base material, approximately 2,500 tons
Placement of thirteen inches of doweled jointed plain concrete pavement (JPCP) approximately 5,640 cy^3

4.1.2 Key Elements of WSDOT Planning

This section describes the key elements of WSDOT construction planning as they relate to construction productivity and closure windows:

1. Selection of the construction closures and windows
2. Sequence of construction activities
3. Preliminary estimation rates
4. Job specific constraints

These elements are further described for the purpose of developing future estimates.

4.1.2.1 Selection of the Construction Window

At the start of scoping level estimation, WSDOT project management initially desired a rapid construction and rehabilitation project that would be completed with three weekend closures (B. Dotson, personal interview, April 22, 2006). Further review of construction productivity showed that four weekend closures would likely be required to complete project work. Each closure would be 55 hours, beginning on a Friday night at 10:00 pm and ending the following Monday morning at 5:00 am. The 55 hour closure windows were established by the state traffic operations department based upon directional traffic volumes. Attempting to increase the construction window by extending lane closures would have resulted in unacceptable levels of traffic congestion. If closed or opened earlier, available lanes would not have had sufficient capacity for historical volumes, resulting in unacceptably long queues and vehicular delay (J. Mizuhata, personal interview, April 6, 2006).

4.1.2.2 The Sequence of Construction Activities

The sequencing of construction activities remained consistent for each of the four construction stages. The following table and the accompanying figures depict the basic progression of construction activities completed during each construction stage.

Table 3 - Construction Activity Progression

Activity
Establish traffic control and install construction barrier (Figure 8)
Mobilize and unload subgrade preparation equipment (Figure 9)
Demolish, load and haul away old PCC pavement (Figure 10)
Grading and preparation of subbase (Figure 11)
Mobilize HMA equipment and place HMA base (Figure 12)
Compact, finish and cool HMA pavement
Survey and establish PCC paving elevations (Figure 13)
Mobilize PCC equipment and place PCC pavement (Figure 14)
Finish and apply curing sealant to PCC pavement
Cure PCC pavement
Stripe, sawcut and place pavement markings (Figure 16)
Remove all construction equipment and traffic control

In general, operations continued sequentially, meaning one activity did not begin until the preceding activity finished. PCC paving activities consisted of both slipform and hand placed concrete. Construction records show the contractor typically finished slipform paving before beginning hand paving operations.

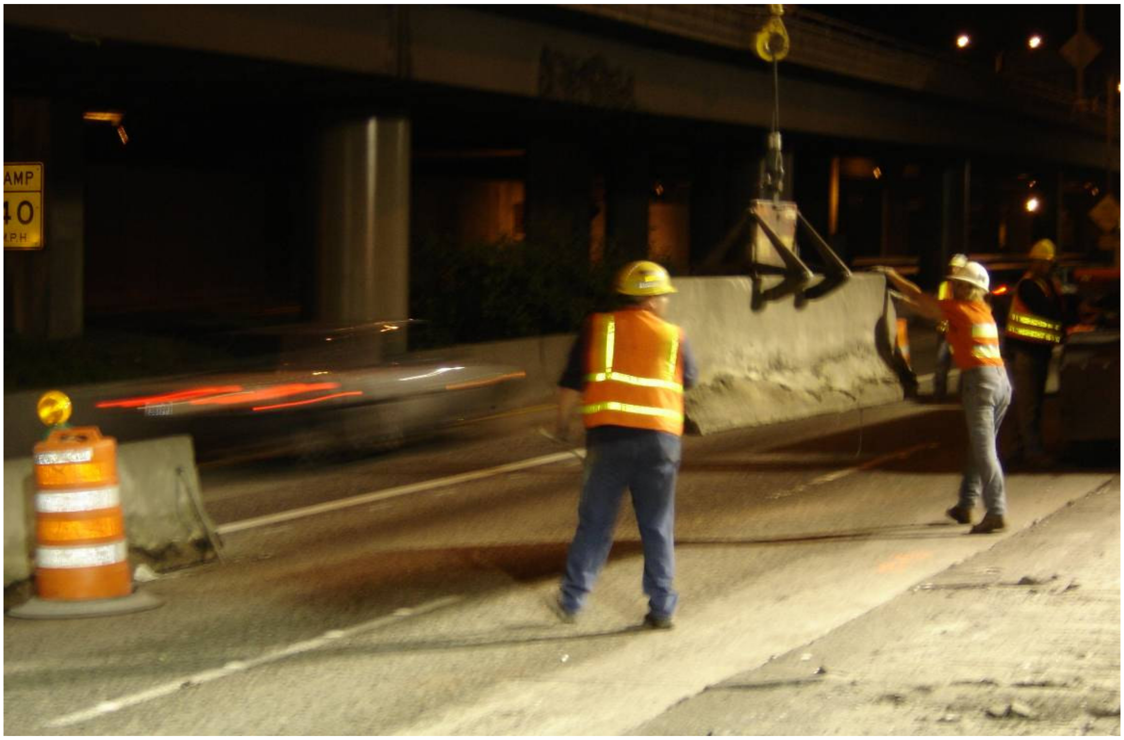

Figure 8 - Truck mounted cranes placing concrete barrier for worker safety and traffic control (Photo courtesy of WSDOT).

Figure 9 - Truck mounted drop hammer breaking PCC pavement under the Washington State trade and Convention Center (Photo courtesy of WSDOT).

Figure 10 – Trucks required sufficient space and time to deliver equipment for all phases of construction (Photo courtesy of WSDOT).

Figure 11- Removal of excess subgrade and subgrade preparation for HMA placement. Trucks were confined to one access lane immediately adjacent to paving lanes (Photo courtesy of WSDOT).

Figure 12 - Delivery, placement and compaction of HMA pavement with one access lane (Photo courtesy of WSDOT).

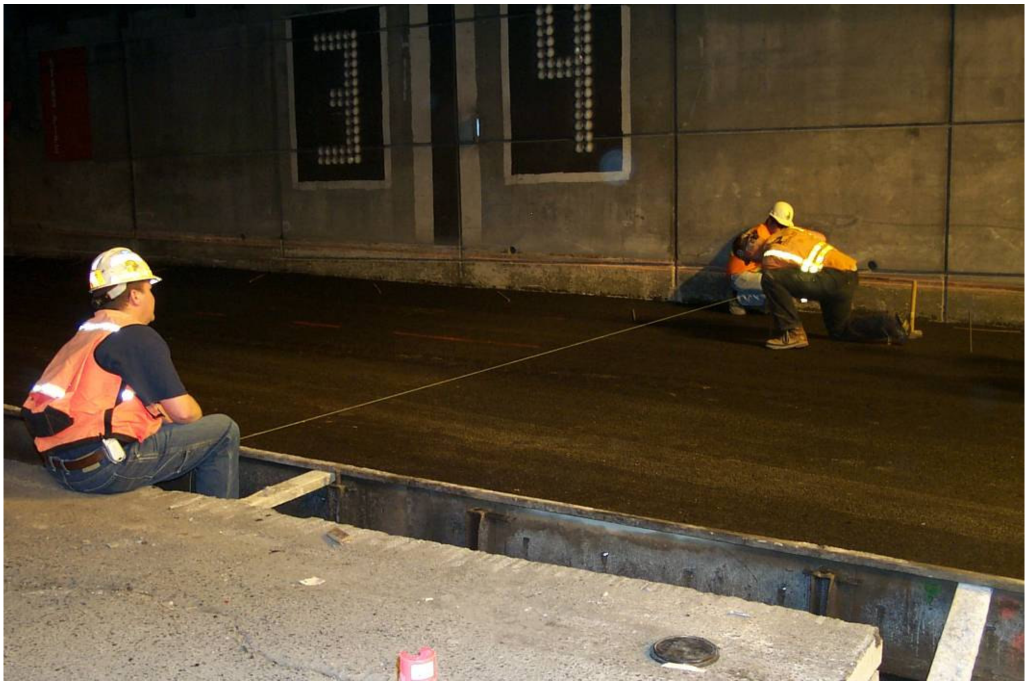

Figure 13 - Setting up forms and checking widths prior to PCC paving (Photo courtesy of WSDOT).


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Figure 14 - Hand PCC paving with a bunion screed (Photo courtesy of WSDOT).

Figure 15 - Slipform PCC paving operation (Photo courtesy of WSDOT).

Figure 16 – Saw cutting PCC slab joints (Photo courtesy of WSDOT).

4.1.3 Job Specific Constraints Affecting Productivity

In developing the estimate for this project, state personnel had to consider a wide variety of factors that could potentially impact construction productivity. Some of the more significant factors included:

1. A narrow work zone,
2. Slipform paving machine constraints,
3. Paving lane access,
4. Nearby development,
5. Nighttime operations and
6. Construction site access from downtown Seattle.

4.1.3.1 Narrow Work Zone

Work in one of the state's most heavily trafficked and highly urbanized corridors presented many unique and demanding construction conditions. Structural retaining walls running almost the entire length of the project presented the first major obstacle to construction. The structural walls and truck access lanes confined excavators, pavers and other equipment into a narrow work zone (Figure 17). Generating an accurate estimate required careful consideration of how many excavators could operate in the work zone and how the equipment productivity would be impacted by a narrow space.

4.1.3.2 Slipform Paving Machine Constraints

Drop lanes, on ramps, off ramps, shoulders and gores limited the efficient use of slipform paving machines. Slipform machines require several hours to mobilize and set at the required paving width. Adjusting the width of a concrete paving screed can require eight to ten hours for some machines (B. Dotson, personal interview, April 22, 2006). As such, slipform paving machines cannot easily handle tapers or segments of varying width. In order to operate efficiently, a contractor typically tries to maximize productivity by paving for as long as possible with a set machine width. Sharp turns, tapers and varying paving widths can limit paver productivity, especially in tight locations.

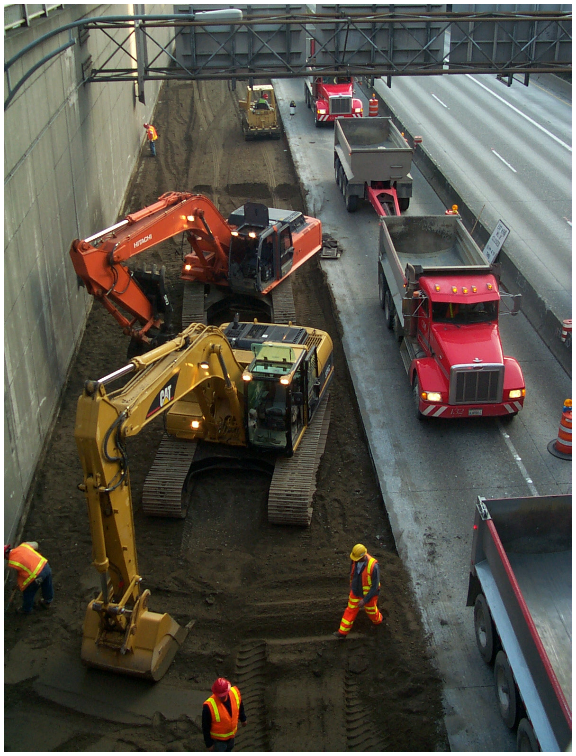


Figure 17 - Excavators working adjacent to structural walls (Photo courtesy of WSDOT).

Structural walls also impacted the productivity of slipform paving equipment. Slipform paving machines commonly require about four feet of clearance on the outside of the lane being paved in order to accommodate the slipform machine (B. Dotson, personal interview, April 22, 2006). Because of the required clearance, slipform machines could not pave up to the structural walls (Figure 18). Areas along the walls or not covered by the machines had to be paved by hand. Hand paving proceeds at about half the rate of machine paving which has significant impacts upon construction productivity (

Table 7 and Table 8).

Figure 18 - Hand paving operations working against a structural wall (Photo courtesy of WSDOT).

4.1.3.3 Paving Lane Access

Demolition teams were scheduled to remove sections of HMA placed over unfinished concrete and nine inches of existing PCC pavement. Additionally, approximately seven inches of the existing base was removed. After demolition and grading, the truck access lane would have a surface elevation sixteen inches higher than the adjacent lane prepared for paving. In order for paving equipment to access the paving lane and the prepared subgrade, paving equipment had to be transferred over a 16 inch ledge. Paving materials would also have to be transferred across the sixteen inch lip from dump trucks to paving machines. To circumvent this material transfer obstacle, the contractor placed two dump trucks into the construction pit with the paving equipment. A material transfer vehicle was stationed at the end of the construction pit to mix and transfer material from delivery dump trucks in the access lanes to dump trucks down in the pit. The pit dump trucks would then back down the construction zone and deposit their load into the paving machine. Figure 19 and Figure 20 show the material transfer process. The contractor used a similar type operation for both HMA and PCC paving.

Figure 19 - HMA material transfer vehicle loading HMA truck in the construction pit (Photo courtesy of WSDOT).

Figure 20 - PCC material transfer vehicle (Photo courtesy of WSDOT).

4.1.3.4 Commercial and Residential Development

Commercial and residential development abuts Interstate 5 through downtown Seattle (Figure 21). In some locations, buildings are within a few hundred feet of the roadway. Operating heavy paving and demolition next to local businesses and homes presented a large noise and disturbance issue for construction planning. City of Seattle noise regulations limited construction noise and set time constrains for when certain types of work could be performed, with potential implications on the type of equipment that could be used and when the work that could be completed. For this job, WSDOT obtained noise variances from the city permitting work to operate continuously around the clock. A significant noise concern arose over the issue of pavement demolition. Typical demolition projects use milling machines, hoe rams, multi-head breakers or a combination of demolition equipment. Demolition operations generate significant noise volumes which can be disruptive to nearby businesses and residences. The use of a drop hammer (Figure 9) circumvented some of the major noise concerns because it produced less noise than some other demolition methods. In order to calculate accurate construction productivity, it is essential that estimators pick appropriate equipment and operating hours that comply with local regulations and policies.

Figure 21 - Construction crews working under the convention center adjacent to commercial development (Photo courtesy of WSDOT).

4.1.3.5 Night Productivity

Continuous closures require construction crews to work at night, which has the potential to impact construction productivity. At night the mobility of construction vehicles and trucks can be severely impaired. Visibility is an important factor for trucks that have to back up long distances to paving machines, which is compounded when navigating a tight construction zone. In past state projects, WSDOT personnel have seen daytime HMA productivities of 200 tons per hour decrease to 150 tons per hour for nighttime construction (B. Dotson, personal interview, April 22, 2006). A combination of existing street lighting and temporary contractor lighting sufficiently illuminated the construction zone to prevent lost productivity (Figure 22). Although loss of visibility was not a factor on this project, proper advance planning helped mitigate potential impacts of night construction.

Figure 22 - Excavation crews working at night (Photo Courtesy of WSDOT).

4.1.3.6 Site Access From Downtown Seattle

Close proximity to the core of downtown also forced estimators to deal with access and potential congestion from city streets. Lane closures and congestion north of the project limited site access from the interstate. During the planning phase, estimators had to determine how trucks would enter and exit the job site, where trucks would idle and how many trucks would be required. Construction vehicles waited on city surface streets as shown in Figure 23. Achieving a reliable productivity estimate for the movement of demolition and paving material was a difficult task and heavily reliant upon considerable planning.

Figure 23 - Construction equipment and personnel waiting on city streets near the construction zone (Photo courtesy of WSDOT).

4.1.4 Available Project Data

The CA4PRS estimates created for this case study have been primarily developed from five sources of information:

1. WSDOT paving material quantities per construction stage and mix design
2. Preliminary WSDOT estimator assumed productivity rates
3. Contractor submitted Primavera schedules
4. WSDOT inspector reports for construction stages 1, 2, 3 and 4 and
5. Truck tickets from construction stages 1,2, 3 and 4

The following section describes the information obtained from each source and how the information was used during the estimate development process in CA4PRS.

4.1.4.1 Paving Lengths and Material Quantities Used Per Construction Stage

WSDOT construction personnel recorded the amount of PCC material placed per construction stage by project stationing and mix design. The quantity and stationing of concrete placed by construction stage is contained in Appendix D, but pertinent information is summarized in Table 4. This information has been used to derive a project pseudo-length in lane-miles per construction stage. The calculation of stage lengths is based on the contractual pavement depth of thirteen inches and an assumed lane width of 12 feet. A 12 foot width is assumed due to the fact that more than 99 percent of all urban interstates have a lane width of twelve feet or greater (FHWA Conditions and Performance Report, 1999). Combining project quantities with an estimated lane profile resulted in a project length of 2.2 lane-miles.

Table 4-Material Quantities and Paving Distances Per Project Stage

Construction Stage	Hand Paving (cy^3)	Slipform Paving (cy^3)	Total Paving Quantity (cy^3)	Stage Length In Lane-Miles
Stage I	776	1,100	1,876	0.738
Stage II	572	995	1,567	0.616
Stage III	488	808	1,296	0.510
Stage IV	364	540	904	0.356
		Total	5,643	2.22
		Average Paving Length Per Construction Stage In Lane Miles		0.555

$$5{,}643\,yd^3 \times 27\,\frac{ft^3}{yd^3} = 152{,}361\,ft^3$$

$$152{,}351\,ft^3 = 12\,ft(width) \times 1.083\,ft(depth) \times length$$

$$\text{Project Length} = 11{,}723\text{ft}$$

$$\text{Project Length} = 2.22\text{mi}$$

4.1.4.2 Contractor Submitted Primavera Schedule

Prior to the start of construction, WSDOT required the contractor to submit anticipated construction schedules. The contractor developed a construction schedule for each of the four construction stages with the scheduling software Primavera. These schedules have been used to develop scheduling input parameters such as mobilization, demobilization and activity lag times for some of the CA4PRS estimates completed for this case study. Appendix G contains the contractor Primavera schedules.

4.1.4.3 Preliminary WSDOT Estimated Productivity Rates

Typical WSDOT estimation techniques require estimation personnel to establish probable contractor productivity rates for construction activities. These assumed rates are used to determine what work a contractor could complete during a construction closure window (B. Dotson, personal interview, April 22, 2006). The preliminary productivity estimates used by WSDOT estimation personnel are contained in Appendix C and summarized in Table 5. The resource profile input parameters have been calculated based on the equipment quantities and characteristics that would be necessary to achieve the predicted estimator productivity rates. The resource input parameters developed from the preliminary WSDOT productivity estimates in this manner have been used for generating a resource profile for a CA4PRS analysis based entirely on preliminary construction information.

Table 5 - WSDOT Estimated Construction Productivity Rates

Activity	Rate
Demolition	
Sawcutting and Preparation for Demolition	200 ft/hr
Demolition Rate Assuming Six Excavators and Four Hoe Rams	1800 ft^2/hr for 9 in slab
Survey and Subgrade Preparation	5,850 ft^2/hr
Installation of 0.15' of CSBC as Needed	1,200 tons/hr
HMA Base Paving	
HMA Paving Rate	100 tons/hr
PCC Paving	
Drilling of Dowel Bar Holes and Installation of Dowel Bars	236 bars/hr, 72 lane-meters/hr
Slipform Machine Placed PCC Pavement	95 cy^3/hr
Hand placed PCC Pavement	40 cy^3/hr
Demobilization and PCC Cure Time	
Crack Control Sawcutting	198 ft/hr
Installation of Delineation	100 ft/hr

4.1.4.4 WSDOT Inspector Reports: Construction Stages 1, 2, 3 and 4

During project construction on stages 1, 2, 3 and 4, WSDOT construction personnel recorded information about construction activity start and stop times as well as information about contractor productivity. The productivity reports and scheduling information recorded for each stage are depicted in Appendix H. The scheduling and resource information from these reports reflect actual construction conditions. This information has been used to develop and evaluate a CA4PRS estimate that is based on actual construction information. By using actual construction information, CA4PRS accuracy can be evaluated by comparing estimated and observed productivity.

4.1.4.4.1 Truck Ticket Information

Truck ticket information from stages 1, 2, 3 and 4 has been used to derive:

1. Paving productivity rates
2. Truck load capacities
3. Truck arrival distributions
4. Truck packing efficiencies

Due to the substantial number of trucks moving in and out of the jobsite during each construction stage, only part of the truck ticket data has been analyzed. The following summary highlights the truck tickets evaluated per construction closure.

Table 6 - Evaluated Truck Ticket Information

Construction Stage	Evaluated Truck Tickets
Slipform PCC Truck Tickets	
Stage 1 4/23/05	85
Stage 2 6/18/05	39
Stage 3 6/25/05	80
Stage 3 6/27/05	87
Stage 4 7/16/05	48
Hand Paving PCC Truck Tickets	
Stage 1 4/23/05	37
Stage 1 4/24/05	40
Stage 3 6/26/05	27
HMA Paving Truck Tickets	
Stage 1 4/23/05	6
Stage 2 6/18/05	19
Stage 3 6/25/05	45
Stage 4 7/16/05	56

4.1.4.4.2 Paving productivity rates

Truck ticket information has been used to derive representative productivity rates for hand and slipform paving operations. Hand paving productivity rates and slipform paving productivity rates are summarized in

Table 7 and Table 8, respectively. The tabulated truck ticket data can be found in Appendix F.

Table 7 – Hand Paving Productivity Based On Truck Ticket Information

	Average Time Between Truck Deliveries (hr:min:sec)	Average Truckload (yd^3)	Average Productivity (yd^3/hr)
Mix #7524-H Hand Pave 4/23/05 Stage 1	0:13:57	10.13	53.37
Mix #7524-H Hand Pave 4/24/05 Stage 1	0:16:04	10.70	45.95
Mix #8049-H Hand Pave 6/26/05 Stage 3	0:14:19	10.85	45.35
	Average Used for Analysis (yd^3/hr)		50.00

Table 8- Slipform Paving Productivity Based On Truck Ticket Information

Mix ID	Average Time Between Truck Deliveries (hr:min:sec)	Average Truckload (yd^3)	Average Productivity (yd^3/hr)
Mix #8049-P Slipform Partial Information From 4/24/05 Stage I	0:04:44	7.5	95.07
Mix #8049-P Slipform Partial Information From 4/24/05 Stage I	0:07:30	10.8	86.40
Mix #8049-P Slipform Partial Information From 7/16/05 Stage IV	0:04:13	7.5	106.72
	Average Used for Analysis (yd^3/hr)		95

4.1.4.4.3 Truck load capacities

The load capacities of PCC paving and HMA delivery trucks have been based upon truck ticket load information. In Appendix H, the majority of the tabulated PCC truck tickets depict a truck load of 7.5 yd^3. A PCC truck capacity of 7.5 yd^3 will be assumed for further estimates. Trucks carrying new HMA base vary in capacity. About half of the evaluated truck tickets show a load capacity of about 16 tons, whereas the other truck tickets show a truck capacity of about 27 to 33 tons. The higher truck loads of 27 to 33 can be attributed to trucks using truck trailers. Truck arrival distributions have arbitrarily been established only from the HMA delivery trucks with a load capacity of 33 tons.

Because trucks with a 33 ton capacity have been used to determine HMA truck arrival rates, HMA trucks are assumed to have a load capacity of 33 tons, or 17 yd^3, unless otherwise noted. No truck ticket information exists for demolition trucks. Construction photos show demolition trucks using truck pup trailers. Demolition trucks will be assumed to have a load capacity of 44 tons.

4.1.4.4.4 Truck arrival distributions

Truck ticket information has been evaluated to provide approximate distributions for truck arrival behavior. The calculated distributions of truck arrival rates for PCC and HMA trucks are shown in Figure 24 and Figure 25. These distributions are applied as noted during the development of the estimate based on observed construction productivity. Since truck ticket information was not collected for demolition trucks, truck arrival rate distribution was not calculated.

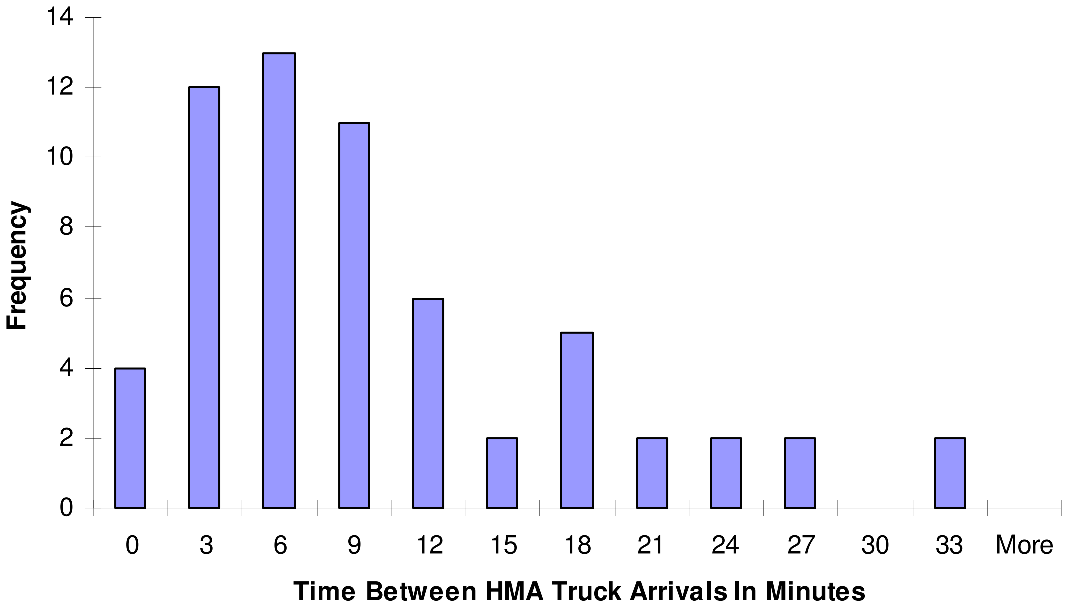


Figure 24 - HMA truck arrival rate distribution for HMA trucks that have a load capacity of 33 tons

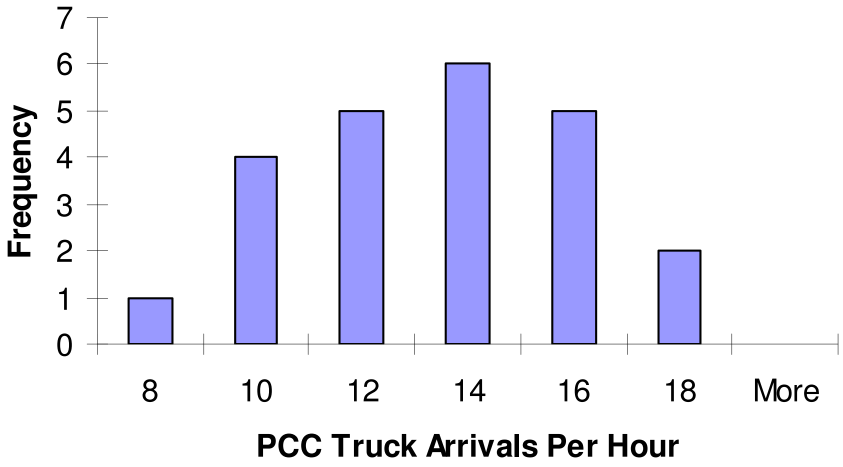


Figure 25 - PCC truck arrival rate distribution.

4.1.4.4.5 Truck packing efficiencies

Truck tickets have been used to determine both HMA and PCC truck packing efficiencies. HMA packing efficiencies have been determined based upon the load information from 24 truck tickets for HMA trucks that had a capacity of 33 tons. All truck tickets showed relatively similar load sizes, which lead to the conclusion that HMA truck packing efficiency has a deterministic value of 100 percent.

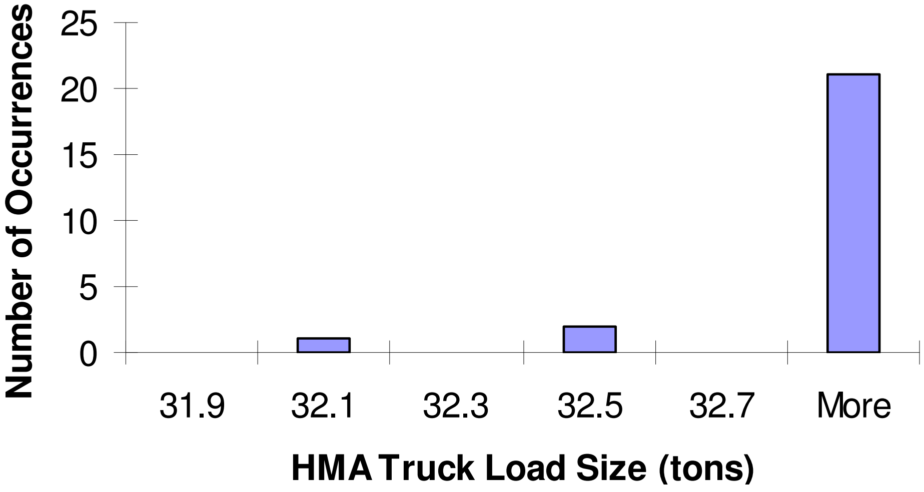


Figure 26 - HMA truck packing efficiency distribution.

A majority of the PCC truck tickets evaluated for this project depicted a truck load quantity of 7.5 yd^3. Because PCC truck loads were consistent and matched the 7.5 yd^3 capacity of the truck, PCC packing efficiencies were set to 100 percent.

4.2 CA4PRS Productivity Estimation

The following analysis of CA4PRS estimation capability uses program version 1.5a to compare estimated software productivity rates with observed productivity rates. Evaluation of program performance will be based upon the programs ability to accurately generate productivity estimates and closure requirements that match the observed construction productivity and closure requirements. This analysis will also seek to identify which stage of project development the CA4PRS tool will be valuable. The evaluation process will progress through the following four analysis stages:

- 1st Analysis: Design Report Level Estimate
- 2nd Analysis: First Estimate Refinement to Incorporate Hand Paving
- 3rd Analysis: Second Estimate Refinement Using Project Specific Scheduling and Resource Profiles
- 4th Analysis: Estimation Based on Observed Construction Productivity

For each level of estimation, (1) a productivity estimate is made using both probabilistic and deterministic analysis, (2) estimation results are compared to recorded results, and (3) conclusions are drawn as to the applicability and usability of CA4PRS.

4.2.1 Estimation Performance Evaluation

CA4PRS program accuracy and applicability are evaluated using the productivity and closure information from the probabilistic report of each completed analysis. Because each analysis corresponds to a different stage of the planning process, how program accuracy and applicability should be interpreted changes. The following sections describe how each analysis will be evaluated through:

(1) construction window closure productivity and
(2) probabilistic ranges of estimated closure requirements.

Throughout these following sections and succeeding CA4PRS analysis, references are made to two different types of productivity. These references have been applied with the following definitions:

> **Observed Productivity**: Weekend paving productivities calculated in lane-miles (using the earlier pseudo lane-mile calculations) achieved by the contractor during the four closure windows used to complete the project (Table 4)
>
> **Estimated Productivity**: Weekend paving productivities produced by CA4PRS

It is important to note that accurate estimates depend on (1) accurate input parameters, and (2) how CA4PRS manipulates those parameters to produce a productivity estimate. While it is desirable to evaluate these items separately, it is not possible to completely de-couple the two. Every effort has been made to provide the most realistic and accurate input parameters that would typically be available for a particular design stage.

4.2.1.1 Evaluation of Productivity per Closure (in lanes-miles per closure)

CA4PRS estimation accuracy and applicability have been evaluated using the 87 percent confidence interval of likely productivity predicted by probabilistic analysis. The 87 percent confidence was selected for evaluation purposes because the 87 percent confidence interval is the default confidence interval displayed on CA4PRS productivity distributions. Estimating contractor productivity for a weekend closure is not adequately represented by a single figure for estimated productivity. Rather, it is best described through ranges of productivity and closure requirements as it is impossible to precisely predict how a contractor will apply resources (i.e. labor and equipment) on a closure to closure basis. On any project, a contractor will attempt to limit operating expenses and maximize the efficiency of construction operations by only utilizing the equipment, labor and time that is necessary to fulfill a contract. A contractor will also balance construction resources around job site constraints. Restrictions such as structural walls or varying jobsite access might require varying levels of construction equipment and personal, which impacts productivity. The paving productivities recorded during the four construction closures on this case study illustrate the impacts of changing conditions and resource utilization. During the first weekend closure, the contractor achieved a weekend paving productivity of 0.738 lane-miles. By the last weekend closure, weekend productivity dropped to 0.356 lane-miles. Due to the variation in construction, productivity and estimation accuracy is best understood by comparing the range of observed productivity with the range of estimated probabilistic productivity.

Accuracy evaluation in this report is based upon how many of the observed weekend construction productivities are encompassed by the range of productivity estimated by the program. Evaluation ratings have been based on the following definitions:

Excellent	Productivity estimates provide beneficial closure decision making information, highly accurate productivity estimates
Good	Productivity estimates provide beneficial closure decision making information, sufficiently accurate productivity estimates
Fair	Productivity estimates provide minimal closure decision making information, productivity estimates are not very accurate
Poor	Productivity estimates are inaccurate and do not provide beneficial decision making information

Table 9 depicts the performance ratings that have been applied to the evaluation criteria. The observed weekend closure productivities are 0.356, 0.510, 0.616 and 0.738 lane-miles and have an average productivity of 0.555 lane-miles (Table 4).

Table 9 - Productivity per Closure Estimation Evaluation Criterion (CA4PRS)

	Number of Observed Weekend Closure Productivities within the 87 percent Confidence Interval				Observed Average Weekend Productivity within 87 percent Confidence Interval?
	3 or 4	2	1	0	
Rating	Excellent	Good	Fair	Poor	Yes/No

The evaluation criteria also includes a column that has been reserved for identifying if the observed average closure productivity is contained by the estimated range. Again, the amount and type of work scheduled can change on a closure-to-closure basis, resulting in large closure productivity variations. Examining the average observed productivity provides another means of evaluating estimated productivity because extremes in production rates may balance one another. If the 87 percent confidence interval productivity ranges encompass observed productivity, it is an indication that CA4PRS can be used to predict average weekend productivity.

4.2.1.2 Evaluation of Total Predicted Number of Closures

The accuracy and value of closure information predicted by CA4PRS will be contingent upon both the type of closure being evaluated and the level of project analysis. For instance, identifying the required number of closures within ± 1 closure windows may be acceptable for a project that uses shorter nighttime closures, but not for longer week-long closures. Or an estimate that identifies closure requirement within ± 1 closure windows may be sufficient to aid design report level decisions, but not daily or hourly planning decisions. Defining what constitutes an accurate prediction is also complicated by the fact that CA4PRS predicts a range of estimated productivity and a range of estimated closure requirements. One- half of a productivity range may be correct, while the remaining half is incorrect. For instance, Figure 27 shows a typical productivity distribution for an analysis completed on this case study. A closure requirement can be calculated for any part of the distribution by dividing project length by anticipated productivity. In this example, with a project length of 2.22 miles, closure requirements can be calculated as follows:

<u>Lower Bound Productivity Closure Requirements</u>

$$= \frac{2.22\ lane - miles}{0.39\ lane - miles} = 5.7 \text{ closure windows}$$

<u>Upper Bound Productivity Closure Requirements</u>

$$= \frac{2.22\ lane - miles}{0.64\ lane - miles} = 3.5 \text{ closure windows}$$

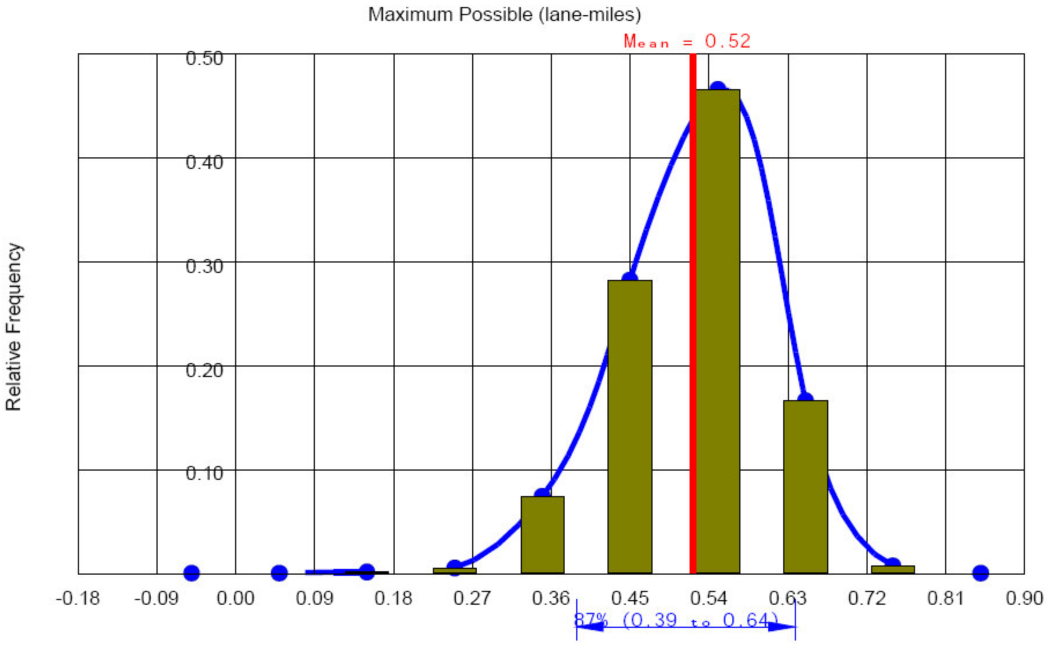


Figure 27 - Typical probabilistic productivity distribution.

To incorporate ranges of productivity and different levels of analysis, evaluation in this report has been accomplished by:

1. defining how fractional closure window requirements are interpreted
2. defining what constitutes accuracy for each stage of analysis and
3. applying a rating criterion.

4.2.1.2.1 Interpreting Fractional Closure Requirements

Understanding the evaluation requirements requires a clarification of how CA4PRS closure outputs should be interpreted. CA4PRS estimates closure requirements based upon maximum contractor productivity. During estimate generation, project scope and paving quantities will most likely be achieved with some fractional closure requirement given maximum productivity. Users should round the fractional closure requirements produced by CA4PRS to the nearest higher integer. If CA4PRS predicts that a project would require 4.3 weekend closures, this result should be rounded up and treated as a five weekend closure requirement. During a fractional closure window, a contractor would consume the same amount of resources for mobilization and demobilization efforts, but would have fewer hours for productive work. Providing the estimated minimum working window would also increase contractor risk by removing any available contingency time.

For evaluation purposes, all further analyses will round up fractional values and treat closure requirements as integers.

4.2.1.2.2 Defining Accuracy for Predicted Total Number of Closures

The accuracy for determining the total number of lanes closures is based on how well CA4PRS estimates match the observed four weekend closures plus or minus a tolerance. The tolerance is an adjustment that accounts for the level of estimate refinement. The first analysis has a higher tolerance because the input parameters are very general, and are not expected to produce estimates with the same degree of accuracy as the fourth estimate. Accuracy has been interpreted with the four following definitions:

1st Analysis

1. Estimated mean closure requirement is considered accurate if within ±50 percent of the observed closure window (2.5< or <4.5)
2. Estimated upper and lower bound closure requirements are considered accurate if within ±50 percent of the observed closure window (2.5< or <4.5)

2nd Analysis

1. Estimated mean closure requirement is considered accurate if within ±30 percent of the observed closure window (2.7< or <4.3)
2. Estimated upper and lower bound closures requirements are considered accurate if within ±40 percent of the observed closure window (2.6< or <4.4)

3rd and 4th Analysis

1. Estimated mean closure requirement is considered accurate if it matches observed closure window requirement (3.0< or <4.0)
2. Estimated upper and lower bound closures requirements are considered accurate if within ±10 percent of the observed closure window (2.9< or <4.1)

For the first two levels of analysis, estimates have been produced using general input parameters. These estimates were produced to evaluate program outputs during early project planning. Due to the general nature of the inputs, the estimates can only be expected to provide an approximation of closure requirements. For this report, accuracy of the first analysis has been interpreted as being within ±50 percent of a closure window to the four closure windows used. For the second analysis, accuracy has arbitrarily been interpreted with slightly smaller tolerances of ±30 and ±40 percent of a closure window.

For the last two analyses, a larger emphasis has been placed on the predicted mean closure requirement matching the observed closure requirement. At higher levels of analysis the input parameters are project specific and should produce more accurate estimates. A small tolerance of ±10 percent of a closure window has been applied to the accuracy definition for the upper and lower bounds of estimation. These bounds can potentially predict an incorrect number of closure windows, yet still be accurate. The uppermost bound of estimated productivity could predict that construction could be completed in 2.96 weekends, or three closures. However, since only the uppermost bound of productivity predicts construction could be complete in three closures, using three closure windows would be a high risk operation contingent upon maintaining maximum productivity. In the same regard, if only the very lower bound of productivity predicts a 4.03 weekend closure requirement, project management would still likely opt to use four closure windows.

4.2.1.2.3 Evaluation Criteria for Predicted Total Number of Closures

The rating criterion combines the aforementioned accuracy definitions with the ranges of estimated closure requirements. Four rating designations have been used and interpreted with the definitions and rating criteria shown in

Table 10. These ratings have been applied at each level of analysis according to the previously stated accuracy definitions.

Table 10 - Closure Estimate Rankings, Definitions and Ranking Criteria

Rank	Definition	Criteria
Excellent	Estimates provide accurate information that is more than adequate for aiding closure and planning decisions	Mean closure estimate is accurate and one upper or lower bound closure estimate is accurate
Good	Estimates provide some level of accuracy and are adequate for aiding closure and planning decisions	Only mean closure estimate is accurate
Fair	Estimates have limited accuracy and provide minimal information for aiding closure and planning	Either lower or upper bound closure estimate is accurate
Poor	Program estimates are inaccurate and do not provide beneficial decision making information	Neither the mean, lower bound or upper bound closure estimates are accurate

4.2.2 1st Analysis: Design Report Level Estimation

This analysis uses input parameters from the CA4PRS default database to test their applicability on the I-5 James to Olive project. CA4PRS saves estimate information in a Microsoft Access database file which is automatically generated within the CA4PRS program folder during program installation. The installed database file contains project information from several of the completed California validation projects. Basic estimates for new highway and interstate rehabilitation or reconstruction projects can be created by altering the scheduling and resource profile information used by the existing database projects. Using input parameters from a comparable project can save time and is generally permissible because scheduling and equipment profiles will likely be similar at the design report level. Users applying information from a comparable project must be familiar with both the new project and the comparable project in order to determine if input parameters need alteration. CA4PRS database information can be applied to a variety of future projects because the program database contains scheduling and resource information stored for different paving materials and closure scenarios.

4.2.2.1 Design Report Level Project Details

Development of a CA4PRS estimate begins with inputting information into the project details window. To complete this window, program users input basic descriptive information about the project such as the project title (identifier), description, route name and location. Most importantly, users are required to input the objective project length in lane-miles or lane-kilometers. CA4PRS uses this information to calculate demolition, base and paving quantities for the entire project.

CA4PRS establishes project size and paving quantities by requiring program users to input a project length, paving lane width and paving depth. For the I-5 James to Olive project, multiple lanes, shoulders, on ramps and off ramps of varying widths and lengths made calculating a uniform project length difficult. Instead, a project pseudo-length of 2.22 miles was back-calculated from truck material quantities as calculated in section 4.1.5.1. New users intending to develop estimates for future projects will have two options for developing project length estimates. If paving areas are lanes, users should use the planned lane widths and estimate the project length in lane-miles. For projects with non-uniform paving segments, users can calculate rough paving quantities based upon estimated surface areas within the project limits. Surface areas can then be converted to a total paving material quantity by multiplying by the proposed pavement depth. A project length in lane-miles can then be derived from the quantity of paving material by combining the paving depth with an assumed paving width. Estimating material quantities and a paving length from a project area will be less accurate and not incorporate the productivity impacts of modifying or moving equipment to accommodate changing paving geometries.

4.2.2.2 Design Report Scheduling Inputs

Program users developing early estimates will be required to make general assumptions about mobilization and demobilization times and how construction activities will be sequenced. The deterministic and probabilistic design report level estimate produced for this case study are based on scheduling inputs from the stored CA4PRS database information on the “I-15 Ontario Weekend” closure for the I-15 Devore project. This analysis assumes little or no project-specific information is available to the user and the I-15 Ontario weekend closure scheduling inputs will be applied to this case study with only modifications to activity lag times. In order to reflect the anticipated tight operating conditions and give equipment enough operating room, the lag time between demolition and base installation as well as the lag time between base installation and PCC paving, has been increased by one hour (

Table 12).

4.2.2.3 Design Report Probabilistic Scheduling Distributions

For this analysis, the estimate has been developed based on the assumption that users would have little information about the expected distribution behavior for the input parameters. As mentioned in Appendix J, triangular distributions are applicable when little information is known about an input parameter. For design report level probabilistic estimate, all of the scheduling input parameters have been assigned triangular distributions and given assumed maximum, minimum and most likely values. For the purposes of this estimate, the most likely values are the deterministic I-15 Ontario weekend closure input parameters. Maximum and minimum values have been assumed to be values 20 percent greater than or less than the most likely value (

Table 11). Values based on a percentage, such as packing efficiency, used a maximum value of 1. A detailed description of the different probability distributions and their application is presented in Appendix J.

4.2.2.4 Scoping Level Resource Input Parameters

Most freeway and highway lane reconstruction projects will share general resource profile and equipment characteristics that are reasonably interchangeable between projects. Users developing new estimates are encouraged to apply information from CA4PRS database projects to develop estimates on new projects. If users can estimate project conditions and scheduling requirement, borrowed input parameters can be further refined and adapted for a specific project. The estimates produced with borrowed input parameters will have sufficient accuracy to provide an indication of construction productivity and closure requirement at low levels of estimation. Additionally, future projects (if adequately documented) should provide users with additional data and construction scenarios on which to base scheduling and resource assumptions. The resource profile inputs in

Table 11 used for this estimate have been obtained from the existing CA4PRS database for the “I-15 Ontario Weekend” closure for the I-15 Devore project. Only three resource inputs have been modified:

1. Demolition Packing Efficiency
2. Paver Speed
3. PCC Cure Time

4.2.2.4.1 Demolition Packing Efficiency

On the I-10 Pomona project, the concrete pavement was cut into sections and removed in large pieces which could not be packed efficiently into demolition trucks. On average, the contractor on that project used only about 47 percent the carrying capacity of the demolition trucks (Lee et al., 2001). Renton Recyclers, a local concrete recycling plant confirmed these findings. A sales representative stated that Renton Recyclers assumes roadway concrete to weigh 4000 lbs/yd^3, but demolition trucks only carry roughly 2000 lbs of concrete per yd^3 (Gretchen Harris, Renton Concrete Recyclers Sales Representative, personal interview July 29th, 2006). This calculation results in a packing efficiency of approximately 50 percent. The demolition packing efficiency for this analysis and all further analyses has been set to 50 percent.

4.2.2.4.2 Paver Speed

Pavers typically have paving speeds that surpass the ability of a contractor to supply sufficient material (B. Dotson, personal interview, April 22, 2006). Because paving machines can operate at high speed, paver speed is not likely to be a limiting factor during construction. The intent of this analysis is to specify a realistic paver speed that is high enough to not limit productivity. In section 4.1.4.3, the preliminary WSDOT estimate of slipform paving productivity is given as 95 yd^3/hr. Assuming a 12 foot lane and given a 13 inch paving depth, this production corresponds to a paver speed of 3.3ft/min. To generate a realistic paver speed that does not limit productivity, WSDOT estimated productivity rate and corresponding speed will be increased by 50 percent to five ft/min for this analysis.

4.2.2.5 Design Report Level Probabilistic Resource Input Parameter Distributions

Due to the minimal distribution information that would likely be available at this level of estimation, the resource input parameters have been assigned triangular probability distributions similar to the scheduling input parameters. The triangular distributions have been assigned assumed maximum, minimum and most likely values for each input parameter. The mean, values for each input parameter are assumed to be the deterministic input parameters shown in

Table 11. Maximum and minimum values have arbitrarily been assumed to be values 20 percent greater than or less than the most likely value (

Table 11). Where applicable, the maximum value of efficiency factors has to 1. A more thorough analysis of triangular distribution assignment is provided in Appendix J.

Table 11 – Design Report Level CA4PRS Inputs

Input	Inputs Modified from I-15	Distribution	Maximum (Mean +20%)	Minimum (Mean -20%)	Most Likely
Mobilization (hrs)	3	Triangular	3.6	2.4	3
Demobilization (hrs)	13	Triangular	15.6	10.4	13
Lag Time from Dem. to New Base Inst. (hrs)	**3**	Triangular	3.6	2.4	3
Lag Time from New Base Inst. to PCCP Inst. (hrs)	**3**	Triangular	3.6	2.4	3
Demolition Dump Truck Capacity (tons)	24.3	-	-	-	24.3
Demolition trucks/hr	10	Triangular	12	8	10
Demolition Packing	0.5	Triangular	0.6	0.4	0.5
Number of Demolition Teams	2	Distribution	2.4	1.6	2
Team Efficiency	0.9	Triangular	1	0.72	0.9
Base Dump Truck Capacity	13.1	-	-	-	13.1
Base trucks/hr	6	Triangular	7.2	4.8	6
Packing Efficiency	1	Triangular	1	0.8	1
Batch Plant Capacity (yd^3/hr)	200	Deterministic	x	x	200
Number of Plants	1	-	-	-	1
PCC Dump Truck Capacity (yd^3)	7.8	-	-	-	7.8
PCC trucks/hr	12	Triangular	14.4	9.6	12
PCC Truck Packing Efficiency	1	Triangular	1	0.8	1
Paver Speed (ft/min)	**5**	Triangular	6	4	5
Number of Pavers	1	-	-	-	1

Note: " – " used where a distribution cannot be assigned in CA4PRS
Note: " x " used where no input is required

4.2.2.6 Design Report Level Analysis Tab

On the analysis tab users specify the last remaining parameters that define construction and paving operations. CA4PRS requires users to specify:

(1) Construction window
(2) Section profile
(3) Lane widths
(4) PCC cure time
(5) And the working method.

Most of these program parameters remain the same between different levels of analysis and are only discussed in this first analysis. Any change to these inputs on future analyses is noted.

4.2.2.6.1 Construction Window

The construction window selection box allows users to produce CA4PRS productivity estimates for specified closure windows. With this feature, users can compare the benefits and impacts of different closure strategies. The following analyses attempt to compare estimated productivity with observed productivity and only specify estimate production for 55-hr weekend closure windows.

4.2.2.6.2 Section Profile

On the analysis tab users either create or select a predefined paving profile. The paving profile used on this project consisted of 13 inches of PCCP placed on three inches of HMA, which does not match any of the existing profiles. In the section profile, users can define a specific project paving profile by inputting a PCCP paving depth and an optional treated base paving depth. The predefined section profiles in CA4PRS use a cement treated base (CTB) and the user defined treated base is designated as CTB by CA4PRS. The 2004 WSDOT Standard Specification 5-05.3(6) states that treated base surface temperature must cool to 90ºF prior PCCP placement. This estimate assumes sufficient time exists for HMA cooling and that HMA can be treated as CTB for productivity calculations.

4.2.2.6.3 Lane Widths

Lanes are assumed to be 12 feet wide according to the project length calculations completed in 4.1.4.1.

4.2.2.6.4 PCC Cure Time

On this case study the contractor used several different mix designs which had varying cure times. A PCC cure time is the duration of time required for a new PCC pavement to gain sufficient strength before being opened to traffic. WSDOT 2004 Standard Specification 5-05.3(17), specifies that new PCC pavements can be opened to traffic when it has reached 2500 psi compressive strength. Compressive strengths are determined by breaking concrete test cylinders that have been poured from the paving mix or by using a concrete maturity meter to test for opening strengths. On this case study, most of the concrete placed conformed to the slipform paver mix (Table 4), which had an eight hour cure time to reach the 2500 psi opening to traffic strength. This productivity estimate and all of the following estimates in further analyses assume new concrete pavement will reach opening strength within eight hours.

4.2.2.6.5 Working Method

Users specify the input parameters associated with a working method in the scheduling profile, but select which working methods to analyze in the analysis tab. Users can generate productivity estimates using only one, or up to six working methods during an analysis. This analysis option contrasts the closure requirements and construction productivities associated with different construction strategies. This analysis assumes sequential operations similar to the I-15 Ontario weekend closure. Future analyses describe the used working method in the scheduling profile with the working method input parameters.

4.2.2.7 Design Report Level CA4PRS Estimation Results

Combining paving quantities from

Table 11 with the modified inputs from the I-15 Ontario weekend closure results in the deterministic CA4PRS outputs shown in

Table 12. The CA4PRS printout reports for this analysis can be found in Appendix E.

Table 12 - CA4PRS Analysis Results With I-15 Inputs And PCC Quantities From Bid Tabs.

	Deterministic Results
Construction Window	Weekend Closure (55 Hours/Weekend)
Working Method	Sequential Single Lane (T2)
Section Profile	PCCP: 13.0 Inches, New Base 3.0 Inches
Curing Time	8-Hours
Objective (lane-miles)	2.22
Maximum Possible (lane-miles)	0.72
Maximum Possible (c/l-miles)	0.72
Construction Windows Needed To Meet Objective	3.09
Demolition Quantity (yd^3)	2251.4
New Base Quantity	422.1
Concrete Quantity (yd^3)	1829.3
Constraint Resources	DT (Demo), EDT (PCC)
Demolition to Paving	01:01.0
Demolition Hours	19.5
Paving Hours	19.5

Note: “ x “ used were no output is provided

Note: Shown quantities are per closure window

4.2.2.7.1 CA4PRS Reports

The deterministic analysis predicts that a maximum of 0.72 lane-miles could be paved in one weekend, while probabilistic analysis predicts that productivity will likely be 0.70 lane-miles, but that productivity could vary between 0.61 and 0.79 lane-miles. Although both types of analysis provide similar figures for construction closures and attainable productivity, the probabilistic results better reflect the true variable nature of construction productivity. The probabilistic production distribution graph displayed in Figure 28 shows both the mean expected paving productivity and the 87th percentile confidence interval. For this analysis 87 percent of the Monte Carlo iterations estimated paving productivities between 0.61 lane-miles and 0.79 lane-miles. By producing a range of attainable productivity, CA4PRS provides an indication of the risk associated with different closure windows and productivity goals.

Both types of analysis correctly identify the number of weekends required for construction. Table 13 summarizes the closure requirements and paving productivities associated with the minimum, mean and maximum probabilistic distribution values. If the contractor can maintain a paving productivity of 0.79 lane-miles, then only three weekend closures would be required. In contrast, if the contractor can only maintain 0.61 lane-miles per weekend, then 3.64 weekends would be required. This distribution of results informs users that construction could be potentially confined to three weekends, but would be a high risk operation reliant upon maximum productivity. If the contract were designed for four weekends, the CA4PRS distribution chart shows that the contractor could most likely meet the 2.2 lane-mile objective with time available for contingencies.

Table 13 - Closure Requirements And Paving Productivities Associated With The Design Report Level Productivity Distribution

	87th Percentile Minimum	Estimated Mean	87th Percentile Maximum
Number of Lane-miles Paved Per Weekend Closure	0.61	0.70	0.79
Number of Required Weekend Closures	3.64	3.17	2.81

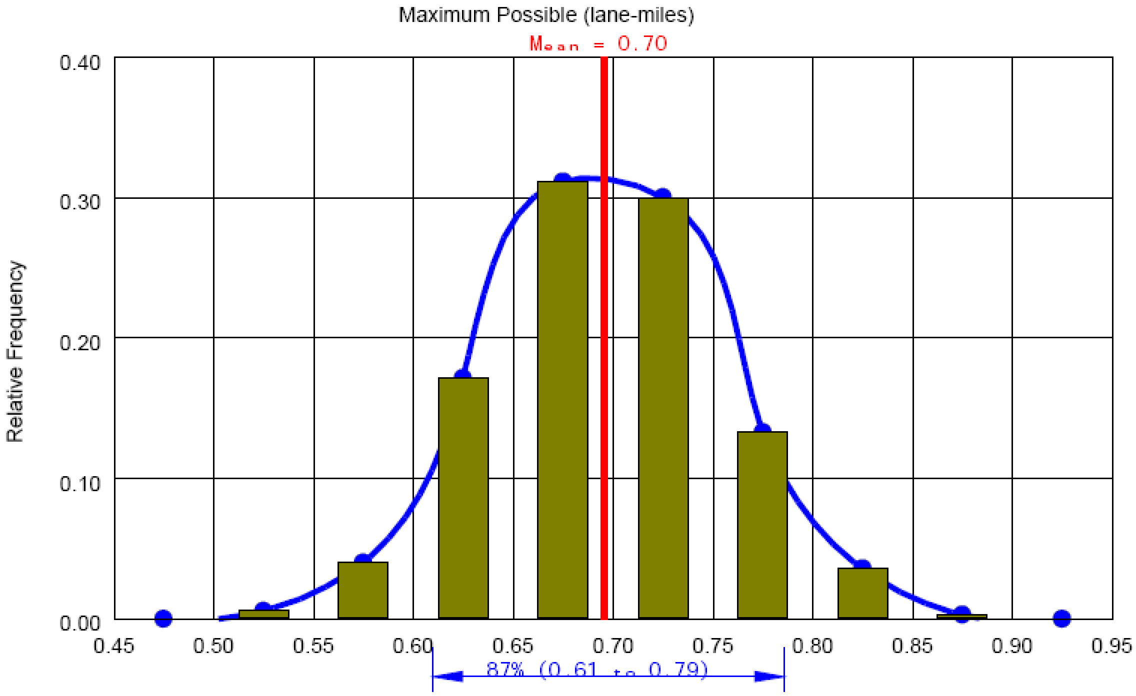


Figure 28 – Probabilistic productivity distribution for the design report level estimate.

The sensitivity chart for this estimate informs program users that paving productivity is most sensitive to the number of dump trucks. With an awareness of sensitive resources, such as demolition trucks, users can potentially take steps to improve productivity or mitigate potential resource constraint risks. For this analysis, two resources have similar Spearman coefficients: (1) the number of dump trucks and (2) dump truck efficiency. The interpretation of the sensitivity chart would be that maximum gains in paving productivity are realized by increasing the number of dump trucks and base trucks as well as improving dump truck efficiency.

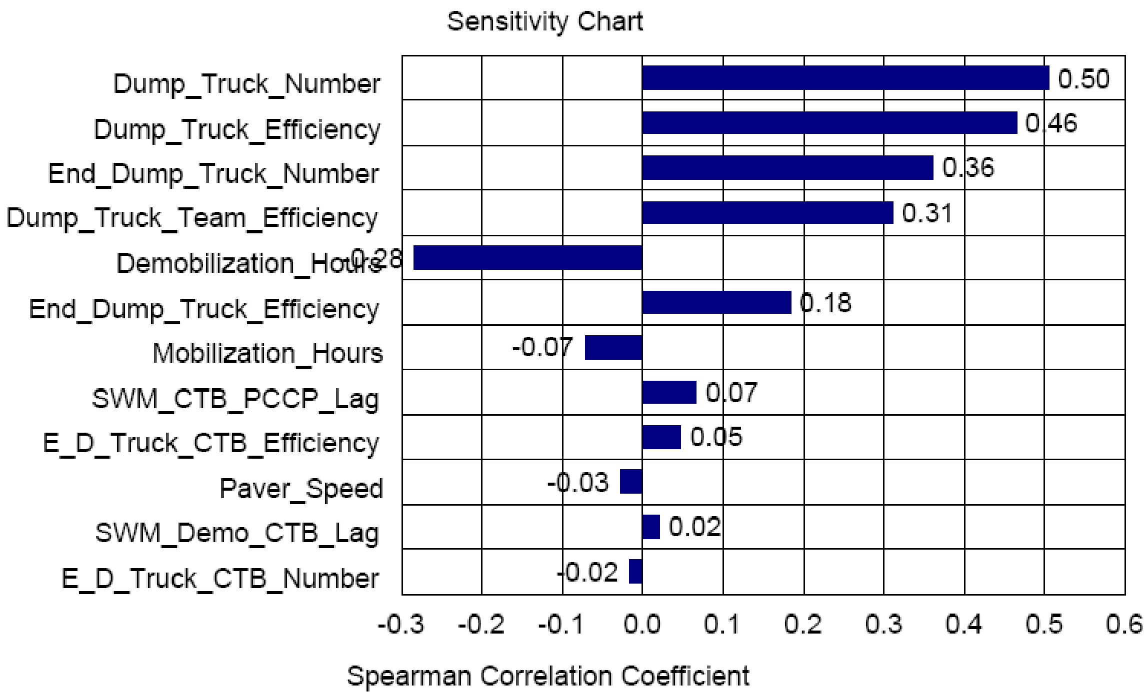


Figure 29 – CA4PRS sensitivity chart for the design report level estimate.

4.2.2.7.2 Results Assessment

The CA4PRS estimates results for this analysis have been evaluated according to the performance criteria outlined in section 4.2.1. The probabilistic range of estimated productivity shown in Figure 28 encompasses two of the observed productivities and warrants a performance rating of ‘Good’ (Table 14). The productivity range does not encompass the observed average productivity.

Table 14 - 1st Analysis Productivity per Closure Estimation Evaluation Criterion (CA4PRS)

	Number of Observed Weekend Closure Productivities within the 87 percent Confidence Interval				Observed Average Weekend Productivity within 87 percent Confidence Interval?
	3 or 4	2	1	0	
Rating	Excellent	***Good***	Fair	Poor	No

Table 14 shows that the predicted mean and 87 percent confidence bounds of the total number of closures meet the criteria established in section 4.2.1.2.2 for a rating of ‘Excellent’. For this analysis the performance ratings of ‘Good’ and ‘Excellent’ have led to the following conclusion:

1. CA4PRS can produce beneficial productivity and closure estimates for early project planning and closure window development

4.2.2.7.3 Possible Sources of Estimation Error

The estimate for this analysis is based upon stored database information and does not include any project specific input parameters. Using information from other projects can provide program users with an approximate estimate, but will contain significant errors without the inclusion of project specific input parameters. Additionally, no distinction is made between slipform and hand paving quantities in addition to other project specific constraints such as site access or equipment availability.

4.2.3 2nd Analysis: First Refinement to Incorporate Hand and Slipform Paving Quantities

The first CA4PRS analysis and estimate assumed that paving proceeded in a linear manner along one continuous lane. During construction on this case study, paving was divided between separate slipform and hand paving operations. Based on past projects, WSDOT estimators assume that hand paving operations are slower than slipform paving operations (Table 5). By not incorporating lower hand paving productivity rate, CA4PRS estimates will predict a higher productivity rate. This first refinement to the original CA4PRS analysis incorporates slower PCC hand paving by controlling the PCC paver rate. The PCC paver rate is controlled using a weighted average of machine and hand paving productivity rates. By incorporating the loss of efficiency due to hand paving, CA4PRS should produce productivity estimates that are more accurate and more closely match observed production rates. Although the estimate is further refined, this analysis is intended to approximate an estimate that would likely be created to aid decision making at the design report phase of project development.

4.2.3.1 First Refinement: Scheduling Profile Input Parameters

The purpose of this estimate is to produce more accurate estimation results and observe the impact of combining hand and machine paving productivities into a weighted deterministic paver rate. All scheduling input parameters and probabilistic distributions remain the same as those used in the previous scoping level estimate.

4.2.3.2 First Refinement: Resource Profile Input Parameter

The basic scoping level estimate can be refined by incorporating the lower productivity associated with hand paving. The following analysis is based upon truck ticket quantities and the calculated paving rates introduced in Table 4,

Table 7 and Table 8. A new paving rate has been determined by using a weighted average of paving rates and paving quantities for hand and slipform paving operations through the following equation:

$$\frac{\left[\left(2200\,yd^{3}\right)\times\left(45\,\frac{yd^{3}}{hr}\right)+\left(3443\,yd^{3}\right)\times\left(95\,\frac{yd^{3}}{hr}\right)\right]}{\left(2200\,yd^{3}\right)+\left(3443\,yd^{3}\right)}=77\,\frac{yd^{3}}{hr}$$

Where:

2200 yd^3 = Total amount of PCC placed by hand (Table 4)

3443 yd^3 = Total amount of PCC placed by slipform paver (Table 4)

45 yd^3/hr = Averaged PCC hand paving productivity rate (

Table 7)

95 yd^3/hr = Averaged PCC slipform paving productivity rate (Table 8)

77 yd^3/hr = Weighted average of PCC paving productivity

The paving rate of 77 yd^3/hr has been converted to ft/min based upon the assumed lane dimensions used in section 4.1.5.1.

$$77\frac{yd^3}{hr}\times\frac{hr}{60\,\text{min}}\times 27\frac{ft^3}{yd^3}=34.65\frac{ft^3}{\text{min}}$$

$$34.65\frac{ft^3}{\text{min}}\div\left(12ft\times 1.083ft\right)=2.67\frac{ft}{\text{min}}$$

Where:

12 ft = Assumed Lane Width

1.083 ft = Specified Slab Depth

With the specified slab depth of 13 inches and an assumed lane width of 12 feet, the placement rate of 77 yd^3/hr equates to a slipform paver speed of 2.67 ft/min.

4.2.3.3 First Refinement: Probabilistic Resource Input Parameter Distributions

The probability distributions assigned to the resource profile inputs for this analysis will remain identical to the previous analysis. The only notable difference is the modified paver speed, which has also been assigned a triangular distribution with maximum and minimum values that are above and below the mean input parameter value by 20 percent, respectively. The assigned distributions are displayed in Table 15.

Table 15 - Inputs For The First Estimate Refinement Using A Weighted Paver Speed.

Input Parameter	Parameter Value	Distribution	Maximum	Minimum	Most Likely
Mobilization (hrs)	3	Triangular	3.6	2.4	3
Demobilization (hrs)	13	Triangular	15.6	10.4	13
Lag Time from Dem. to New Base Inst. (hrs)	3	Triangular	3.6	2.4	3
Lag Time from New Base Inst. to PCCP Inst. (hrs)	3	Triangular	3.6	2.4	3
Demolition Dump Truck Capacity (tons)	24.3	-	-	-	24.3
Demolition trucks/hr	10	Triangular	12	8	10
Demolition Packing Efficiency	0.5	Triangular	0.6	0.4	0.5
Number of Demolition Teams	2	Deterministic	x	x	2
Team Efficiency	0.9	Triangular	1	0.72	0.9
Base Dump Truck Capacity (yd^3)	13.1	-	-	-	13.1
Base trucks/hr	6	Triangular	7.2	4.8	6
Packing Efficiency	1	Triangular	1	0.8	1
Batch Plant Capacity (yd^3/hr)	200	Deterministic	x	x	200
Number of Plants	1	-	-	-	1
PCC Dump Truck Capacity (yd^3)	7.8	-	-	-	7.8
PCC trucks/hr	12	Triangular	14.4	9.6	12
PCC Truck Packing Efficiency	1	Triangular	1	0.8	1
Paver Speed (ft/min)	**2.67**	Triangular	3.20	2.22	2.67
Number of Pavers	1	-	-	-	1

Note: “ – “ used where a distribution cannot be assigned in CA4PRS

Note: “ x “ used where no input is required

4.2.3.4 First Refinement CA4PRS Estimation Results

A CA4PRS analysis with the new paver speed generates the outputs displayed in Table 16. The CA4PRS printout reports for this analysis are stored in Appendix D.

Table 16 - CA4PRS Results For The First Refinement Using A Weighted Paver Speed

	Deterministic Results
Construction Window	Weekend Closure (55 Hours/Weekend)
Working Method	Sequential Single Lane (T2)
Section Profile	PCCP: 13.0 Inches, New Base 3.0 Inches
Curing Time	8-Hours
Objective (lane-miles)	2.22
Maximum Possible (lane-miles)	0.65
Maximum Possible (c/l-miles)	0.65
Construction Windows Needed To Meet Objective	3.42
Demolition Quantity (yd^3)	2030.9
New Base Quantity	380.8
Concrete Quantity (yd^3)	1650.1
Constraint Resources	DT (Demo), EDT (PCC)
Demolition to Paving	01:01.2
Demolition Hours	17.6
Paving Hours	21.4

Note: “ x “ used were no output is provided

Note: Shown quantities are per closure window

4.2.3.5 CA4PRS Reports

The deterministic analysis predicts a mean paving productivity of 0.64 lane-miles. The probabilistic productivity distribution chart shows a productivity range of 0.57 lane-miles to 0.72 lane-miles with an expected mean of 0.64 lane-miles (Figure 30). The productivity distribution chart for this analysis has a range of 0.15 lane-miles between the 87th percentile confidence interval minimum and maximum.

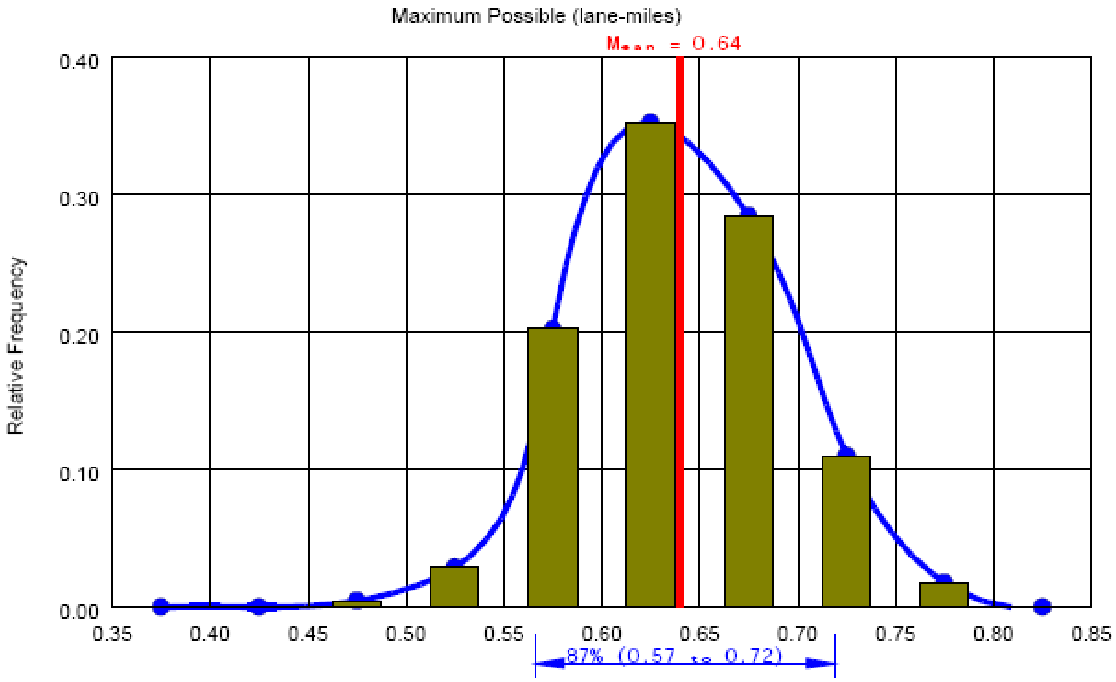


Figure 30 - Probabilistic productivity distribution for the first estimate refinement.

The closure requirements associated with the 87th percentile confidence interval are shown in Table 17. All paving productivities within the 87th percentile confidence interval predict a four weekend closure requirement for project completion.

Table 17 -Closure Requirements and Paving Productivities Associated With The First Refinement Probabilistic Productivity Distribution

	87th Percentile Minimum	Estimated Mean	87th Percentile Maximum
Number of Lane-miles Paved Per Weekend Closure	0.57	0.64	0.72
Number of Required Weekend Closures	3.89	3.47	3.08

The sensitivity chart for this estimate shows that paving productivity is the most sensitive to the paver speed and demolition input parameters. The high sensitivity to the paver speed is expected, as the reduced paver speed is intended to accommodate for slower hand paving operations and depicts the productivity impacts of slower hand paving.

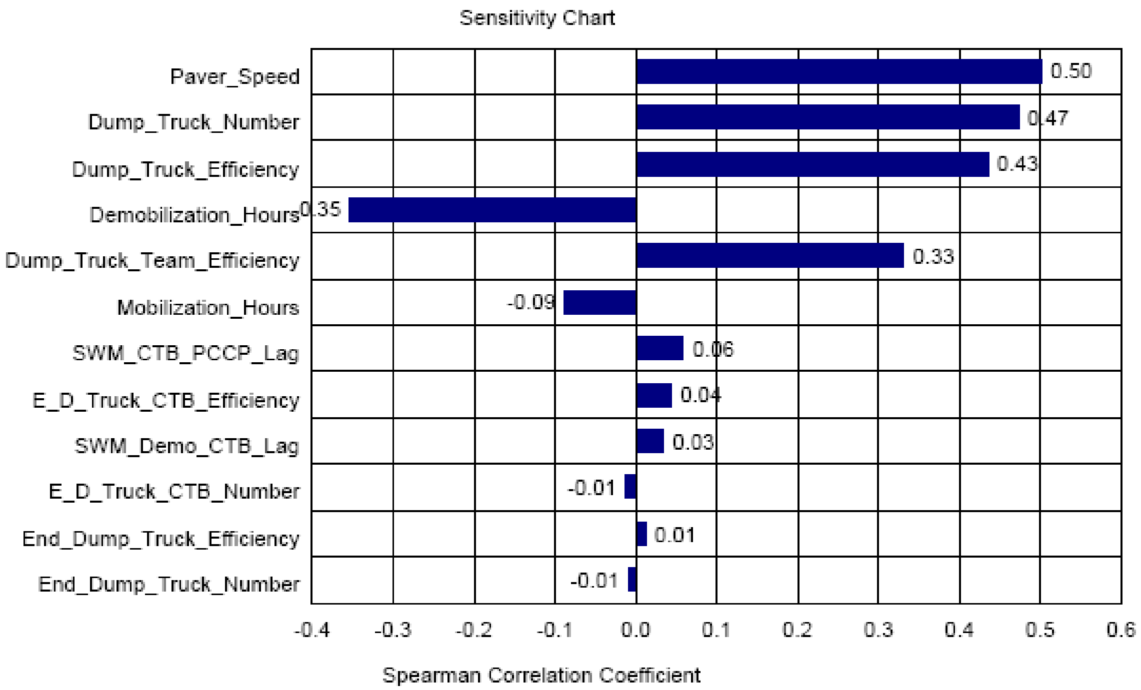


Figure 31 - Sensitivity chart for the first estimate refinement.

4.2.3.5.1 Results Assessment

The productivity range estimated by CA4PRS for this analysis encompasses one of the observed productivities. Based on the evaluation criteria, CA4PRS productivity estimation for this analysis has been interpreted as 'Fair' (Table 18). Although CA4PRS does accurately reproduce the observed productivity range, the estimate misses enclosing the maximum observed productivity and a Good rating by .018 lane-miles.

Table 18 -2nd Analysis Productivity per Closure Estimation Evaluation Criterion (CA4PRS)

	Number of Observed Weekend Closure Productivities within the 87 percent Confidence Interval				Observed Average Weekend Productivity within 87 percent Confidence Interval?
	3 or 4	2	1	0	
Rating	Excellent	Good	***Fair***	Poor	No

Table 18 shows that the predicted mean and 87 percent confidence bounds of the total number of closures meet the criteria established in section 4.2.1.2.2 for a rating of 'Excellent'. Although part of the estimation results for this analysis received a 'Fair' performance rating, overall, the estimation results still provide information that would benefit planning decisions. During early project development, accurately determining closure window requirements is likely more important for planning purposes than knowing accurate weekend construction productivity. The refined estimation results further support the conclusion thatCA4PRS estimates can provide accurate information for early project planning and closure decisions. Additionally, estimate results also show that reliable closure predictions and construction productivities can be developed for projects that have both hand and machine paving areas.

4.2.3.5.2 Possible Sources of Estimation Error

The use of a weighted paving speed is heavily reliant upon accurate identification of hand and machine paving areas and quantities. In order to develop a weighted paver speed on future projects, users will have to estimate hand paving areas and quantities. Identification of hand paving locations requires both knowledge of slipform paving machine capabilities and how a contractor will build a project. If experienced and knowledgeable personnel are available, the production of accurate hand paving quantities may require a significant amount of agency resources and time. Inaccurate identification of hand and slipform paving quantities can negatively impact the estimate by not accurately representing paving conditions. If the estimated hand paving quantity is smaller than the actual quantity, the average paver speed input parameter will be set to a faster rate. If the estimated quantity is larger than the actual quantity, then the paver speed will be too slow. Along with the risks associated with accurately identifying hand and slipform paving quantities, this estimate is also missing project specific scheduling and resource input parameters. In order for CA4PRS to be usable and applicable to specific projects, the program must demonstrate the ability to generate reliable estimates with input parameters specifically developed for a particular project.

4.2.4 3rd Analysis: Second Refinement to Incorporate Project Specific Scheduling and Equipment Input Parameters

The purpose of this analysis is to demonstrate the applicability and accuracy of CA4PRS estimation capabilities with pre-construction project-specific information, similar to an estimate that could be developed at the 30 percent PS&E. At higher levels of analysis project estimates can be further refined by including project specific scheduling and resource input parameters. Project specific inputs incorporate unique job constraints such as job-site access and equipment availability. Combining CA4PRS input parameters with project specific restraints should produce accurate estimates of construction productivity. Developing project specific input parameters requires construction experience and knowledge of the construction process, as well as an awareness of how project constraints will likely impact productivity. The estimates produced by CA4PRS will be compared to observed field productivity to evaluate preliminary estimation accuracy. The following CA4PRS estimate is based upon preliminary contractor Primavera schedules and WSDOT construction department productivity rate assumptions.

4.2.4.1 Second Refinement: Project Specific Scheduling Profile Input Parameters

This refinement replaces the previously used default scheduling profile input parameters with project-specific scheduling input parameters. Developing more accurate and project-specific input parameters for future estimates will require users to employ resources such as past project experience or existing project productivity documentation. This refinement attempts to duplicate the accuracy and quality of the input parameters that WSDOT personnel could potentially develop at higher levels of project planning. For this analysis preconstruction scheduling input parameters have been developed from contractor submitted Primavera software schedules. WSDOT personnel would not have contractor Primavera schedules during early estimate development, but this analysis assumes that the scheduling input parameters WSDOT personnel could develop would be similar to the input parameters obtained from the Primavera schedules. The contractor Primavera schedules for construction stages 1, 2, 3 and 4 can be found in Appendix G and have been used to determine the following input parameters:

- Construction sequencing
- Activity lag times
- Mobilization and demobilization times
- Modified mobilization time

4.2.4.1.1 Construction Sequencing

At this level of design, program users should evaluate construction access and the appropriate type of construction sequencing. For a new project, users will need to know or assume traffic management and mitigation plans. WSDOT personnel designed this project to limit congestion by providing lanes to the traveling public through the construction site (J. Mizuhata, personal interview, April 6, 2006). By providing more traveling lanes to the general public, WSDOT increased vehicular mobility, but limited construction operations to one access lane. The previous analyses were based upon the I-15 Ontario weekend closure sequential construction operations. For this refined estimate, the traffic management policies used for this case study require the continued use of sequential operations.

In addition to construction access, program users will be required to estimate the construction sequencing a contractor will use for building a future project. For this refinement construction sequencing is based on the Primavera schedules submitted by the contractor. This posed a key modeling problem: the contractor Primavera schedules depict a type of sequential operation that does not match the CA4PRS model of sequential operations. The CA4PRS user manual describes sequential operations as:

> "A construction method in which the demolition and paving activities of PCCP rehabilitation cannot proceed simultaneously. Instead, the paving activity can start only after the demolition activity is finished. Same construction access lane can be used for both demolition and PCCP installation, in sequence."

When using sequential operations, CA4PRS models new base installation starting after but progressing with demolition. Importantly, both new base installation and demolition activities are depicted as ending at the same time. This relationship between demolition and new base activities can be seen in a typical CA4PRS scheduling chart shown in Figure 32.

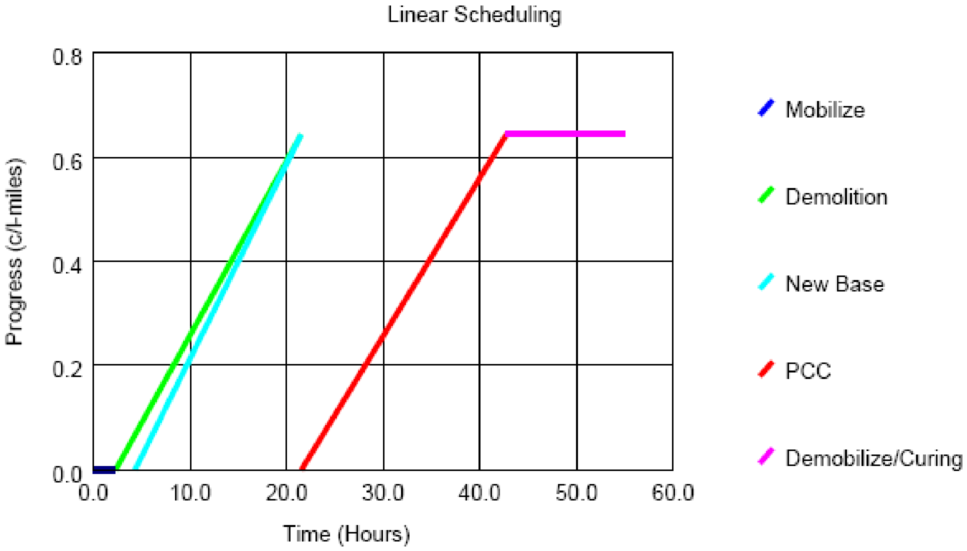


Figure 32 - Typical linear productivity chart for a sequential CA4PRS estimate.

For this Project, the contractor Primavera schedules show new base paving beginning only after demolition is entirely complete. To correctly model this sequence of activity, the activities of demolition, new base paving and PCC paving should not overlap. The current operational definitions of CA4PRS cannot accommodate this construction sequence. For this report, this sequencing limitation is handled by modifying the mobilization time (discussed in detail in section 4.2.3.1.4). Despite this limitation, the CA4PRS estimate for this analysis assumes sequential operations.

4.2.4.1.2 Activity Lag Times

The Primavera estimates contain separate scheduling information for hand and machine paving activities. Because the slipform paving mix comprises the majority of all material placed (Table 4), activity lag times from the Primavera schedules are based upon the sequencing times of slipform paving operations. The approximate activity lag times obtained from the Primavera schedules are displayed in Table 19. The lag times from all four stages have been averaged to produce a mean lag time. One lag time is depicted as having a negative value due to the use of concurrent operations during Stage 3 where the contractor Primavera schedules show HMA base paving scheduled to begin before demolition is complete.

Table 19 - HMA Paving Scheduling Information

Stage	Lag From Demo. Completion to Start of HMA Paving (Hrs)	Lag From End of HMA Paving to Start of PCC Paving (Hrs)
Stage 1	1	3
Stage 2	1	1
Stage 3	-1	4
Stage 4	3	1
Average	1	2.25

Modeling the sequence of construction activities on this project requires an important distinction for the definition of the demolition to base installation lag time:

> CA4PRS Operational Definition: Time required between the **start** of demolition and the **start** of new base installation.
>
> I-5 Olive to James Definition: Time required between the **end** of demolition and the **start** of new base installation.

4.2.4.1.3 Mobilization and Demobilization Times

The initial mobilization and demobilization times have been calculated from the stage 1, 2, 3 and 4 contractor Primavera schedules (Table 20). Mobilization time is defined as the time required by the contractor to begin demolition activities after the start of a closure window. The four mobilization times have been averaged to provide a representative figure for the mean mobilization time requirement. Demobilization time is defined as the time required between the end of PCC paving and the completion of temporary barrier removal. The demobilization times for each stage have also been averaged to determine a representative figure for CA4PRS estimation.

Table 20 - Mobilization And Demobilization Times From Primavera Schedules

Construction Stage	Mob. (hrs)	Demob. (hrs)
Stage 1	1	8

Stage 2	4	14
Stage 3	3	13
Stage 4	1	14
Average	2.25	12.25

4.2.4.1.4 Modified Mobilization Time

In order to correctly model the sequence of construction activities shown in the Primavera schedules, time within the estimate must be allotted for the:

- demolition to new base installation lag time
- time required for base installation and
- base installation to PCC installation lag time

These three times have been derived from the Primavera schedules (Table 21). Adding these times together results in a time gap of 6.75 hours which should separate demolition completion and the start of PCC installation.

Table 21 - Mobilization, Paving and Demobilization Times For New Base Installation

Stage	Lag From Demo. Completion to Start of HMA Paving (Hrs)	Lag From End of HMA Paving to Start of PCC Paving (Hrs)	End of Demo. To Start of PCC Paving (Hrs)
Stage 1	1	3	7
Stage 2	1	1	7
Stage 3	-1	4	8
Stage 4	3	1	5
Average	1	2.25	6.75

In order to accurately model construction scheduling in CA4PRS, 6.75 hours need to be assigned to base paving. These hours can be input into the CA4PRS schedule by increasing mobilization time by 6.75 hours. Time is added to mobilization rather than demobilization because some demobilization times can be controlled by concrete curing times. Mobilization times can be simply considered the amount of time that is unavailable for construction activities during a closure window. Combining the initial mobilization time with the time required for new base paving results in a new project mobilization time of nine hours.

$$6.75hrs + 2.25hrs = 9hrs$$

Where:

6.75 hrs = time required for base mobilization, paving and demobilization

2.25 hrs = initial mobilization time

Adding base installation time to the mobilization time requires omitting lag time input parameters and removing base paving from the CA4PRS schedule and section profile. Demolition quantities have been kept consistent by specifying that an additional three inches material will be removed during demolition within the section profile window.

4.2.4.2 Second Refinement: Project Specific Probabilistic Scheduling Input Parameter Distributions

As described in Appendix J, the scheduling inputs at this level of estimation may still only be approximate. Due to the uncertain distributions of the scheduling input parameters, the parameters have been assigned triangular distributions. New users will be required to define applicable distributions, as well as appropriate: i.) most likely, ii.) maximum, iii.) minimum, and iv.) standard deviation values. These values will have to be set based upon logical user assumptions and predictions. Because this analysis uses a modified mobilization time to model this case studies construction schedule, only the mobilization and demobilization scheduling input parameters have been used. The scheduling input parameters for activity lag times are contained within the modified mobilization time. The maximum and minimum values for the mobilization and demobilization triangular distribution interval have been established by increasing or decreasing the maximum and minimum values observed on one of the four Primavera schedules by ten percent in order to inject some variability into these times. For instance, the largest demobilization time from construction stages 1 through 4 was observed to be fourteen hours (Table 20). Increasing the observed maximum of 14 hours by ten percent resulted in the distribution maximum of 15.4 hours. This factor of ten percent was selected to provide a range for input parameter variability. For the modified mobilization distribution, the calculated most likely, maximum, and minimum values have been added to the 6.75 hours required for base paving. These recorded values for activity lag times are displayed in Table 22.

Table 22 Scheduling Inputs For The Second Refinement Using Project Specific Inputs

Input Parameter	Mean	Distribution	Observed Maximum	Maximum +10%	Observed Minimum	Minimum -10%
Mobilization (hrs)	2.25	Triangular	4	4.4	1	0.9
Modified Mobilization (hrs)	9	Triangular	x	11.15	x	7.65
Demobilization	12.25	Triangular	14	15.4	8	7.2

4.2.4.3 Second Refinement: Project Specific Resource Input Parameters

Estimated production rates developed by WSDOT construction personnel during project planning have been used to develop the following resource input parameters for this estimate refinement:

- Pavement demolition
- HMA base installation
- PCC installation
- PCC paver operations

Appendix C depicts the estimated initial productivity rates which have been used to determine the resource input parameters for this estimate.

4.2.4.3.1 Pavement Demolition

WSDOT estimators predicted PCC demolition would progress at 1800 ft^2/hr for concrete nine inches thick (Appendix C). This demolition rate was achieved by using the following assumptions:

- PCC density is 150 lb/ft^3
- Two teams in operation with five 44-ton trucks/team/hour (trucks w/ pups)
- Demolition rate correlates to 101 tons/hr per team
- Team efficiency of 92 percent, packing efficiency 50 percent

For the estimate produced during this level of analysis on this case study, the team efficiency is based upon the demolition production rate. Inspector reports do not provide information about truck capacities or arrival rates, only an overall average demolition rate. Achieving this productivity rate required assumptions about truck arrivals per hour, truck load capacity, number of demolition teams and team efficiency. The inputs for truck arrivals, load capacity and number of demolition teams were initially assigned values so the estimated demolition rate would approximate the recorded demolition rate. The estimated demolition rate was then refined to match the observed demolition rate by solving for team efficiency. Team efficiency was derived because as it is a percentage that can be more easily modified in comparison to the whole numbers as used for truck load capacity and truck arrival rates. The following calculations depict team efficiency derivation:

$$101\,\frac{tons}{hr} \times 1team \;=\; 44\,\frac{tons}{truck} \times 5\,\frac{trucks}{hr} \times team \;\; efficiency \;\; \times 0.5 \times 1team$$

$$team\,efficiency = 0.92$$

While using CA4PRS, users will need to make assumptions about the load capacity of demolition, base and PCC paving trucks. Material delivery trucks come in a variety of different configurations and have varying load and volume capacities. Any likely capacity can be assigned to demolition, base and paving trucks. The load capacity established for material trucks was previously noted in section 4.1.5.5.2.

4.2.4.3.2 New Base Paving

As discussed in section 4.1.5.5.2, the load capacity of HMA delivery trucks varied. A majority of the truck tickets evaluated belonged to trucks with an HMA carrying capacity of 33 tons. The CA4PRS input parameter for base delivery truck capacity is in yd^3. Truck capacity in tons was converted to yd^3 through the following equation:

$$33\frac{tons}{truck} \times 2000\frac{lbs}{ton} \div 145\frac{lbs}{ft^3} \div 27\frac{ft^3}{yd^3} = 17\frac{yd^3}{truck}$$

State estimators predicted that HMA paving would progress at 150 tons/hr (Appendix C). This rate was attained by using the following assumptions and input parameters:

- HMA density assumed to be 145 lb/ft^3

- Paving rate in tons correlates to 77 yd^3/hr
- 4.5 trucks per hour with 17 yd^3 capacity
- Packing efficiency of 1

$$150\frac{tons}{hr}\times 2000\frac{lbs}{ton}\div 145\frac{lb}{ft^3}\div 27\frac{ft^3}{yd^3}=17\frac{yd^3}{truck}\times 4.5\frac{trucks}{hr}\times 100\%\left(packing\ efficiency\right)$$

4.2.4.3.3 PCC Paving

Slipform paving progresses faster than hand paving and requires higher material delivery rates. The PCC paving input parameters have been based on the higher truck and material handling requirements of slipform operations because they represent the upper range of achievable contractor productivity. The slipform PCC paving rate was calculated to be 95 yd^3/hr based on the truck ticket derivations in section 4.2.2.2. This productivity rate was achieved using the following input parameters:

- Truck capacity of 7.5 yd^3
- 12.5 trucks/hr
- Packing efficiency of 1

4.2.4.3.4 PCC Paver

According to the previous refined estimate, paver speed has been set at 2.67 ft/min to account for slower hand paving rates.

4.2.4.4 Second Refinement: Project Specific Probabilistic Resource Input Parameter Distributions

As discussed in Appendix J, at this point in the estimation process distributions can be applied based upon past project documentation or user assumption. As described in Appendix J section 11.5.2.2, I-10 documentation has been used to assign:

- Demolition truck arrival rates
- Demolition truck team efficiency
- PCC delivery truck arrival rates

Similarly, user assumption and triangular distributions have been applied to:

- Demolition packing efficiency
- Base truck arrival rates
- PCC paver speed

A summary of the distributions and distributions parameters assigned to the input parameters used for this probabilistic analysis are depicted in Table 23.

Table 23 -Project Specific Resource Inputs For The Second Estimate Refinement.

Input Parameter	Parameter Value	Distribution	Max.	Min.	Standard Deviation
Demolition Dump Truck Capacity (tons)	44.00	-	-	-	-
Demolition trucks/hr	5.00	Normal	X	x	1.25
Demolition Packing Efficiency	0.50	Triangular	0.60	0.40	x
Number of Demolition Teams	2.00	Deterministic	X	x	x
Team Efficiency	0.92	Normal	X	x	0.08
Base Dump Truck Capacity (yd^3)	17.00	-	-	-	-
Base trucks/hr	4.50	Triangular	5.40	3.60	x
Base Truck Packing Efficiency	1.00	Deterministic	X	x	x
Batch Plant Capacity (yd^3/hr)	200.00	Deterministic	X	x	x
Number of Plants	1.00	-	-	-	-
PCC Dump Truck Capacity (yd^3)	7.50	-	-	-	-
PCC trucks/hr	12.50	Normal	X	x	2.63
PCC Truck Packing Efficiency	1.00	Deterministic	X	x	x
Paver Speed (ft/min)	2.67	Probabilistic	2.94	2.4	x
Number of Pavers	1.00	-	-	-	-

Note: “ – “ used where a distribution cannot be assigned in CA4PRS

Note: “ x “ used where no input is required

Demolition and base truck capacities assume trucks operating with trailers

4.2.4.5 Second Refinement CA4PRS Estimation Results

A CA4PRS analysis with project specific scheduling and resource input parameters produced the productivity outputs shown in Table 24. The actual CA4PRS reports for both probabilistic and deterministic analysis are in Appendix E.

Table 24 - CA4PRS Estimation Results For The Second Refinement Using Project Specific Scheduling And Resource Input Parameters

	Deterministic Results
Construction Window	Weekend Closure (55 Hours/Weekend)
Working Method	Sequential Single Lane (T2)
Section Profile	PCCP: 13.0 Inches, New Base 0.0 Inches
Curing Time	8-Hours
Objective (lane-miles)	2.22
Maximum Possible (lane-miles)	0.54
Maximum Possible (c/l-miles)	0.54
Construction Windows Needed To Meet Objective	4.09
Demolition Quantity (yd^3)	1698.4
New Base Quantity	0
Concrete Quantity (yd^3)	1379.9
Constraint Resources	Demo. Hauling Truck, Paver
Demolition to Paving	1:1.13
Demolition Hours	15.9
Paving Hours	17.9

Note: “ x “ used where no output provided

4.2.4.5.1 CA4PRS Reports

The deterministic analysis predicts that a contractor could pave 0.52 lane-miles in a 55-hour weekend closure. The probabilistic analysis predicts a range of maximum paving productivity from 0.39 lane-miles to 0.64 lane-miles with an expected mean paving productivity of 0.52 lane-miles (Figure 33). From the first estimate refinement to the second estimate refinement, the difference between the estimated lower and upper bounds of productivity increases from 0.15 lane-miles to 0.25 lane-miles. A greater range of estimated productivity implies higher variability and more risk in identifying expected productivity. A large range of potential productivity will make construction scheduling more difficult, but is probably a more accurate representation of construction given the large variation in weekend productivity observed on this project.

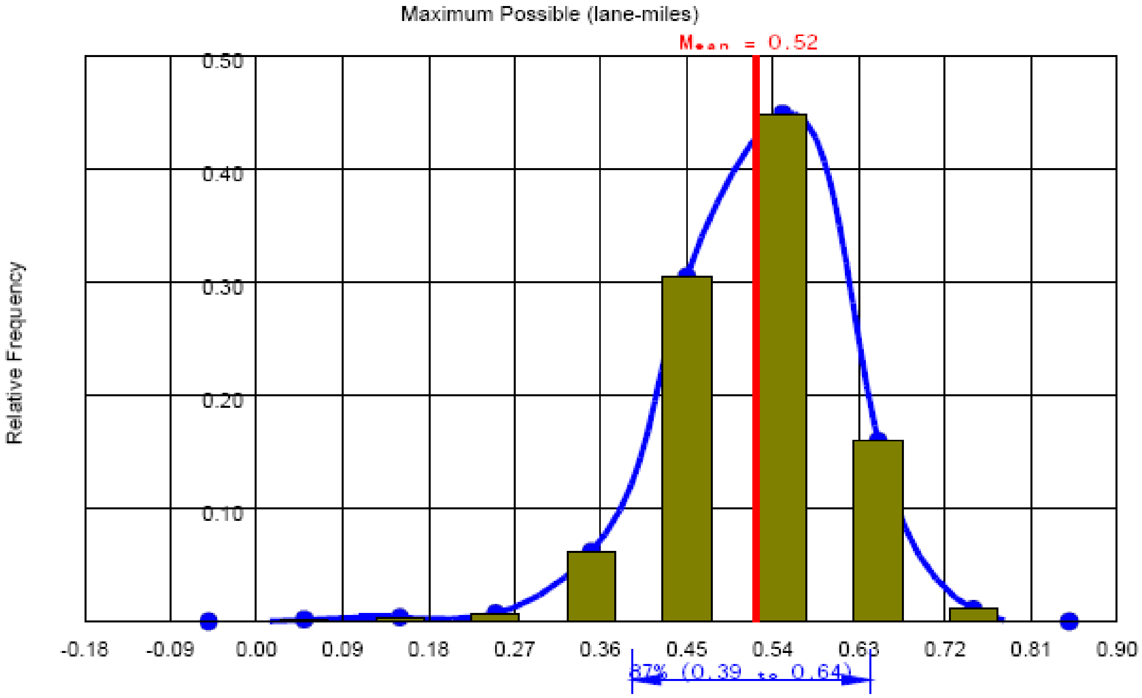


Figure 33 - Probabilistic productivity distribution for the second estimate refinement.

Within the 87 percent confidence interval, only the upper range of achievable productivity will provide for project completion within four weekends (Table 25). The middle and lower ranges of productivity would require five or six weekend closures for project completion.

Table 25 - Closure Requirements and Paving Productivities Associated With The Second Refinement Probabilistic Productivity Distribution

	87th Percentile Minimum	Estimated Mean	87th Percentile Maximum
Number of Lane-miles Paved Per Weekend Closure	0.39	0.52	0.64
Number of Required Weekend Closures	5.69	4.27	3.47

The linear scheduling chart from the deterministic output report depicts the intended sequencing of construction activities. HMA base paving is incorporated within the project mobilization time, decreasing the total number of hours available for demolition and PCC paving activities. PCC paving begins after demolition is complete, progressing at a slower rate and for a longer period of time.

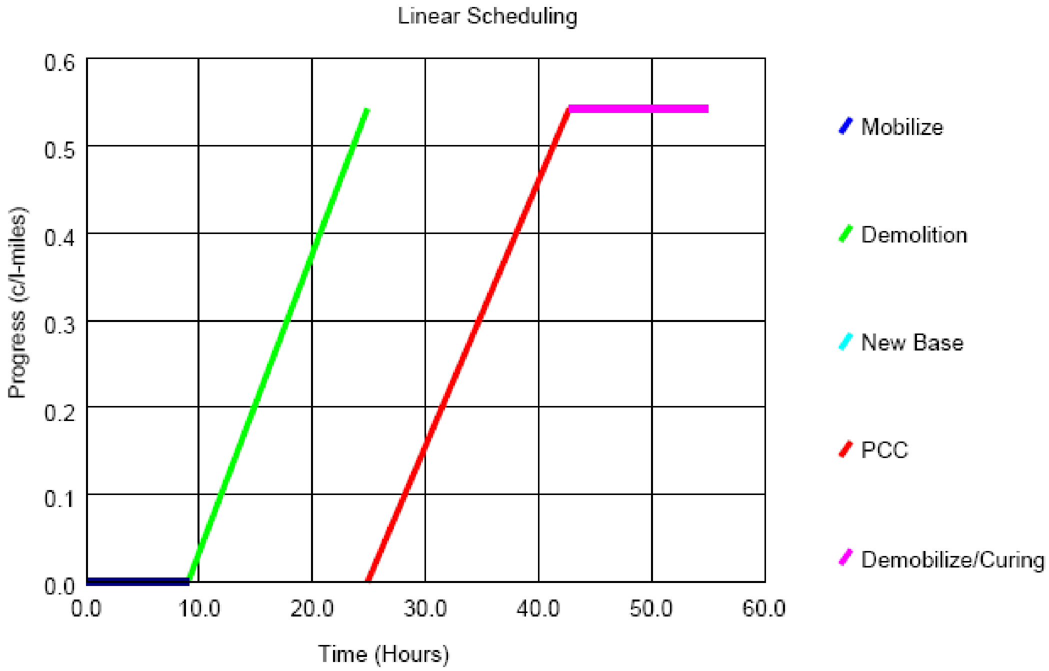


Figure 34 - Deterministic linear productivity chart output for the second estimate refinement.

The sensitivity chart for the estimate shows that production has a positive correlation with the number of demolition trucks. If the number of available demolition trucks could be increased, production would increase. Productivity is also sensitive to the other demolition input parameters including the number of dump trucks, dump truck efficiency and dump truck team efficiency, which exhibit higher Spearman correlation coefficients.

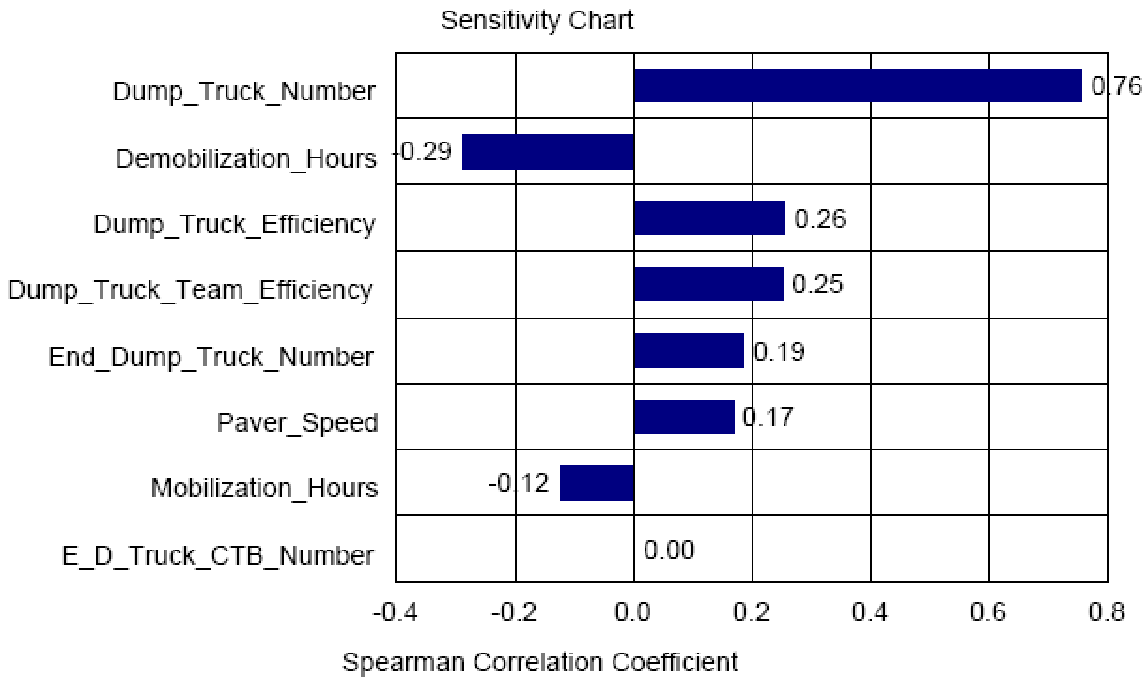


Figure 35 - Input parameter sensitivity chart for the second estimate refinement.

4.2.4.5.2 Results Assessment

The range of productivity estimated by probabilistic analysis encompasses two of the observed weekend construction productivities and merits a performance rating of 'Good' (Table 26). The range of estimated productivity does include the observed average weekend productivity. The estimated mean productivity of 0.52 lane-miles is 0.035 lane-miles less than the observed average weekend productivity of 0.555 lane-miles. Although CA4PRS estimates do not necessarily capture the full range of observed productivity, the mean estimated productivity can be accurate. These results show that although individual closure productivity may not be accurate, general productivity estimation is accurate.

Because the estimated mean productivity closely approximates the mean observed productivity and only two of the weekend productivities are enclosed in the productivity distribution, it is possible that the assigned probabilistic distributions and distribution parameters did not provide for enough variability. Appendix J describes the distributions and distribution parameters assigned to the three demolition input parameters:

- Demolition packing efficiency

- Base truck arrival rates
- PCC paver speed

Applying distributions and distribution parameters based on collected data may provide greater estimation variability and improve productivity estimation.

Table 26 – 3rd Analysis Productivity per Closure Estimation Evaluation Criterion (CA4PRS)

	Number of Observed Weekend Closure Productivities within the 87 percent Confidence Interval				Observed Average Weekend Productivity within 87 percent Confidence Interval?
	3 or 4	2	1	0	
Rating	Excellent	***Good***	Fair	Poor	Yes

Table 25 shows that only the predicted 87 percent confidence interval upper bound of the total number of closures meets the criteria established in section 4.2.1.2.2 for a rating of 'Fair'. A 'Fair' rating implies limited accuracy and minimal planning and closure information is provided. CA4PRS successfully predicted parts of the observed productivity range, but the closure results indicate that construction would most likely require five weekend closures. This analysis was completed to verify CA4PRS estimation abilities for a project using estimated rates and preconstruction information. Provided with this estimate information, project management could make incorrect planning and closure decisions. The results of this analysis lead to the following conclusions:

1. CA4PRS may not produce a large enough distribution to encompass all closure productivities, but mean productivity estimation appears to be accurate
2. Assigned distribution and distributions may not have provided for enough estimation variability to correctly encompass all observed weekend productivities
3. CA4PRS can produce accurate closure and productivity estimates, but
4. Analysis results are only as accurate as the used input parameters.

4.2.4.5.3 Possible Sources of Estimation Error

For this analysis, estimate error evaluation has been divided into two sections:

1. Potential sources of error in the modeling process, and

2. Sources of error in the input parameter selection process.

4.2.4.5.3.1 Potential Sources of Error in the Modeling Process

The analysis intended to use a construction sequence where HMA paving started one hour after demolition finished and PCC paving started 2.25 hours after base installation had completed. CA4PRS cannot produce estimates for construction operations where base paving begins after demolition is complete. By not modeling this activity sequence, the estimate does not include the time that is required for the mobilization, demobilization and paving times associated with HMA base paving. By not including these activity times in the schedule, the program assumes more time is available for construction and paving productivity. Adding these times to the project mobilization time is a viable work-around but can be confusing.

Incorporating HMA base paving into the mobilization time impacts the accuracy of the probabilistic estimate. In the scheduling profile window of the probabilistic analysis, users have the option of assigning distributions to activity lag times. If HMA activity lag times are collectively modeled with a larger mobilization time users cannot assign distributions to the base scheduling input. The probabilistic schedule does not include the probability distributions for:

- Demolition to new base installation lag time
- New base installation to PCC installation lag time

Omitting the probabilistic distributions for these two scheduling input parameters may not have a large impact for this case study due to the fact that both the probabilistic and deterministic estimation results are similar. Future estimates that have higher variability or uncertainty associated with new base paving CA4PRS estimates produced with a modified mobilization time will be less accurate and less comprehensive.

4.2.4.5.3.2 Sources of error in the input parameter selection process

An incorrect prediction of closure requirements is not necessarily indicative of poor program estimation accuracy or usability. Rather, this illustrates that CA4PRS estimates will only be as accurate as the information used to develop the program input parameters.

The input parameters for this refined estimate have been developed from available information, including: (1) contractor schedules and (2) preliminary productivity assumptions provided by WSDOT construction personnel. In developing preliminary schedules both the contractor and WSDOT personnel likely attempted to identify and limit risk within their productivity estimates. Risk pertains to the degree of confidence that predicted productivity rates or construction conditions will be within an identified range. Risk can be controlled through measures such as the use of conservative productivity rates (i.e., using low average values or high variation) or allotting time for contingencies. In order to detect the use of conservative rates, the estimated mobilization and demobilization times have been compared to the mobilization and demobilization times recorded in WSDOT inspector reports (Table 27).

Table 27 - Differences Between Estimated And Observed Mobilization and Demobilization Times

Input Parameter	Mobilization	Demobilization
Estimated Average Time Derived From Preliminary Schedules (hrs)	2.25	12.25
Observed Average Time Derived From Inspector Reports (hrs)	0.94	11.63
Difference (hrs)	1.31	0.62

The estimated mobilization and demobilization times predicted that approximately two less hours would be available for construction activities per construction closure window. During an aggressive and tight construction closure such as the 55-hour weekend closure used on this project, the addition of two more hours of available productivity has a significant impact. Performing another probabilistic analysis with two hours removed from the mobilization and demobilization times produces an estimated productivity range that still contains construction productivities observed on two of the weekends. However, both the mean and the upper end of the productivity distribution of this modified analysis correctly identifies the number of required weekend closures.

The mean closure requirement of 4.27 weekends produced during the first estimate generation with the more conservative input parameters does not match the observed closure requirement, but the estimate results can be interpreted as accurate given the conservative nature of the input parameters. If the estimate were to be developed with more accurate inputs that more closely reflected construction conditions and equipment, the closure requirements calculated by CA4PRS would be more similar to observed closure requirements. This analysis illustrates that CA4PRS has the capability of producing accurate and usable estimates; however, CA4PRS estimation accuracy depends on the ability of the user to determine accurate input parameters.

4.2.5 4th Analysis: Estimation Based on Observed Construction Productivity

The fourth estimate developed on this case study will use productivity rates and scheduling times recorded during project construction to evaluate CA4PRS estimation accuracy. This analysis uses resource and scheduling information from truck tickets and WSDOT construction inspector reports to generate the input parameters for a CA4PRS estimate. CA4PRS estimation accuracy will be based on the ability of the software to produce construction productivity estimates and weekend closure requirements that match observed construction productivity and closure requirements.

4.2.5.1 Estimation Based on Observed Construction Productivity: Scheduling Profile Input Parameters

During construction, WSDOT personnel gathered information about the times construction activities started and completed. The activity information collected by WSDOT inspectors has been used to determine:

1. Construction sequencing
2. Activity lag times input parameters
3. Mobilization and demobilization input parameters
4. Modified mobilization input parameter

The construction records used for developing the input parameters used in this analysis are in Appendix G, but pertinent information is summarized in Table 28.

4.2.5.1.1 Construction Sequencing

As in the previous analysis, the sequencing of construction activities on this project does not match any of the operational sequencing definitions supported by CA4PRS. Operations will still be modeled as sequential but will continue to use a modified mobilization time to account for base paving as in the 3rd analysis.

4.2.5.1.2 Activity Lag Times

Activity lag times have been calculated as the time required between the completion of one construction activity and the start of the following construction activity. For PCC paving, inspector reports provide activity start and completion times for hand and slipform paving. The lag times for PCC paving are based upon slipform paving because the majority of pavement placed on this project conformed to the slipform PCC mix design. The lag times calculated from each construction stage are depicted in Table 28. The averaged lag time results from all of the construction stages are shown in Table 29.

4.2.5.1.3 Mobilization and Demobilization Time

Mobilization times have been calculated as the time between the start of the closure window and the start of pavement demolition. The demobilization time is calculated as the amount of time elapsed between the end of PCC paving and completion of traffic barrier removal. The mobilization and demobilization times from each stage are shown in Table 28, while the averaged times from all three stages are shown in Table 29.

Table 28 - Major Activity Start And Completion Times

Stage 1 (4/22-4/25) Construction Times	**Start**	**End**	**Duration**	**Lag**
Mobilization	Friday 22:00	Friday 22:30	0:30	-
Pavement Demo & Excavation	Friday 22:30	Saturday 6:40	8:10	0:30
Subgrade Preparation	Saturday 4:30	Saturday 23:25	18:55	Sequential
HMA Paving	Saturday 11:10	Saturday 15:20	4:10	4:30
Slipform PCC Paving	Saturday 23:00	Sunday 11:50	12:50	7:40
Hand PCC Paving	Sunday 11:00	Sunday 20:30	9:30	-
Demobilization	-	-	13.5	-
Stage 2 (6/17-6/20) Construction Times	**Start**	**End**	**Duration**	**Lag**
Mobilization	Friday 22:00	Friday 23:00	1:00	-
Pavement Demo & Excavation	Friday 23:00	Saturday 10:37	11:37	1:00
Subgrade Preparation	Saturday 2:30	Saturday 13:00	10:30	Sequential
HMA Paving	Saturday 11:10	Saturday 15:22	4:12	0:33
Slipform PCC Paving	Saturday 17:55	Sunday 2:05	8:10	2:33
Hand PCC Paving	Sunday 6:00	Sunday 14:00	8:00	-
Demobilization	-	-	11	-
Stage 3 (6/24-6/27) Construction Times	**Start**	**End**	**Duration**	**Lag**
Mobilization	Friday 22:00	Friday 23:00	1:00	-
Pavement Demo & Excavation	Friday 23:00	Saturday 7:15	8:15	1:00
Subgrade Preparation	Saturday 3:15	Saturday 10:40	7:25	Sequential
HMA Paving	Saturday 10:30	Saturday 14:45	4:15	3:15
Slipform PCC Paving	Saturday 15:39	Sunday 2:50	10:02	0:54
Hand PCC Paving	Sunday 9:05	Sunday 14:40	5:35	-
Demobilization	-	-	11	-
Stage 4 (7/16-7/18) Construction Times	**Start**	**End**	**Duration**	**Lag**
Mobilization	Friday 22:00	Friday 23:15	1:15	-
Pavement Demo & Excavation	Friday 23:15	Saturday 5:30	5:15	1:15
Subgrade Preparation	Saturday 3:00	Saturday 9:00	6:00	Sequential
HMA Paving	Saturday 9:35	Saturday 14:00	4:25	4:05
Slipform PCC Paving	Saturday 16:35	Saturday 21:20	4:45	2:35
Hand PCC Paving	Saturday 6:30	Saturday 12:50	6:20	1:55
Demobilization	-	-	11	-

Table 29 - Averaged Scheduling Inputs From WSDOT Inspector Reports From Construction Stages 2, 3 & 4

Average Times Derived From Stages 1, 2, 3 & 4	**Duration**
Mobilization (hrs)	0.94
Demobilization (hrs)	11.63
Pavement Demolition to HMA Paving Lag Time (hrs)	3.10
HMA Paving to Concrete Paving Lag Time (hrs)	3.26

4.2.5.1.4 Modified Mobilization Time

In order to specify sequential operations in CA4PRS and incorporate the time required for HMA base installation, the mobilization time has been modified similar to the second estimate refinement completed in the previous analysis. Table 30 shows that an average of 10.78 hours was required for:

- demolition to new base installation lag time
- time required for base installation and
- base installation to PCC installation lag time

Table 30 Activity Lag and Duration Times for HMA Base Paving

Stage	End of Demo. To Start of HMA Paving (hrs)	Duration Of HMA Paving (hrs)	End of HMA Paving to Start of PCC Paving (hrs)	Total (hrs)
Stage 1	4.5	4.17	7.67	16.33
Stage 2	0.55	4.20	2.55	7.3
Stage 3	3.25	4.25	0.90	8.40
Stage4	4.08	4.42	2.58	11.08
			Average	**10.78**

Combining the initial mobilization time with the time required for new base paving results in a new project mobilization time of 11.72 hours:

$$10.78hrs + 0.94hrs = 11.72hrs$$

Where:

10.78 hrs = time required for base mobilization, paving, and demobilization

0.94 hrs = initial mobilization time

4.2.5.2 Estimation Based On Observed Construction Productivity: Probabilistic Scheduling Input Parameter Distributions

Probabilistic input parameters have been assigned distributions based on project documentation and user assumption. For this analysis, input parameter behavior is based on observations from four weekend closures. A data sample set of four provides a weak estimation of scheduling input distribution parameters. Thus, triangular distributions have been applied to the scheduling input parameters. The most likely value for the distribution is the average value calculated from inspector reports, while the maximum and minimum values have been assigned the observed maximum and minimum values. The distribution, maximum, minimum and mean associated with each scheduling input are depicted in Table 31. The development of the probabilistic distributions and distribution parameters is further discussed in Appendix J.

Table 31 - Scheduling Inputs and Distributions Used For Developing the Observed Construction Productivity Estimate

Deterministic Inputs		Probabilistic Inputs		
Input	Mean	Distribution	Observed Max.	Observed Min.
Mobilization (hrs)	0.940	Triangular	1.25	0.5
Modified Mobilization (hrs)	11.720	Triangular	12.03	11.280
Demobilization (hrs)	11.63	Triangular	13.5	11

4.2.5.3 Estimation Based on Observed Construction Productivity: Resource Input Parameters

The resource profile input parameters have been derived from truck ticket information and WSDOT construction inspection reports. The inspector report-based information used for establishing the resource input parameters for this estimate is in Appendix G and summarized in

Table 32.

4.2.5.3.1 Pavement Demolition

Inspector reports from construction stages 1, 2, 3 & 4 show that the contractor achieved an average demolition rate of 149 yd^3/hr (Table 33). In CA4PRS this demolition rate was achieved by inputting the following assumptions into the resource profile window:

- PCC density assumed to be 150 lb/ft^3, demolition is equivalent to 301.7 tons/hr
- An average of 2.8 teams, rounded to three teams (Table 33)
- Demolition rate correlates to 100.6 tons/hr per team
- Packing efficiency set to 50 percent
- Each team assumed to operate with 6, 44-ton capacity trucks
- Team efficiency calculated to be 76 percent

$$301.7\frac{tons}{hr} = 3teams \times 100.6\frac{tons}{hr} \times \frac{1}{team}$$

$$301.7\frac{tons}{hr} = 3teams \times 6\frac{trucks}{hr} \times \frac{1}{team} \times 44\frac{tons}{truck} \times .5 \times team\ efficiency$$

$$team\ efficiency = 0.76$$

The average number of demolition teams shown in Table 33 is actually 2.8. CA4PRS does allow the use of decimal factors for this input. In order to achieve the specified productivity rate with three teams, the team efficiency has been lowered.

Table 32 - Productivity Rates and Labor Derived From Inspector Reports

Stage 1 Construction Rates	**Rate**	**Crews**	**Labor**	**Operators**
Install Temporary Barrier (lf/hr)	420.00	2	4	2
Pavement Demo And Excavation (yd^3/hr)	74.13	2	7	5
Subgrade Preparation (ft^2/hr)	178.26	1	4	5
HMA Paving (ton/hr)	156.00	1	6	3
Hand PCC Paving (yd^3/hr)	39.16	1	18	
Slipform PCC Paving (yd^3/hr)	85.68	1	9	4
Remove Temporary Barrier (lf/hr)	329.41	2	5	3
Stage 2 Construction Rates	**Rate**	**Crews**	**Labor**	**Operators**
Install Temporary Barrier (lf/hr)	259.93	2	7	2
Pavement Demo And Excavation (yd^3/hr)	155.04	3	8	7
Subgrade Preparation (ft^2/hr)	386.86	2	12	4
HMA Paving (ton/hr)	166.67	1	6	3
Hand PCC Paving (yd^3/hr)	45.00	1	18	
Slipform PCC Paving (yd^3/hr)	81.43	2	14	2
Remove Temporary Barrier (lf/hr)	436.36	2	8	3
Stage 3 Construction Rates	**Start**	**End**	**Duration**	**Lag**
Install Temporary Barrier (lf/hr)	290.91	2	8	2
Pavement Demo And Excavation (yd^3/hr)	181.33	3	6	6
Subgrade Preparation (ft^2/hr)	455.06	2	12	4
HMA Paving (ton/hr)	136.47	1	6	3
Hand PCC Paving (yd^3/hr)	44.78	1	13	2
Slipform PCC Paving (yd^3/hr)	84.55	1	14	3
Remove Temporary Barrier (lf/hr)	426.67	2	8	3
Stage 4 Construction Rates	**Start**	**End**	**Duration**	**Lag**
Install Temporary Barrier (lf/hr)	275.56	2	8	2
Pavement Demo And Excavation (yd^3/hr)	184.00	3	6	6
Subgrade Preparation (ft^2/hr)	363.17	2	12	4
HMA Paving (ton/hr)	86.04	1	6	3
Hand PCC Paving (yd^3/hr)	32.24	1	8	3
Slipform PCC Paving (yd^3/hr)	105.68	1	14	3
Remove Temporary Barrier (lf/hr)	137.78	2	8	3

Table 33 - Productivity Rates Averaged From Inspector Reports

Average Construction Rates	Rate	Crews	Labor	Operators
Install Temporary Barrier (lf/hr)	312	2.0	6.8	2.0
Pavement Demo And Excavation (yd^3/hr)	149	2.8	6.8	6.0
Subgrade Preparation (ft^2/hr)	346	1.8	10.0	4.3
HMA Paving (ton/hr)	136	1.0	6.0	3.0
Hand PCC Paving (yd^3/hr)	40	1.0	14.3	2.5
Slipform PCC Paving (yd^3/hr)	89	1.3	12.8	3.0
Remove Temporary Barrier (lf/hr)	333	2.0	7.3	3.0

4.2.5.3.2 New Base Paving

The construction inspector reports provide an average HMA paving rate of 136 tons/hour (Table 33). To attain this productivity rate, the following assumptions were used:

- HMA density assumed to be 145 lb/ft^3
- Paving rate correlates to 80 yd^3/hr
- Eight trucks arrived per hour with 10 yd^3 capacity
- Average packing efficiency set to 100 percent

$$80\frac{yd^3}{hr} = 10\frac{yd^3}{truck} \times 8\frac{trucks}{hr} \times 100\%$$

4.2.5.3.3 PCC Paving

The PCC productivity rate was calculated previously using a sample set of PCC delivery truck tickets. This information resulted in an average paving rate of 95 yd^3/hr. This paving rate is incorporated into the CA4PRS estimate by using the following assumptions.

- Truck capacity of 7.5 yd^3
- 12.5 trucks per hour

4.2.5.3.4 PCC Paver

According to previous estimates, paver speed has been set at 2.67 ft/min to account for slower hand paving rates.

4.2.5.4 Estimation Based on Observed Construction Productivity: Probabilistic Resource Input Parameter Distributions

The resource inputs for this estimate have been assigned probabilistic distributions according to the analysis completed in Appendix J, Section 11.5.2.3. The distribution analysis describes which distributions and distribution parameters have been assigned to each input parameter. The resulting distributions and distribution parameters are summarized in Table 34.

Table 34 - Resource Input Parameters for the Estimate Based On Observed Construction Productivity

Input Parameter	Parameter Value	Distribution	Maximum	Minimum	Std Deviation
Demolition Dump Truck Capacity (tons)	44.00	-	-	-	-
Demolition trucks/hr	6.00	Normal	x	X	1.50
Demolition Packing Efficiency	0.50	Triangular	0.60	0.40	x
Number of Demolition Teams	3.00	Deterministic	x	X	x
Demolition Team Efficiency	0.76	Normal	x	X	0.08
HMA Base Dump Truck Capacity (yd^3)	10.00	-			-
HMA Base trucks/hr	8.00	Log Normal	x	X	2.00
HMA Packing Efficiency	1.00	Deterministic	x	X	x
Batch Plant Capacity (yd^3/hr)	200.00	Deterministic	x	X	x
Number of Plants	1.00	-	-	-	-
PCC Dump Truck Capacity (yd^3)	7.50	-	-	-	-
PCC trucks/hr	12.50	Normal	x	X	2.70
PCC Truck Packing Efficiency	1.00	Deterministic	x	X	x
Paver Speed (ft/min)	2.67	Probabilistic	2.40	2.94	x
Number of Pavers	1.00	-	-	-	-

Note: " – " used where a distribution cannot be assigned in CA4PRS

Note: " x " used where no input is required

4.2.5.5 Estimation Based On Observed Construction Productivity: CA4PRS Results

The CA4PRS estimation results based on observed construction productivity are contained in Table 35. CA4PRS reports for both the probabilistic and deterministic analysis can be found in Appendix D.

Table 35 - CA4PRS Estimate Results Based On Observed Construction Productivity

	Deterministic Results
Construction Window	Weekend Closure (55 Hours/Weekend)
Working Method	Sequential Single Lane (T2)
Section Profile	PCCP: 13.0 Inches, New Base 3.0 Inches
Curing Time	8-Hours
Objective (lane-miles)	2.22
Maximum Possible (lane-miles)	0.60
Maximum Possible (c/l-miles)	0.60
Construction Windows Needed To Meet Objective	3.69
Demolition Quantity (yd^3)	1882.4
New Base Quantity	0
Concrete Quantity (yd^3)	1529.5
Constraint Resources	Demo Truck, Paver
Demolition to Paving	1:1.68
Demolition Hours	11.8
Paving Hours	19.8

* -x used where no output is provided

4.2.5.5.1 CA4PRS Reports

The 87 percent confidence interval for the probabilistic analysis estimates that a contractor will be able to pave between 0.44 and 0.67 lane-miles per closure (Figure 36). The expected paving productivity of this distribution is 0.57 lane-miles. The difference in the upper and lower bound for this estimate is slightly smaller than the previous estimate, decreasing from a difference of 0.25 lane-miles to 0.23 lane-miles. The closure requirements associated with the mean and the lower and upper bounds of the productivity distribution are depicted in Table 36. Most of the productivity range estimated by the probabilistic analysis correctly identifies the observed weekend closure requirements.

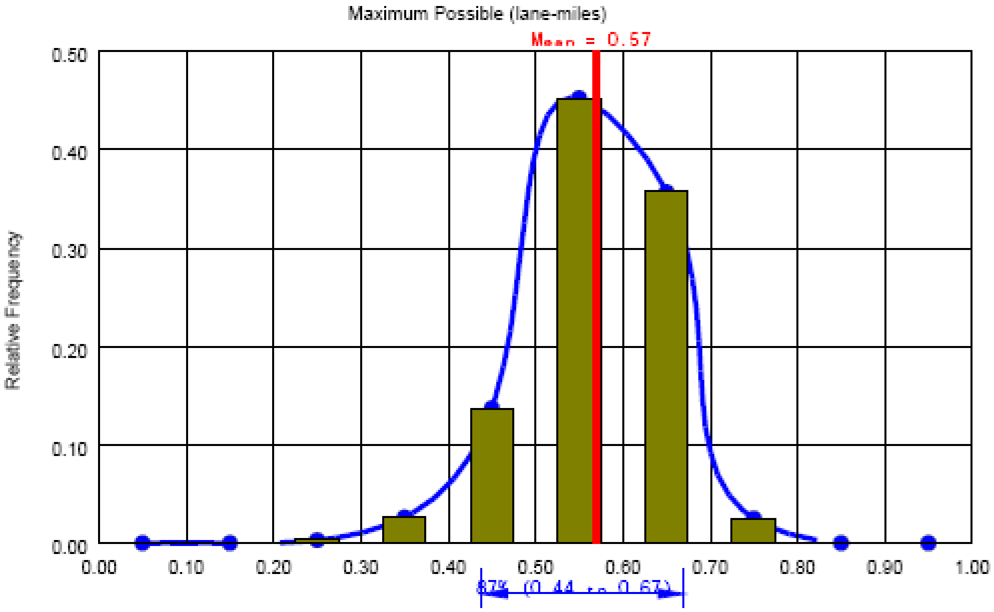


Figure 36 - Probabilistic productivity distribution for the estimate based on observed construction productivity.

Table 36 - Closure Requirements and Paving Productivities Associated With Estimate Based On Observed Construction Productivity

87th Percentile Minimum	Estimated Mean	87th Percentile Maximum
0.44	0.57	0.67
5.05	3.89	3.31

The linear scheduling chart from the deterministic output report depicts the intended sequencing of construction activities. HMA base paving is incorporated within the project mobilization time, decreasing the total number of hours available for demolition and PCC paving activities. Demolition can be observed as requiring less time and progressing much faster in comparison to PCC paving.

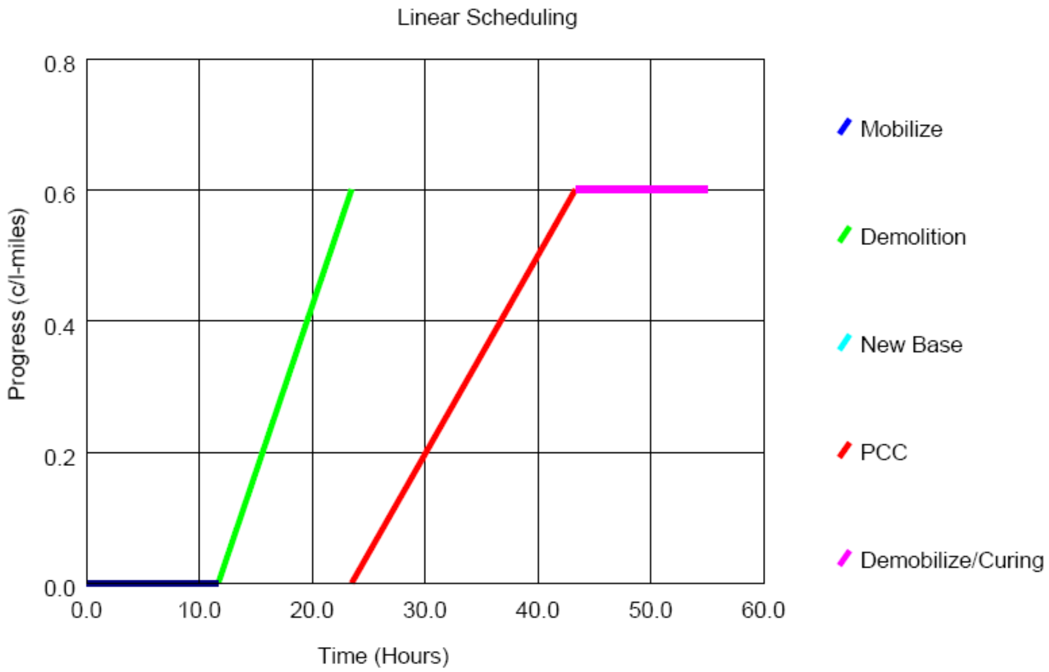


Figure 37 - Deterministic linear productivity chart output for the estimate produced based on observed construction productivity.

The sensitivity chart for the estimate shows that production is most sensitive to the number of demolition trucks. Productivity also has some sensitivity to the other input parameters associated with demolition.

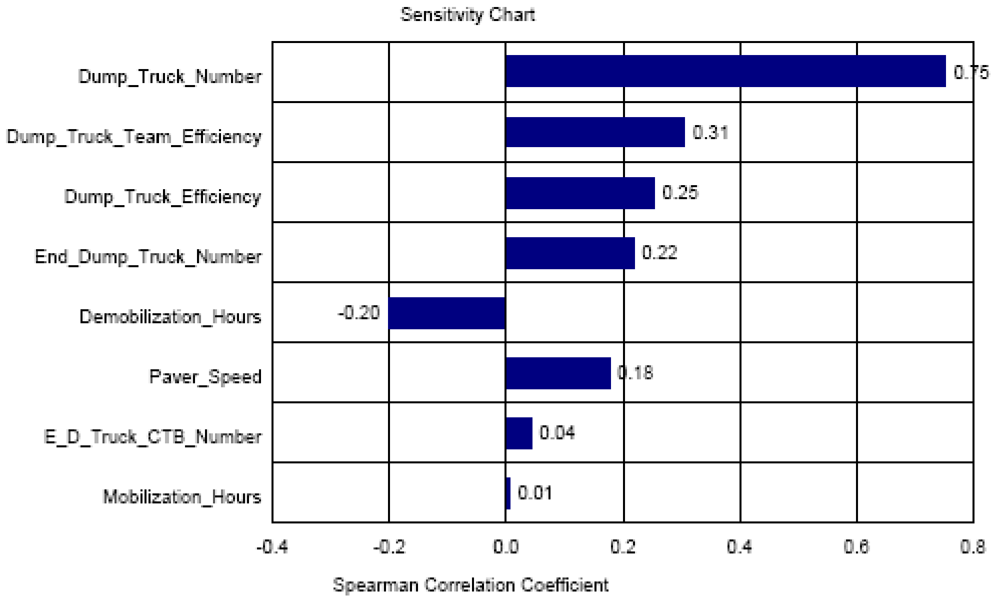


Figure 38 - Input parameter sensitivity chart for estimation based on observed construction productivity.

4.2.5.5.2 Results Assessment

The range of estimated productivity contains two of the weekend productivities observed during construction of the project. According to the rating criteria, productivity estimation for this analysis has been rated as ‘Good’. Similar to the previous analysis, several of the resource input parameters were assigned distribution functions and distribution parameters using engineering judgment. If more information was known about the distributions and behavior of these input parameters, the distribution of estimated productivity could be larger and include more of the observed productivities.

The estimated productivity distribution also encloses the observed average weekend productivity. The estimated mean productivity of 0.57 lane-miles is larger than the observed average paving productivity of 0.555 lane-miles by only 0.015 lane-miles, or three percent. These results further support the conclusion that individual closure estimation may be inaccurate, mean productivity estimation can still be accurate.

Table 37 – 4th Analysis Productivity per Closure Estimation Evaluation Criterion (CA4PRS)

	Number of Observed Weekend Closure Productivities within the 87 percent Confidence Interval				Observed Average Weekend Productivity within 87 percent Confidence Interval?
	3 or 4	2	1	0	
Rating	Excellent	***Good***	Fair	Poor	Yes

Table 36 shows that the predicted mean and 87 percent confidence bounds of the total number of closures meet the criteria established in section 4.2.1.2.2 for a rating of ‘Excellent’. The results of this analysis led to the following conclusion:

1. CA4PRS can accurately reproduce or predict construction productivity and closure requirements given accurate input parameters.

4.2.5.5.3 Possible Sources of Estimation Error

During more advanced stages of project planning, estimation personnel attempt to incorporate all of the factors that require equipment and personal time, or impact productivity. Many of these productivity impacts are present in the previously completed analyses and not specifically addressed. For instance, a modified paver speed accounts for slipform and hand-paving rates, but does not include any loss of productivity due to the additional movement of equipment. Moving hand paving equipment and personnel as well as slipform equipment and personnel will cause some loss of productivity and remove minutes or hours of time from construction schedules. Concrete strength gain times and how equipment and labor can work around uncured concrete is also not incorporated into estimates. At the highest level of construction review, estimators will also examine how grade breaks, roadway profiles, the location of joints and disjointed paving sections will impact productivity. Attempting to factor these productivity impacts into a CA4PRS estimate may be difficult, if feasible.

In addition to constraints that can potentially decrease productivity, CA4PRS does not incorporate factors that will increase productivity. A contractor on any project will have viable options for increasing productivity. On this project, the contractor varied the amount of personnel and equipment dedicated to the project. Two demolition teams operated during construction stage 2. Three teams operated during both stages 3 and 4. By adding an additional team to demolition activities, the contractor increased demolition productivity. Productivity can also be increased by manipulating construction sequencing. On Stage 1, the contractor overlapped demolition and base paving operations. By modifying the equipment or sequencing used during one construction stage, a contractor can significantly increase the maximum attainable productivity.

4.3 CA4PRS Estimation Applicability

The productivity and closure estimate results from all four analyses is collectively presented in Table 38 and Table 39.

Table 38 – Weekend Productivity Estimation Summary For I-5 James To Olive Case Study

	Number of Observed Weekend Closure Productivities within the 87 percent Confidence Interval				Observed Average Weekend Productivity within 87 percent Confidence Interval?
Analysis	3 or 4	2	1	0	
1st Analysis	Excellent	***Good***	Fair	Poor	No
2nd Analysis	Excellent	Good	***Fair***	Poor	No
3rd Analysis	Excellent	***Good***	Fair	Poor	Yes
4th Analysis	Excellent	***Good***	Fair	Poor	Yes

Table 39 - Closure Estimation Summary For The I-5 James To Olive Case Study.

Analysis	Expected Prod. and Either Lower or Upper Prod. Bound Predict 4 Closures	Expected Prod. Predicts 4 Closures	Lower Or Upper Prod. Bound Predicts 4 Closures	No Part of Prod. Distribution Predicts 4 Closures
All Analyses	Excellent	Good	Fair	Poor
1st Analysis	***Excellent***	-	-	-
2nd Analysis	***Excellent***	-	-	-
3rd Analysis	-	-	***Fair***	-
4th Analysis	***Excellent***	-	-	-

The tabulated results show that for the majority of analyses CA4PRS consistently produced ‘Good’ productivity and ‘Excellent’ closure estimate results. According to the evaluation criteria, these performance ratings indicate that CA4PRS outputs would benefit project planning and decision making. The following conclusions have been established based on these estimation results:

1. **CA4PRS estimates should be produced from probabilistic analysis.** The high variation in observed construction productivity for this case study (0.356-0.738 lane-miles/weekend closure) can be attributed to changing construction conditions and resource utilization. These variations in productivity are not captured in a deterministic output. Probabilistic analyses are more comprehensive because they

depict the variations in construction productivity and provide an indication of the risk associated with anticipating an achievable productivity. Future project planning and decisions should be made based on the information provided by a probabilistic analysis.

2. **CA4PRS estimates are accurate and realistic.** All of the completed CA4PRS analyses produced either weekend productivity or closure estimates that approximated observed productivity and closure requirements. The third and fourth analyses also produced distributions with mean productivities close to the observed average weekend productivity. Furthermore, the fourth and final analysis was intended to evaluate CA4PRS estimation accuracy by using input parameter information recorded during project construction and comparing estimated and observed productivity.
3. **CA4PRS estimate accuracy is dependent upon input parameter development.** The third analysis was completed to test estimation accuracy based on preliminary construction information. The result of this analysis produced mediocre results. A comparison between pre-construction and observed input parameters showed that the pre-construction input parameters were conservative. Conservative input parameters will produce conservative estimates. Developing accurate estimates will require users to input realistic input parameters.
4. **CA4PRS estimation accuracy is dependent on project conditions and input parameter variability.** The project was completed in an urban corridor with variable construction conditions and constraints. Changing construction conditions and contractor resource utilization resulted in a range of observed weekend productivity with a minimum productivity of 0.356 lane-miles and a maximum productivity of 0.738. None of the completed estimates captured this range of observed productivity. In the same regard, the mean productivity estimated by the third and fourth analyses closely approximates the observed average weekend productivity. These results indicate that CA4PRS can make accurate productivity predictions, but the probabilistic estimates should have provided for greater productivity variability. This implies that future estimate development for complex and variable projects should

use greater probabilistic distribution parameters for input parameters that are not confidently known.

5. **CA4PRS should be used during early project planning and closure development.** The first two analyses showed that CA4PRS analyses with general input parameters can approximate observed contractor productivity and predict closure requirements. Based on the first two analyses results of this case study, CA4PRS should be used during early stages of project development to establish or confirm probable paving schedules and closure requirements.

5 Case Study 2

I-5 Pierce County Line to Tukwila – Stage 2N PCCP Reconstruction

WSDOT's first documented use of CA4PRS as a productivity and estimation tool was the I-5 Pierce County Line to Tukwila – Stage 2N PCCP Reconstruction project. In September 2002, WSDOT project engineers used CA4PRS to develop four construction alternatives during scoping level planning and estimation. In order to determine the best construction alternative, project planners used CA4PRS to analyze the construction productivity and traffic impacts associated with each construction alternative. The resulting alternatives and productivities were then used by project engineers in selecting the preferred alternative in terms of construction costs, societal costs and traffic impacts. The following analysis documents how project engineers used CA4PRS at the scoping level and evaluates the benefits of using CA4PRS for assessing construction alternatives.

Information regarding this case study has been acquired from existing project documentation and a personal interview. Where applicable, documentation has been cited. Unreferenced material is the result of a personal interview conducted with Project Engineer Ziyad Zaitoun on July 17th, 2006

5.1 Project Background

In 1996 WSDOT began developing the PS&E to improve the I-5 corridor in the vicinity of the interstate intersection with State Route 516; however, a lack of funding delayed the project. The original project limits established in 1996 were eventually overlapped by other corridor development projects in the region. Due to this overlap, the original project was split into two smaller projects: I-5 Stage 2 South and I-5 Stage 2 North. The I-5 Pierce County Line to Tukwila Stage 2 South project was completed in 2002. As of the publication of this report, the I-5 Pierce County Line to Tukwila Stage 2 North was in design, but had yet to receive construction funding.

The Stage 2 North project entailed improvements to grading, drainage and retaining walls as well as roadway widening, HMA paving, cement concrete paving, pavement grinding and the installation of illumination. A major portion of the work will consist of repairing the cement concrete pavement on the two outside trucking lanes of Southbound I-5. In 2002, during the planning and scoping process, before the design of the Stage 2 North project, the project's design office produced a report that evaluated options for reconstructing the outside two trucking lanes. At the time of report composition, over 40 percent of the two outside trucking lanes of Southbound I-5 in the project area contained moderate to severe cracking (Zaitoun, 2002). Fixing the deteriorated pavement would require rebuilding 1.5 center-lane miles of the two outside I-5 trucking lanes between MP 150.55 to 152.44 with PCC. **Error! Reference source not found.**

5.2 Project Quantities

At the start of the alternative analysis, project engineers made assumptions about the material quantities involved with the project, as well as projections about the amount and type of equipment that would be available to potential contractors. The following table summarizes the assumed material and equipment quantities required for pavement reconstruction (Zaitoun, 2002).

Table 40 - Summarized Pierce County Line to Tukwila Material And Equipment Quantities

Assumed Material And Equipment Quantities
Nine inches of concrete to be removed totaling ~5280 yd^3
Two inches of base material to be removed totaling ~ 1174 yd^3
Total Material Removed ~ 6455 yd^3
25 demolition trucks available with a 12 yd^3 capacity
Two demolition crews
Replace 875 yd^3 of base material
Pave 6780 yd^3 of new concrete
Concrete placed at 120 yd^3/hr with 12 trucks

5.3 Project Closures

The closure window for weekend construction activities would consist of an extended 62-hour closure. Construction activities would begin at 8 p.m. Friday night and progress until 10 a.m. Monday morning. 55-hour weekend closures were used on the I-5 James to Olive project in order to accommodate rush hour traffic Friday evening and Monday morning. The closure window for the I-5 Tukwila project was extended by seven hours because project engineers anticipated lighter directional traffic volumes Monday morning which could be accommodated by the reduced lane configuration with closure warnings. Project engineers used CA4PRS to develop productivity estimates in order to determine the length of time it would take a contractor to repave the three miles of truck lanes. CA4PRS predicted that construction activities could potentially be completed in one extended weekend; however, this did not allow for additional time should contingencies, such as unexpected conditions or delays, arise. Attempting to complete the work with one weekend closure would necessitate a large mobilization and construction operation which would entail high risk for contractors. Recognizing the difficulties associated with a one-weekend closure led to the development of four construction alternatives.

5.4 Construction Alternatives

Project engineers developed four construction alternatives in order to weigh the risks, construction costs, societal costs associated with different closure windows and construction scenarios. The four construction alternatives developed and evaluated are presented below (Zaitoun, 2002).

Alternative One

Complete weekend closure of Lanes 1, 2 & 3, truck climbing lane and outside shoulder. Replacing two lanes between Friday 8:00 PM and Monday 10:00 AM: 62 hours.

Alternative Two

Complete 2-weekend closures of Lanes 1 & 2, truck climbing lane and the outside shoulder. Replacing one lane between Friday 8:00 PM and Monday 10:00 AM: 62 hours each.

Alternative 3

Nightly closure of Lanes 1 & 2 plus truck climbing lane and outside shoulder to be closed only from 8:00 PM until 10:00 AM. 14 hours per night.

Alternative 4

Complete 2-weekend closure of Lanes 1, 2 & 3, truck climbing lane and outside shoulder. Replacing two lanes between Friday 8:00 PM and Monday 10:00 AM: 62 hours each.

Engineers used CA4PRS to estimate productivity estimates and closure requirements for each alternative.

5.5 Calculation of Societal Costs

For each alternative, state traffic personnel calculated an associated societal cost. These costs provide a quantitative interpretation of the societal costs incurred due to vehicular delay and lost productivity because of construction. Traffic engineers look at historical traffic flows and existing capacity and compare these figures with anticipated traffic flows and capacity through the future construction work zone. Differences are attributed to congestion and delay caused by construction.

State traffic personnel assign passenger cars and trucks costs for the time a vehicle spends idling. Combining assigned idling costs with the projected construction delay generates a societal cost. Societal costs represent one variable considered when measuring aggregate impacts, but are not the key driver that controls project decision making. If two project alternatives have identical construction costs, but different societal costs, the project with the lower societal cost is not always selected. Other factors such as safety, public perception and political issues play a strong role in choosing the preferred alternative. Societal costs are not a definitive means for establishing decision between construction alternatives, but provide an indication for potential project impacts.

5.6 Calculation of Construction Costs

For each alternative, an estimated construction cost was developed. Although the materials and type of work remain the same for each alternative, the constraints imposed by the different closure windows control the amount and type of construction equipment and personnel needed to complete the work. Most importantly, the different construction windows dictate the level of risk associated with each alternative. For this particular project, alternative costs were developed using WSDOT unit price analysis. Cost figures for components of the work were further verified by receiving input from material suppliers and contractors. The cost estimates for each alternative incorporated the input from two contractors, Kiewit Pacific and Scarcella Brothers Construction.

5.7 Selecting the Preferred Alternative

Construction costs, traffic impacts, access, public support, product quality and safety are major issues considered during the decision making process. Weighing these costs leads to the selection of the preferred alternative. Table 41 provides a summary for the construction costs, societal costs, and safety issues related to each alternative.

5.7.1 Alternative 1

The first alternative was eliminated due to the large amount of risk associated with attempting to pave all 1.5 center-lane miles in one weekend. Although a deterministic CA4PRS analysis predicted that paving could be completed in one weekend, unexpected conditions or equipment failure could extend construction operations into Monday evening. Extending the closure window would have serious traffic impacts, causing unacceptable and severe traffic congestion. CA4PRS modeled this alternative as using concurrent double-lane construction operations. Providing sufficient space for access and equipment for concurrent double-lane operations would also require providing the contractor with almost all of Southbound I-5 for the 62-hour weekend closure. Due to the increased closure requirements, WSDOT engineers anticipated that this option would have a high societal cost and poor public support.

5.7.2 Alternative 2

The second alternative was eliminated because paving one lane at a time creates additional work and construction costs. If one lane is paved one weekend, the second adjacent lane would be paved the following weekend. On the second weekend, the contractor would be required to drill and install reinforcement between the two new lanes. Reinforcement can be installed without the use of drilling if both lanes are paved at the same time by using a twenty-four foot paving width.

5.7.3 Alternative 3

Estimators eliminated the third alternative on the basis of safety issues. In order to accommodate lighting, paving equipment and paving crews, the work zone would be extremely confined. A tighter work zone would limit productivity and place construction personnel closer to traffic. To keep lanes open and traffic moving during paving on the middle trucking lane, the contractor would most likely have to operate in a construction island. Traffic would pass on both sides of the work zone, reducing worker and traveler safety.

5.7.4 Alternative 4

Estimators and design personnel selected the fourth alternative as the preferred alternative based on construction cost and safety. This alternative enabled the use of an enclosed work zone, which would improve safety by separating motorists from construction workers. Secondly, paving two lanes at the same time reduced construction costs for installing transverse reinforcement between the two trucking lanes. One of the largest benefits of this alternative is that it provides protected access to the work zone on the second weekend. The first weekend, paving equipment would finish a segment of pavement between two different on/off-ramps. These ramps could be used solely by construction equipment the second weekend, guaranteeing good access and mobility. With secured access, risk and the amount of required trucking are both reduced. Combining these factors resulted in substantial cost savings.

5.8 Applicability and Evaluation of CA4PRS Usability

CA4PRS proved to be a useful resource for developing and evaluating construction alternatives on this project. An estimator with no prior experience or knowledge of CA4PRS was able to generate the entire report and deliver a preferred alternative within approximately 72 working hours. Without the aid of CA4PRS, the report would have taken an estimated four times longer. Although CA4PRS facilitated rapid estimates and the creation of an alternative evaluation report, this savings in time can be partially attributed to the construction and design experience of the estimator. The engineer assigned to develop the report was familiar with the area and the equipment that would be involved on the project. A new engineer and estimator may have difficulty using CA4PRS without prior background experience and knowledge of the construction process. CA4PRS has the ability to reduce the amount of construction knowledge necessary for estimates, but is not a replacement for experience. The only cited difficulties in using the software involved questions about program terminology.

Table 41 – Alternative cost comparison table.

Option	Description	Impacts to Traffic	Safety Concern	Cost of replacing the panels	Societal Cost Per Day
1	Complete weekend closure of Lanes, 1, 2 & 3, Truck Climbing Lane and outside shoulder. Replacing two lanes between Friday 8:00 PM and Monday 10: AM :62 hours	3 narrow lanes will be open to traffic for one weekend plus S 188th off ramp and Military Road on/off ramp will be closed for one weekend	Less safety concern to construction workers due to adjacent lanes closure. High Safety concern to the traveling public due to limited narrow lanes	$3,000,000 includes incentives for early completion	$4,000,000
2	Complete 2-weekend closure of Lanes 1 & 2, Truck Climbing Lane and the outside shoulder. Replacing one lane between Friday 8:00 PM and Monday 10:00 AM: 62 hours each.	3 narrow lanes will be open to traffic for one weekend and 4 narrow lanes will be open to traffic the following weekends. All on and off ramps will be closed during the weekend	Less safety concern to construction workers due to adjacent one lane closure. High safety concern to the traveling public due to limited narrow lanes	$2,700,000	$3,000,000
3	Nightly closure of Lanes 1 & 2 plus Truck Climbing Lane and outside shoulder to be closed only from 8:00 PM until 10:00 AM. 14 hours per night	4 Narrow lanes plus HOV lane will be open to traffic during PM peak traffic hours	High safety concern to both the traveling public and construction workers due o having traffic on both sides	$3,200,000	$12,000
4	Complete 2-weekend closure of Lanes 1, 2 & 3, Truck Climbing Lane and outside shoulder. Replacing two lanes Friday 8:00 PM and Monday 10:00 AM : 62 hours each	3 narrow lanes will be open to traffic for two weekends plus S 188th St. on ramp will be closed for the first weekend and Military Road on/off ramp will be closed the following weekend	Less safety concern to construction workers due to adjacent lane closure. High safety concern to the traveling public due to limited narrow lanes	$2,700,000	$4,000,000

6 Current CA4PRS Development Plans

CA4PRS developers have a schedule for improving its functionality. Over the next several years, the addition of traffic analysis, cost evaluation and new rehabilitation strategies will equip the software with a greater capacity for aiding the planning and design process. The following Table 42 provided by Dr. E. B. Lee from University of California, Berkeley (personal communication, July 14, 2006) outlines the development history and plans for the software.

Table 42 - CA4PRS Development Schedule

Version	Features	Completion
1.0	**Construction Analysis for Pavement Rehabilitation Strategies** -Basic Schedule Comparison: PCC, CSO, FDAC	2003
1.5a	**Improve User Interface** -Linked with Road User Cost Spreadsheet	2005
1.5b	**Adding Rehabilitation Strategies** -Continuous Reinforced Concrete Pavement -On-line Training Course Development	2006
2.0	**Including Cost Comparison Modules** -Road User Cost and Queue Evaluation -Agency Cost Comparison	2007
2.5	**Expand Rehabilitation Strategies** -Interchange Improvement -Roadway Widening	2008
3.0	**Integrated Pavement Rehabilitation Strategies Analysis** -Life Cycle Cost Analysis Module	2009

In August of 2007, after all the analysis completed within this report, enhanced versions of CA4PRS 1.5 and 2.0 were released.

Table 43 contains a description of these latest program enhancements.

Table 43 - Recent CA4PRS Enhancements

Version 1.5 Enhancements
Added milling and AC overlay (MACO) construction strategy
Added continuous reinforced concrete pavement (CRCP) construction strategy
Added elevation change interface to accommodate longitudinal elevation changes
Added multilane rehabilitation to analyze a flexible number of lanes for the full-depth AC replacement and AC overlay strategy modules
Added internet links for resource and help information within the Help menu
Improved program help file by adding more information to the program user manual and brochure
Improved sequential method input interface to incorporate rehabilitation strategies where construction activities follow one another
Version 2.0 Enhancements
Added a calculation model for traffic delay in the construction work zone as a demand-capacity model based on the highway capacity manual

7 Case Study Conclusions and Recommendations

The planning and design of new road construction projects is a time-intensive and complicated process. One major component of the project development process is the selection of a preferred construction alternative and the selection of a construction closure window. Selecting a preferred construction alternative and developing a project closure window is contingent upon the accurate estimation of contractor productivity and the amount of work which can be completed during different closure periods. As a productivity estimation program CA4PRS has the potential to save agency resources by quickly and accurately developing contractor productivity estimates given a closure window and scheduling and resource input parameters. The potential benefits of CA4PRS productivity estimation have been evaluated in two case studies: the completed I-5 James to Olive Project and the preliminary construction alternative analysis report for the Pierce County Line to Tukwila Pavement Reconstruction Project. Analysis of CA4PRS applicability and accuracy on the two evaluated case studies has led to the following conclusions and recommendations.

CA4PRS Should Be Applied During Early Planning and Alternative Analysis

CA4PRS should only be used for generating estimates for where the program has a corresponding level of detail. CA4PRS is applicable for alternative evaluation and early planning because the program can predict probable paving productivities and closure requirements with acceptable accuracy. At higher levels of design and review, CA4PRS estimates may not have sufficient detail or accuracy.

CA4PRS Estimates Should Be Produced From Probabilistic Analysis

Probabilistic analyses are more comprehensive and typically more conservative than a deterministic analysis. Potential construction productivity is not one specific value, but rather a range of potential values. By producing a distribution and a range of potential productivity, a probabilistic estimate depicts the potential variation in productivity and provides an indication of the risk associated with anticipated construction schedules.

CA4PRS Can Be Used to Verify Contractor Schedules

CA4PRS can accurately identify ranges of expected productivity given scheduling and resource input parameters based on demolition, base paving and surface course paving activities. The estimates produced by CA4PRS in this manner are accurate enough to verify the feasibility of schedules and productivity estimates submitted by contractors. If project staff regards contractor productivity estimates to be significantly lower or greater than a CA4PRS estimate, contractor schedules estimates should be given further examination.

CA4PRS Can Accommodate Complex and Variable Construction Conditions Through Input Parameter Modification

On complex projects such as the I-5 Olive to James Streets Pavement Rehabilitation case study, paving productivity was impacted by constraints such as:

- Lane tapers
- Disjointed paving sections
- Varying concrete cure times
- Structural walls
- Changing lane widths
- Variations in scheduling and activity sequencing

Accommodating complex or variable construction conditions can be difficult but is feasible with CA4PRS. For the I-5 James to Olive case study, a modified paver speed limited productivity to account for the productivity impacts of construction constraints. Constraints can be included into a program estimate by modifying any of the input parameters, but users are cautioned to exercise care developing modified estimates.

Probabilistic Distributions Should Be Given More Variable Distribution Parameters For Projects With Changing Construction Conditions Or Inexact Input Parameters

On the I-5 James to Olive case study changing construction conditions and contractor resource utilization resulted in weekend productivity that varied from a productivity low of 0.356 lane-miles and a high of 0.738 lane-miles. While none of the completed estimates captured this range of observed productivity, the third and fourth analyses produced mean weekend productivity estimates that closely approximated the observed average weekend productivity. These results indicate that the probabilistic estimates should have provided for greater productivity variability. Future estimate development for both variable projects and unknown input parameters should use greater probabilistic distribution parameters to provide for greater productivity variability.

Curing and Demobilization Times Must Be Carefully Evaluated For All Pavement Sections

All of the analyses on the James to Olive project assumed one mix design and that concrete quantities were placed in a traveling lane that needed to be opened to traffic. CA4PRS estimates incorporate the pavement cure time into the demobilization time. Some concrete quantities on roadway shoulders or gores may be allowed to cure after opening general traveling lanes to traffic. If some concretes can cure after the end of a closure window, a contractor may be able to pave more than CA4PRS predicts. Future CA4PRS estimate development should consider the curing requirements for all paving locations.

Current CA4PRS Operational Definition For Sequential Construction Operations Limits Program Applicability

The observed sequencing of construction operations on the I-5 James to Olive case study could not be modeled by CA4PRS without estimate input parameter modification. CA4PRS models construction operations as they progressed on the Californian validation projects, such as I-10 where base preparation and installation consisted of cleaning the CTB and completing localized spot repairs (Lee et al., 2001). In order to model the progression of activities observed on the I-5 Olive to James Street Pavement Rehabilitation project, CA4PRS must be provided with further operational definitions. Specifically, CA4PRS should accommodate base paving between the completion of demolition and start of surface course paving activities.

The Current (v 1.5a) CA4PRS Operational Definition For Concurrent Construction Operations Limits CA4PRS Construction Modeling Ability

When CA4PRS models concurrent construction scheduling, demolition, base paving and surface course paving activities are depicted as progressing at the same rate. This progression of construction can be seen in the linear scheduling chart of a typical deterministic analysis (Figure 39). On the I-5 James to Olive project, demolition, base paving and PCC paving had different durations and productivity rates (Table 44). When modeling concurrent operations, CA4PRS appears to set all activity progression rates to the limiting activity rate (Figure 39).

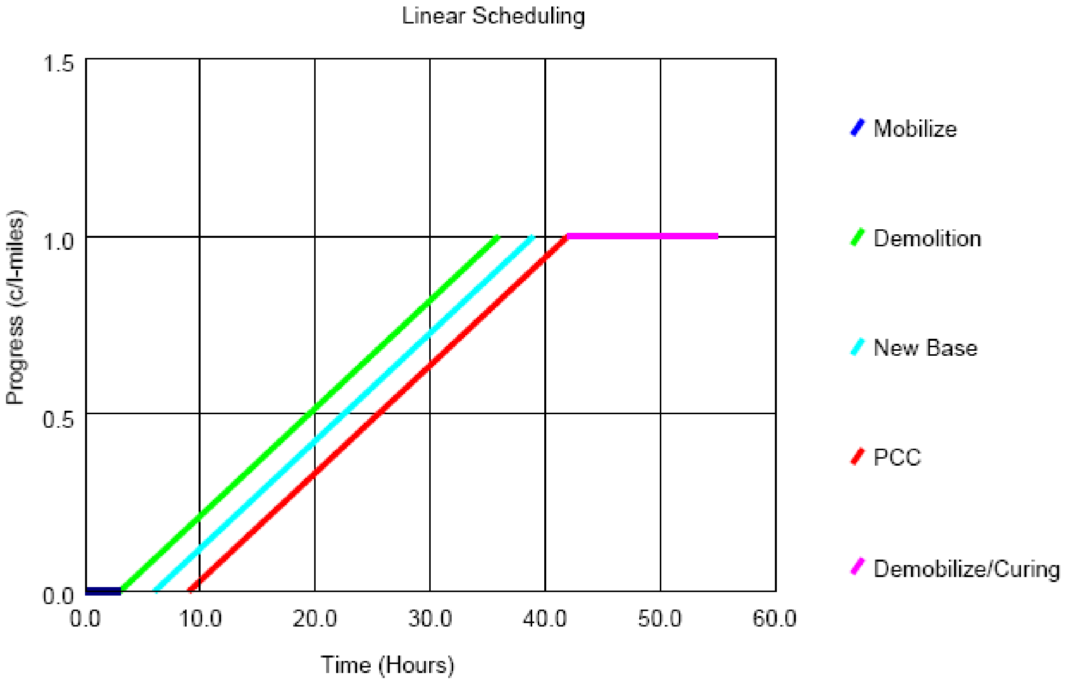


Figure 39 - Typical linear scheduling chart from a deterministic analysis modeling concurrent construction operations.

Table 44 - Observed Activity Durations From Inspector Reports

Construction Activity	Stage 1 (hrs)	Stage 2 (hrs)	Stage 3 (hrs)	Stage 4 (hrs)	Average
Demolition (hrs)	8.17	11.62	8.25	5.25	8.32
Base Paving (hrs)	4.17	4.20	4.25	4.42	4.26
Slipform PCC Paving (hrs)	12.83	8.17	10.03	4.75	8.95

The current operational definition of concurrent operations appears to be suited to the construction operations used on the I-10 Pomona project. During construction on the I-10 Pomona project, Caltrans used a contingency plan that specified that demolition activities could not progress past paving activities by more than 20 PCC panels (Lee et al. 2001). With this stipulation, the demolition progression rate was limited to the PCC paving rate. Without this limitation, demolition would have progressed far more rapidly (Lee et al. 2001). Because of the imposed demolition restriction, CA4PRS accurately models activity progression on the I-10 Pomona project. In order for CA4PRS to accurately model construction sequencing on future construction projects, the progression rate of all construction activities should not necessarily be identical when using concurrent operations.

CA4PRS Would Be More Comprehensive With Additional Scheduling and Resource Input Parameters

CA4PRS will have greater flexibility and applicability on construction projects if program users have the option of using additional input parameters. To apply CA4PRS at higher levels of estimation and scheduling, users should have the option to include some secondary construction activities into an estimate. Future versions of CA4PRS could benefit users by having the capability to model additional construction activities such as:

- Base or subgrade preparation
- Localized base repair
- Surveying and elevation control
- PCC panel sawcutting
- Lane striping

CA4PRS Requires Improved Program Documentation

CA4PRS contains inherent assumptions about the activities included under each construction phase. These incorporated assumptions are not clearly delineated within the project documentation. CA4PRS would be more useable if software documentation contained more description and information for users about the progression of secondary construction activities and other inherent assumptions about construction sequencing.

CA4PRS PCC Paving Should Include MultiCool

On the I-5 James to Olive Project, three inches of HMA served as the base for the concrete pavement. WSDOT standard specification 5-05.3(6) requires treated bases to cool to 90º F before PCC pavement placement (WSDOT Standard Specification, 2004). The CA4PRS input window for PCC paving does not include base cooling analysis with MultiCool. Future program development should include provisions for MultiCool analysis to be incorporated with PCC paving. Lastly, in the section profile window users have the option of specifying a 'Treated Base' paving depth. This input parameter should be changed to simply 'Base Material'. Treated base is a misleading description because state DOTs use a range of base materials that would not necessarily categorized as Treated Bases.

CA4PRS Estimates Should Always be Reviewed by Experienced Users

During the I-5 James to Olive project, six job-specific constraints were noted in section 4.1.4. All of these constraints impacted productivity rates for key activities such as paving and demolition. CA4PRS can incorporate construction constraints, but does so with the use of the inputs in the resource profile. If limited construction access and a tight work zone is a project constraint, inputs such as truck arrival rates may need to be modified. CA4PRS will use the assumptions input into the scheduling and resource profiles, but will not help users identify productivity constraints. Generating accurate inputs that reflect construction constraints will require experienced estimators who know how productivity rates are influenced.

WSDOT Should Collect Construction Data and Productivity Rates to be Used for Developing CA4PRS Estimates

CA4PRS estimates are produced from scheduling and resource input parameters and input parameter distributions. Accurate estimates cannot be produced without accurate input parameters and input parameter distributions; the accuracy of CA4PRS output is only as good as the accuracy of its inputs. WSDOT should collect and catalogue input parameter data from construction projects that have different closure requirements and construction conditions. Program users developing estimates for future projects can use these catalogued input parameters for CA4PRS estimates.

WSDOT Should Develop Accurate Input Parameter Distributions and Distribution Parameters

The case study analyses completed in this report used many input parameter distributions that were based upon assumptions or small data samples. Accurate probability distributions and distribution parameters cannot be assigned without reliable distribution data. WSDOT could improve the accuracy and reliability of future estimation by collecting and cataloging input parameter distribution information.

8 Rapid Concrete Panel Rehabilitation

8.1 Introduction

As substantial portions of the concrete roadways near the end of their service life, WSDOT is faced with important decisions regarding the repair of deteriorated roadway segments. Complete lane reconstruction is an expensive and disruptive method for replacing damaged roadway. Many portions of concrete roadways may be old, but still provide an acceptable level of service. Panel replacement is one attractive repair alternative that balances construction costs, traffic impacts and pavement service life. Using rapid panel replacement, a contractor can rapidly and efficiently replace failed panels in a roadway segment. Repairing only the failed panels maximizes the lifespan of the existing pavement that still supports traffic, while keeping construction costs and traffic impacts low by avoiding full lane rehabilitation. As panel replacement projects increase, more design offices and engineers will be generating plans and specifications for panel replacement. This report is meant to be used as a design aid and introductory text for transportation personnel unfamiliar with panel replacement. Included in this documentation is a description of (1) the slab replacement construction process and (2) general contractor comments on productivity, construction costs and project development.

8.2 Slab Replacement Process

8.2.1 Identifying Panels to Repair

Panel placement projects begin with identifying panels that require replacement and the mechanism of panel failure. Concrete panels requiring replacement are typically those that are broken in three or more pieces. However, panels with only one crack could qualify for replacement depending on the degree of distress. Panels with only one transverse or longitudinal crack usually have remaining service life if traffic loads can be transferred across the crack without panel movement or displacement. Although most panels in three or more pieces will qualify for replacement, current panel selection practices depend upon the judgment of those providing repair recommendations, typically

Region Materials Engineers (WSDOT Pavement Design Engineer Jeff Uhlmeyer, personal interview, February 12, 2007).

Panel failure can be caused by a variety of mechanisms such as pumping, faulting, transverse cracking, longitudinal cracking, corner breaks and joint spalls. Some of these failures are caused by extended periods of traffic wear, but can also be the result of failures in the subbase or subgrade material. For panels where failure can be attributed to insufficient subbase support, engineers must ensure that sufficient measures are taken to repair both the failed panel and subbase/subgrade. Within WSDOT, the majority of panel repair observed around the state is simply a matter of removing the distressed concrete, recompacting the subbase material and pouring back concrete to match the existing panel depth. Some high volume traffic sections have experienced severe panel cracking due to the loss of support from eroded cement treated base. However, these sections are becoming more infrequent (J. Uhlmeyer, personal interview, June 10, 2007). WSDOT engineers have several test methods at their disposal such as pavement coring and Falling Weight Deflectometers (FWDs) to identify failure modes and the level of panel failure.

8.2.2 Traffic Control and Mobilization

The start of a project closure window begins with establishing traffic control and mobilizing equipment and personnel. Traffic control is essential for providing both a safe working zone for construction personnel and moving traffic safely through a work zone. Traffic control can consist of different devices such as cones, barrels, concrete barriers, signage, pavement markings, detours and other traffic control measures. The type and amount of traffic control used for a project is determined by a variety of job site factors including traffic volumes, time of construction, equipment operating room requirements, the amount of equipment, project size and the geometric layout of the roadway segment. Setup of traffic control is essential for project safety but has direct impacts on paving productivity. Longer time requirements for establishing traffic control can reduce time available for construction activities.

Mobilization times also influence how much time is available for paving productivity. At the start of every closure window, a contractor will have to move all equipment and personnel from a staging area to the work zone. Mobilization time requirements will depend upon site access and how much equipment must be moved.

8.2.3 Sawcutting

Concrete panels identified for replacement are separated from adjacent panels by full-depth sawcutting around the perimeter of the area that is to be removed. Extending saw cuts the full depth of the slab ensures that no loads are transferred to surrounding panels during slab removal. If panels are to be removed intact, then the existing pavement must be sawed into sections small enough for equipment to handle. Caltrans has developed a suggested saw cut pattern and removal procedure for panel replacements that is shown in Figure 40. In this diagram, the first concrete pieces identified for removal are in the center of the panel. By removing the center pieces first, the remaining panel pieces can be moved towards the empty center and separated from nearby panels to avoid any load transfer during removal.

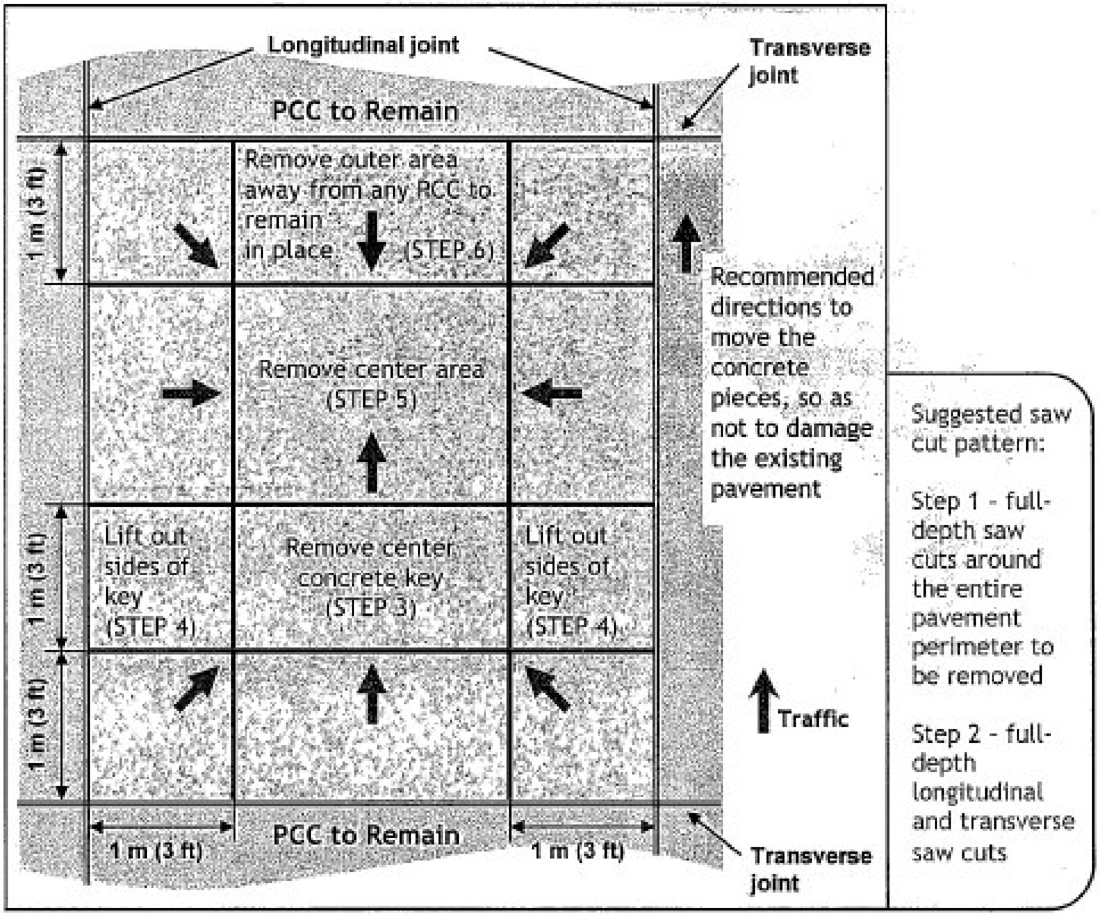


Figure 40 - Caltrans suggested saw cut and concrete removal diagram (Caltrans, 2004).

Sawcutting can progress either alongside construction crews or may be completed prior to replacement. The decision to saw cut panels alongside construction crews or during previous closures has a significant impact on productivity. Sawcutting prior to the start of a construction closure enables panel removal and replacement work to begin immediately, whereas otherwise equipment and crews must wait for sawcutting crews to finish before starting panel removal. Sawcutting prior to a closure window can improve productivity, but also has the added benefit of not disrupting vehicular traffic outside of the closure window. Sawcutting does not necessarily prevent traffic operations because sawed panels on a firm base are capable of supporting traffic loads and providing a safe driving surface. Although saw cut panels can support traffic loads, WSDOT does not typically allow contractors to saw panels more than two days prior to panel replacement.

How sawcutting progress, either prior to or during a closure, depends on WSDOT allotted construction windows and contractor resources and scheduling.

8.2.4 Demolition

Demolition and removal of identified concrete panels immediately follows mobilization. Panel demolition can be classified into impact and non-impact methods. Impact methods involve demolishing a concrete panel with a variety of equipment including Hoe-rams and hammers. Impact methods are not commonly used because they are disruptive to the subgrade and may necessitate additional subgrade compaction and grading (CALTRANS, 2004). Impact methods are also noisier, which is an important issue in locations near residential or commercial development. Non-impact methods use concrete saws to cut a failed slab into pieces which can be removed intact, or broken into smaller pieces with an excavator bucket and then removed. Using sufficient well-paced and full-depth saw cuts is essential in order to avoid damaging nearby panels. If sawcuts do not run full-depth, excavation or further demolition can transfer harmful stresses and loads to connecting panels (WSDOT Forensic Report, 2006). Non-impact demolition begins with the careful removal of one concrete segment. Care must be taken when removing the first panel piece because demolition stresses and forces can still be transferred throughout a sawcut, but intact panel, to adjacent panels. The use of a lift pin and a steel chain is one common method used for removing the first slab segment, whereby a pin is inserted into a hole that has been drilled into the slab. A steel chain is then attached to both an excavator and the pin. The excavator then vertically lifts and removes the first slab piece. Other methods involve using hand teams with pry bars and smaller hand-demolition equipment. After the first segment has been removed, excavators, forklift devices and torque claw attachments for front-end loaders can be used to remove the other pieces of the concrete slab. Removing concrete in relatively intact sections can be faster, requiring less labor and slab demolition. Although faster, removing slabs intact can pose several problems which have to be addressed (CALTRANS, 2004):

1. Pre-sawing may not have been completed to the full slab depth
2. Panels may shatter when they are lifted
3. Panels thickness may vary and be thicker than anticipated

4. Base material may bond with the slab

During demolition as well as all other phases of construction where heavy equipment is used, care should be exercised when operating equipment at open panel edges. After sawcutting and panel removal, the adjacent existing panels can lose support at the sawcut face. On a recent WSDOT panel replacement contract, this loss of support combined with a soft subgrade and equipment operations potentially led to panel cracking two to four feet away from the panel edge (WSDOT Forensics Report, 2006). Contract design and construction inspection for future panel replacement contracts on soft subgrade should address how to protect panels from cracking due to equipment operations.

8.2.5 Base Preparation and Repair

Slab removal is followed by subbase preparation. A compact and level base is essential for establishing a solid foundation for the replacement slab. Repairs are typically required for areas where the subbase/subgrade is excessively wet or where there are pockets of loose or missing material. WSDOT specifications specify a repair procedure if subbase/subgrade repair is required. If contaminated or non-compactable subbase/subgrade material is encountered, WSDOT Standard Specifications require existing base to be excavated to a depth of two feet and covered with a soil stabilization construction geotextile. The excavated area can then be backfilled with asphalt concrete or crushed surfacing base course. Where subbase repairs are not required, the original surfacing is graded level and recompacted. Crushed surfacing is often added to further stabilize the base surface where subbase is disturbed or removed during the demolition process.

8.2.6 Dowel and Tie Bar Installation

WSDOT specifications require that new panel replacement have both longitudinal tie and transverse dowel bars installed to aid the transfer of loads between panels. Partial panel replacement does not require the installation of tie bars. Slab reinforcement installation begins with drilling holes for transverse dowel and longitudinal tie bars. Reinforcement drilling should use automatic equipment such as slab-rider or base-rider drills. Automatic drilling equipment is faster, more consistent and more accurate than hand drilling

(CALTRANS, 2004). Slab drilling equipment can require several feet of operating space around the perimeter of a slab and requires the allocation of sufficient maneuvering room during closure plan development. Compressed air is then used to clear the drilled reinforcement of deleterious dust and debris. Before insertion, new reinforcement is covered with a concrete bond breaker such as form oil or grease. However, over application of a bond breaker should be avoided to prevent voids being created around dowels. By preventing bonding, two adjacent slabs are free to move independently and alleviate some slab stresses (CALTRANS, 2004). Appendix K contains WSDOT's current Standard Plan A-6 Cement Concrete Pavement Repair which details dowel bar and tie bar placement. According to WSDOT Standard Specification 5-01.3(4) Replace Portland Cement Concrete Panel, reinforcement installation is permitted with the following placement tolerances:

Dowel Bars Placement Tolerances

1. ±1 inch of the middle of the concrete slab depth
2. ±1 inch of being centered over the transverse joint
3. ±½ inch from parallel to the centerline
4. ±½ from parallel to the roadway surface

Tie Bars Placement Tolerance

1. ±1 inch of the middle of the concrete slab depth
2. ±1 inch of being centered over the transverse joint
3. ±1 inch from perpendicular to the centerline
4. ±1 inch from parallel to the roadway surface

Specifications require that tie bars are set into existing pavement with an approved epoxy bonding agent. Installation is completed by filling the voids between slab concrete and reinforcement with a non-shrink grout to eliminate air voids.

During dowel bar installation it is important to drill clean reinforcement holes without spalling or deteriorating existing concrete. WSDOT recently had problems with a panel replacement contract where reinforcement drilling caused panel spalling and fracturing at the sawcut panel face. In locations where drilling caused too much damage, dowel bars were omitted. A combination of spalled concrete and omitted dowel bars are thought to have led to additional panel cracking and a need for additional panel repairs (WSDOT Forensic Evaluation, 2006).

8.2.7 Bond Breaker

A PCC bond breaker is installed before PCC placement to separate PCC panel pavement from the subgrade and the concrete of adjacent panels. This separation from the adjacent panels and subgrade enables the new panel to move independently to relieve stresses that are developed and transmitted to the panel as it cures or is exposed to external loads and temperature gradients. WSDOT specifications call for a polyethylene film or equivalent to be used as a bond breaker. On many WSDOT projects, a light weight roofing paper (30 pound) has become the material of choice (J. Uhlmeyer, personal interview, June 10, 2007).

8.2.8 Concrete Placement

Reinforcement and bond breaker installation is followed by placing PCC pavement in accordance with WSDOT standard specification 5-01.3. PCC is typically delivered to the job site and poured into the demolished slab area by a PCC mixing truck. The PCC mix is then consolidated and finished to a textured surface that is level with adjacent panels per referenced specification.

Predominately the mix type for rapid panel replacement work has been Type III cement. Typically these mixes consist of 750 pounds of cement per cubic yard with non calcium chloride accelerators and set retarders. Opening to traffic times for these mixes have been in the six to eight hour range. Type I-II cements have also been used with opening to traffic in the nine to ten hour range (J. Uhlmeyer, personal interview, June 10, 2007).

Today, for rapid concrete work WSDOT allows the contractor to submit concrete mix proposals based on the proposed construction windows. Concrete suppliers continue improve their mix capabilities. Other options, such as the Caltrans 4x4 mix options (Caltrans Slab Repair Guidelines) are available; however, WSDOT has no experience with these mixes. Generally, WSDOT contractors have avoided the Rapid Set type materials due to additional costs and risks with using these products. More comments on the use of Rapid Set type materials are discussed in the following sections.

8.2.9 Joint Installation

For panel replacement contract, WSDOT requires concrete panels to have longitudinal and transverse joints sawed and sealed in accordance with standard specification 5-05.3(8) and WSDOT Standard Plan A-1 This specification outlines the spacing and depth of sawcuts, acceptable equipment and that sawing must proceed in a timely manner to control cracking. Joints used by WSDOT are single sawcuts two to five mm in width. Joint construction is finished by sealing the joints with a hot poured sealant to prevent the intrusion of water and fines into the joint.

8.3 Contractor Comments On Concrete Panel Replacement

Rapid panel replacement contract development and project costs are dependent upon contractor productivity and operational capabilities. The purpose of this section is to provide insight about construction productivity, windows, costs and contract development from panel replacement contractors to aid future contract development. Data presented in the following sections was collected from two interviews with paving contractors that have worked on WSDOT panel replacement contracts. Due to the proprietary nature of some of the discussed productivity information, details and transcripts of these interviews are not provided in the appendix. Presented data has been grouped into three panel replacement topics:

1. Productivity
2. Costs, and
3. Contract development considerations

8.3.1 Panel Placement Productivity

1. Mobilization Time Requirements

Prior to the start of a closure window contractor equipment and construction personnel are readied and wait in a staging area near the project or on roadway ramps. Traffic control immediately begins at the start of the closure window by installing equipment such as barrels and signage to secure the construction work zone. For typical night closures, contractors cited traffic control installation as requiring approximately one hour for completion. Traffic control may take an hour, but equipment unloading and crew mobilization begins when sufficient work space has been secured. Dependent upon project constraints and traffic control specifications, excavator demolition and pavement removal activities can begin 30 to 75 minutes after window establishment. If the contractor is mobilizing sawcutting equipment, work will likely begin 30 to 60 minutes after the start of the closure.

2. Critical Path Construction Activities

The contractors were asked to identify which, if any, activities usually control scheduling and productivity. In general, contractor productivity estimation and scheduling is completed by lumping activities together and looking at how many panels are likely to be placed during a closure. No single activity was identified as being a controlling factor for construction schedules, but both demolition and tie and dowel bar drilling were both noted as requiring special consideration. Accurate scheduling of demolition is important because once pavement removal starts, a full panel placement crew has to be mobilized and the contractor must be confident work can be completed and the road opened to traffic. Tie and dowel bar drilling was also noted to require special consideration due to potential variations in panel concrete hardness. Productivity and providing sufficient equipment and crew requires estimating existing concrete hardness and how many reinforcement holes can be drilled per minute.

3. Variation of Slab Replacement Productivity Per Closure Window

Contractors were asked to provide typical panel replacement productivity rates for different closure windows scenarios to aid future construction schedule development. The contractors expressed expected productivity in ranges to accommodate differences in construction conditions and materials (Table 45). These ranges assume that panels have not been cut prior to the start of construction.

Table 45 Closure type and number of panels to be replaced – one crew

Type of Closure	Panels Completed within the Closure
8-Hour Night Closure	4 – 8
10 Hour Night Closure	5 – 11
12 Hour Night Closure	5 – 14
55 Hour Weekend Closure	Unknown, but high productivity expected. WSDOT has experience 50-60 panels completed in a 29 hour period.

4. Productivity Impacts of Slab Spacing

The spacing and distribution of panels was one of the factors contractors cited as having the strongest influence on replacement productivity. For one, panel spacing impacts how much available construction time will be spent moving construction equipment and personal between work areas. During a 12-hour closure, the upper productivity range of 11-14 panels per hour can be achieved when panels are clumped or in rows. Within the same closure window, productivity can fall to five or six panels if the panels are widely spaced or distributed and crews and equipment have to repeatedly mobilized and demobilized between individual panels.

Secondly, productivity can also drop due to increased work requirements of spaced panels. In a replacement scenario where ten panels are in a row, a contractor may have 650 feet of sawcutting if sawcutting is included within the closure provided. If all ten panels were independently spaced, there could potentially be 1,900 feet of sawcutting. Due to the high variability in construction conditions, the mobility and additional work impacts of panel spacing must typically be addressed and factored on a case-to-case basis.

5. Demolition Trucking Requirements

For the purpose of aiding future estimation of trucking requirements on rapid panel replacement projects, the interviewed contractors were asked how they determined trucking needs. A general rule was given that for each excavator about three dump trucks are typically required. However, the distance required to dispose of the excavated panel also has an effect. A dump truck can typically hold 1.5 panels whereas a side dump truck can hold 2-2.5 panels. Dump trucks cannot be over-filled with large slab pieces; otherwise demolished concrete can get stuck on truck gates during dumping. Side dump trucks do not have problems unloading demolished concrete, but should only carry 2-2.5 panels so truck loads do not exceed WSDOT road axle weight restrictions.

Precise identification of trucking requirements requires calculating truck cycles. This process includes estimating time requirements for loading, hauling to a storage/disposal site, unloading, and returning to the job site. Given cycle times, truck load capacity, and a demolition rate, trucking requirements can be calculated. One issue that does occur with night work is that material handling and disposal centers are frequently closed. If material disposal sites are closed, a contractor will have to make provisions for temporary material storage. In some instances, contractors can negotiate agreements with disposal sites and be granted access on an honor system. When using an honor system, a contractor will be given a key or access code to a disposal site and will track the material that they deliver.

8.3.2 Panel Replacement Costs

6. Construction Costs and Closure Windows

Construction costs and what WSDOT pays per rehabilitated panel are directly influenced by the type of closure window specified within project specifications. For one, contractor resource and labor utilization is more efficient for longer closures. For an eight hour closure, a one hour requirement for mobilization and demobilization may leave a contractor with six hours to complete work. If concrete curing requires three to four hours, only two or three hours are available for replacing panels. Specifying a three to four hour curing window also predicates the use of a rapid set proprietary cement product. Providing a contractor with two more hours can potentially double viable productivity time while the closure duration is only increased by 25 percent. Both of these closure scenarios also require the same costs and resources for mobilization and demobilization.

The construction cost impacts of this efficiency gain on panel replacement costs can be partially understood by looking at labor costs. If 15 crew members work an eight hour shift, a contractor must pay personnel for 120 hours of labor. If labor was to cost $50 per hour, the contractor would need to recover $6000 in labor costs. If six panels are replaced, the labor cost per panel will be $1000. In contrast, for a 12 hour closure, personnel must be paid for 180 hours of labor, or $9000. If the contractor can be expected to replace 12 panels in this window, labor costs decrease to $750 per panel. In this scenario, a single replacement panel is 25 percent less expensive or $250 less per panel.

The closure window duration also influences the project mix design, which in turn impacts material costs. Concrete for roadway paving can have a wide range of curing times. More conventional mixes are designed to set in 12 or even 24 hours. As was discussed previously, concrete with Type III cement can be engineered for opening to traffic requirements in six to eight hours. Extremely short closure windows require the use of rapid set concretes which have higher material costs and are more risky construction materials. With a two or four hour cure time, a contractor using rapid set concrete must accurately control construction progress. Delays in delivery or material finishing pose significant risks because entire batches of material can set within a delivery truck, or set before pavement finishing. In the first scenario, the contractor would have to pay for material to be chipped and removed from the delivery truck. In the second scenario, the contractor would have to demolish and remove the newly placed slab. In addition to additional labor costs of material removal, the contractor will also have to absorb the costs associated with wasted material.

The risk associated with rapid set materials is also factored into the material cost. For riskier quick-setting mixes, a contractor could charge as much a $900 for a cubic yard of concrete. A slightly less aggressive cement Type I-II mix with a nine hour cure time could have a potentially much lower cost of $110 to $150 per cubic yard. The cited unit prices may be on the upper and lower bounds of cubic yard costs, but provide an indication of the increased material and handling costs required by short construction windows and fast-setting paving materials.

7. Mobilization Costs

To provide a brief introduction to mobilization and the costs associated with mobilization, contractors were asked what mobilization includes and how they calculate mobilization fees.

Mobilization costs are bid as a lump sum item which contractors use to recoup construction costs that are not directly calculated. A contractor will expend financial resources on non-productive construction activities and items that can include moving equipment to the jobsite, a job trailer, crew standby time and moving equipment from the jobsite. All of the various activities that are not directly billed can get wrapped into the mobilization fee. Contractors described two methods used for calculating mobilization costs: lump sum estimation and item calculation.

Lump sum estimation is a simple and straightforward technique where contractors estimate a lump sum cost based on experience. If a contractor has completed a project of similar size and scope, they will know approximate operating costs and can estimate a lump sum cost. Lost operational costs can be estimated and developed on a weekly, monthly, or project basis.

Item calculation is more precise and is used when a lump sum cannot be estimated with sufficient confidence. During item calculation, a contractor will identify, calculate and sum the costs associated with construction activities not covered in a WSDOT bid list. For instance, a contractor may require crews and equipment to be at a jobsite and on standby 30 minutes prior to the start of a construction closure. The contractor then must calculate how much idle sawing, demolition, drilling and pourback crews and equipment will cost per closure over the duration of the project. Other factors such as bid development costs, management personnel costs and equipment trucking may also be individually calculated and included in the mobilization cost.

Mobilizing equipment and personnel for a construction contract can drain contractor financial resources. Finances can be further strained if a contractor is also required to pay upfront for lead items such as tie and dowel bars. Mobilization fees are typically one of the first items billed to WSDOT and collected in the first pay application. By modifying the mobilization lump sum, contractors can increase early project cash flows and mitigate the drain on their financial reserves. Mobilization sums can be modified by decreasing the unit bid price of another item and increasing the mobilization sum by a corresponding amount. This practice of changing unit costs and modifying the mobilization fee ensures that a contractor will have adequate cash flows available prior to and during construction.

8. Addressing Unknown Subbase/Subgrade Conditions

For most panel replacement projects, contractors are replacing failed panels that have supported traffic for 20, 30 and 40 or more years. The subbase/subgrade under the existing pavement is typically in excellent condition and tightly compacted after years of supporting traffic. Poor subbase/subgrade is infrequent and does not usually pose a significant problem. If subbase/subgrade issues exist, they can frequently be identified during pre-bid inspections. During site inspections contractors look for pumping failures and indications of wet subbase/subgrade such as moisture on roadway shoulders and surface water in adjacent roadway ditches. Payment methods for repairing subbase/subgrade vary between WSDOT regions. Contractors typically accommodate subbase/grade rehabilitation by using force account or by adding estimated costs into bid items for the anticipated subbase/subgrade repairs.

8.3.3 Contract Development

9. Identifying Panel Replacement Risks

The risks associated with completing a panel replacement contract impact project delivery costs. To identify the largest potential risks, contractors were asked what they perceived as the most important risks when looking at a contract. The two most significant risk factors were given as concrete mix design set time and panel spacing.

Contractors cited using rapid-setting concrete as risky and scary due to the potential for concrete batches set in a truck. The risks and cost impacts of rapid-setting concrete were discussed previously, but were again mentioned and emphasized by the interviewed contractors. A contract requirement for rapid setting-concrete is one the greatest risks a contractor identifies during project bid development and has strong impacts on construction costs.

Panel spacing and distribution was the second greatest risk identified by contractors. The impacts of panel spacing on construction spacing must be addressed on a project to project basis. Contractors have to base productivity estimates on prior experience and judgment. Contractor personnel consider the productive time available during a closure window and then look to see if panels are stretched, grouped, single panels or half panels. Because productivity estimates are based on judgment, contractors must also carefully balance the financial impacts from any potential error in judgment.

10. Operational Room Requirements

Panel replacement closure plans should ideally provide a contractor with at least two lanes to accommodate an excavator and a truck. At a minimum, for handpaving and concrete panel finishing, at least two feet of clearance must be provided between traffic control and the new pavement. If slipform operations are being used, three feet is required. For slab reinforcement drilling, slab rider drills require five feet of operational space whereas grade riders require about one foot. These clearance requirements represent the minimum amount of space necessary to complete work and can have strong impacts on replacement productivity. By providing more space, work can progress faster and more efficiently. In terms of productivity impacts, one contractor cited that panel productivity in a 12-hour closure could increase by at least two panels per closure if one access lane was provided on either side of a replacement panel.

11. Preferred Contractor Construction Closure

Contractors cited that they preferred longer closure windows in order to efficiently use crews and equipment. Weekend and extended closures are the most desirable, followed by 12-hour nighttime closures.

12. Contractor Comments on Contract Incentives and Disincentives

WSDOT has used incentives and disincentives in order to manage traffic impacts and construction costs. Panel replacement contractors were asked to share general comments and opinions about their impressions of contract incentives and disincentives.

The general opinion amongst the interviewed contractors was that they preferred contracts without incentives and disincentives. For one, they cited that the disincentives are always larger than the incentives. A contract with a $5,000 incentive for finishing work a day early may have a much greater disincentive of $45,000-$50,000 for each day late. Managing the increased risk of larger disincentives is not generally offset by a smaller incentive. Achieving the incentive was also cited as not typically being very profitable. To complete work on an incentive schedule, a contractor usually has to pay for additional labor and equipment, or provide higher compensation to personnel working longer hours. Expending greater funds and effort on more equipment, labor and planning diminishes the returns of an incentive. If additional equipment and labor costs a contractor $65 out of every potential $100 earned, than the incentive will not be as attractive or may not justify the additional effort. Incentives were also blamed for enticing unqualified contractors to bid on work. Contractors with insufficient experience assume that they will get the incentive and lower their bid price which enables them to win the contract but not have the ability to meet deadlines. In general, the interviewed contractors stated they preferred not using incentives and disincentives.

13. Contractor Comments On WSDOT Contract Development

At the end of each interview, contractors were asked to provide comments on any reoccurring issues or problems they frequently saw in WSDOT panel replacement contracts. The first cited issue was that WSDOT schedules sometimes omitted, or did not correctly allot time for panel relief cut sawing. This issue was cited as having been a problem, but an infrequent one.

The second contractor comment addressed the use of shorter construction windows. The contractor's opinion was that WSDOT project management is typically more concerned with public traffic impacts than completing a project. The contractor pointed out that a significant amount of contractor and state resources are consumed in mobilizing equipment and personnel during short construction windows. Material and labor costs are also far greater per panel with rapid set materials and short construction window. In the same regard, the contractor felt that traffic impacts were the same, if not greater, using short construction windows. The loss of equipment and personal efficiency extends a project and prolongs lighter traffic impact closures. The contractor cited one example in which a WSDOT contract that specified one year of night closure could have been completed using four 24-hour closures. The contractor felt that stretched construction schedules have an overall larger impact on traffic than extended closures and that WSDOT should use more extended closures. However, the contractors also recognize that when project plans, specifications and engineering is done the state does not know specific contractor equipment or workforce capabilities. Because these issues are not known, it is more expedient for WSDOT to award a contract that provides shorter construction windows with less traffic impacts than to award a contract that may have shorter working days yet provide unbearable traffic impacts. In WSDOT's view, it is easier to award a contract that is doable yet allows the contractor flexibility to adjust the schedule to longer closure periods if the contractor requests a change based on a more efficient operation (J. Uhlmeyer, personal interview, June 10, 2007).

8.4 Conclusions

The purpose of this section was to provide an introduction to the panel replacement construction process and present productivity, cost and contract development comments from panel replacement contractors. The following conclusions summarize major panel replacement comments provided during the contractor interviews.

1. WSDOT contract development should carefully weigh the productivity benefits and traffic disadvantages of longer closure windows. Extended closure windows provide large gains in construction productivity and efficiency; given a 50 percent time increase from an 8-hour to a 12-hour closure, slab replacement productivity can be expected to double.
2. Contract development must recognize and manage the financial implications of eight and 10-hr night closures. Shorter construction windows can increase both labor and material costs, which results in more expensive panel replacement contracts.
3. Rapid set concretes that are typically used on panel replacement contracts with short closure windows are significantly more expensive. The higher material costs and increased risks associated with these materials result in more expensive projects.
4. Given the option, a contractor prefers a closure window of at least 12 hours.
5. Contractors prefer not to use incentives and disincentives. Financial incentives are typically much lower than disincentives; adding further risk management to a project. Second, paying for the increased equipment and personnel required to pursue an incentive is expensive which reduces the value of the incentive return.
6. One contractor offered the opinion that frequent low-impact closures have greater overall traffic consequences in comparison to infrequent high-impact closures. For one construction scenario a contractor suggested that one year of night closure could have been replaced with four 24-hour closures.

9 Polymer Concrete

As with highways, closing bridge lanes or an entire bridge for maintenance and construction work can impact road-user mobility. Because of the potentially large and negative impacts to traffic, bridge deck maintenance and rehabilitation is ideally suited for rapid construction. To address the unique constraints associated with bridge maintenance and construction, WSDOT has the option to use fast-setting polymer concrete overlays when rapid construction is needed. Polymer concrete refers to a family of materials that use a polymerizing monomer and aggregate to form a composite material. These composite materials can have several unique material properties which make them ideally suited for a variety of paving conditions. The following points summarize the major benefits of polymer concrete as a rapid rehabilitation and construction material (Maggenti, 2001).

1. **Rapid Curing Times** Polymer concretes react aggressively and can cure to acceptable levels of pavement strength within one and a half to four hours, allowing construction lanes to be quickly returned to general traffic
2. **Chloride Protection** Polymer concretes develop a dense material matrix that is almost totally impermeable and protects bridge reinforcement steel from the intrusion of water and deicing salts that could contain corrosive chlorides
3. **Surface Restoration** Polymer pavements can be placed in thin layers over uneven and rough surfaces in order to restore skid resistance and provide an even driving surface. Properly placed pavements are abrasion resistant and estimated to provide acceptable levels driving surface performance for between ten and 20 years.
4. **Lightweight** Polymer concretes are lighter than traditional concrete or latex modified concrete overlays and can be applied with a thin overlay. Some bridges do not have the strength or clearance to support the additional load or height of a concrete overlay.

Polymer concrete have paving is a specialized process that requires customized equipment and construction management and is very sensitive to construction conditions and moisture. The unique labor, equipment and material composition of polymer concretes contribute to a high material cost. Because polymer concretes are typically more expensive, they are only used as a paving material on rehabilitation projects that maximize the unique material benefits of polymer concretes (Baker, Smith, & Weston, 2003). WSDOT has limited the future use of the 3/8 inch thick epoxy and methyl methacrylate polymer overlays on bridges due to poor past performance. Over the last several years, WSDOT and other public transportation agencies have gained further experience with the ¾ inch thick polyester polymer concrete on bridges. The section provides a general reference for polymer pavements and their use by WSDOT. This is achieved by (1) providing a general description of polymer pavement use in Washington State (2) describing the polymer concrete chemical reaction process (3) introducing pavement performance and testing methods (4) summarizing the pavement construction process (5) discussing polymer concrete issues and (6) providing some general comments in regards to polymer paving from a polymer paving contractor.

9.1 Polymer Concretes In Washington State

In Washington State, some of the first polymer concrete overlays were placed in the mid- to late 1980's. One of the first polymer concrete applications was in 1984 on the Chehalis River Bridge near Aberdeen. By 1984, the Chehalis River Bridge deck was worn and in need of restorative measures. Engineers developing a contract to repair the bridge were faced with unique project constraints. Part of the bridge consisted of a movable span that could not support the additional load of a more traditional concrete overlay. Additionally, the bridge was an essential link in the regional transportation network and could not be closed for extended periods of time. WSDOT engineers addressed these unique constraints by using a thin polymer concrete overlay to minimize both the addition of excess structure load and construction closure requirements. After the successful application of the first polymer concrete overlays, WSDOT completed several additional polymer overlays in the following years. Although WSDOT had been gaining experience with polymer concrete as a paving material, by 1991 polymer use in Washington State was still fairly limited. In 1991 WSDOT funded a contract to use a ¾ inch polyester polymer concrete overlay on the Port Washington Narrows Bridge in

Bremerton. Within two years the overlay began exhibiting signs of pavement failure due to improper overlay curing and necessitated rehabilitation efforts (Sherrell, 2002). According to an end of project report composed by Sherrell of Appia Engineering Consultants (2002), failure of the overlay was attribute to five factors:

1. Moisture on both the deck and in the aggregate
2. Temperature variations during the project that were not accommodated by adjustments to the paving mix
3. A Project Engineer's office that lacked the tools to recognize and correct problems
4. Inspectors did not take fields sample of raw or mixed materials to check proper and proportional mixing
5. An inexperienced contractor who was working with new and untested equipment that did not monitor raw material delivery systems

In 1993 restorative measures were implemented to fix the observed pavement failures. After the repairs and as of 2007, the restored bridge deck has provided 16 years of service with little to no repair (DeWayne Wilson WSDOT Bridge Management Engineer, personal communication, March 27, 2007). Although the overlay was functional after rehabilitative efforts, WSDOT did not implement any further polyester polymer concrete contracts for the next ten years based on its poor experience with the project.

In 2002, polyester polymer concretes were again evaluated as a paving material as WSDOT engineers were faced with deteriorating I-5 bridge decks in the Northgate vicinity. The existing concrete driving surface on these bridges had worn away, which led to prominent rutting and the exposure of bridge reinforcement steel (Figure 41). State engineers were faced with difficult decisions regarding construction operations and lane closures. In the Northgate corridor, I-5 supported daily traffic volumes in excess of 200,000 vehicles (WSDOT Annual Traffic Report, 2002). Traditional concrete rehabilitation efforts would have required several days of lane closures for construction and concrete curing. These long closures would have caused severe congestion and disruption to the regional transportation network (WSDOT Projects, 2002). In order to limit traffic impacts and protect the bridge reinforcement steel, WSDOT engineers developed a contract to place a new polymer concrete bridge deck overlay. Other than some performance issues related to improperly sawed expansion joints, these Northgate polymer overlays have performed up to WSDOT expectations (DeWayne Wilson WSDSOT Bridge Management Engineer, personal communication, March 27, 2007).

Figure 41 - Exposed bridge reinforcement steel Puyallup River Bridge. (Tharp, 2004)

As of 2005, WSDOT reported the use and maintenance of polymer concrete on eighteen bridges, for a total of 386,000 square feet of polymer overlay (Appendix L). Since 2002, WSDOT has continued to develop and implement further polyester polymer concrete overlay contracts. In 2003 WSDOT successfully completed a major polyester polymer concrete rehabilitation on the I-5 Puyallup River Bridge. Polyester polymer concrete was again used as an overlay material on Northbound I-5 bridge decks at SR-18 and S 336th Street through Federal Way in 2006. The use of traditional concrete overlay materials on this project would have produced estimated traffic backups ten to sixteen miles long (Tharp, 2004). As of August 2007, WSDOT has finalized the plans and awarded a contract for repaving I-5 bridge decks from approximately the Spokane Street exit to I-90 with polyester polymer concrete. The contract would consist of placing 1.13 miles of bridge deck on Northbound I-5 (WSDOT Projects, 2006).

Although WSDOT did not use polymer concretes for several years after problems with initial projects, the repeated use of polymer pavements as a bridge overlay material on heavily trafficked sections of I-5 depict a trend of growing polymer concrete use and reliance as a rapid construction material by WSDOT.

9.2 Polymer Classification

Polymer concretes are composite materials similar to traditional PCC cements and consist of a binder combined with aggregates such as sand and gravel. Unlike PCC pavements, polymer concretes use a synthetic organic polymer and monomer as the binding material. Different types of PC are produced from a wide variety of different monomer and polymer units. Polymer binders can be loosely grouped into two broad families on the basis of how they react to heat: thermoplastics and thermosetting polymers (Blaga & Beaudoin, 1985). Thermoplastics can soften with exposure to heat, whereas the chemical reaction that produced thermosetting materials produces rigid cross-linked materials that cannot be reformed (Blaga & Beaudoin, 1985). Due to the rigid nature of the thermoplastics, most polymer concretes are formed from this group of binders. The four most common polymer binders include: methyl methacrylate (MMA), polyester prepolymer-styrene, epoxide prepolymer hardner (cross-linking monomer) and furfuryl alcohol (Blaga & Beaudoin, 1985). WSDOT typically uses MMA and epoxy polymer concretes for road overlays (Wilson & Henley, 1995).

Table 46 – Physical Properties Of Typical Polymer Concretes (Blaga & Beaudoin, 1985)

Type of Binder	Density kg/dm^3	Water Soprtion %	Comp. Strength, Mpa	Tensile Strength, Mpa	Flexural Strength, Mpa	Modulus of Elasticity, Gpa	Poisson Ratio	Thermal Coefficient of Exp. 10^6C^{-1}
Poly(methyl methacrylate)	2.0-2.4	0.05-0.60	70-210	9-11	30-35	35-40	0.22-0.33	10-19
Polyester	2.0-2.4	0.30-1.0	50-150	8-25	15-45	20-40	0.16-0.30	10-30
Epoxy	2.0-2.4	0.02-1.0	50-150	8-25	15-50	20-40	0.30	10-35
Furan Polymer	1.6-1.7	0.20	48-64	7-8	-	-	-	38*,61*
Concrete**	1.9-2.5	5-8	13-35	1.5-3.5	2-8	20-30	20-30	10-12

*Carbon and silica filled mortars, respectively

**Portland cement concrete

9.3 The Polymerization Process

In a typical polymer concrete mix, aggregates are combined with a liquid polymer resin and an initiator. The process by which polymer resin and initiator react and form polymer concrete is known as polymerization. During the polymerization process, the monomers or polymers within a paving mix link to form a polymer matrix around the aggregate. The linking of polymers is the result of a chemical reaction that occurs when free radicals, or initiators, are mixed with unsaturated monomers or polymers (Vipulanandan & Paul, 1993). A free radical is an unstable atom that has an unpaired electron in the outer electron shell. In order to return to a lower energy state, free radicals can attack other molecules to find other electrons for their unpaired electron. Electrons can be stolen from another atom, or be shared between two atoms to form an atomic bond (Vipulanandan & Paul, 1993). Table 47 shows the chemical constituents of a typical polymer concrete mix. For this mix, Cobalt Napthenate acts as a promoter and breaks bonds within the relatively unstable Methyl Ethyl Ketone Peroxide (MEKPO) to form a free radical.

The resins, or unsaturated polymer molecules, are the second important component of polymerization reaction. Within the unsaturated polymer molecules, carbon atoms are bound together with double covalent bonds. The MEKPO free radical breaks the double bonds within the polymer molecules and forms polymer free radicals. The final component of the polymerization process, the coupling agent, forms a bond with the unpaired carbon bond of the polymer monomer. As successive bonds form between polymer monomers and the coupling agents, a three-dimensional polymer matrix is formed.

Table 47 - Mix constituents and percentage by weight of a typical polymer concrete (Vipulanandan & Paul, 1993).

Polymeric Matrix Constituent	Composition	Percentage By Weight
Resin	Polyester Dion Iso-6315 (Kopper Co., Pittsburgh, Pa.)	10-20
Initiator	Methyl Ethyl Ketone Peroxide (MEKPO)[4]	2
Promoter	Cobalt Napthenate	0.2
Coupling Agent	3 Methacryloxypropyltrimethoxysilane	0-2
Sand	Ottawa 20-30	80-90

The rate of the polymerization reaction is controlled by three factors: temperature and the concentration and type of initiator (Sprinkel, 1993). At higher temperatures and with more initiator, fresh polymer concrete mixes will react aggressively and set much more rapidly. It is essential that the amount of initiator and resin and mix temperature are controlled to ensure that the polymerization process has time to progress to completion. A series of detailed tests have been performed in order to determine mix proportioning that provides a workable, wear resistant material that gains strength in acceptable time frame. Tests completed in California indicate that the best performing polymer concretes typically have resin contents between ten and 14 percent (Maggenti, 2001). Depending upon the mix design, polymer concretes overlays can be opened to traffic between two and four hours after placement. Polymer concretes develop typical compressive strengths of approximately 8,000 psi and flexural strengths of 2200 psi (Vipulanandan & Paul, 1993). Polymer concrete density varies based upon mix design and aggregate selection, but density tests on 17 project cylinders from the 2002 WSDOT overlay project in Northgate showed an average material density of 139.58lbs/ft^3 (Sherrell, 2002).

9.4 Polymer Concrete Testing and Performance

Polymer concrete performance as an overlay material is evaluated using tests for overlay bond strength, delamination, abrasion resistance, skid resistance and chloride permeability. The following sections describe observed polymer concrete performance and the test methods used evaluating performance.

9.4.1 Evaluating Polymer Concrete Overlay Bond Strength

A major component of polymer concrete overlay performance is determined by the overlay bond strength. Insufficient bonding between the polymer overlay and the substrate results in overlay delamination and premature pavement failure. Overlay bond strength can be evaluated using the bond pull-off test, according to the American Concrete Institute’s (ACI) test method 503R. The test consists of drilling a 2-inch diameter pavement core through the overlay into the substrate. Steel plugs are epoxied to both ends of the sample. The core is placed into a reaction frame which attaches to the steel plugs. The reaction frame applies a gradually increasing tensile force to separate the sample. The separation force and where the separation occurred in the sample are both recorded. Separation can occur in the base substrate, at the bond between two layers, within the overlay, or at the epoxied steel plugs. WSDOT pull-off tests have showed that failure typically occurs in the substrate and the tests do not provide a true indication of bond strength (Wilson & Henley, 1995). According to national polymer committees such as the AASHTO Task Force 34, polymer overlays should achieve bond pull-off strengths of 250 psi (Wilson & Henley, 1995). Table 48 and Table 49 depict the initial and latest recorded bond strengths recorded for several WSDOT epoxy and MMA polymer concrete overlays. The test results from the epoxy overlays show average bond pull-off values that exceed the recommended strengths. The MMA overlays have not performed as well and test results indicate average bond pull-off values that fall below the recommended value.

Table 48 – Recorded overlay bond strength test results for several WSDOT epoxy bridge overlays (Wilson & Henley, 1995).

Bridge Number	Brand Name	Year Applied	Initial Ave. Bond (psi) {no. of tests}	Latest Ave. Bond (psi) {no. of tests}	Overlay Age @ Latest Bond Test
161/10	EPI/Flex III	1986	294 {10}	not tested	
82/115S	Concresive 3070	1987	392 {8}	276 {3}	3 years
5/316	EPI/Flex III	1990	363 {15}	266 {5}	4 years
82/10S	Flexolith	1985	359 {12}	355 {6}	3 years
900/12W	Flexolith	1986	201 {12}	327 {6}	5 years
101/115	Flexogrid	1984	399 {6}	191 {5}	4 years
12/915	Flexogrid	1986	259 {21}	252 {6}	3 years
167/102	Flexogrid	1987	267 {5}	377 {6}	1 year
167/104	Flexogrid	1987	215 {5}	257 {3}	1 year
167/106	Flexogrid	1987	342 {5}	287 [3}	1 year
104/5.2	Flexogrid	1988	308 {27}	244 {6}	1 year
529/20E	Flexogrid	1988	267 {5}	187 {6}	3 years
		Average	306	274	2.6 years

Table 49 - Recorded overlay bond strength test results for several MMA polymer concrete bridge deck overlays (Wilson & Henley, 1995).

Bridge Number	Brand Name	Year Applied	Initial Ave. Bond (psi) {no. of tests}	Latest Ave. Bond (psi) {no. of tests}	Overlay Age @ Latest Bond Test
5/523E	Conkryl	1988	12	not tested	
82/114S	Concresive 2020	1987	284	258	3 years
27/3	Silikal R66	1990	229	not tested	
101/514	Degadur 330	1985	155	128	3 years
4/106A	Degadur 330	1986	113	85	5 years
167/21E	Degadur 330	1987	290	111	1 year
512/40N	Degadur 330	1987	259	135	1 year
16/120	Degadur 330	1988	189	not tested	
97/2	Degadur 330	1989	217	not tested	
		Average	194	143.4	2.6 years

9.4.2 Delamination

One of the functions of a polymer concrete overlay on a bridge deck is to provide an impermeable barrier to water and deicing salts to protect deck reinforcing steel from corrosion. De-icing salts that penetrate a concrete bridge deck will come into contact with bridge reinforcement which leads to steel corrosion and delamination. Corroding reinforcement steel expands, which generates cracks or fracture planes in the concrete surrounding the reinforcement. Cracking and fracture planes can be small and localized, or spread throughout a bridge deck. Failure to repair delaminations can result in material spalling and deck potholes. The intrusion of deicing salts and resulting delamination is the leading cause of deterioration in bridge decks (Wilson & Henley, 1995). Bridge inspectors identify delaminations by using a steel chain test according to ASTM D4580-86. Steel chains drug across a delamination location create a distinctly different audible sound. By dragging chains over an entire bridge deck, existing delaminations can be identified prior to the placement of an overlay. WSDOT performs delamination and debonding surveys on bridge decks that are patched and appear worn. WSDOT performs deck delamination surveys on about 3-5 bridges per year on an as-needed basis. Bridges are listed for rehabilitative measures when previous patching and identified chain drag delaminations total more than 2 percent of the bridge deck area. Rehabilitative overlays should repair all bridge deck delaminations (DeWayne Wilson, personal communications, February 14, 2007).

Table 50 and Table 51 contain delamination survey information for several polymer overlays applied in the late 1980's (Wilson and Henley, 1995). Delamination tests on these polymer overlays showed deck debonding on 0.0-12.1 percent of the deck surface. These scattered results show that polymer overlays can be successful, but also show that many early polymer overlays were unsuccessful and exhibited debonding.

Table 50 - Delamination chain drag test results for several WSDOT epoxy polymer concrete bridge deck overlays (Wilson and Henley, 1995).

Bridge Number	Brand Name	Year Applied	Chain Drag % of deck debonded
161/10	EPI/Flex III	1986	1/92 - 0.1%
82/115S	Concresive 3070	1987	4/92 - 2.5%
82/10S	Flexolith	1985	4/92 - 4.6%
900/12W	Flexolith	1986	8/92 - 0.3%
101/115	Flexogrid	1984	5/92 - 0.1%
12/915	Flexogrid	1986	4/92 - 2.1%
529/20E	Flexogrid	1988	7/92 - 0.2%
		Average	1.4%

Table 51 - Delamination chain drag test results for several WSDOT MMA polymer concrete bridge deck overlays.

Bridge Number	Brand Name	Year Applied	Chain Drag % of deck debonded
82/114S	Concresive 2020	1987	11/92 - 12.1%
101/514	Degadur 330	1985	1/92 - 2.0%
4/106A	Degadur 330	1986	4/93 - 0.0%
167/21E	Degadur 330	1987	1/92 - 0.0%
512/40N	Degadur 330	1987	1/92 - 0.0%
97/2	Degadur 330	1989	6/92 - 17.0%
		Average	4.4%

9.4.3 Durability and Wear Resistance

Pavements that require more maintenance or that need to be replaced more frequently can cause greater traffic disruption and congestion problems. Because of traffic impact issues, pavement design life and maintenance requirements are significant factors in the paving material selection process. Pavement durability is a function of overlay ability to maintain chloride protection, skid resistance and resist deformation. Tests based on resin flexibility and resistance to wear have been projected to estimate polyester overlay service life to be somewhere between 15 and 20 years (Vipulanandan & Paul, 1993).

9.4.4 Friction Testing

Friction and skid resistance are necessary for braking and vehicle control, especially in wet weather conditions. Successful pavements provide acceptable levels of surface friction for the entirety of their service life, not just briefly after installation. Roadway surface friction is commonly tested by using a tow vehicle, water tank, friction trailer and a mobile data processor. Friction measurements are recorded by the friction trailer and data processor as the tow vehicle pulls a specially designed locked tire over a wet pavement surface. The recorded data is expressed as a Skid Number, which provides an indication of skid resistance and pavement friction. More precise information about skid resistance tests can be found under AASHTO T 242 and ASTM E 274 test methods.

Table 52 provides a summary of how pavement surfaces can be evaluated using a skid number.

Table 52 -Sample skid resistance evaluation criteria. (Muench et al., 2003)

Skid Number	Comments
< 30	Take measures to correct
≥ 30	Acceptable for low volume roads
31 - 34	Monitor pavement frequently
≥ 35	Acceptable for heavily traveled roads

WSDOT data shows that epoxy polymer overlays initially start with friction numbers around 70, which fall to approximately 20 in the span of seven years (Wilson & Henley, 1995). In contrast, friction tests on MMA overlays initially show lower values of 40, but still post friction values around 39 after nine years (Wilson & Henley, 1995). The results indicate that MMA overlays maintain higher levels of surface friction and that skid resistance is acceptable for heavily traveled roads.

9.4.5 Chloride Permeability

Chloride permeability is an important characteristic of bridge deck pavements because chloride permeability indicates how easily deicing salts and other ions can pass through the pavement material and contact steel reinforcement. As described in section 9.5, ion and deicing salt intrusion is one of the leading causes of steel reinforcement deterioration and overlay delamination. WSDOT tests for chloride permeability with the test method outlined by AASHTO T-277-831 “The Rapid Determination of the Chloride Permeability of Concrete”. The test involves applying a 60 volt DC current across a concrete sample for six hours. During the test the amount of current, or charge, that is passed through the sample is recorded. The amount of charge is then converted and reported in Coulombs. A sample with a high resistance will not pass much charge and will protect against deicing salt penetration. Figure 42 depicts chloride permeability ratings. Typical chloride permeability test results for polymer concrete pavements as well as other common bridge overlay materials are also shown in Figure 43. Epoxy and MMA polymer concrete samples tested for chloride permeability pass a negligible amount of coulombs, demonstrating their superior reinforcement protection qualities.

Chloride Permeability	Charge Passed (coulombs)
High	>4,000
Moderate	2,000-4,000
Low	1,000-2,000
Very Low	100-1,000
Negligible	<100

Figure 42 -Chloride permeability ratings (FHWA, 2006).

Overlay Type	Range (coulombs)	Average (coulombs)
Polymer-Epoxy	0-6	3
Polymer-MMA	0-0	0
Latex Mod. Concrete	101-1,117	365
Microsilica Concrete	149,1,410	577
Low Slump Concrete	438-2,400	1,443
Standard WSDOT Bridge Deck Concrete	1,400-6,840	2,983

Figure 43 - Chloride permeability ratings of typical paving materials (Wilson & Henley, 1995)

9.5 The Polymer Concrete Paving Process

Polymer concrete overlays can be loosely divided into two placement methods: "Broom and Seed" (a simplified overlay method that is primarily used to improve or restore roadway skid resistance) and pre-mixed. In the broom and seed application process, the polymer resin is brushed or painted into a clean substrate. Sand or other aggregates are then broadcast, or scattered, upon the exposed resin. This process can be repeated several times until a desired thickness has been achieved. Premix methods refer to more traditional paving methods where polymer concrete is mixed prior to paving and then placed similar to traditional hand or slipform paving methods. Pre-mixed methods are used to provide skid resistance, as well as restore roadway grade and protect reinforcing steel. The broom and seed paving method is straightforward and a detailed description of this process is not provided. The following section provides an introduction and describes the key components of the pre-mixed paving process.

A typical bridge deck overlay paving project begins with the chain-dragging and the identification and repair of bridge reinforcement delaminations. Bridge deck repairs commonly require as much as one or more weeks prior to the start of construction and paving (D. Brown, personal interview, April 22, 2006).

Overlay construction begins with milling or removing existing material to a desired surface elevation. The exposed substrate or paving surface is then cleaned with a special steel shot abrader or shot-blasting machine designed for concrete removal and cleaning. Shot-blasting systems propel steel grit or shot at high velocities into a concrete surface. The steel grit or shot dislodges loose and foreign material. Both the steel shot and the loose material are collected by the same machine. The steel shot abrading machine separates the shot from the debris for reuse. After the paving surface has been prepped, no equipment or vehicles are allowed on the paving surface. The shot-blasting equipment is followed by a bridge deck prime coat which is brushed, painted, rolled, or sprayed into the deck. The primer binds to the substrate and also provides a surface for the polymer concrete to adhere to. The priming coats also help reduce the risk of premature overlay de-bonding (Wilson & Henley, 1995). The primer fills cracks and voids in the substrate, so the amount of primer applied is typically dependent upon the substrate roughness and absorbency (Maggenti, 2001). Polymer concrete can be placed anytime after the application of the primer. Test completed by Caltrans suggest that overlay bond strength is not dependent on the cure time of methacrylate prime coat (Maggenti, 2001). Although paving can begin immediately after the application of the prime coat, the primer can be sticky or tacky and care is required so the primer is not pulled off the substrate (M. Rhodes, personal interview, September 5, 2006).

Pre-mixed polymer concrete is placed similar to traditional hand or slipform PCC paving methods. With hand paving operations, the polymer material is placed in forms or screed rails. Excess material is struck off and the paving surface is finished by hand trowels and hand floating. Slipform polymer pavements are placed by specially modified polymer paving machines which automatically perform and complete most of the pavement finishing. Paving is concluded by broadcasting or throwing sand onto the polymer concrete to provide a friction and wearing surface. For the pre-mixed paving method, a tined or broomed finish can also be applied. After the polymer concrete has cured according to contract specifications, loose or excess material is then removed from the driving surface.

9.6 Typical Polymer Overlay Costs

Many factors contribute to the overall cost of a polymer concrete paving contract which makes estimating paving costs on a quantity basis difficult. Foremost, the chemical materials and components of a polymer concrete mix are more expensive than the materials used in traditional HMA and concrete pavements. Secondly, polymer concretes are infrequently used and require expensive specialized equipment and labor. Combining expensive material costs with high labor and equipment costs renders polymer concretes extremely sensitive to construction conditions and contract specifications. Two contracts that use identical quantities of polymer concrete could have very different unit prices based upon contract disincentives, closure windows, project location, anticipated weather conditions and other construction-related factors. In order to provide an indication of unit cost, bid tab information from four recent WSDOT polymer concrete paving contracts is presented below in Table 53 through Table 56.

Table 53 - I-5 Northgate WSDOT Polymer Concrete Project Bid Tab

NE NORTHGATE WAY TO 175TH ST VIC BRIDGE DECK RESURFACING

Contract No. 006403 5/20/2002

				Low Bid	Second Bid
			Engineer's Est.	Conc. Barrier Inc.	Mowat Const. Company
Item Description	Estimated Quantity	Unit Meas.	Price Per Unit Total Amount	Price Per Unit Total Amount	Price Per Unit Total Amount
			$100.00	$135.00	$75.00
Polyester Conc. Overlay	3,559.00	ft^3	$355,900.00	$480,465.00	$266,925.00
Contract Total			$1,292,460.13	$1,378,852.50	$1,765,976.00

Table 54 I-5 Federal Way WSDOT Polymer Concrete Project Bid Tab

I-5 FEDERAL WAY - S 317TH STREET HOV DIRECT ACCESS

Contract No. 006403 4/28/2004

				2nd Bidder	3rd Bidder
			Engineer's Est.	Icon Materials	Wilder Construction Co.
Item Description	Estimated Quantity	Unit Meas.	Price Per Unit Total Amount	Price Per Unit Total Amount	Price Per Unit Total Amount
		m^3	$4,500.00	$8,500.00	$9,000.00
Polyester Conc. Overlay	26.00	m^3	$117,000.00	$221,000.00	$234,000.00
Base Contract Total			$25,259,230.00	$22,212,120.38	$23,843,000.00

Table 55 I-405 WSDOT Polymer Concrete Project Bid Tab.

I-405 I/C EAST TO NORTH RAMP BRIDGE DECK
Contract No. 006608 5/20/2003

			Engineer's Est.	Concrete Barrier Inc.
Item Description	Estimated Quantity	Unit Meas.	Price Per Unit Total Amount	Price Per Unit Total Amount
			$135.00	$155.00
Polyester Conc. Overlay	669.00	ft^3	$90,315.00	$103,695.00
Base Total			$124,913.08	$125,137.00

Table 56 - I-5 Puyallup WSDOT Polymer Concrete Project Bid Tab.

I-5 PUYALLUP R RR OC 5/456W DECK OVERLAY
Contract No. 006515 3/25/2003

				Low Bid	Second Bid
			Engineer's Est.	Conc. Barrier Inc.	American Civil Constructors
Item Description	Estimated Quantity	Unit Meas.	Price Per Unit Total Amount	Price Per Unit Total Amount	Price Per Unit Total Amount
			$135.43	$69.00	$110.00
Polyester Conc. Overlay	10,300.00	yd^2	$1,394,929.00	$710,700.00	$1,133,000.00
Contract Total			$2,473,170.87	$1,459,162.00	$2,314,922.00

From the presented bid tab information, polymer paving quantities varied from 669ft^3 to 3,559ft^3. Cost per ft^3 varied from a low of $75 to a high $254.96. The fourth bid tab uses a unit measure of yd^2 and the unit price can be seen to vary from a low of $69/$yd^2$ to $110/$yd^2$.

Based on observations from past projects, accepting project bids on an estimated yd^2 or yd^3 volume can lead to payment issues. Polymer concrete overlays are commonly placed on a clean concrete substrate at a lift thickness of ¾" (D. Brown, personal interview, April 22, 2006). Substrates that have been milled and cleaned can have irregular and pocketed surfaces. Because of the irregular and uneven paving substrate, achieving a ¾" overlay on an uneven substrate can require more paving material than what would be estimated by basing project quantities on cubic or square feet of paving. In 2002, WSDOT completed three polymer bridge deck overlays in the Northgate vicinity of I-5. The project contract specified an overlay depth of ¾", but due to the irregularity of the bridge deck surface the overlay thickness was closer to one inch. This overrun in material quantities was cited as the primary reason for the contractor bid price of $1,378,852 increasing to an estimated final project cost of $1,563,463 (Sherrell, 2002). Instead of basing payment on project area, payment for polymer pavements can be based upon the total amount of polymer resin used or resin content of the pavement mix. Basing payment methods on the amount of resin used is less subjective and reduces the amount of risk contractors have to incorporate when developing project bids (Sherrell, 2002).

9.7 Issues Associated With Polymer Concrete Paving

Polymer concretes provide several advantages as an overlay material, but several material constraints and issues have been documented from both WSDOT and other state DOT paving projects. This section outlines some of the important issues that engineers and project management should be aware of when working with polymer concrete projects.

9.7.1 Water Sensitivity

The polymerization process is extremely sensitive to moisture. Any water that is present in the aggregate or on the paving substrate will be trapped within the polymer concrete matrix and interfere with the polymerization process. Interference with the polymerization process leads to a sub-standard paving material that is likely to have a reduced service life and exhibit some form of pavement failure. Moisture problems on past projects have been successfully addressed by minimizing the amount of moisture within the mix aggregate and on the paving substrate. Polymer concrete aggregates should be kiln dried and not exposed to moisture. California polymer concrete contracts typically specify that the aggregate moisture content cannot exceed 0.2 percent by weight (Maggenti, 2001). Aggregate can be kept dry by using covered storage or aggregate that has been delivered in sealed waterproof packaging. Substrate moisture has also been successfully addressed by stipulating drying periods after the substrate has been exposed to moisture. Previous WSDOT contracts have mandated a 24-hour drying time if the substrate has been exposed to moisture (Sherrell, 2002). Wet substrates are not only the result of rain, but can also result from cold conditions and dew as well as fog.

9.7.2 Temperature Variations

Polymer pavement quality has also been observed to be influenced by temperature variations (Sherrell, 2002). Temperature variations strongly influence both polymer concrete gel and cure times (Sprinkel, 1993). The polymer gel time refers to the amount of time that elapses before the polymer concrete increases in viscosity and becomes resistant to flow. Gel times are influenced by the rate of polymerization which is in turn influenced by temperature. Warmer conditions speed the polymerization process while colder conditions have the opposite effect. A sufficient gel time is necessary to provide sufficient time for concrete finishing. The rate of polymerization also influences material strength gain after the gel time. Colder temperature conditions can increase the time necessary for material strength gain and impact closure windows. The impact of temperature variations on material gel and cure times can be avoided by modifications to the proportioning of the mix materials. During past WSDOT project administration, the contractor specifically addressed changing temperature conditions by adjusting the percentage of primary catalyst used within the mix (Sherrell, 2002). Successful polymer paving contract administration will incorporate some mix flexibility and personnel who have the experience to modify the mix design according to construction conditions.

9.7.3 Standardization Of Material Testing and Characteristics

Because polymer concretes have not seen widespread use, one of the biggest concerns with polymer concrete is that material specifications and testing procedures have not been standardized (Vipulanandan & Paul, 2001). On past projects, WSDOT frequently included polymer paving into a contract as special work and did not incorporate polymer concretes by using a standard specification (D. Brown, personal interview, April 22, 2006). Documentation from past state projects has also cited poor material testing and quality control as one of the decisive factors that has lead to poor pavement performance (Sherrell, 2002). In Washington State, WSDOT has addressed past project issues by continuing to develop a cohesive standard specification for material production and testing. WSDOT bridge personnel are also continuing to track the performance of bridge polymer overlays which provides further performance based information for improving standard specifications (D. Brown, personal interview, April 22, 2006). Problems pertaining to material testing and placement during construction paving have been addressed by instituting a formal training program for WSDOT construction inspection personnel. Polyester concrete inspection training is offered through WSDOT's Construction Training Inspection Program (Construction Inspection Program, 2006). The continued development of cohesive polymer concrete specifications and the implementation of construction inspection training will contribute to the successful implementation of future polymer concrete overlay projects.

9.7.4 Expansion Joints

Expansion joints enable bridge sections to move and reduce stresses in response to external or internal forces. Polymer concrete rehabilitation projects on bridge decks need to address how the contractor will incorporate expansion joints into a new overlay. On past polymer concrete bridge overlays, state DOTs have observed overlay debonding at expansion joints (Maggenti, 2001). Polymer bridge deck overlay contracts have to specify how movement across the joint will be maintained. WSDOT standard plans and specifications for bridges outline the variety of different expansion joints suitable for WSDOT bridges. Because of this wide variety of joint types, addressing overlay paving at expansion joints is evaluated on a project to project basis. Some state DOTs have had success in installing overlays of 0.5 inches or less without modifying expansion joints (Doody & Morgan, 1994). Joints can be maintained by sawcutting the polymer overlay at expansion joints after the polymer has cured (Maggenti, 2001).

9.7.5 Magnesium Phosphate Concrete

Magnesium Phosphate Concretes (MPC) are frequently used by WSDOT and other state DOTs as a patching and repair material for bridge deck failures such as potholes and spalls. MPCs are not formed by hydration, but rather a chemical reaction that uses magnesium and calcium oxides. Magnesium phosphate concretes can set in as little as 25 minutes, making them suitable repair materials for reopening roads to traffic quickly (Neal & Krauss, 1985). On some of the earlier polymer concrete paving projects in California, magnesium phosphate concretes were used to repair localized pavement failures prior to the start of overlay construction. In areas where polymer pavements were placed on magnesium phosphate concrete repairs that were less than three days old, the polymer concretes overlay debonded (Maggenti, 2001). Both Caltrans and WSDOT now mandate that polymer concretes or prime coats cannot be placed on magnesium phosphate concrete that has not cured for at least 72 days. Future polymer concrete paving contracts should provide ample magnesium phosphate cure times or use alternative repair materials.

9.7.6 Polymer Concrete Emissions

The polymer paving process produces very strong and pungent emissions. Polymer concrete emissions consist primarily of styrenes, which can be described as having a concentrated chemical odor. Because of the chemical odor of the emitted styrenes, concerns arose in state DOTs such as Caltrans about the effects of styrene inhalation on worker health. In 1985 Caltrans funded air sampling on polymer concrete paving projects in order to monitor the concentration of styrene emissions. The sampling results showed that styrene exposure levels were below the Permissible Exposure Level (PEL) of 100 parts per million in an 8-hour time-weighted average (Maggenti, 2001). Although the sampling studies demonstrated styrene emissions were not at harmful levels, air quality regulations drove the polymer concrete paving industry to reduce emissions by incorporating a special wax into polymer mixes. During the paving and curing process, the wax works by floating to the concrete surface and forming a wax seal at the concrete surface. The wax seal dramatically reduces the amount of styrene emissions that escape into the environment. Material testing and sampling demonstrated that including the wax into the mix had no negative impacts on performance. By 1990 Caltrans incorporated the emission reducing wax into the state polymer concrete specification (Maggenti, 2001). Current preliminary WSDOT polymer paving specifications do not require mix designs to incorporate a wax for emission control.

9.7.7 Snow Plowing and Aggregate Removal

As an overlay matures, the polyester matrix wears faster than the aggregate. Because of the differences in wearing, the aggregate is exposed and provides a skid resistant drive surface. WSDOT achieves polymer concrete overlay skid and resistance by specifying a 5/8” aggregate which is larger than the aggregates specified on other overlay projects (Wilson & Henley, 1995). Concerns during early polyester paving contracts arose over the possibility of the exposed larger aggregate to be removed by snowplows. Polymer concrete patches exposed to snowplows have shown that aggregate removal or chipping is not a problem (D. Brown, personal interview, April 22, 2006).

9.7.8 Closure Windows and Paving Productivity

Polymer concretes are commonly applied on projects where high traffic volumes and potential traffic impacts eliminate alternative rehabilitation methods. Polymer contracts are typically executed during tight closure windows at night or during off-peak travel times. Closure windows are commonly between nine or twelve hours. Depending upon traffic closure and curing requirements, the actual window available for paving may only be a few hours. For engineers and transportation personal unfamiliar with polymer paving, it is important to have a general idea of activity progression and activity time requirements. For demonstration purposes, the following description outlines approximate activity time requirements for a general polymer overlay project. The construction times presented below in Table 57 are loosely based on inspection reports on the NE Northgate Way to 175th St Bridge Deck Resurfacing project and assume a ten hour closure window (Sherrell, 2002).

Table 57 - Typical Polymer Paving Activity Time Requirements

Time Requirement (hrs.)	Closure Activity
1.0-1.5	Mobilization and traffic control setup
1.5-2.5	Surface preparation and shotblasting
0.5-1.0	Primer application and paver mobilization
3.0-4.0	Paving
2.0	Pavement curing

This construction sequence assumes a two hour pavement curing time requirement. With a four hour specified cure, the closure window would have to be extended by a few hours or the time available for polymer concrete paving would be roughly halved.

9.8 Contractor Comments

An interview was conducted with a polymer paving contractor to collect information about the factors contractors evaluate for developing productivity rates and cost estimates for contract bids. The interview questions were formatted to find information that could be used by state DOT personnel developing preliminary schedules and productivity estimates. Key ideas from the interview are summarized in the following points.

1. Contractors will almost always prefer a longer closure window to maximize time available for paving activities. Closure windows will have similar time requirements for unproductive paving activities such as traffic control setup, equipment mobilization, pavement curing and demobilization. Longer closures use time more efficiently because more paving time is provided per unproductive lost time requirements for mobilization and demobilization.

2. Construction productivity has to be estimated on a project-to-project basis. Too many factors impact productivity and general production rates cannot be provided. The following table of factors were cited as having large productivity impacts:

Table 58 - Polymer Paving Productivity Factors

Specified material cure time (varies from two to four hours)
Type of lane closure and traffic control
Lane closure setup and removal times
Available maneuvering room for shotblasting and paving equipment
Size and amount of available shotblasting and paving equipment
How grade is established (ski or stringline)
Paving lane width
Paving depth
Job-site access and location
Amount and type of expansion joint modifications
Amount of mixers that can be mobilized
Contract incentives and disincentives

3. Polyester paving equipment has been rapidly evolving and cannot be easily assigned general productivity capabilities.
    a. Pump and chemical monitoring systems are constantly evolving which influence paving rates as well as material quality.
    b. On past projects, paving productivity has been observed to double from the first to fifth day. The high variability in observed productivity makes estimating foreseeable productivity on future projects difficult.
    c. Too many factors are tied to productivity which eliminates the ability to assume a base paving rate in yd^3/hr.

4. Expansion joints do not have an easily quantifiable impact on paving productivity. There are too many different types of expansion joints and possible expansion joint modifications to assume a general productivity impact.

5. Polyester paving is a small and specialized industry which limits the number of contractors that are capable of performing polyester overlay work.
    a. Polymer concretes are expensive and relatively new materials whose use is only justified on specific contracts. Currently, the industry is fairly small and cannot support multiple polymer paving contractors.
    b. Because of the specialized nature of polyester concrete paving equipment and construction management, the polyester paving industry has significant fiscal and experience-related barriers for new paving contractors.

6. Workable paving mixes are dependent upon the resin content and the type and amount of aggregates used. With too much resin, the mix becomes to wet and produces a driving surface with a sheen. Too little resin, the mix can tear during finishing. For WSDOT projects, a 12 percent resin content mix has had good consistency and workability.

7. Bidding contracts on a material or volume basis is more cost efficient. For projects bid based upon estimated surface areas and volumes, wheel rutting and unknown grade requirements increase contractor risks and results in higher material prices.

9.9 Conclusions

The following conclusions about PC as a rapid rehabilitation tool have been made based upon literature review and a paving contractor interview:

Paving Material Benefits

1. Polyester concrete pavements cure rapidly and can be opened to traffic with 2-4 hours
2. Polyester concretes are nearly impermeable to chlorides and can provide excellent protection for pavement reinforcement
3. Polyester concretes are relatively lightweight and are an excellent overlay material for repairing load sensitive bridges

Material Performance

4. WSDOT had repeat problems with initial polymer overlays completed in the late 1980's and early 1990's due to problems with moisture and inexperience
5. A better understanding of polymer materials, increased contractor experience and increased WSDOT experience has led to several recent successful polymer concrete overlays
6. Early polyester overlay performance showed mixed results. Delamination tests on rehabilitative overlays exhibited debonding on 0.0-12.1 percent of the overlay surface area. These test result polymer concrete overlays have the potential to rehabilitate bridge decks, but polymer overlays were not always successful.
7. WSDOT test results on overlay bond strength have provided mixed results, some overlays have sufficient overlay bond strength whereas some overlays have insufficient overlay bond strength
8. Polymer concrete overlays have shown to be durable and can be expected to have a service life of 15 to 20 years based on current performance
9. MMA polymer concrete have been shown to provide acceptable levels of skid resistance for up to nine years and are still being monitored

Material Issues

10. The polymer concrete curing process is extremely sensitive to moisture and is negatively impacted by the presence of moisture on the paving surface and or in the air
11. Polymer concrete polymerization reaction is susceptible to changes in ambient temperature which impacts workability and curing; experienced personal are

required during construction to make slight modifications to paving materials to accommodate temperature variation

12. Polymer concrete is in the process of becoming a standardized paving material, but is still often incorporated into a contract as special work
13. Polymer concretes can’t be used in conjunction with magnesium phosphate concrete that has not cured for 72 hours
14. Polymer concrete emits a strong chemical odor
15. Snow plows can operate on polymer concrete overlays

Contractor Observations

16. Contractors prefer longer closure windows to use resources more efficiently
17. Polymer paving productivity is very sensitive to project conditions and must be evaluated on a project to project basis; construction estimates and schedules cannot be developed from general paving rates
18. Polymer equipment and contractor experience is rapidly evolving which adds to the complexity of productivity estimation
19. Polymer concrete paving is currently a specialized field with a limited number of contractors that have the requisite experience and equipment
20. Paving experience with a 12 percent mix resin content has good consistency and workability
21. Project bidding should be based on the amount of material used

10 Developing Construction Windows for Rapid Rehabilitation Projects

Establishing construction lane closures and closure windows is a major component of every rapid road construction project. Developing a construction window requires balancing closure traffic impacts while providing sufficient space and time for a contractor to efficiently complete project work. For most WSDOT road construction projects, the Traffic Department follows a traffic analysis procedure and informs project engineers and management about which roadway closure scenarios would provide acceptable levels of traffic service. Rapid construction contracts can require larger construction windows or construction windows during periods of high roadway demand. Implementing these types of closures can have significant impacts on motorists, businesses and local communities. Mitigating and managing the problems and issues associated with closure implementation leads to a complex decision process in which construction costs, agency costs, contractor capabilities, road user costs and other impacts must be evaluated.

The intent of this section is to provide a general introduction to how WSDOT engineers currently establish lane closures and what types of closure windows are feasible for typical and rapid construction roadway construction projects. An understanding of traffic closure procedures is established by (1) describing the traffic factors that are evaluated in the decision-making process for typical lane closures (2) describing different closure scenarios and their benefits and (3) providing a list of decision factors and issues that should be considered during lane closure planning.

10.1 The Process of Establishing Typical Lane Closures

Traffic engineers establish lane closures by comparing historical roadway volume data and existing roadway capacity with projected construction volumes and existing roadway capacity. Normal operating freeway capacities are controlled by many factors such as the posted speed limit, lane width and interchange spacing. Interstates operating under good conditions can support maximum lane capacities of up to 2,250 passenger cars per hour per lane (pc/h/ln) and 2,400 pc/h/ln for 55mi/hr and 70mi/hr facilities, respectively

(HCM, 2000). In contrast, the capacity of an interstate or highway lane through a construction site can be significantly lower. Reduced capacity in a construction zone has been attributed to multiple factors, including the factors shown in Table 59.

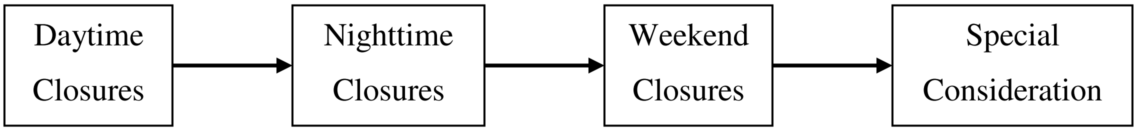
Table 59 - Factors That Impact Construction Zone Capacity (Kim, Lovell and Paracha, 2000):

The intensity of the work being performed and the resulting distraction to drivers
Percentage of heavy vehicles
Location and density of ramps
Work duration
Closure lane configurations
Driver population
Lengths of grades and work zone
Lateral clearances, and
Weather

Various research projects have been completed to develop different capacity formulas that can be applied for project specific work zone conditions. Descriptions of these formulas and their parameters can be found in the previously referenced paper by Kim et. al. (2000). Although lane capacities change with varying project conditions, typical freeway and highway traffic volumes through construction zones have been recorded during past research projects. 45 hours of freeway counts from 33 work zones in Texas resulted in researchers recommending freeway construction zone lane capacities of 1600 passenger cars per hour per lane (Kim et al., 2000). A different study on highways in Iowa found that construction zone highway lane capacities vary between 1,400-1,600 passenger car equivalents (Maze, Schrock and Kamyab, 2000). Combining these recorded construction zone lane capacities with projected volumes enables engineers to develop appropriate closure windows.

The following description of typical WSDOT construction closure establishment practices is based on a personal interview with WSDOT Northwest Region Design/Construction Traffic Engineer Phil Fordyce on July 24th, 2006. One of the key steps in developing road closures is identifying when and where traffic volumes occur and how these volumes will be impacted and accommodated by the construction zone.

For most urban regions and closure planning, this typically leads to a 3-step capacity analysis procedure:



If proposed daytime lane closure plans provide sufficient capacity for historical volumes, then the closure is permissible. If lane capacity will be exceeded during the construction closure, engineers then examine nighttime closures possibilities. Nighttime closures are advantageous because traffic volumes are typically much lower between late evening and early morning. If nighttime lane closures are still anticipated to generate undesired levels of congestion, engineers examine weekend lane closures. Traffic disruption on weekends is typically more preferable than traffic disruption during the week because weekend trips are usually more flexible. If sufficient roadway capacity cannot be provided through either day, night or weekend lane closures, closure windows are then developed on a project specific basis.

10.2 Alternative Closure Windows

One of the most common methods for reducing delay and roadway construction impacts is to perform roadway work at night when traffic volumes are lower (FHWA, 2003). Night construction windows can reduce the impacts on travelers during peak travel hours, but provide a smaller operational time frame in which contractors can complete work. Night closures often result in longer periods of construction and longer periods of low to moderate periods of traffic impact (FHWA, 2003). As more interstate pavements in urban corridors approach the end of their design lives, state DOTs have begun using alternative closure window strategies to expedite work on heavily trafficked routes (Lee et. al, 2005). These windows are characterized by high traffic impacts, but for typically shorter periods of time. Examples of alternative closures that have been successfully used by state DOTs include Full Road Closure, Weekend Full Road Closure and Limited Capacity Closure.

These closure scenarios have resulted in the recorded benefits shown in Table 60 (FHWA, 2003):

Table 60 - Recorded Benefits Of Alternative Closure Windows

Improved public perception of state DOT operational abilities
Increased public and worker safety
Increased contractor operational space and increased contractor efficiency
Reduced project completion time
Reduced project costs
Reduced overall traveler impact, and
Higher construction quality

The benefits of alternative lane closure strategies have been documented in several FHWA and state DOT reports. The following discussion contains a summary of data and observations from several projects that used alternative road closure strategies for project construction. The intent of this document is to present existing report conclusions and findings to produce a more comprehensive document for rapid construction project development. The information depicts many of the benefits observed from these successfully completed projects to encourage future planning and consideration of other viable closure options. Presented information has been categorized and discussed based on three closure types:

- Full Road Closure
- Weekend Full Road Closure
- Limited Capacity Closure

10.2.1 Full Road Closure

A Full Road Closure consists of shutting down traffic operations in either one or both directions of a roadway segment. Four projects have been summarized to depict the benefits of Full Road Closures: M-10 Detroit, Michigan, I-95 Wilmington, Delaware, I-405 Tukwila to Factoria, Washington, and I-15 Devore, California. A description of the scope and benefits noted for each project has been presented.

10.2.1.1 M-10 Detroit, Michigan

The following project data has been obtained from an FHWA article, *Full Road Closure for Work Zone Operations* (FHWA, 2003).

Project Description

- $12.5 million project
- 97,900 average daily traffic
- 1 percent commercial vehicle traffic
- Reconstruction of a 1.27-mile section of roadway (7.6 miles)
- Project consisted of pavement removal and replacement with HMA (including shoulders and barriers), surface and substructure rehabilitation for five bridges and other improvements
- Project dates – July 9, 2002 through August 30, 2002

Project Benefits

- Facilitated project completion in one paving season in lieu of two
- Project duration reduced by 71 percent, contractor completed work in 53 days
- No serious injuries, dramatically lower damage claims
- No quantitative cost reduction but costs anticipated to be lower due to reduced traffic control maintenance, improved contractor access, staging and storage
- Reduced joints and seams for superior product quality

10.2.1.2 I-95 Wilmington, Delaware

The following project data has been obtained from an FHWA article, Full Road Closure For Work Zone Operations (FHWA, 2003).

Project Description

- $23.5 million total construction cost
- 100,000 average daily traffic
- 11 percent commercial vehicle traffic
- Reconstruction of 6.1 mile roadway section (24.4 lane miles)
- Project dates – April to October 2000

Project Benefits

- Project duration reduced by 75 percent, project work reduced from two years to 185 days
- Improved safety cited
- Costs were not reduced due to the need for alternate route capacity improvements, but the funded improvements were noted as having long-term value
- High construction quality noted due to fewer joints which resulted in a smoother pavement surface and a more quiet ride
- Positive public feedback, few negative comments noted

10.2.1.3 I-405, Tukwila to Factoria, Washington

Information about the I-405 Tukwila to Factoria project has been obtained from a WSDOT sponsored research project (Dunston and Mannering, 1998).

Project Description

- Pavement rehabilitation of 5.5-mile section of a 6-lane roadway (33 lane-miles), 0.15-ft ACP Class A overlay, 29,393 tons southbound and 19,019 tons northbound
- Project dates – two weekend closures, one closure for all three lanes of travel in each direction, August 15, 1997 and August 22, 1997

Project Benefits

- Complete closure facilitated the installation of a mobile rotary drum plant 0.25 miles from southern end of the work zone
- Average shift production (12-hour shifts) of 350 tons per hour, the continuous and unobstructed paving was sited as having a 21 percent higher productivity compared to a similar night-paving project on nearby I-5
- Project access, batch plant location and paving techniques led to twice the truck productivity compared to a similar night-paving project on nearby I-5
- Profilograph measurements indicated a ride smoothness associated with a high quality pavement
- Mean overlay density measurements showed less density variation and relatively higher average density in comparison to similar overlay characteristic measurements

- Quality measurements indicated relatively smaller aggregate gradation and asphalt content variability
- Public response via motorist and business surveys were positive:
  - 87 percent were decidedly in favor of weekend closure strategy over frequent partial closures
  - 88 percent agreed closure notification enabled travel planning to avoid work zone closures

10.2.1.4 I-15 Devore, California

Information presented about the I-15 Devore, California project has been obtained from Lee et. al, 2005.

Project Description

- Project cost of approximately $16 million
- 110,000 average daily traffic, peak hourly volume of 5,500 vehicles in each direction
- 10 percent commercial vehicle traffic
- Pavement rehabilitation of 4.5-km of two trucking lanes, both directions
  - 150 mm of new asphalt-concrete (AC) base
  - 290mm of new concrete slab
- Reconstruction occurred over two 215 hour (about 9-day) closures in October 2004

Project Benefits

- Construction staging used median crossovers for a counter-flow traffic system which provided 2-3 traveling lanes in each direction
- A Quickchange Moveable Barrier (QMB) enabled flexible traffic control to modify lane configurations to accommodate directional traffic, adjustments were made twice a day without major disruption to traffic
- Project duration with nighttime closures was estimated to be ten months, continuous closures required 80 percent less closure time compared to nighttime closures
- Road User Costs and DOT agency costs both cited as reduced

- Construction costs reduced by an estimated $6 million
- Improvements in worker and motorist safety cited
- Validated use of CA4PRS Software for construction closure scenarios

10.2.2 Weekend Full Closure

Weekend Full Closures consist of a shutting down traffic operations in either one or both directions of a roadway segment over a weekend. These types of closures are used to avoid impacting workday commuters and periods of typically higher roadway volumes. Previous projects have used 55-hr closure windows which start after the Friday peak period at 8:00 p.m. and end before Monday peak periods at 5:00 p.m. Three projects have been summarized to depict the benefits of Weekend Full Closures: I-15 Devore, California, I-84 Portland, Oregon, and I-65 Louisville, Kentucky. A description of project scope and the observed closure benefits are summarized for each project.

10.2.2.1 I-84 Portland, Oregon

Project data for I-84 Portland, Oregon, has been obtained from the FHWA article, *Full Road Closure for Work Zone Operations* (FHWA, 2003).

Project Description

- $5 million total construction cost
- 180,000 average daily traffic
- 7 percent commercial vehicle traffic
- HMA pavement rehabilitation of 5.5-mile section of a 6-lane roadway (33 lane-miles)
- Project dates – August 2, 2002 through August 12, 2002

Project Benefits

- Project duration reduced by 85 percent, 32 night closures reduced to 4.7 days of construction
- No serious crashes or injuries during construction, gains in worker and traveler safety cited
- Estimated project savings of $100,000 attributed to increased contractor efficiency and reduced traffic management

- Construction personnel cited fewer joints, a quieter ride, and higher quality project
- Positive community feedback, no project complaints

10.2.2.2 I-65 Louisville, Kentucky

The following project data has been obtained from an FHWA article, *Full Road Closure for Work Zone Operations* (FHWA, 2003).

Project Description

- $4.15 million total construction cost
- 130,000 average daily traffic
- 50 percent commercial truck traffic
- Rehabilitation/maintenance work over a 6-mile section of roadway, major work consisted of replacing 44 bridge expansion joints, resealing eight other expansion joints and other maintenance
- Project dates – August 11-14, 2000 and September 15-18, 2000

Project Benefits

- Project duration reduced by 95 percent, 90 traditional closures reduced to approximately five days of construction
- Project personnel felt conditions were safer
- Project costs increased due to public outreach, incentives and additional traffic maintenance
- Project quality believed to have been superior
- 95 percent of received calls positive, DOT perceived public satisfaction, perceived public would prefer full closure in comparison to traditional methods

10.2.3 Limited Capacity Closure

Limited Capacity Closures suspend traffic operations on part of a roadway segment. Construction equipment and motorists share the roadway in one direction of travel. Three projects have been summarized to depict the benefits of Limited Capacity Closures: I-5 James to Olive Streets Seattle, Washington, Southbound I-5 Seattle, Washington and I-10 Pomona, California. A description of the scope and benefits noted for each project has been presented.

10.2.3.1 I-5 James to Olive Seattle, Washington

Information about the I-5 James to Olive project has been compiled from interviews with WSDOT project personnel and other agency documentation.

Project Description

- Project was completed using four 55-hour weekend closures between April and July in 2005
- Construction efforts required the closure of several interstate ramps and typically 2-3 lanes of southbound I-5, leaving only 1-2 available traveling lanes
- $3,948,000 project bid
- Corridor average daily traffic of 180,000 vehicles
- Project consisted of I-5 lane reconstruction from MP 164.41 to 166.36 with new PCC pavement and the following approximate project quantities:
    - Demolition and removal of 6,500 cy^3 of material
    - Placement of 2,500 tons of HMA base pavement
    - Placement of 5,640 cy^3 of JPCP

Project Benefits

- Project was completed in an urban corridor adjacent to businesses and residences with only two noise complaints
- 15 mile backups expected during most limiting lane closures, only 2-3 mile backups observed due to intensive public outreach
- A High-level of cooperation between WSDOT, the City of Seattle and the contractor was cited as one of the crucial factors that led to project delivery. Project success demonstrated achieving high-level cooperation between various agencies is feasible on projects
- Problems that arose during construction were dealt with efficiently and quickly and did not impact the schedule

- Project completion improved WSDOT public image by demonstrating agency ability to deliver projects within budget and on schedule
- Project success demonstrated the viability and value of short-term high-impact closures for future WSDOT project
- 17 Change orders addressed timely and efficiently, no outstanding work or issues were addressed after construction
- Concrete barriers improved both motorist and worker safety, one sprained ankle was cited as the sole project injury
- The innovative schedule, closure plan and work effort by project management earned internal WSDOT recognition and an accolade for excellence in contract administration

10.2.3.2 I-10 Pomona, California

The information about the I-10 Pomona, California project has been obtained from a report prepared by the University of California, Berkley, Institute of Transportation Studies Pavement Research Center (Lee et al., 2001).

Project Description

- $15.9 million project
- As high as 240,000 average daily traffic
- 9 percent commercial vehicle traffic
- Reconstruction of about five centerline-km (20 lane-km) of concrete pavement
- Project started in April 1999 and completed in February 2000, (1) 55-hr weekend October 22, 1999, other work completed during various seven and ten hour nighttime closures
- Two lanes open to traffic, two lanes reserved for construction

Project Benefits

- Closure information dissemination about 55-hr weekend closure reduced peak hour traffic volumes by 30-60 percent eastbound, total eastbound traffic volume reduced by 5-35 percent
- Weekend closure showed major gains in productivity, with an average of 14 slabs paved per hour during

- Weekend closure was 54 percent more productive than nighttime paving in terms of slabs replaced per hour
- One 55-hr weekend closure was found to be equivalent to 16.4 nighttime closures

10.2.3.3 I-5, Seattle, Washington 1986

In 1986 WSDOT reconstructed southbound lanes of I-5 north of Seattle's Central Business District (CBD). In order to understand the traffic impacts of construction and closing lanes on I-5, WSDOT funded a research project to collect and analyze travel data before, during and after project construction. Changes in travel behavior due to roadway closures will vary on a project to project basis due to differences in local traffic volumes, alternate route availability and project information dissemination. The findings of this research report are project specific, but can still provide readers with general information about how travel patterns can change in response to freeway or interstate lane closures in an urban area. The following referenced information has been retrieved from the analysis report, *Evaluation of the Effects of Closing Interstate 5 Lanes and Ramps*, (Hallenbeck and Lin, 1986).

Project Description

- All southbound lanes of Interstate 5 north of the Seattle CBD were reconstructed
- Several ramps and portions of the interstate were closed, but two lanes remained open to motorists for the duration of the project
- I-5 serves as the primary north/south through the City of Seattle and King County on the West side of Lake Washington, alternative North/South routes in the vicinity of I-5 included:
    - Aurora Boulevard (SR 99)
    - Four reversible interstate express lanes
    - Several city arterials
- Project completed in the summer of 1985

Project Findings

- The reduction in two lanes of capacity resulted in roughly 4,700 fewer vehicles in the peak hour (33.7 percent decrease)

  - Half of the volume decrease was attributed to vehicles taking city arterials during the peak hour
  - Travel on the city arterials was seen to increase during the early morning time periods from 6:00 AM to 7:15 AM
  - Peak hour travel on Aurora increased by 18.5 percent during the peak hour and 25 percent from 6AM to 9AM (arterial operated near capacity pre-construction)
  - Peak hour travel on another city arterial, Eastlake, increased by 83 percent in the peak hour and a 92 percent increase from 6AM to 9AM (arterial operated with low volumes pre-construction)
- Daily traffic volumes were reduced by 37,200 vehicles (31 percent decrease)
  - Of these vehicles 21,700 switched to other routes
  - Remaining 15,500 switched modes or did not travel
- Express lane ramp usage increased throughout the project
- Ramp and freeway usage increased during earlier commute hours
- In general, no significant change in automobile occupancy was noted
- Bus ridership increased by approximately 5 percent at measured points
- The majority of new travel growth in the surrounding transportation network was primarily attributed to an increase of single vehicle occupancy roadway utilization

10.3 Alternative Rapid Construction Lane Closures

Unique closures require a high level of project planning, coordination and mitigation that combines engineering, political and social considerations. Managing and mitigating traffic impacts associated with unique construction closures is a difficult process that often requires months of planning. This section provides a basic introduction to issues commonly addressed during construction closure development. The following checklist of closure considerations and issues is an excerpt from a traffic management report composed by the American Concrete Pavement Association (AMCAP) (AMCAP, 2000).

Traffic Management

1. Capacity analyses – lanes required, length of queues anticipated
2. Time restrictions – peak hours – seasonal peaks

3. Limits to work areas
4. Capacity of detour routes
5. Work vehicle access and worker parking
6. Bicycle and pedestrian traffic
7. Warning sign locations – detours, long queues, intersecting roads
8. Railroad crossings and train schedules
9. Nighttime delineation and illumination
10. Signals, turning lanes, bus stops
11. Traffic service – residential/business
12. Future rehabilitation

Concrete Pavement Construction Requirements

1. Lead time for bid preparation
2. Fast Track – planning, concrete materials, construction requirements, curing, jointing
3. Opening to traffic – maturity, pulse velocity, strength requirements
4. Rehabilitation considerations
5. Phasing of work – length of work zone – project limits
6. Special conditions such as drop-offs, sign bridge installation, etc.
7. Curing time – or any other factor that affects how long the work will take
8. Special contract provisions needed
9. Short duration closures anticipated
10. Temporary drainage
11. Lights for night work
12. Temporary roadway lighting

Performance

1. Speed management
2. Enforcement (where to stop violators)
3. Start-up procedures and phase changes
4. Barrier installation

5. Geometries of temporary roadways

Safety

1. Work zone crash rates
2. Traffic management strategies
3. Interstate system
4. Congestion
5. Nighttime
6. Large trucks
7. Workers on foot
8. Pedestrians
9. Local experience

Constructability

1. Structural capacity of bridges, shoulders and pavement
2. Timing of phases versus probable starting date
3. Strategy to allow contractor to finish project
4. Status of existing traffic control devices – signals, signs, railroad crossings, etc.
5. Wintertime restrictions – snow removal, etc.

Emergency Planning

1. Incident management plan
2. Emergency medical assistance
3. Accidents, breakdowns, tow trucks
4. Snow removal
5. Emergency closures
6. Utility interruptions
7. State police
8. Local law enforcement

Public Information and Coordination

1. Public information – public hearings, media, motorist service agencies, residents, local businesses, motor carriers
2. Local officials – police, fire, hospitals, schools, environmental agencies, utilities, toll facilities, ferries, railroads, airports
3. Special events
4. Intra-agency coordination- maintenance crews, permits section, adjacent projects
5. Public Transit

10.4 Closure Application Conclusions and Recommendations

Review of existing documentation from projects that utilized alternative closure strategies has lead to the following recommendations and conclusions:

1. **Alternative construction windows are viable planning options.** Alternative construction windows have successfully been used by several state DOTs to balance user impacts, safety, agency costs, construction costs and construction quality. Future project development should weigh the benefits of high-impact short-term projects in comparison to more frequently used night closures.
2. **Project planning and budget should include a dedicated public outreach program.** Extensive public outreach is essential for reducing roadway volumes and congestion. If given proper warning and information, motorists will modify their traveling behavior to reduce or eliminate vehicle travel through a construction work zone.
3. **Alternative closure projects should be provided with significant planning and public outreach time.** Alternative construction closures have the potential to impact many motorists, communities, businesses and agencies. Project management staff should be given sufficient planning time to address and manage the impacts to all affected parties.
4. **Alternative closure projects must have adequate alternative and detour routes.** Construction closures will disrupt the travel behavior of motorists and vehicles whose mobility depends upon the closed roadway. The vehicle trips that are displaced by construction closures must have adequate alternative and detour routes. If sufficient alternative routes are not available, congestion and traffic

volumes on available routes will likely have unacceptable levels of congestion and delay. Alternative closure projects must be planned for projects in areas where the transportation network can accommodate the vehicles and trips displaced by construction closures.

5. **Alternative closure projects must have strong interagency cooperation.** Roadway rehabilitation projects that use alternative closures may have project limits and consideration with overlapping agency jurisdictions. Planning and mitigating the impacts of a project can involve agencies at the state, county and city level. Successful and efficient contract delivery for a project using an alternative closure window will require strong interagency cooperation.
6. **Alternative closure projects should be let and bid based upon alternative closure plan.** To maximize potential construction cost savings, projects should be let and bid based upon the alternative closure plan. The benefits of an alternative closure will not be fully realized if developed through a change order.
7. **Project management should coordinate between projects.** Alternative closure windows can have far-reaching impacts on traffic behavior and local or regional mobility. Additionally, local material suppliers and contractors may not have sufficient material, resources and labor to supply competing projects. Project and closure development should coordinate between regional and local projects.
8. **Construction sites should be protected from theft and vandalism.** Closed roadway sections may be susceptible to theft and vandalism. Measures should be implemented to protect the jobsite from potential damage and loss.
9. **High stress environment.** Projects that use an alternative closure window will likely have tight schedules. Maintaining a schedule under tight time requirements can place stress on both project owner and contractor personnel. Stress can tire project personnel which can lead to decreased production and a difficult working environment.
10. **Alternative closures should still be considered for projects with unknown factors.** Longer continuous closures may be beneficial for projects that have unknown factors or conditions. With a longer continuous closure window, the

contractor has more flexibility and more time to adjust the project schedule in dealing with unknowns.

11. **Project signing should be balanced.** Signage and warnings about lane closures, detours and project conditions is essential for aiding motorists, but should not be overdone. Over signing can potentially confuse drivers and needlessly drain project budgets.

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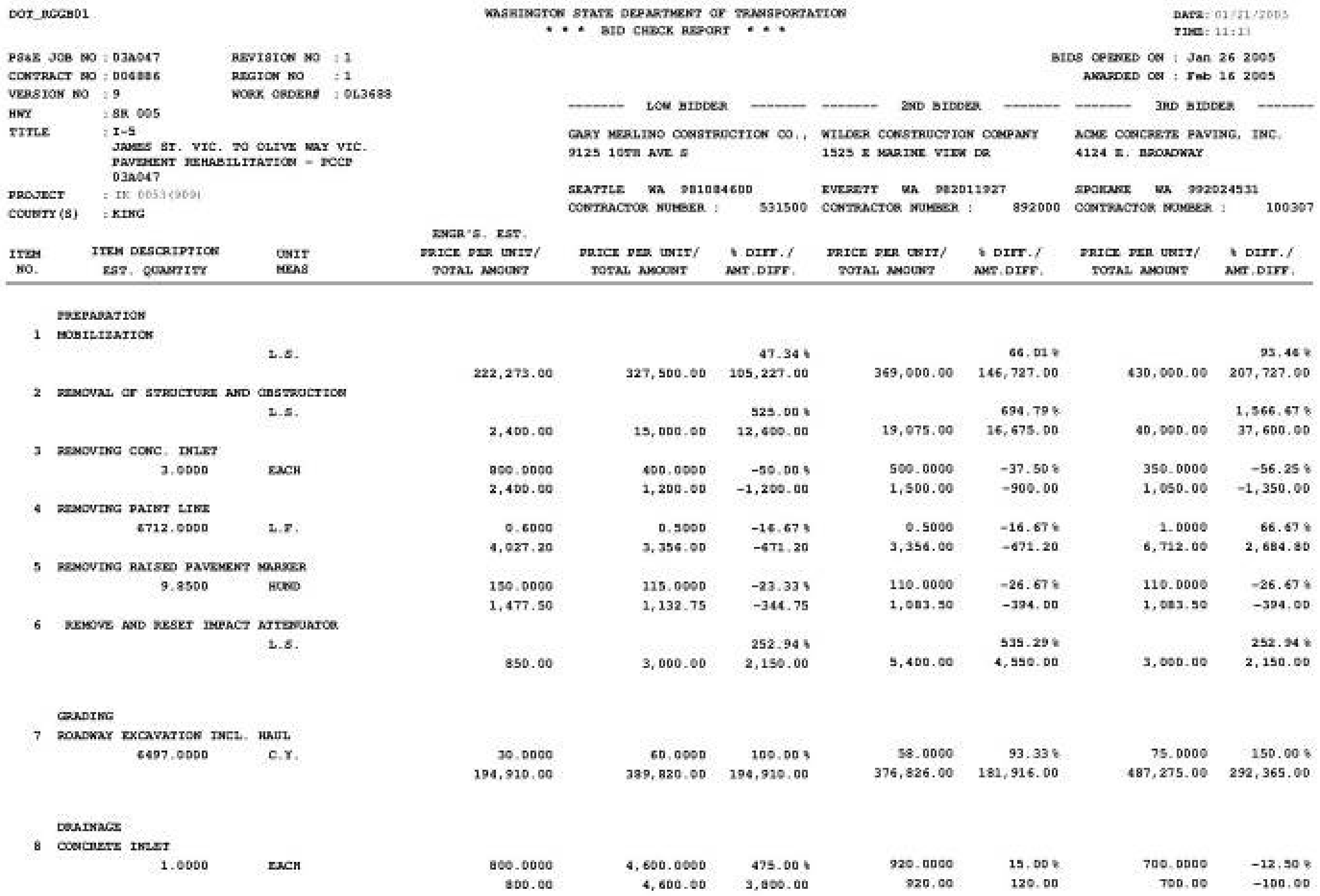
Appendix A: Bid tabs for the I-5 James to Olive Project



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PS&E JOB NO : 03A047          REVISION NO  : 1                                                                                          BIDS OPENED ON : Jan 26 2005
CONTRACT NO : 006886          REGION NO    : 1                                                                                              AWARDED ON : Feb 16 2005
VERSION NO  : 9               WORK ORDER#  : 0L3688
HWY         : SR 005                                          -------   LOW BIDDER   -------  -------   2ND BIDDER   -------  -------   3RD BIDDER   -------
TITLE       : I-5
              JAMES ST. VIC. TO OLIVE WAY VIC.                GARY MERLINO CONSTRUCTION CO.,  WILDER CONSTRUCTION COMPANY     ACME CONCRETE PAVING, INC.
              PAVEMENT REHABILITATION - PCCP                  9125 10TH AVE S                 1525 E MARINE VIEW DR           4124 E. BROADWAY
              03A047
PROJECT     : IK 0053(909)                                    SEATTLE   WA  981084600         EVERETT   WA  982011927         SPOKANE   WA  992024531
COUNTY(S)   : KING                                            CONTRACTOR NUMBER :     531500  CONTRACTOR NUMBER :     892000  CONTRACTOR NUMBER :     100307
                                               ENGR'S. EST.
ITEM     ITEM DESCRIPTION      UNIT          PRICE PER UNIT/   PRICE PER UNIT/   % DIFF./   PRICE PER UNIT/   % DIFF./   PRICE PER UNIT/   % DIFF./
 NO.      EST. QUANTITY        MEAS           TOTAL AMOUNT      TOTAL AMOUNT     AMT.DIFF.   TOTAL AMOUNT     AMT.DIFF.   TOTAL AMOUNT     AMT.DIFF.
_______________________________________________________________________________________________________________________________________________________

      PREPARATION
  1   MOBILIZATION
                           L.S.                                                   47.34 %                     66.01 %                      93.46 %
                                                222,273.00        327,500.00   105,227.00      369,000.00  146,727.00      430,000.00  207,727.00
  2   REMOVAL OF STRUCTURE AND OBSTRUCTION
                           L.S.                                                  525.00 %                    694.79 %                   1,566.67 %
                                                  2,400.00         15,000.00    12,600.00       19,075.00   16,675.00       40,000.00   37,600.00
  3   REMOVING CONC. INLET
                  3.0000   EACH                   800.0000          400.0000     -50.00 %        500.0000    -37.50 %        350.0000    -56.25 %
                                                  2,400.00          1,200.00    -1,200.00        1,500.00     -900.00        1,050.00   -1,350.00
  4   REMOVING PAINT LINE
               6712.0000   L.F.                     0.6000            0.5000     -16.67 %          0.5000    -16.67 %          1.0000     66.67 %
                                                  4,027.20          3,356.00      -671.20        3,356.00     -671.20        6,712.00    2,684.80
  5   REMOVING RAISED PAVEMENT MARKER
                  9.8500   HUND                   150.0000          115.0000     -23.33 %        110.0000    -26.67 %        110.0000    -26.67 %
                                                  1,477.50          1,132.75      -344.75        1,083.50     -394.00        1,083.50     -394.00
  6    REMOVE AND RESET IMPACT ATTENUATOR
                           L.S.                                                  252.94 %                    535.29 %                     252.94 %
                                                    850.00          3,000.00     2,150.00        5,400.00    4,550.00        3,000.00    2,150.00


      GRADING
  7   ROADWAY EXCAVATION INCL. HAUL
               6497.0000   C.Y.                    30.0000           60.0000     100.00 %         58.0000     93.33 %         75.0000    150.00 %
                                                194,910.00        389,820.00   194,910.00      376,826.00  181,916.00      487,275.00  292,365.00


      DRAINAGE
  8   CONCRETE INLET
                  1.0000   EACH                   800.0000        4,600.0000     475.00 %        920.0000     15.00 %        700.0000    -12.50 %
                                                    800.00          4,600.00     3,800.00          920.00      120.00          700.00     -100.00
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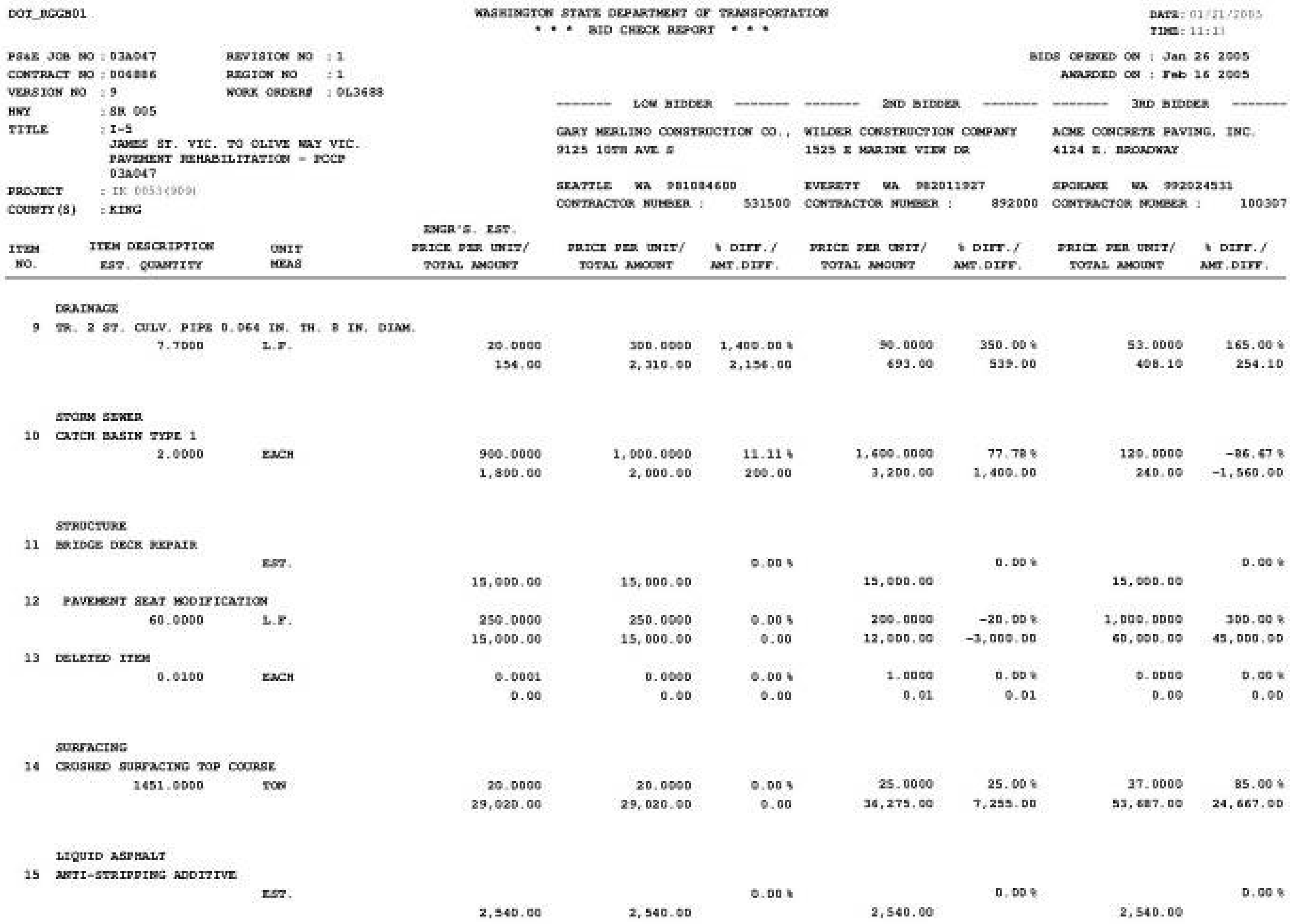

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PS&E JOB NO : 03A047          REVISION NO  : 1                                                                            BIDS OPENED ON : Jan 26 2005
CONTRACT NO : 006886          REGION NO    : 1                                                                               AWARDED ON : Feb 16 2005
VERSION NO  : 9               WORK ORDER#  : 0L3688
HWY         : SR 005                                       -------  LOW BIDDER  ------- -------  2ND BIDDER  ------- -------  3RD BIDDER  -------
TITLE       : I-5
              JAMES ST. VIC. TO OLIVE WAY VIC.             GARY MERLINO CONSTRUCTION CO., WILDER CONSTRUCTION COMPANY    ACME CONCRETE PAVING, INC.
              PAVEMENT REHABILITATION - PCCP               9125 10TH AVE S                1525 E MARINE VIEW DR         4124 E. BROADWAY
              03A047
PROJECT     : IK 0053(909)                                 SEATTLE   WA  981084600        EVERETT   WA  982011927       SPOKANE   WA  992024531
COUNTY(S)   : KING                                         CONTRACTOR NUMBER :     531500 CONTRACTOR NUMBER :     892000 CONTRACTOR NUMBER :     100307
                                            ENGR'S. EST.
ITEM     ITEM DESCRIPTION      UNIT       PRICE PER UNIT/  PRICE PER UNIT/  % DIFF./  PRICE PER UNIT/  % DIFF./  PRICE PER UNIT/  % DIFF./
 NO.      EST. QUANTITY        MEAS        TOTAL AMOUNT     TOTAL AMOUNT    AMT.DIFF.  TOTAL AMOUNT    AMT.DIFF.  TOTAL AMOUNT    AMT.DIFF.
______________________________________________________________________________________________________________________________________________

     DRAINAGE
  9  TR. 2 ST. CULV. PIPE 0.064 IN. TH. 8 IN. DIAM.
                 7.7000       L.F.             20.0000         300.0000  1,400.00 %        90.0000   350.00 %        53.0000   165.00 %
                                                154.00         2,310.00  2,156.00           693.00    539.00          408.10    254.10


     STORM SEWER
 10  CATCH BASIN TYPE 1
                 2.0000       EACH            900.0000       1,000.0000    11.11 %      1,600.0000    77.78 %       120.0000   -86.67 %
                                              1,800.00         2,000.00    200.00         3,200.00  1,400.00          240.00 -1,560.00


     STRUCTURE
 11  BRIDGE DECK REPAIR
                              EST.                                          0.00 %                     0.00 %                    0.00 %
                                             15,000.00        15,000.00                  15,000.00                  15,000.00
 12   PAVEMENT SEAT MODIFICATION
                60.0000       L.F.            250.0000         250.0000     0.00 %        200.0000   -20.00 %     1,000.0000   300.00 %
                                             15,000.00        15,000.00      0.00        12,000.00 -3,000.00       60,000.00 45,000.00
 13  DELETED ITEM
                 0.0100       EACH              0.0001           0.0000     0.00 %          1.0000     0.00 %         0.0000     0.00 %
                                                  0.00             0.00      0.00             0.01      0.01            0.00      0.00


     SURFACING
 14  CRUSHED SURFACING TOP COURSE
              1451.0000       TON              20.0000          20.0000     0.00 %         25.0000    25.00 %        37.0000    85.00 %
                                             29,020.00        29,020.00      0.00        36,275.00  7,255.00       53,687.00 24,667.00


     LIQUID ASPHALT
 15  ANTI-STRIPPING ADDITIVE
                              EST.                                          0.00 %                     0.00 %                    0.00 %
                                              2,540.00         2,540.00                   2,540.00                   2,540.00
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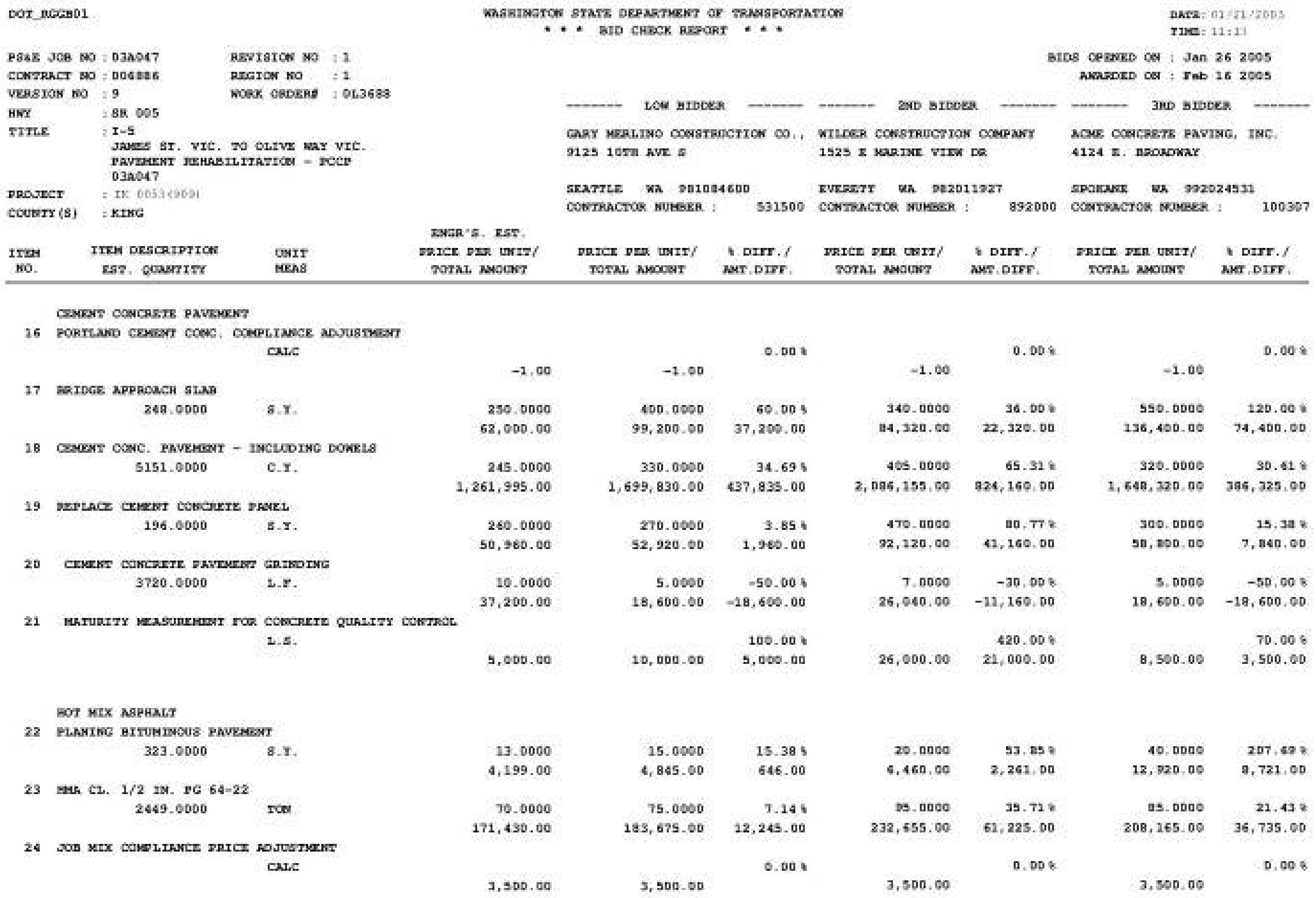

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DOT_BGGB01                                               WASHINGTON STATE DEPARTMENT OF TRANSPORTATION                                              DATE: 01/21/2005
                                                              * * *  BID CHECK REPORT  * * *                                                      TIME: 11:11

PS&E JOB NO : 03A047         REVISION NO  : 1                                                                                     BIDS OPENED ON : Jan 26 2005
CONTRACT NO : 006886         REGION NO    : 1                                                                                         AWARDED ON : Feb 16 2005
VERSION NO  : 9              WORK ORDER#  : 0L3688
HWY         : SR 005                                         -------   LOW BIDDER   ------- -------   2ND BIDDER   ------- -------   3RD BIDDER   -------
TITLE       : I-5
              JAMES ST. VIC. TO OLIVE WAY VIC.               GARY MERLINO CONSTRUCTION CO., WILDER CONSTRUCTION COMPANY    ACME CONCRETE PAVING, INC.
              PAVEMENT REHABILITATION - PCCP                 9125 10TH AVE S                1525 E MARINE VIEW DR          4124 E. BROADWAY
              03A047
PROJECT     : IK 0053(909)                                   SEATTLE   WA  981084600        EVERETT   WA  982011927        SPOKANE   WA  992024531
COUNTY(S)   : KING                                           CONTRACTOR NUMBER :     531500 CONTRACTOR NUMBER :     892000 CONTRACTOR NUMBER :     100307
                                                 ENGR'S. EST.
ITEM     ITEM DESCRIPTION       UNIT           PRICE PER UNIT/   PRICE PER UNIT/   % DIFF./   PRICE PER UNIT/   % DIFF./   PRICE PER UNIT/   % DIFF./
 NO.      EST. QUANTITY         MEAS            TOTAL AMOUNT      TOTAL AMOUNT    AMT.DIFF.    TOTAL AMOUNT    AMT.DIFF.    TOTAL AMOUNT    AMT.DIFF.
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      CEMENT CONCRETE PAVEMENT
  16  PORTLAND CEMENT CONC. COMPLIANCE ADJUSTMENT
                                CALC                                                  0.00 %                         0.00 %                         0.00 %
                                                          -1.00             -1.00                       -1.00                          -1.00
  17  BRIDGE APPROACH SLAB
                248.0000        S.Y.                   250.0000          400.0000    60.00 %         340.0000      36.00 %         550.0000     120.00 %
                                                      62,000.00         99,200.00  37,200.00        84,320.00   22,320.00       136,400.00   74,400.00
  18  CEMENT CONC. PAVEMENT - INCLUDING DOWELS
               5151.0000        C.Y.                   245.0000          330.0000    34.69 %         405.0000      65.31 %         320.0000      30.41 %
                                                   1,261,995.00      1,699,830.00 437,835.00     2,086,155.00  824,160.00     1,648,320.00  386,325.00
  19  REPLACE CEMENT CONCRETE PANEL
                196.0000        S.Y.                   260.0000          270.0000     3.85 %         470.0000      80.77 %         300.0000      15.38 %
                                                      50,960.00         52,920.00   1,960.00        92,120.00   41,160.00        58,800.00    7,840.00
  20   CEMENT CONCRETE PAVEMENT GRINDING
               3720.0000        L.F.                    10.0000            5.0000   -50.00 %           7.0000     -30.00 %           5.0000     -50.00 %
                                                      37,200.00         18,600.00 -18,600.00        26,040.00  -11,160.00        18,600.00  -18,600.00
  21   MATURITY MEASUREMENT FOR CONCRETE QUALITY CONTROL
                                L.S.                                                100.00 %                       420.00 %                        70.00 %
                                                       5,000.00         10,000.00   5,000.00        26,000.00   21,000.00         8,500.00    3,500.00


      HOT MIX ASPHALT
  22  PLANING BITUMINOUS PAVEMENT
                323.0000        S.Y.                    13.0000           15.0000    15.38 %          20.0000      53.85 %          40.0000     207.69 %
                                                       4,199.00          4,845.00     646.00         6,460.00    2,261.00        12,920.00    8,721.00
  23  HMA CL. 1/2 IN. PG 64-22
               2449.0000        TON                     70.0000           75.0000     7.14 %          95.0000      35.71 %          85.0000      21.43 %
                                                     171,430.00        183,675.00  12,245.00       232,655.00   61,225.00       208,165.00   36,735.00
  24  JOB MIX COMPLIANCE PRICE ADJUSTMENT
                                CALC                                                  0.00 %                         0.00 %                         0.00 %
                                                       3,500.00          3,500.00                    3,500.00                       3,500.00
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DOT_RGGB01                                            WASHINGTON STATE DEPARTMENT OF TRANSPORTATION                                                    DATE: 01/21/2005
                                                            * * *  BID CHECK REPORT  * * *                                                             TIME: 11:11

PS&E JOB NO : 03A047        REVISION NO  : 1                                                                                                  BIDS OPENED ON : Jan 26 2005
CONTRACT NO : 006886        REGION NO    : 1                                                                                                     AWARDED ON : Feb 16 2005
VERSION NO  : 9             WORK ORDER#  : OL3688
HWY         : SR 005                                     -------  LOW BIDDER  -------  -------  2ND BIDDER  -------  -------  3RD BIDDER  -------
TITLE       : I-5
              JAMES ST. VIC. TO OLIVE WAY VIC.           GARY MERLINO CONSTRUCTION CO., WILDER CONSTRUCTION COMPANY    ACME CONCRETE PAVING, INC.
              PAVEMENT REHABILITATION - PCCP             9125 10TH AVE S                1525 E MARINE VIEW DR          4124 E. BROADWAY
              03A047
PROJECT     : IK 0053(909)                               SEATTLE   WA  981084600        EVERETT   WA  982011927        SPOKANE   WA  992024531
COUNTY(S)   : KING                                       CONTRACTOR NUMBER :     531500 CONTRACTOR NUMBER :     892000 CONTRACTOR NUMBER :     100307
                                               ENGR'S. EST.
ITEM    ITEM DESCRIPTION       UNIT          PRICE PER UNIT/    PRICE PER UNIT/   % DIFF./    PRICE PER UNIT/   % DIFF./    PRICE PER UNIT/   % DIFF./
 NO.     EST. QUANTITY         MEAS           TOTAL AMOUNT       TOTAL AMOUNT     AMT.DIFF.    TOTAL AMOUNT     AMT.DIFF.    TOTAL AMOUNT     AMT.DIFF.
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      HOT MIX ASPHALT
  26  LONGITUDINAL JOINT SEAL
                800.0000      L.F.                 10.0000             6.0000     -40.00 %           2.0000     -80.00 %           4.5000     -55.00 %
                                                  8,000.00           4,800.00   -3,200.00          1,600.00   -6,400.00          3,600.00   -4,400.00


      EROSION CONTROL AND PLANTING
  25  ESC LEAD
                 32.0000      DAY                 100.0000            50.0000     -50.00 %         180.0000      80.00 %         640.0000     540.00 %
                                                  3,200.00           1,600.00   -1,600.00          5,760.00    2,560.00         20,480.00   17,280.00
  27  STREET CLEANING
                 38.0000      HR                  100.0000           120.0000      20.00 %         130.0000      30.00 %         200.0000     100.00 %
                                                  3,800.00           4,560.00      760.00          4,940.00    1,140.00          7,600.00    3,800.00
  28  INLET PROTECTION
                 33.0000      EACH                 90.0000           100.0000      11.11 %         110.0000      22.22 %         190.0000     111.11 %
                                                  2,970.00           3,300.00      330.00          3,630.00      660.00          6,270.00    3,300.00
  29  EROSION/WATER POLLUTION CONTROL
                              EST.                                                  0.00 %                        0.00 %                        0.00 %
                                                 30,000.00          30,000.00                     30,000.00                     30,000.00


      TRAFFIC
  30  CEMENT CONC. TRAFFIC CURB
                 23.0000      L.F.                 50.0000           150.0000     200.00 %          11.0000     -78.00 %          90.0000      80.00 %
                                                  1,150.00           3,450.00    2,300.00            253.00     -897.00          2,070.00      920.00
  31  REMOVING AND RESETTING BEAM GUARDRAIL
                 36.0000      L.F.                 12.0000            25.0000     108.33 %          11.0000      -8.33 %          20.0000      66.67 %
                                                    432.00             900.00      468.00            396.00      -36.00            720.00      288.00
  32  REMOVING AND RESETTING EXISTING PERMANENT BARRIER
                675.0000      L.F.                 11.0000            15.0000      36.36 %          11.0000       0.00 %          13.0000      18.18 %
                                                  7,425.00          10,125.00    2,700.00          7,425.00        0.00          8,775.00    1,350.00
  33  TEMPORARY IMPACT ATTENUATOR
                 21.0000      EACH              4,500.0000         4,000.0000     -11.11 %       1,500.0000     -66.67 %       3,600.0000     -20.00 %
                                                 94,500.00          84,000.00  -10,500.00         31,500.00  -63,000.00         75,600.00  -18,900.00
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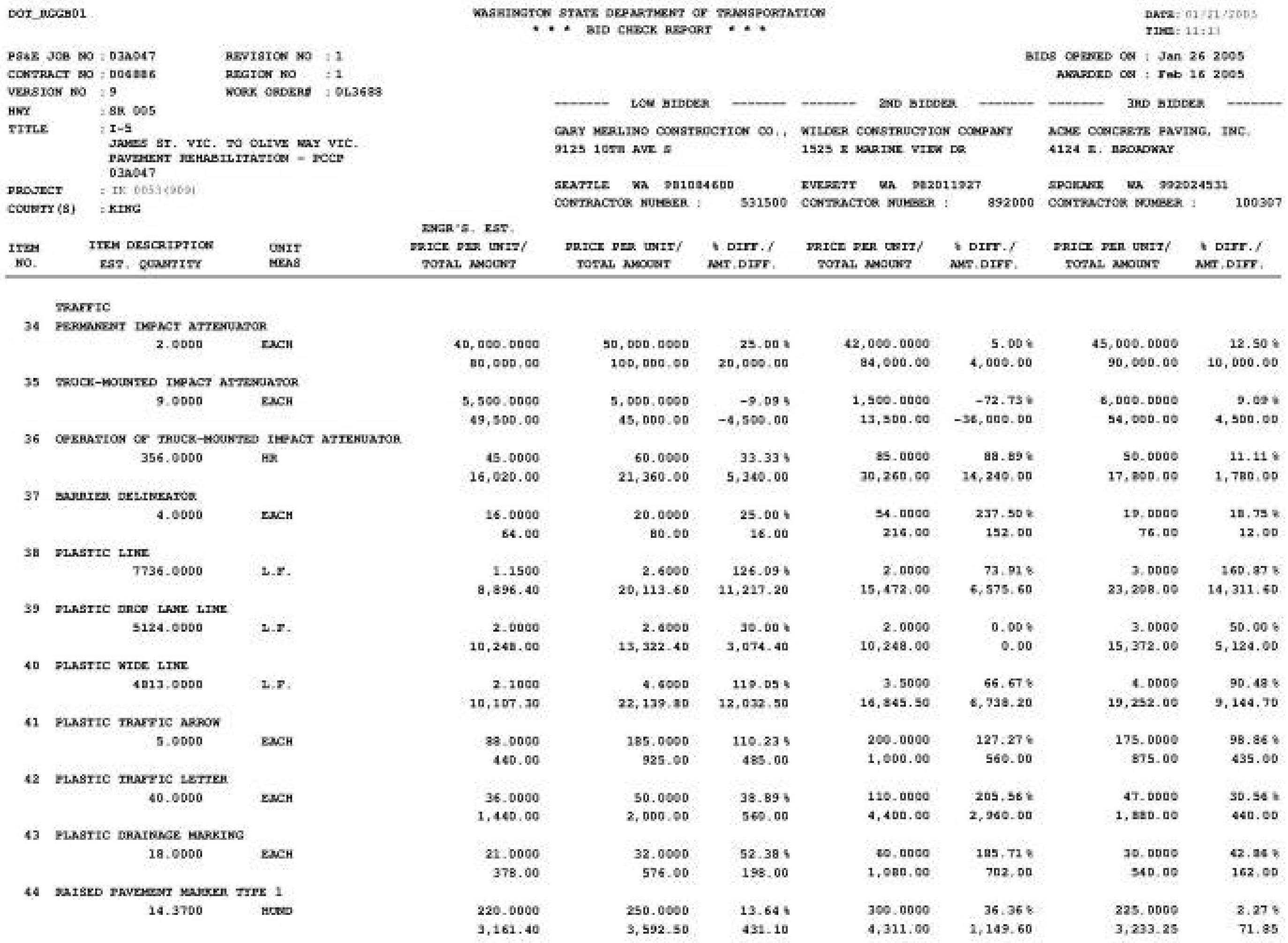

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DOT_RGGB01                                         WASHINGTON STATE DEPARTMENT OF TRANSPORTATION                                               DATE: 01/21/2005
                                                           * * *  BID CHECK REPORT  * * *                                                      TIME: 11:11

PS&E JOB NO : 03A047          REVISION NO  : 1                                                                                    BIDS OPENED ON : Jan 26 2005
CONTRACT NO : 006886          REGION NO    : 1                                                                                        AWARDED ON : Feb 16 2005
VERSION NO  : 9               WORK ORDER#  : 0L3688
HWY         : SR 005                                               -------  LOW BIDDER  ------- -------  2ND BIDDER  ------- -------  3RD BIDDER  -------
TITLE       : I-5                                                  GARY MERLINO CONSTRUCTION CO., WILDER CONSTRUCTION COMPANY   ACME CONCRETE PAVING, INC.
              JAMES ST. VIC. TO OLIVE WAY VIC.                     9125 10TH AVE S                1525 E MARINE VIEW DR         4124 E. BROADWAY
              PAVEMENT REHABILITATION - PCCP
              03A047
PROJECT     : IK 0053(909)                                         SEATTLE   WA  981084600        EVERETT   WA  982011927       SPOKANE   WA  992024531
COUNTY(S)   : KING                                                 CONTRACTOR NUMBER :     531500 CONTRACTOR NUMBER :     892000 CONTRACTOR NUMBER :     100307
                                                    ENGR'S. EST.
ITEM      ITEM DESCRIPTION       UNIT              PRICE PER UNIT/   PRICE PER UNIT/   % DIFF./   PRICE PER UNIT/   % DIFF./   PRICE PER UNIT/   % DIFF./
 NO.       EST. QUANTITY         MEAS               TOTAL AMOUNT      TOTAL AMOUNT     AMT.DIFF.   TOTAL AMOUNT     AMT.DIFF.   TOTAL AMOUNT     AMT.DIFF.
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      TRAFFIC
  34  PERMANENT IMPACT ATTENUATOR
                2.0000       EACH                  40,000.0000       50,000.0000     25.00 %     42,000.0000      5.00 %     45,000.0000      12.50 %
                                                     80,000.00        100,000.00   20,000.00       84,000.00    4,000.00       90,000.00   10,000.00
  35  TRUCK-MOUNTED IMPACT ATTENUATOR
                9.0000       EACH                   5,500.0000        5,000.0000     -9.09 %      1,500.0000    -72.73 %      6,000.0000       9.09 %
                                                     49,500.00         45,000.00   -4,500.00       13,500.00  -36,000.00       54,000.00    4,500.00
  36  OPERATION OF TRUCK-MOUNTED IMPACT ATTENUATOR
              356.0000       HR                        45.0000           60.0000     33.33 %         85.0000     88.89 %         50.0000      11.11 %
                                                     16,020.00         21,360.00    5,340.00       30,260.00   14,240.00       17,800.00    1,780.00
  37  BARRIER DELINEATOR
                4.0000       EACH                      16.0000           20.0000     25.00 %         54.0000    237.50 %         19.0000      18.75 %
                                                         64.00             80.00       16.00          216.00      152.00           76.00       12.00
  38  PLASTIC LINE
             7736.0000       L.F.                       1.1500            2.6000    126.09 %          2.0000     73.91 %          3.0000     160.87 %
                                                      8,896.40         20,113.60   11,217.20       15,472.00    6,575.60       23,208.00   14,311.60
  39  PLASTIC DROP LANE LINE
             5124.0000       L.F.                       2.0000            2.6000     30.00 %          2.0000      0.00 %          3.0000      50.00 %
                                                     10,248.00         13,322.40    3,074.40       10,248.00        0.00       15,372.00    5,124.00
  40  PLASTIC WIDE LINE
             4813.0000       L.F.                       2.1000            4.6000    119.05 %          3.5000     66.67 %          4.0000      90.48 %
                                                     10,107.30         22,139.80   12,032.50       16,845.50    6,738.20       19,252.00    9,144.70
  41  PLASTIC TRAFFIC ARROW
                5.0000       EACH                      88.0000          185.0000    110.23 %        200.0000    127.27 %        175.0000      98.86 %
                                                        440.00            925.00      485.00        1,000.00      560.00          875.00      435.00
  42  PLASTIC TRAFFIC LETTER
               40.0000       EACH                      36.0000           50.0000     38.89 %        110.0000    205.56 %         47.0000      30.56 %
                                                      1,440.00          2,000.00      560.00        4,400.00    2,960.00        1,880.00      440.00
  43  PLASTIC DRAINAGE MARKING
               18.0000       EACH                      21.0000           32.0000     52.38 %         60.0000    185.71 %         30.0000      42.86 %
                                                        378.00            576.00      198.00        1,080.00      702.00          540.00      162.00
  44  RAISED PAVEMENT MARKER TYPE 1
               14.3700       HUND                     220.0000          250.0000     13.64 %        300.0000     36.36 %        225.0000       2.27 %
                                                      3,161.40          3,592.50      431.10        4,311.00    1,149.60        3,233.25       71.85
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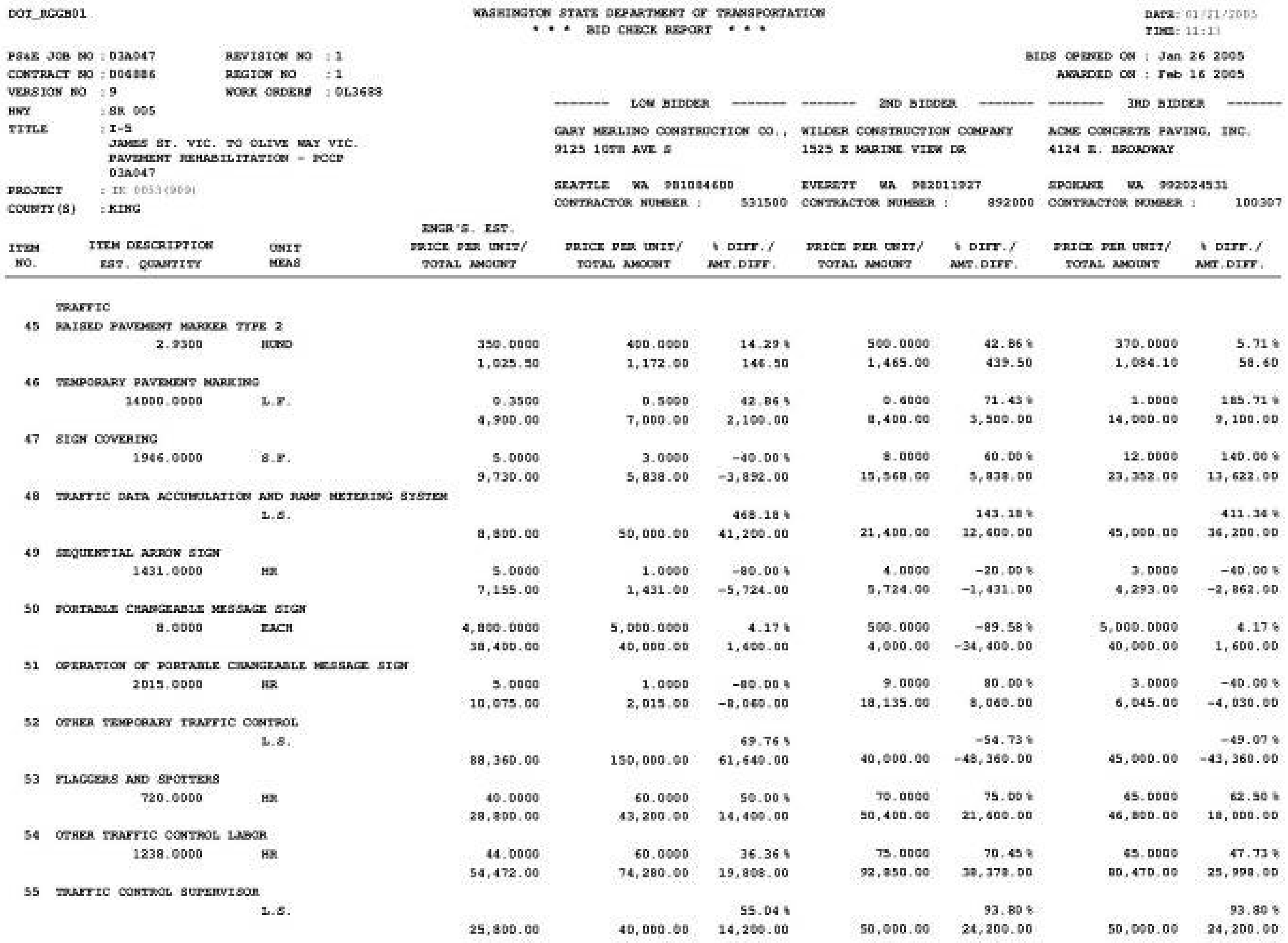

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DOT_RGGB01                          WASHINGTON STATE DEPARTMENT OF TRANSPORTATION                                         DATE: 01/21/2005
                                            * * *  BID CHECK REPORT  * * *                                                TIME: 11:11

PS&E JOB NO : 03A047        REVISION NO  : 1                                                                  BIDS OPENED ON : Jan 26 2005
CONTRACT NO : 006886        REGION NO    : 1                                                                      AWARDED ON : Feb 16 2005
VERSION NO  : 9             WORK ORDER#  : 0L3688
HWY         : SR 005                                  -------  LOW BIDDER  ------- -------  2ND BIDDER  ------- -------  3RD BIDDER  -------
TITLE       : I-5
              JAMES ST. VIC. TO OLIVE WAY VIC.        GARY MERLINO CONSTRUCTION CO., WILDER CONSTRUCTION COMPANY    ACME CONCRETE PAVING, INC.
              PAVEMENT REHABILITATION - PCCP          9125 10TH AVE S                1525 E MARINE VIEW DR          4124 E. BROADWAY
              03A047
PROJECT     : IK 0053(909)                            SEATTLE   WA  981084600        EVERETT   WA  982011927        SPOKANE   WA  992024531
COUNTY(S)   : KING                                    CONTRACTOR NUMBER :    531500  CONTRACTOR NUMBER :    892000  CONTRACTOR NUMBER :    100307
                                         ENGR'S. EST.
ITEM      ITEM DESCRIPTION    UNIT     PRICE PER UNIT/   PRICE PER UNIT/  % DIFF./   PRICE PER UNIT/  % DIFF./   PRICE PER UNIT/  % DIFF./
 NO.       EST. QUANTITY      MEAS      TOTAL AMOUNT      TOTAL AMOUNT    AMT.DIFF.   TOTAL AMOUNT    AMT.DIFF.   TOTAL AMOUNT    AMT.DIFF.


     TRAFFIC
  45 RAISED PAVEMENT MARKER TYPE 2
              2.9300        HUND            350.0000          400.0000     14.29 %       500.0000      42.86 %       370.0000       5.71 %
                                          1,025.50          1,172.00     146.50       1,465.00      439.50       1,084.10        58.60
  46 TEMPORARY PAVEMENT MARKING
          14000.0000        L.F.              0.3500            0.5000     42.86 %         0.6000      71.43 %         1.0000     185.71 %
                                          4,900.00          7,000.00   2,100.00       8,400.00    3,500.00      14,000.00     9,100.00
  47 SIGN COVERING
           1946.0000        S.F.              5.0000            3.0000    -40.00 %         8.0000      60.00 %        12.0000     140.00 %
                                          9,730.00          5,838.00  -3,892.00      15,568.00    5,838.00      23,352.00    13,622.00
  48 TRAFFIC DATA ACCUMULATION AND RAMP METERING SYSTEM
                            L.S.                                        468.18 %                   143.18 %                     411.36 %
                                          8,800.00         50,000.00  41,200.00      21,400.00   12,600.00      45,000.00    36,200.00
  49 SEQUENTIAL ARROW SIGN
           1431.0000        HR                5.0000            1.0000    -80.00 %         4.0000     -20.00 %         3.0000     -40.00 %
                                          7,155.00          1,431.00  -5,724.00       5,724.00   -1,431.00       4,293.00    -2,862.00
  50 PORTABLE CHANGEABLE MESSAGE SIGN
              8.0000        EACH          4,800.0000        5,000.0000      4.17 %       500.0000     -89.58 %     5,000.0000       4.17 %
                                         38,400.00         40,000.00   1,600.00       4,000.00  -34,400.00      40,000.00     1,600.00
  51 OPERATION OF PORTABLE CHANGEABLE MESSAGE SIGN
           2015.0000        HR                5.0000            1.0000    -80.00 %         9.0000      80.00 %         3.0000     -40.00 %
                                         10,075.00          2,015.00  -8,060.00      18,135.00    8,060.00       6,045.00    -4,030.00
  52 OTHER TEMPORARY TRAFFIC CONTROL
                            L.S.                                         69.76 %                   -54.73 %                     -49.07 %
                                         88,360.00        150,000.00  61,640.00      40,000.00  -48,360.00      45,000.00   -43,360.00
  53 FLAGGERS AND SPOTTERS
            720.0000        HR               40.0000           60.0000     50.00 %        70.0000      75.00 %        65.0000      62.50 %
                                         28,800.00         43,200.00  14,400.00      50,400.00   21,600.00      46,800.00    18,000.00
  54 OTHER TRAFFIC CONTROL LABOR
           1238.0000        HR               44.0000           60.0000     36.36 %        75.0000      70.45 %        65.0000      47.73 %
                                         54,472.00         74,280.00  19,808.00      92,850.00   38,378.00      80,470.00    25,998.00
  55 TRAFFIC CONTROL SUPERVISOR
                            L.S.                                         55.04 %                    93.80 %                      93.80 %
                                         25,800.00         40,000.00  14,200.00      50,000.00   24,200.00      50,000.00    24,200.00
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DOT_RGGB01

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION
* * * BID CHECK REPORT * * *

DATE: 01/21/2005
TIME: 11:11

PS&E JOB NO : 03A047 REVISION NO : 1
CONTRACT NO : 006886 REGION NO : 1
VERSION NO : 9 WORK ORDER# : 0L3688
HWY : SR 005
TITLE : I-5
JAMES ST. VIC. TO OLIVE WAY VIC.
PAVEMENT REHABILITATION - PCCP
03A047
PROJECT : IK 0053(909)
COUNTY(S) : KING

BIDS OPENED ON : Jan 26 2005
AWARDED ON : Feb 16 2005

------- LOW BIDDER -------
GARY MERLINO CONSTRUCTION CO.,
9125 10TH AVE S
SEATTLE WA 981084600
CONTRACTOR NUMBER : 531500

------- 2ND BIDDER -------
WILDER CONSTRUCTION COMPANY
1525 E MARINE VIEW DR
EVERETT WA 982011927
CONTRACTOR NUMBER : 892000

------- 3RD BIDDER -------
ACME CONCRETE PAVING, INC.
4124 E. BROADWAY
SPOKANE WA 992024531
CONTRACTOR NUMBER : 100307

ITEM NO.	ITEM DESCRIPTION EST. QUANTITY	UNIT MEAS	ENGR'S. EST. PRICE PER UNIT/ TOTAL AMOUNT	LOW BIDDER PRICE PER UNIT/ TOTAL AMOUNT	% DIFF./ AMT.DIFF.	2ND BIDDER PRICE PER UNIT/ TOTAL AMOUNT	% DIFF./ AMT.DIFF.	3RD BIDDER PRICE PER UNIT/ TOTAL AMOUNT	% DIFF./ AMT.DIFF.
	TRAFFIC								
56	CONSTRUCTION SIGNS CLASS A								
	1162.0000	S.F.	35.0000	28.0000	-20.00 %	24.0000	-31.43 %	30.0000	-14.29 %
			40,670.00	32,536.00	-8,134.00	27,888.00	-12,782.00	34,860.00	-5,810.00
57	INITIAL DELIVERY AND PLACEMENT OF QMB								
		L.S.			-100.00 %		100.00 %		60.00 %
			25,000.00	0.00	-25,000.00	50,000.00	25,000.00	40,000.00	15,000.00
58	MOVING QMB WITH TTV								
	11500.0000	L.F.	2.0000	0.0000	-100.00 %	0.7000	-65.00 %	5.0000	150.00 %
			23,000.00	0.00	-23,000.00	8,050.00	-14,950.00	57,500.00	34,500.00
59	TTV MOBILIZATION								
		L.S.			-100.00 %		53.33 %		-40.00 %
			3,000.00	0.00	-3,000.00	4,600.00	1,600.00	1,800.00	-1,200.00
60	REPLACEMENT PARTS FOR TTV								
		EST.			0.00 %		0.00 %		0.00 %
			7,000.00	7,000.00		7,000.00		7,000.00	
	OTHER ITEMS								
61	INCENTIVE EARLY COMPL.								
		EST.			0.00 %		0.00 %		0.00 %
			150,000.00	150,000.00		150,000.00		150,000.00	
62	STRUCTURE EXCAVATION CLASS B INCL. HAUL								
	5.6300	C.Y.	50.0000	50.0000	0.00 %	100.0000	100.00 %	60.0000	20.00 %
			281.50	281.50	0.00	563.00	281.50	337.80	56.30
63	SHORING OR EXTRA EXCAVATION CLASS B								
	40.8000	S.F.	10.0000	10.0000	0.00 %	20.0000	100.00 %	4.0000	-60.00 %
			408.00	408.00	0.00	816.00	408.00	163.20	-244.80
64	WATER								
	156.0000	MGAL	35.0000	30.0000	-14.29 %	51.0000	45.71 %	6.0000	-82.86 %
			5,460.00	4,680.00	-780.00	7,956.00	2,496.00	936.00	-4,524.00
65	ROADWAY SURVEYING								
		L.S.			614.29 %		185.71 %		1,042.86 %
			7,000.00	50,000.00	43,000.00	20,000.00	13,000.00	80,000.00	73,000.00

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DOT_RGGB01                                    WASHINGTON STATE DEPARTMENT OF TRANSPORTATION                                        DATE: 01/21/2005
                                                  * * *  BID CHECK REPORT  * * *                                                   TIME: 11:11

PS&E JOB NO : 03A047         REVISION NO  : 1                                                                          BIDS OPENED ON : Jan 26 2005
CONTRACT NO : 006886         REGION NO    : 1                                                                             AWARDED ON : Feb 16 2005
VERSION NO  : 9              WORK ORDER#  : 0L3688
HWY         : SR 005                                      -------  LOW BIDDER  ------- -------  2ND BIDDER  ------- -------  3RD BIDDER  -------
TITLE       : I-5
              JAMES ST. VIC. TO OLIVE WAY VIC.            GARY MERLINO CONSTRUCTION CO., WILDER CONSTRUCTION COMPANY    ACME CONCRETE PAVING, INC.
              PAVEMENT REHABILITATION - PCCP              9125 10TH AVE S                1525 E MARINE VIEW DR          4124 E. BROADWAY
              03A047
PROJECT     : IK 0053(909)                                SEATTLE   WA  981084600        EVERETT   WA  982011927        SPOKANE   WA  992024531
COUNTY(S)   : KING                                        CONTRACTOR NUMBER :     531500 CONTRACTOR NUMBER :     892000 CONTRACTOR NUMBER :     100307
                                             ENGR'S. EST.
ITEM     ITEM DESCRIPTION     UNIT         PRICE PER UNIT/   PRICE PER UNIT/   % DIFF./   PRICE PER UNIT/   % DIFF./   PRICE PER UNIT/   % DIFF./
 NO.      EST. QUANTITY       MEAS          TOTAL AMOUNT      TOTAL AMOUNT     AMT.DIFF.   TOTAL AMOUNT     AMT.DIFF.   TOTAL AMOUNT     AMT.DIFF.
____________________________________________________________________________________________________________________________________________________

     OTHER ITEMS
  66 CONNECTION TO DRAINAGE STRUCTURE
              3.0000         EACH               400.0000        1,000.0000     150.00 %       2,000.0000     400.00 %         600.0000      50.00 %
                                              1,200.00          3,000.00     1,800.00         6,000.00     4,800.00         1,800.00       600.00
  67 ADJUST MANHOLE
              4.0000         EACH               500.0000          500.0000       0.00 %         460.0000      -8.00 %         400.0000     -20.00 %
                                              2,000.00          2,000.00         0.00         1,840.00      -160.00         1,600.00      -400.00
  68 ADJUST CATCH BASIN
             15.0000         EACH               400.0000          500.0000      25.00 %         460.0000      15.00 %         400.0000       0.00 %
                                              6,000.00          7,500.00     1,500.00         6,900.00       900.00         6,000.00         0.00
  69 ROADSIDE CLEANUP
                             EST.                                                0.00 %                        0.00 %                        0.00 %
                                              7,500.00          7,500.00                      7,500.00                      7,500.00
  70 REIMBURSEMENT FOR THIRD PARTY DAMAGE
                             EST.                                                0.00 %                        0.00 %                        0.00 %
                                                  5.00              5.00                          5.00                          5.00
  71 MINOR CHANGE
                             CALC                                                0.00 %                        0.00 %                        0.00 %
                                                 -1.00             -1.00                         -1.00                         -1.00
  72 SPCC PLAN
                             L.S.                                              -50.00 %                      -50.00 %                      150.00 %
                                              1,000.00            500.00      -500.00           500.00      -500.00         2,500.00     1,500.00
  73 SITE MAINT. FOR BIO.  AND PHYSICAL HAZARDS
                             L.S.                                                0.00 %                      400.00 %                        0.00 %
                                              1,000.00          1,000.00         0.00         5,000.00     4,000.00         1,000.00         0.00
  74 FA-PERIODIC SITE MAINT. FOR BIO. AND PHYSICAL HAZARDS
                             EST.                                                0.00 %                        0.00 %                        0.00 %
                                              5,000.00          5,000.00                      5,000.00                      5,000.00
  75 CONSTRUCTION GEOTEXTILE FOR SOIL STABILIZATION
             48.7000         S.Y.                12.0000           10.0000     -16.67 %          10.0000     -16.67 %           6.0000     -50.00 %
                                                584.40            487.00       -97.40           487.00       -97.40           292.20      -292.20
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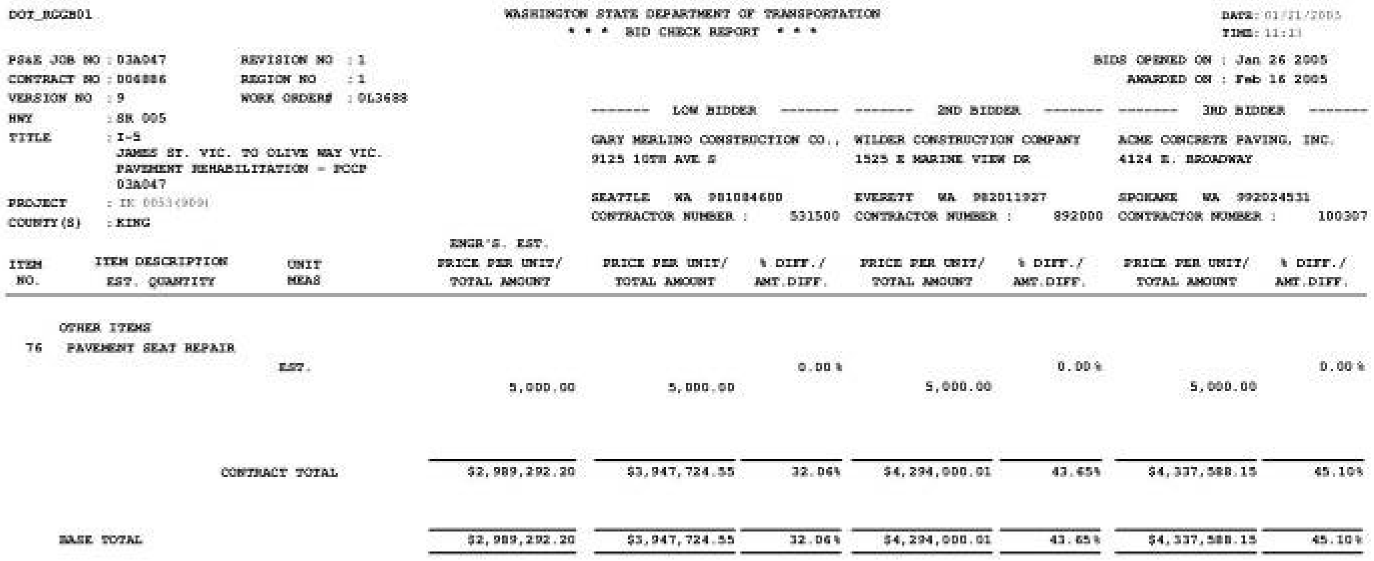

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DOT_RGGB01                                         WASHINGTON STATE DEPARTMENT OF TRANSPORTATION                                                      DATE: 01/21/2005
                                                        * * *  BID CHECK REPORT  * * *                                                                TIME: 11:11

PS&E JOB NO : 03A047        REVISION NO  : 1                                                                                             BIDS OPENED ON : Jan 26 2005
CONTRACT NO : 006886        REGION NO    : 1                                                                                                 AWARDED ON : Feb 16 2005
VERSION NO  : 9             WORK ORDER#  : 0L3688
HWY         : SR 005                                          -------  LOW BIDDER  ------- -------  2ND BIDDER  ------- -------  3RD BIDDER  -------
TITLE       : I-5                                             GARY MERLINO CONSTRUCTION CO., WILDER CONSTRUCTION COMPANY     ACME CONCRETE PAVING, INC.
              JAMES ST. VIC. TO OLIVE WAY VIC.                9125 10TH AVE S                1525 E MARINE VIEW DR           4124 E. BROADWAY
              PAVEMENT REHABILITATION - PCCP
              03A047
PROJECT     : IK 0053(909)                                    SEATTLE   WA  981084600        EVERETT   WA  982011927         SPOKANE   WA  992024531
COUNTY(S)   : KING                                            CONTRACTOR NUMBER :     531500 CONTRACTOR NUMBER :     892000  CONTRACTOR NUMBER :     100307
                                                  ENGR'S. EST.
ITEM     ITEM DESCRIPTION      UNIT             PRICE PER UNIT/   PRICE PER UNIT/   % DIFF./   PRICE PER UNIT/   % DIFF./   PRICE PER UNIT/   % DIFF./
 NO.      EST. QUANTITY        MEAS              TOTAL AMOUNT      TOTAL AMOUNT     AMT.DIFF.   TOTAL AMOUNT     AMT.DIFF.   TOTAL AMOUNT     AMT.DIFF.

    OTHER ITEMS
 76  PAVEMENT SEAT REPAIR
                               EST.                                                   0.00 %                       0.00 %                       0.00 %
                                                      5,000.00          5,000.00                     5,000.00                     5,000.00


                   CONTRACT TOTAL             $2,989,292.20     $3,947,724.55      32.06%   $4,294,000.01      43.65%   $4,337,588.15      45.10%


    BASE TOTAL                                $2,989,292.20     $3,947,724.55      32.06%   $4,294,000.01      43.65%   $4,337,588.15      45.10%
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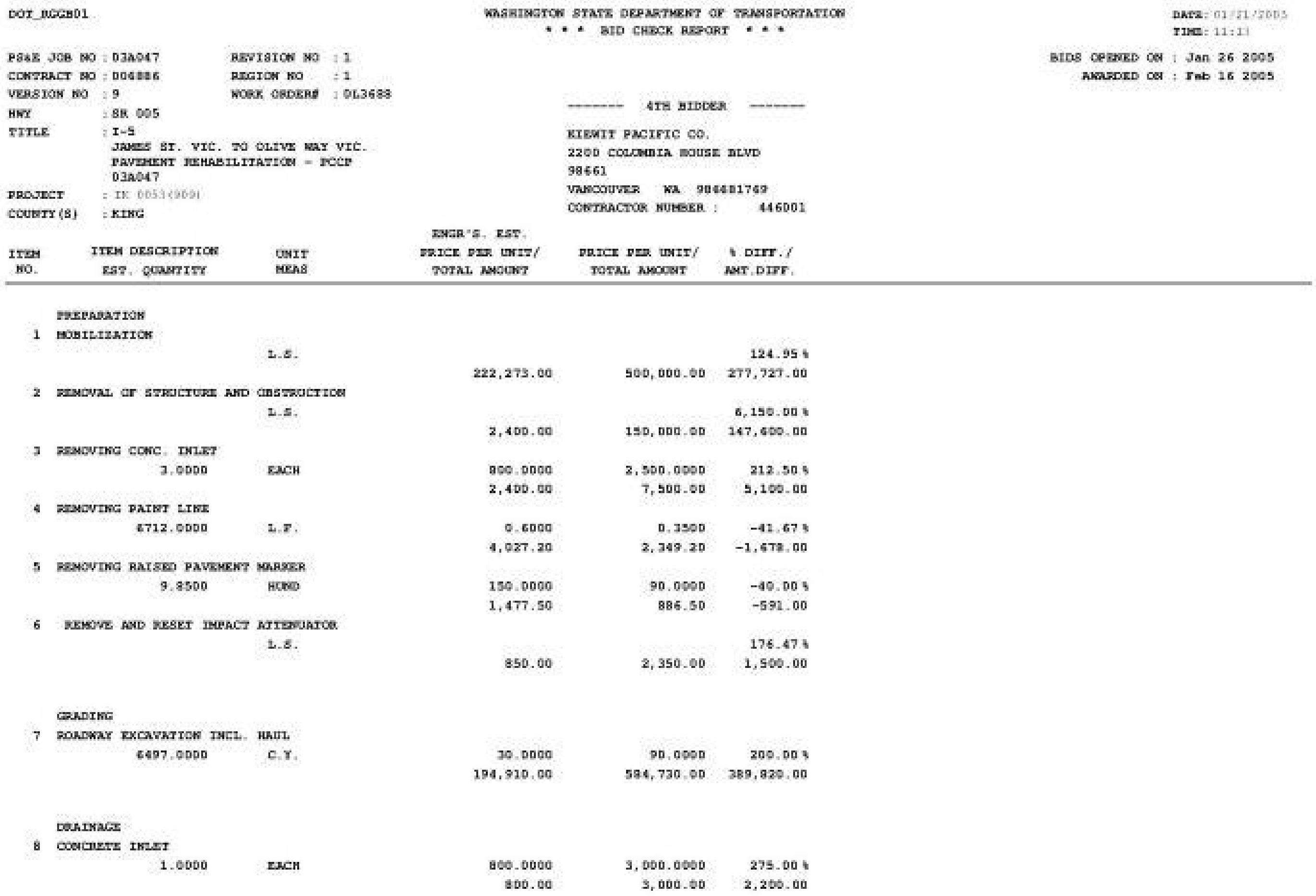

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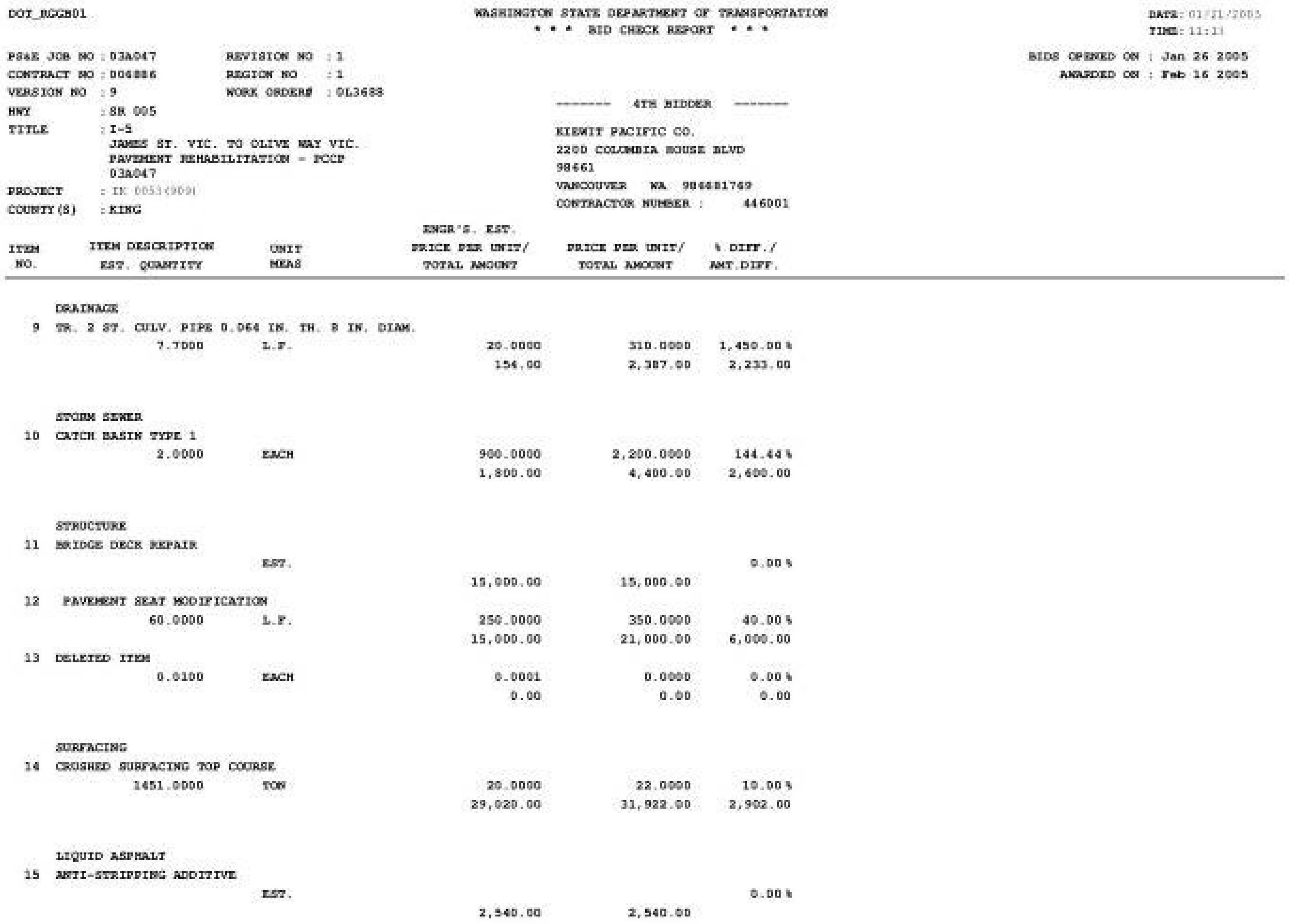
DOT_RGGB01                                   WASHINGTON STATE DEPARTMENT OF TRANSPORTATION                                  DATE: 01/21/2005
                                                  * * *  BID CHECK REPORT  * * *                                            TIME: 11:13

PS&E JOB NO : 03A047        REVISION NO  : 1                                                                     BIDS OPENED ON : Jan 26 2005
CONTRACT NO : 006886        REGION NO    : 1                                                                        AWARDED ON : Feb 16 2005
VERSION NO  : 9             WORK ORDER#  : 0L3688
HWY         : SR 005                                              -------  4TH BIDDER  -------
TITLE       : I-5
              JAMES ST. VIC. TO OLIVE WAY VIC.                    KIEWIT PACIFIC CO.
              PAVEMENT REHABILITATION - PCCP                      2200 COLOMBIA HOUSE BLVD
              03A047                                              98661
PROJECT     : IK 0053(909)                                        VANCOUVER   WA  984481749
COUNTY(S)   : KING                                                CONTRACTOR NUMBER :     446001
                                                   ENGR'S. EST.
ITEM     ITEM DESCRIPTION      UNIT             PRICE PER UNIT/    PRICE PER UNIT/   % DIFF./
 NO.       EST. QUANTITY       MEAS              TOTAL AMOUNT       TOTAL AMOUNT    AMT.DIFF.
_____________________________________________________________________________________________

     PREPARATION
  1  MOBILIZATION
                               L.S.                                                   124.95 %
                                                   222,273.00         500,000.00   277,727.00
  2  REMOVAL OF STRUCTURE AND OBSTRUCTION
                               L.S.                                                 6,150.00 %
                                                     2,400.00         150,000.00   147,600.00
  3  REMOVING CONC. INLET
                  3.0000       EACH                  800.0000         2,500.0000      212.50 %
                                                     2,400.00           7,500.00     5,100.00
  4  REMOVING PAINT LINE
               6712.0000       L.F.                    0.6000             0.3500      -41.67 %
                                                     4,027.20           2,349.20    -1,678.00
  5  REMOVING RAISED PAVEMENT MARKER
                  9.8500       HUND                  150.0000            90.0000      -40.00 %
                                                     1,477.50             886.50      -591.00
  6   REMOVE AND RESET IMPACT ATTENUATOR
                               L.S.                                                   176.47 %
                                                       850.00           2,350.00     1,500.00


     GRADING
  7  ROADWAY EXCAVATION INCL. HAUL
               6497.0000       C.Y.                   30.0000            90.0000      200.00 %
                                                   194,910.00         584,730.00   389,820.00


     DRAINAGE
  8  CONCRETE INLET
                  1.0000       EACH                  800.0000         3,000.0000      275.00 %
                                                       800.00           3,000.00     2,200.00
```



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DOT_RGGB01                                            WASHINGTON STATE DEPARTMENT OF TRANSPORTATION                                    DATE: 01/21/2005
                                                           * * *  BID CHECK REPORT  * * *                                              TIME: 11:11

PS&E JOB NO : 03A047          REVISION NO  : 1                                                                            BIDS OPENED ON : Jan 26 2005
CONTRACT NO : 006886          REGION NO    : 1                                                                               AWARDED ON : Feb 16 2005
VERSION NO  : 9               WORK ORDER#  : 0L3688
HWY         : SR 005                                                  -------   4TH BIDDER   -------
TITLE       : I-5                                                     KIEWIT PACIFIC CO.
             JAMES ST. VIC. TO OLIVE WAY VIC.                         2200 COLUMBIA HOUSE BLVD
             PAVEMENT REHABILITATION - PCCP                           98661
             03A047                                                   VANCOUVER   WA  986681749
PROJECT     : IK 0053(909)                                            CONTRACTOR NUMBER :     446001
COUNTY(S)   : KING
                                                      ENGR'S. EST.
ITEM      ITEM DESCRIPTION       UNIT               PRICE PER UNIT/    PRICE PER UNIT/    % DIFF./
 NO.       EST. QUANTITY         MEAS                 TOTAL AMOUNT       TOTAL AMOUNT      AMT.DIFF.

     DRAINAGE
  9  TR. 2 ST. CULV. PIPE 0.064 IN. TH. 8 IN. DIAM.
                  7.7000         L.F.                    20.0000           310.0000    1,450.00 %
                                                          154.00           2,387.00     2,233.00


     STORM SEWER
 10  CATCH BASIN TYPE 1
                  2.0000         EACH                   900.0000         2,200.0000      144.44 %
                                                        1,800.00           4,400.00     2,600.00


     STRUCTURE
 11  BRIDGE DECK REPAIR
                                 EST.                                                      0.00 %
                                                       15,000.00          15,000.00
 12   PAVEMENT SEAT MODIFICATION
                 60.0000         L.F.                   250.0000           350.0000       40.00 %
                                                       15,000.00          21,000.00     6,000.00
 13  DELETED ITEM
                  0.0100         EACH                     0.0001             0.0000        0.00 %
                                                            0.00               0.00         0.00


     SURFACING
 14  CRUSHED SURFACING TOP COURSE
               1451.0000         TON                     20.0000            22.0000       10.00 %
                                                       29,020.00          31,922.00     2,902.00


     LIQUID ASPHALT
 15  ANTI-STRIPPING ADDITIVE
                                 EST.                                                      0.00 %
                                                        2,540.00           2,540.00
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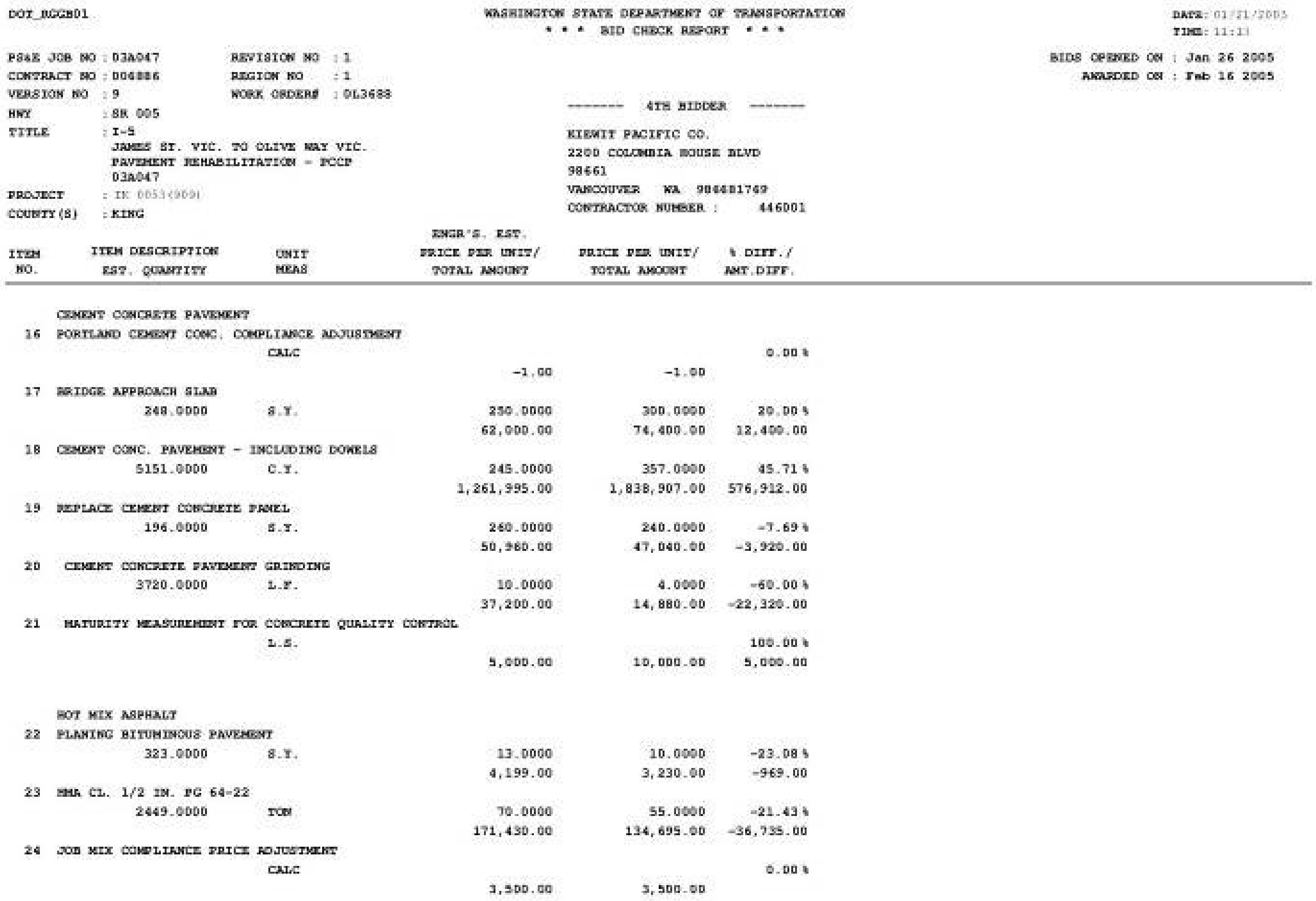

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DOT_RGGB01                                              WASHINGTON STATE DEPARTMENT OF TRANSPORTATION                                    DATE: 01/21/2005
                                                             * * *  BID CHECK REPORT  * * *                                              TIME: 11:11

PS&E JOB NO : 03A047         REVISION NO  : 1                                                                            BIDS OPENED ON : Jan 26 2005
CONTRACT NO : 006886         REGION NO    : 1                                                                               AWARDED ON : Feb 16 2005
VERSION NO  : 9              WORK ORDER#  : 0L3688
HWY         : SR 005                                              -------  4TH BIDDER  -------
TITLE       : I-5
              JAMES ST. VIC. TO OLIVE WAY VIC.                    KIEWIT PACIFIC CO.
              PAVEMENT REHABILITATION - PCCP                      2200 COLUMBIA HOUSE BLVD
              03A047                                              98661
PROJECT     : IK 0053(909)                                        VANCOUVER   WA  986681749
COUNTY(S)   : KING                                                CONTRACTOR NUMBER :      446001
                                                   ENGR'S. EST.
ITEM      ITEM DESCRIPTION       UNIT           PRICE PER UNIT/     PRICE PER UNIT/   % DIFF./
 NO.        EST. QUANTITY        MEAS             TOTAL AMOUNT        TOTAL AMOUNT    AMT.DIFF.
----------------------------------------------------------------------------------------------------------------------------------------------

     CEMENT CONCRETE PAVEMENT
 16  PORTLAND CEMENT CONC. COMPLIANCE ADJUSTMENT
                                  CALC                                                    0.00 %
                                                         -1.00             -1.00
 17  BRIDGE APPROACH SLAB
              248.0000            S.Y.                250.0000          300.0000         20.00 %
                                                    62,000.00         74,400.00     12,400.00
 18  CEMENT CONC. PAVEMENT - INCLUDING DOWELS
             5151.0000            C.Y.                245.0000          357.0000         45.71 %
                                                 1,261,995.00      1,838,907.00    576,912.00
 19  REPLACE CEMENT CONCRETE PANEL
              196.0000            S.Y.                260.0000          240.0000         -7.69 %
                                                    50,960.00         47,040.00     -3,920.00
 20   CEMENT CONCRETE PAVEMENT GRINDING
             3720.0000            L.F.                 10.0000            4.0000        -60.00 %
                                                    37,200.00         14,880.00    -22,320.00
 21   MATURITY MEASUREMENT FOR CONCRETE QUALITY CONTROL
                                  L.S.                                                  100.00 %
                                                     5,000.00         10,000.00      5,000.00


     HOT MIX ASPHALT
 22  PLANING BITUMINOUS PAVEMENT
              323.0000            S.Y.                 13.0000           10.0000        -23.08 %
                                                     4,199.00          3,230.00       -969.00
 23  HMA CL. 1/2 IN. PG 64-22
             2449.0000            TON                  70.0000           55.0000        -21.43 %
                                                   171,430.00        134,695.00    -36,735.00
 24  JOB MIX COMPLIANCE PRICE ADJUSTMENT
                                  CALC                                                    0.00 %
                                                     3,500.00          3,500.00
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DOT_RGGB01                                                    WASHINGTON STATE DEPARTMENT OF TRANSPORTATION                                    DATE: 01/21/2005
                                                                    * * *  BID CHECK REPORT  * * *                                              TIME: 11:11

PS&E JOB NO : 03A047          REVISION NO  : 1                                                                                 BIDS OPENED ON : Jan 26 2005
CONTRACT NO : 006886          REGION NO    : 1                                                                                     AWARDED ON : Feb 16 2005
VERSION NO  : 9               WORK ORDER#  : 0L3688
HWY         : SR 005                                                    -------   4TH BIDDER   -------
TITLE       : I-5
              JAMES ST. VIC. TO OLIVE WAY VIC.                          KIEWIT PACIFIC CO.
              PAVEMENT REHABILITATION - PCCP                            2200 COLUMBIA HOUSE BLVD
              03A047                                                    98661
PROJECT     : IK 0053(909)                                              VANCOUVER   WA  986681749
COUNTY(S)   : KING                                                      CONTRACTOR NUMBER :     446001
                                                       ENGR'S. EST.
ITEM      ITEM DESCRIPTION      UNIT                 PRICE PER UNIT/    PRICE PER UNIT/   % DIFF./
 NO.       EST. QUANTITY        MEAS                  TOTAL AMOUNT       TOTAL AMOUNT     AMT.DIFF.
-----------------------------------------------------------------------------------------------------------------------------------------------

     HOT MIX ASPHALT
 26  LONGITUDINAL JOINT SEAL
            800.0000       L.F.                          10.0000             2.7000      -73.00 %
                                                        8,000.00           2,160.00    -5,840.00


     EROSION CONTROL AND PLANTING
 25  ESC LEAD
             32.0000       DAY                          100.0000            10.0000      -90.00 %
                                                        3,200.00             320.00    -2,880.00
 27  STREET CLEANING
             38.0000       HR                           100.0000           150.0000       50.00 %
                                                        3,800.00           5,700.00     1,900.00
 28  INLET PROTECTION
             33.0000       EACH                          90.0000           250.0000      177.78 %
                                                        2,970.00           8,250.00     5,280.00
 29  EROSION/WATER POLLUTION CONTROL
                           EST.                                                            0.00 %
                                                       30,000.00          30,000.00


     TRAFFIC
 30  CEMENT CONC. TRAFFIC CURB
             23.0000       L.F.                          50.0000            70.0000       40.00 %
                                                        1,150.00           1,610.00       460.00
 31  REMOVING AND RESETTING BEAM GUARDRAIL
             36.0000       L.F.                          12.0000            18.0000       50.00 %
                                                          432.00             648.00       216.00
 32  REMOVING AND RESETTING EXISTING PERMANENT BARRIER
            675.0000       L.F.                          11.0000            11.0000        0.00 %
                                                        7,425.00           7,425.00         0.00
 33  TEMPORARY IMPACT ATTENUATOR
             21.0000       EACH                       4,500.0000         3,200.0000      -28.89 %
                                                       94,500.00          67,200.00   -27,300.00
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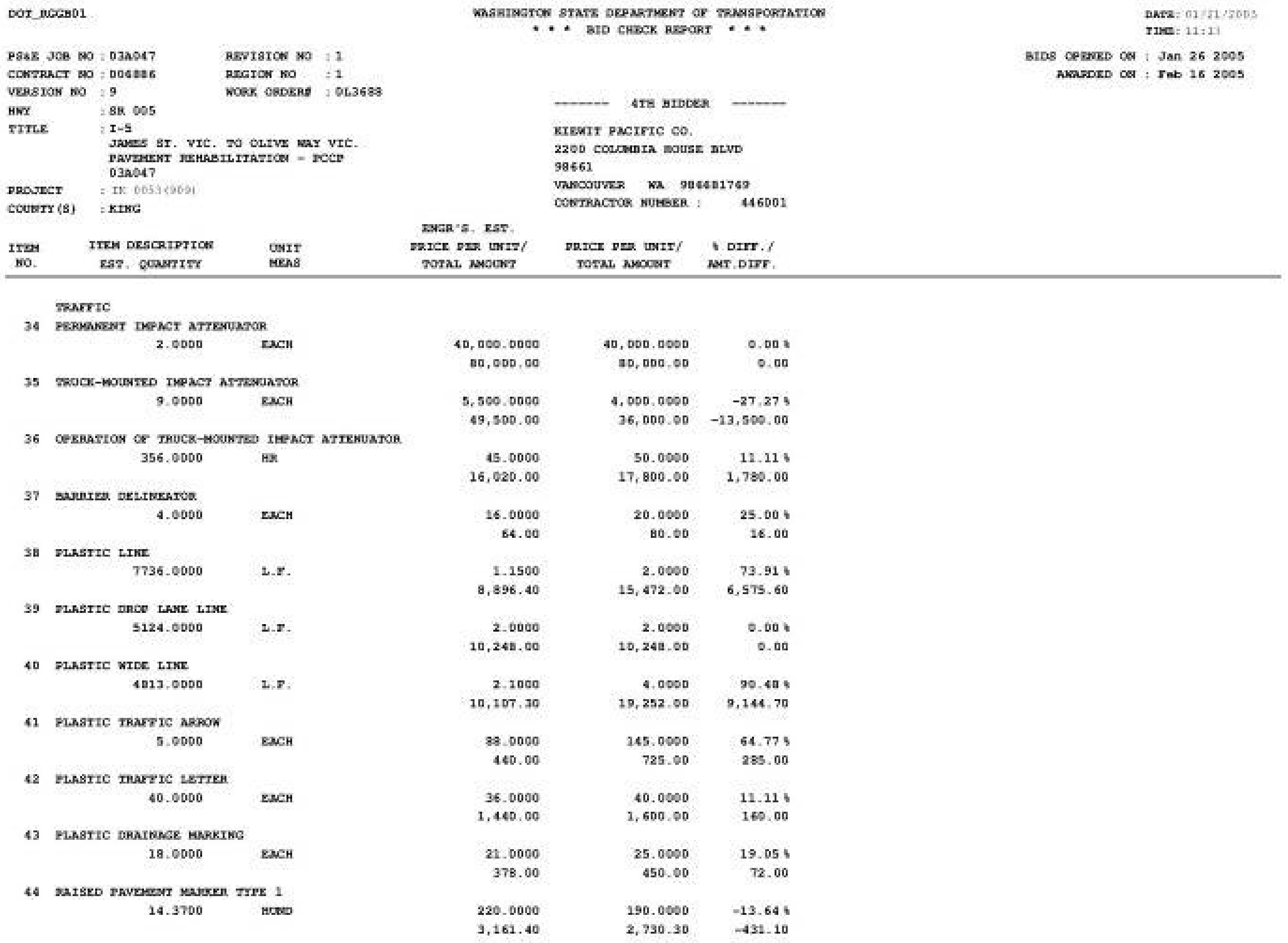

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DOT_RGGB01                                        WASHINGTON STATE DEPARTMENT OF TRANSPORTATION                                  DATE: 01/21/2005
                                                           * * *  BID CHECK REPORT  * * *                                      TIME: 11:11

PS&E JOB NO : 03A047        REVISION NO  : 1                                                                  BIDS OPENED ON : Jan 26 2005
CONTRACT NO : 006886        REGION NO    : 1                                                                     AWARDED ON : Feb 16 2005
VERSION NO  : 9             WORK ORDER#  : 0L3688
HWY         : SR 005                                               -------  4TH BIDDER  -------
TITLE       : I-5
              JAMES ST. VIC. TO OLIVE WAY VIC.                      KIEWIT PACIFIC CO.
              PAVEMENT REHABILITATION - PCCP                        2200 COLUMBIA HOUSE BLVD
              03A047                                                98661
PROJECT     : IK 0053(909)                                          VANCOUVER   WA  984681749
COUNTY(S)   : KING                                                  CONTRACTOR NUMBER :     446001
                                                     ENGR'S. EST.
ITEM       ITEM DESCRIPTION       UNIT             PRICE PER UNIT/    PRICE PER UNIT/   % DIFF./
 NO.        EST. QUANTITY         MEAS              TOTAL AMOUNT       TOTAL AMOUNT     AMT.DIFF.
--------------------------------------------------------------------------------------------------

    TRAFFIC
 34 PERMANENT IMPACT ATTENUATOR
              2.0000        EACH                    40,000.0000        40,000.0000        0.00 %
                                                     80,000.00          80,000.00         0.00
 35 TRUCK-MOUNTED IMPACT ATTENUATOR
              9.0000        EACH                     5,500.0000         4,000.0000      -27.27 %
                                                     49,500.00          36,000.00    -13,500.00
 36 OPERATION OF TRUCK-MOUNTED IMPACT ATTENUATOR
            356.0000        HR                          45.0000            50.0000       11.11 %
                                                     16,020.00          17,800.00      1,780.00
 37 BARRIER DELINEATOR
              4.0000        EACH                        16.0000            20.0000       25.00 %
                                                         64.00              80.00         16.00
 38 PLASTIC LINE
           7736.0000        L.F.                         1.1500             2.0000       73.91 %
                                                      8,896.40          15,472.00      6,575.60
 39 PLASTIC DROP LANE LINE
           5124.0000        L.F.                         2.0000             2.0000        0.00 %
                                                     10,248.00          10,248.00         0.00
 40 PLASTIC WIDE LINE
           4813.0000        L.F.                         2.1000             4.0000       90.48 %
                                                     10,107.30          19,252.00      9,144.70
 41 PLASTIC TRAFFIC ARROW
              5.0000        EACH                        88.0000           145.0000       64.77 %
                                                        440.00             725.00        285.00
 42 PLASTIC TRAFFIC LETTER
             40.0000        EACH                        36.0000            40.0000       11.11 %
                                                      1,440.00           1,600.00        160.00
 43 PLASTIC DRAINAGE MARKING
             18.0000        EACH                        21.0000            25.0000       19.05 %
                                                        378.00             450.00         72.00
 44 RAISED PAVEMENT MARKER TYPE 1
             14.3700        HUND                       220.0000           190.0000      -13.64 %
                                                      3,161.40           2,730.30       -431.10
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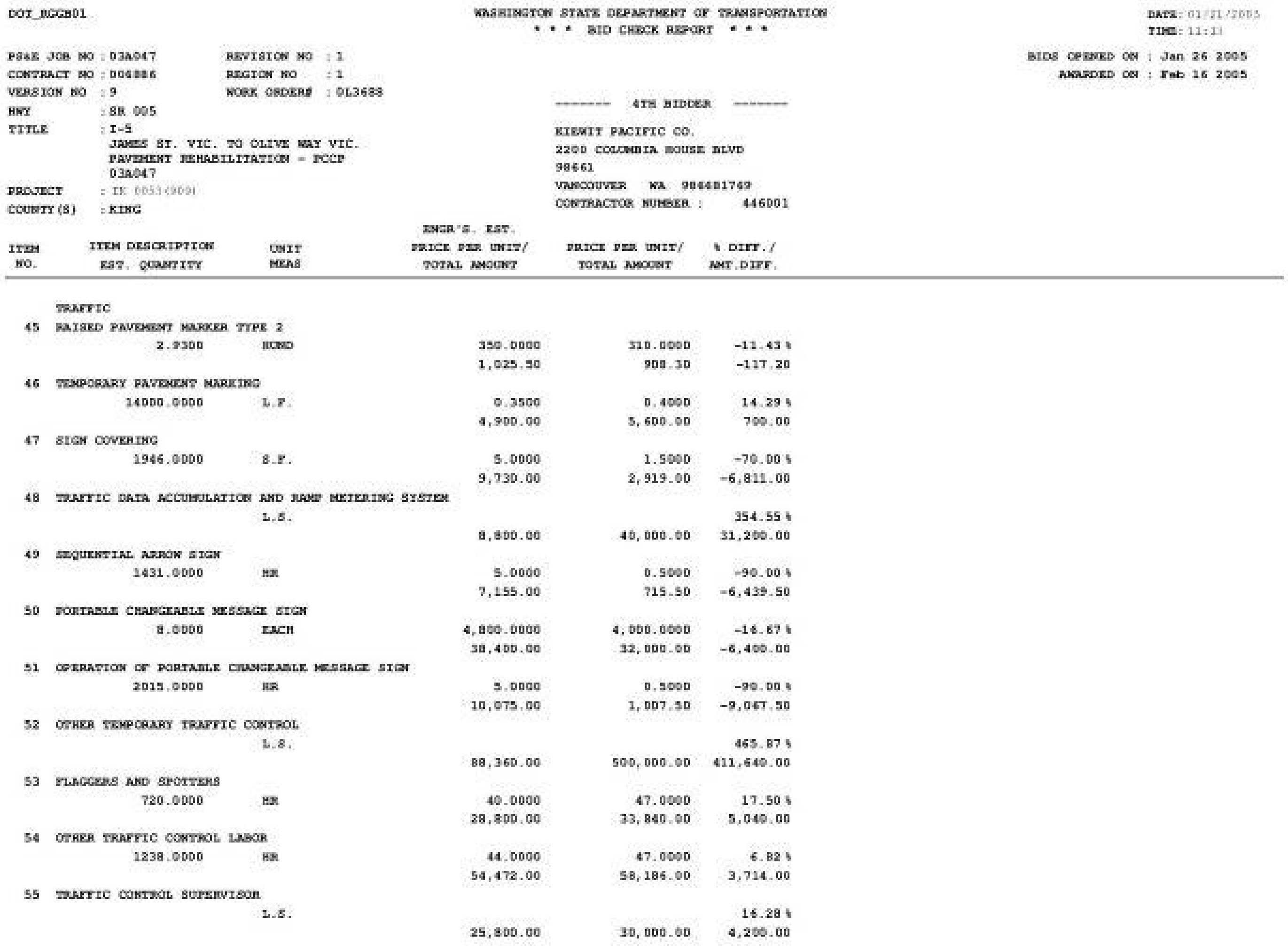

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DOT_RGGB01                                         WASHINGTON STATE DEPARTMENT OF TRANSPORTATION                                  DATE: 01/21/2005
                                                        * * *  BID CHECK REPORT  * * *                                            TIME: 11:11

PS&E JOB NO : 03A047         REVISION NO  : 1                                                                  BIDS OPENED ON : Jan 26 2005
CONTRACT NO : 006886         REGION NO    : 1                                                                      AWARDED ON : Feb 16 2005
VERSION NO  : 9              WORK ORDER#  : OL3688
HWY         : SR 005                                          -------  4TH BIDDER  -------
TITLE       : I-5                                             KIEWIT PACIFIC CO.
              JAMES ST. VIC. TO OLIVE WAY VIC.                2200 COLUMBIA HOUSE BLVD
              PAVEMENT REHABILITATION - PCCP                  98661
              03A047                                          VANCOUVER   WA  986681749
PROJECT     : IK 0053(909)                                    CONTRACTOR NUMBER :    446001
COUNTY(S)   : KING
                                                ENGR'S. EST.
ITEM     ITEM DESCRIPTION     UNIT            PRICE PER UNIT/    PRICE PER UNIT/   % DIFF./
 NO.      EST. QUANTITY       MEAS             TOTAL AMOUNT       TOTAL AMOUNT    AMT.DIFF.
--------------------------------------------------------------------------------------------

     TRAFFIC
  45 RAISED PAVEMENT MARKER TYPE 2
                2.9300        HUND                 350.0000          310.0000      -11.43 %
                                                   1,025.50            908.30      -117.20
  46 TEMPORARY PAVEMENT MARKING
            14000.0000        L.F.                   0.3500            0.4000       14.29 %
                                                   4,900.00          5,600.00       700.00
  47 SIGN COVERING
             1946.0000        S.F.                   5.0000            1.5000      -70.00 %
                                                   9,730.00          2,919.00    -6,811.00
  48 TRAFFIC DATA ACCUMULATION AND RAMP METERING SYSTEM
                              L.S.                                                 354.55 %
                                                   8,800.00         40,000.00    31,200.00
  49 SEQUENTIAL ARROW SIGN
             1431.0000        HR                     5.0000            0.5000      -90.00 %
                                                   7,155.00            715.50    -6,439.50
  50 PORTABLE CHANGEABLE MESSAGE SIGN
                8.0000        EACH               4,800.0000        4,000.0000      -16.67 %
                                                  38,400.00         32,000.00    -6,400.00
  51 OPERATION OF PORTABLE CHANGEABLE MESSAGE SIGN
             2015.0000        HR                     5.0000            0.5000      -90.00 %
                                                  10,075.00          1,007.50    -9,067.50
  52 OTHER TEMPORARY TRAFFIC CONTROL
                              L.S.                                                 465.87 %
                                                  88,360.00        500,000.00   411,640.00
  53 FLAGGERS AND SPOTTERS
              720.0000        HR                    40.0000           47.0000       17.50 %
                                                  28,800.00         33,840.00     5,040.00
  54 OTHER TRAFFIC CONTROL LABOR
             1238.0000        HR                    44.0000           47.0000        6.82 %
                                                  54,472.00         58,186.00     3,714.00
  55 TRAFFIC CONTROL SUPERVISOR
                              L.S.                                                  16.28 %
                                                  25,800.00         30,000.00     4,200.00
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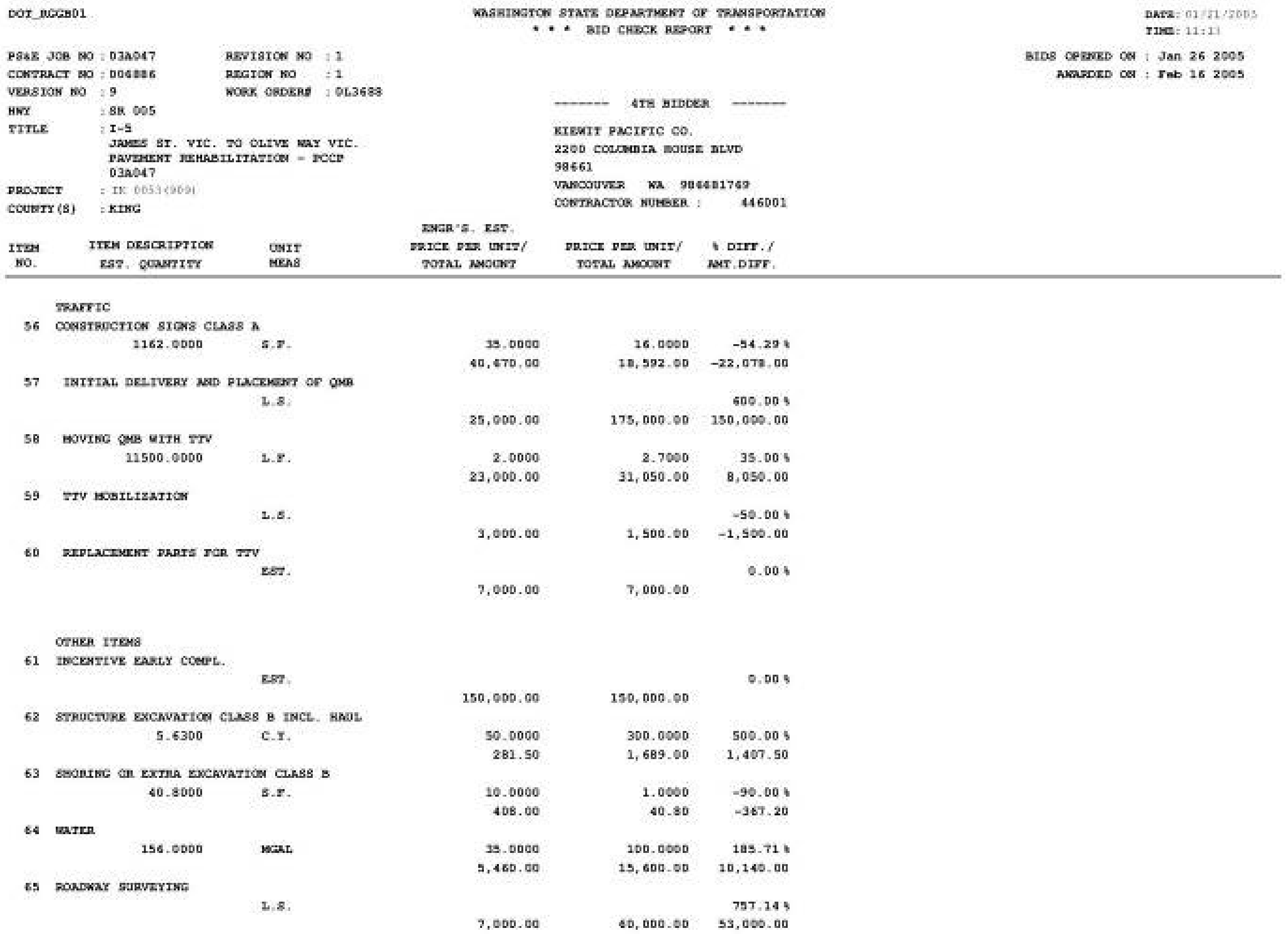

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DOT_RGGB01                                    WASHINGTON STATE DEPARTMENT OF TRANSPORTATION                                   DATE: 01/21/2005
                                                     * * *  BID CHECK REPORT  * * *                                           TIME: 11:11

PS&E JOB NO : 03A047        REVISION NO  : 1                                                                  BIDS OPENED ON : Jan 26 2005
CONTRACT NO : 006886        REGION NO    : 1                                                                    AWARDED ON : Feb 16 2005
VERSION NO  : 9             WORK ORDER#  : 0L3688
HWY         : SR 005                                            -------   4TH BIDDER   -------
TITLE       : I-5
              JAMES ST. VIC. TO OLIVE WAY VIC.                  KIEWIT PACIFIC CO.
              PAVEMENT REHABILITATION - PCCP                    2200 COLOMBIA HOUSE BLVD
              03A047                                            98661
PROJECT     : IK 0053(909)                                      VANCOUVER   WA  986681749
COUNTY(S)   : KING                                              CONTRACTOR NUMBER :     446001
                                                ENGR'S. EST.
ITEM     ITEM DESCRIPTION      UNIT           PRICE PER UNIT/    PRICE PER UNIT/   % DIFF./
 NO.       EST. QUANTITY       MEAS            TOTAL AMOUNT       TOTAL AMOUNT     AMT.DIFF.
-----------------------------------------------------------------------------------------------------------------------------------------

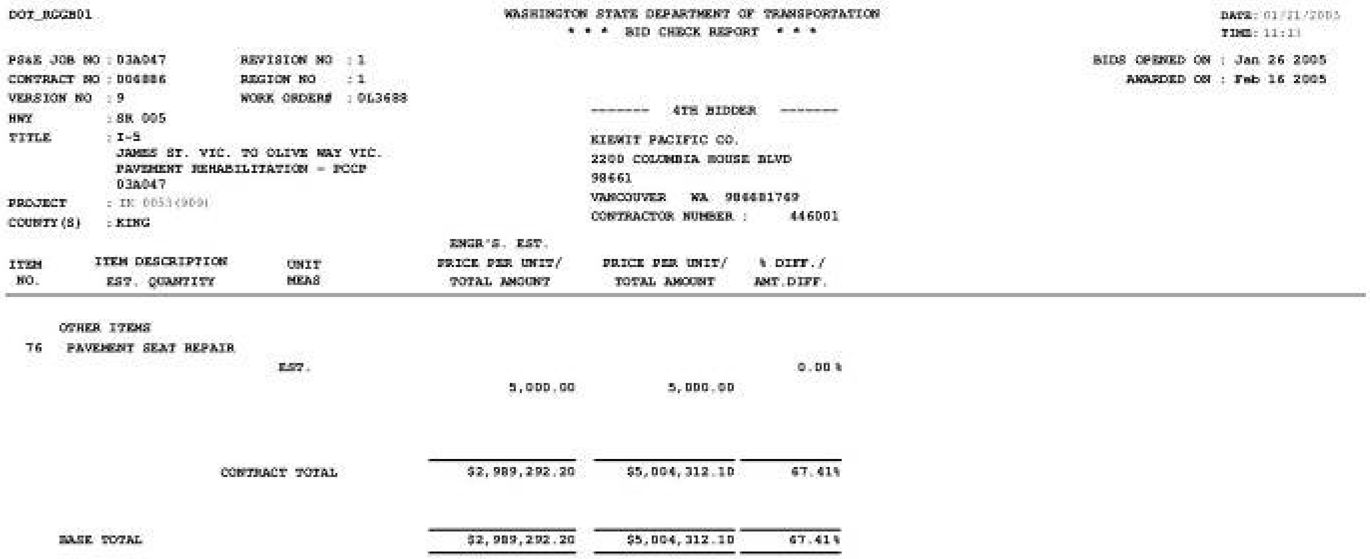
    TRAFFIC
 56 CONSTRUCTION SIGNS CLASS A
           1162.0000         S.F.                35.0000            16.0000       -54.29 %
                                               40,670.00          18,592.00   -22,078.00
 57  INITIAL DELIVERY AND PLACEMENT OF QMB
                             L.S.                                                 600.00 %
                                               25,000.00         175,000.00   150,000.00
 58  MOVING QMB WITH TTV
          11500.0000         L.F.                 2.0000             2.7000        35.00 %
                                               23,000.00          31,050.00     8,050.00
 59  TTV MOBILIZATION
                             L.S.                                                 -50.00 %
                                                3,000.00           1,500.00    -1,500.00
 60  REPLACEMENT PARTS FOR TTV
                             EST.                                                   0.00 %
                                                7,000.00           7,000.00


    OTHER ITEMS
 61 INCENTIVE EARLY COMPL.
                             EST.                                                   0.00 %
                                              150,000.00         150,000.00
 62 STRUCTURE EXCAVATION CLASS B INCL. HAUL
              5.6300         C.Y.                50.0000           300.0000       500.00 %
                                                  281.50           1,689.00     1,407.50
 63 SHORING OR EXTRA EXCAVATION CLASS B
             40.8000         S.F.                10.0000             1.0000       -90.00 %
                                                  408.00              40.80      -367.20
 64 WATER
            156.0000         MGAL                35.0000           100.0000       185.71 %
                                                5,460.00          15,600.00    10,140.00
 65 ROADWAY SURVEYING
                             L.S.                                                 757.14 %
                                                7,000.00          60,000.00    53,000.00
```

```
DOT_RGGB01                                       WASHINGTON STATE DEPARTMENT OF TRANSPORTATION                                   DATE: 01/21/2005
                                                     * * *  BID CHECK REPORT  * * *                                              TIME: 11:11

PS&E JOB NO : 03A047        REVISION NO  : 1                                                                          BIDS OPENED ON : Jan 26 2005
CONTRACT NO : 006886        REGION NO    : 1                                                                             AWARDED ON : Feb 16 2005
VERSION NO  : 9             WORK ORDER#  : 0L3688
HWY         : SR 005                                             -------  4TH BIDDER  -------
TITLE       : I-5
              JAMES ST. VIC. TO OLIVE WAY VIC.                   KIEWIT PACIFIC CO.
              PAVEMENT REHABILITATION - PCCP                     2200 COLUMBIA HOUSE BLVD
              03A047                                             98661
PROJECT     : IK 0053(909)                                       VANCOUVER   WA  984681749
COUNTY(S)   : KING                                               CONTRACTOR NUMBER :     446001
                                                ENGR'S. EST.
ITEM     ITEM DESCRIPTION      UNIT            PRICE PER UNIT/    PRICE PER UNIT/   % DIFF./
 NO.      EST. QUANTITY        MEAS             TOTAL AMOUNT       TOTAL AMOUNT     AMT.DIFF.
-------------------------------------------------------------------------------------------------------------------------------------

    OTHER ITEMS
 66 CONNECTION TO DRAINAGE STRUCTURE
              3.0000        EACH                   400.0000        3,500.0000      775.00 %
                                                 1,200.00         10,500.00      9,300.00
 67 ADJUST MANHOLE
              4.0000        EACH                   500.0000        1,200.0000      140.00 %
                                                 2,000.00          4,800.00      2,800.00
 68 ADJUST CATCH BASIN
             15.0000        EACH                   400.0000        1,500.0000      275.00 %
                                                 6,000.00         22,500.00     16,500.00
 69 ROADSIDE CLEANUP
                            EST.                                                     0.00 %
                                                 7,500.00          7,500.00
 70 REIMBURSEMENT FOR THIRD PARTY DAMAGE
                            EST.                                                     0.00 %
                                                     5.00              5.00
 71 MINOR CHANGE
                            CALC                                                     0.00 %
                                                    -1.00             -1.00
 72 SPCC PLAN
                            L.S.                                                   400.00 %
                                                 1,000.00          5,000.00      4,000.00
 73 SITE MAINT. FOR BIO.  AND PHYSICAL HAZARDS
                            L.S.                                                 1,400.00 %
                                                 1,000.00         15,000.00     14,000.00
 74 FA-PERIODIC SITE MAINT. FOR BIO. AND PHYSICAL HAZARDS
                            EST.                                                     0.00 %
                                                 5,000.00          5,000.00
 75 CONSTRUCTION GEOTEXTILE FOR SOIL STABILIZATION
             48.7000        S.Y.                    12.0000           20.0000       66.67 %
                                                   584.40            974.00        389.60
```



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DOT_RGGB01                                    WASHINGTON STATE DEPARTMENT OF TRANSPORTATION                          DATE: 01/21/2005
                                                    * * *  BID CHECK REPORT  * * *                                    TIME: 11:11

PS&E JOB NO : 03A047        REVISION NO  : 1                                                       BIDS OPENED ON : Jan 26 2005
CONTRACT NO : 006886        REGION NO    : 1                                                          AWARDED ON : Feb 16 2005
VERSION NO  : 9             WORK ORDER#  : 0L3688
HWY         : SR 005                                      -------  4TH BIDDER  -------
TITLE       : I-5
              JAMES ST. VIC. TO OLIVE WAY VIC.            KIEWIT PACIFIC CO.
              PAVEMENT REHABILITATION - PCCP              2200 COLUMBIA HOUSE BLVD
              03A047                                      98661
PROJECT     : IK 0053(909)                                VANCOUVER   WA  986681749
COUNTY(S)   : KING                                        CONTRACTOR NUMBER :      446001
                                           ENGR'S. EST.
ITEM      ITEM DESCRIPTION     UNIT      PRICE PER UNIT/   PRICE PER UNIT/   % DIFF./
 NO.       EST. QUANTITY       MEAS       TOTAL AMOUNT      TOTAL AMOUNT     AMT.DIFF.
-----------------------------------------------------------------------------------------------------------------------------

   OTHER ITEMS
 76  PAVEMENT SEAT REPAIR
                               EST.                                             0.00 %
                                              5,000.00          5,000.00

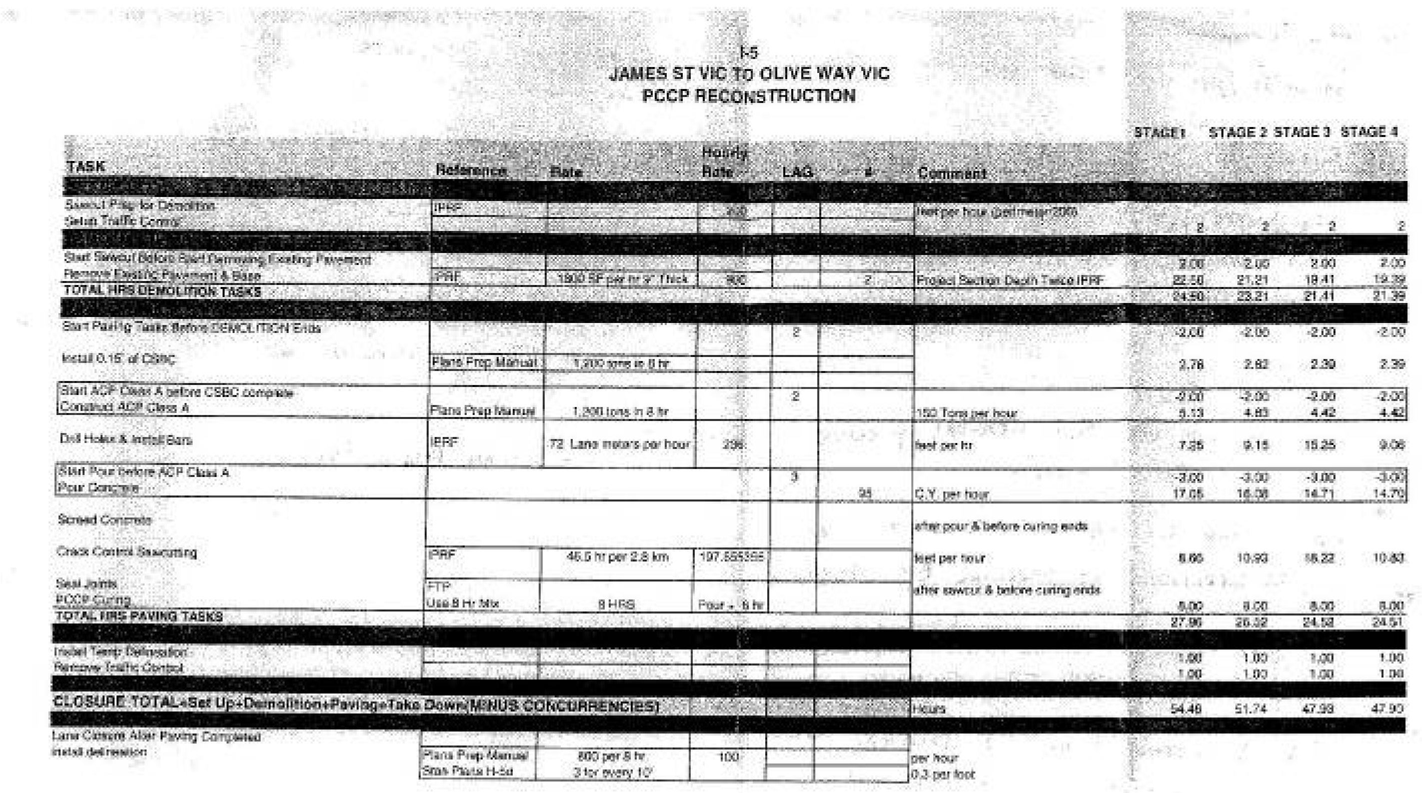


                CONTRACT TOTAL           $2,989,292.20     $5,004,312.10       67.41%


   BASE TOTAL                            $2,989,292.20     $5,004,312.10       67.41%
```

Appendix B: WSDOT Plans Used to Identify Hand-Paving and Slipform Paving Segments

Appendix C: WSDOT Estimated Productivity Rates



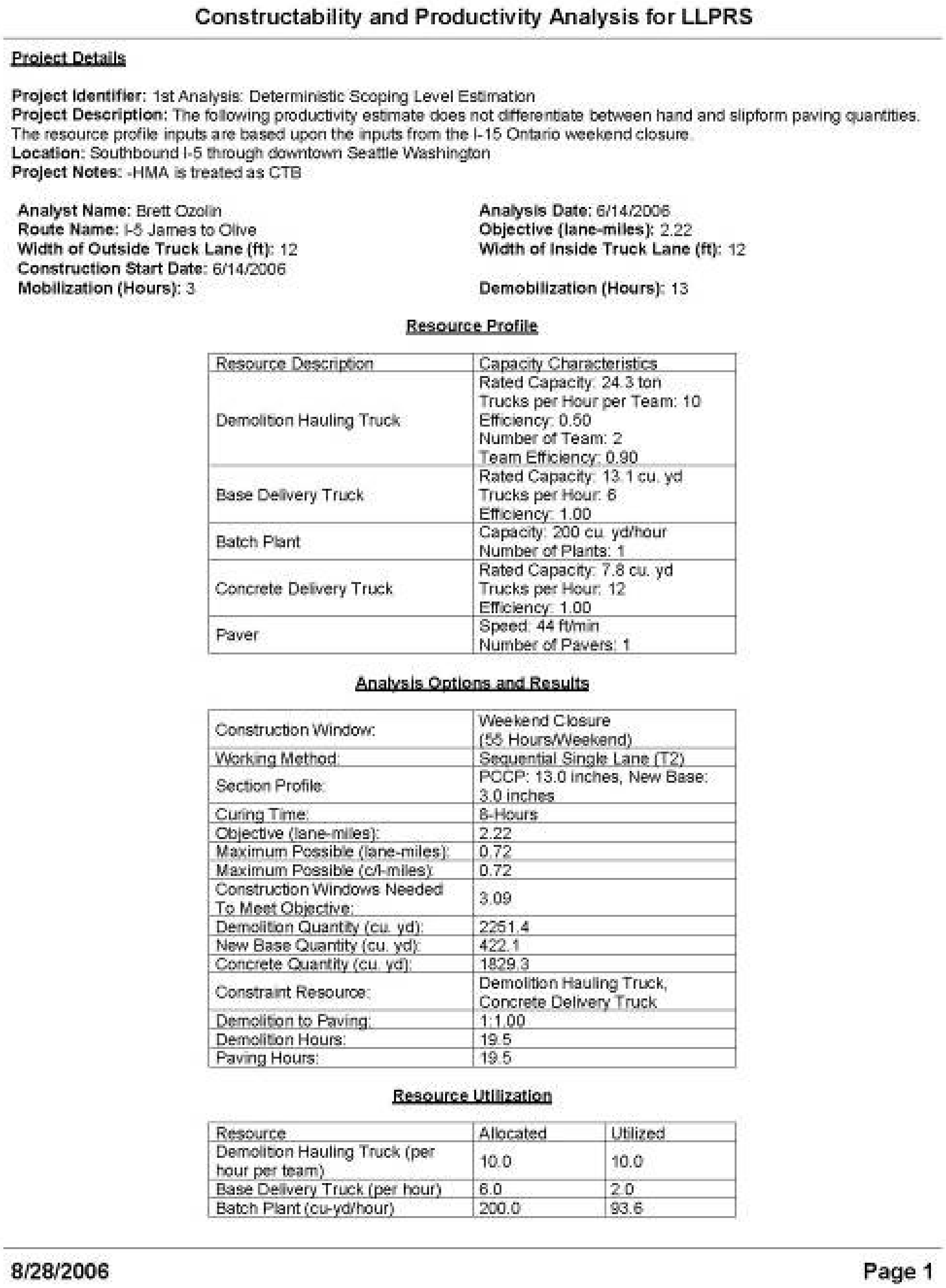
I-5
JAMES ST VIC TO OLIVE WAY VIC
PCCP RECONSTRUCTION

TASK	Reference	Rate	Hourly Rate	LAG	#	Comment	STAGE1	STAGE 2	STAGE 3	STAGE 4
Sawcut Prep for Demolition	IPRF		200			feet per hour @estimate 2000				
Setup Traffic Control							2	2	2	2
Start Sawcut Before Start Removing Existing Pavement							2.00	2.00	2.00	2.00
Remove Existing Pavement & Base	IPRF	1900 SF per hr 9" Thick	900		2	Project Section Depth Twice IPRF	22.50	21.21	18.41	19.39
TOTAL HRS DEMOLITION TASKS							24.50	23.21	21.41	21.39
Start Paving Tasks Before DEMOLITION Ends				2			-2.00	-2.00	-2.00	-2.00
Install 0.15' of CSBC	Plans Prep Manual	1,200 tons in 8 hr					2.76	2.62	2.39	2.39
Start ACP Class A before CSBC complete				2			-2.00	-2.00	-2.00	-2.00
Construct ACP Class A	Plans Prep Manual	1,200 tons in 8 hr				150 Tons per hour	5.13	4.83	4.42	4.42
Drill Holes & Install Bars	IPRF	72 Lane meters per hour	236			feet per hr	7.25	9.15	15.25	9.06
Start Pour before ACP Class A				3			-3.00	-3.00	-3.00	-3.00
Pour Concrete					95	C.Y. per hour	17.05	16.08	14.71	14.70
Screed Concrete						after pour & before curing ends				
Crack Control Sawcutting	IPRF	46.5 hr per 2.8 km	197.555556			feet per hour	8.60	10.93	18.22	10.83
Seal Joints	FTP					after sawcut & before curing ends				
PCCP Curing	Use 8 Hr Mix	8 HRS	Pour + 8 hr				8.00	8.00	8.00	8.00
TOTAL HRS PAVING TASKS							27.96	26.32	24.58	24.51
Install Temp Delineation							1.00	1.00	1.00	1.00
Remove Traffic Control							1.00	1.00	1.00	1.00
CLOSURE TOTAL=Set Up+Demolition+Paving+Take Down(MINUS CONCURRENCIES)						Hours	54.46	51.74	47.93	47.90
Lane Closure After Paving Completed										
install delineation	Plans Prep Manual	800 per 8 hr	100			per hour				
	Stds Plans H-5a	3 for every 10'				0.3 per foot				

Appendix D: Concrete Mix Quantities and Locations Used Per Construction Stage

Mix Design	From	To	Location	Date	CY
Stage I					
7524-H	123+90	121+26	South Union Ramp	4/23/2005	254
	138+45	125+00	C3 Main Line (shoulder)	4/24/2005	372
8049-H	124+73.55	124+00	South Union Ramp	4/23/2005	84
	126+00	124+73	C3 Main Line (wedge)	4/24/2005	66
8049-P	138+34	124+80	Mainline	4/23-24/2005	1099.5
Stage II					
8049-P	124+71	115+60	James Street Line Left	6/18-19/2005	705
	120+19.96	226+45	C1 Line	6/18/2005	290
8049-H	123+65	124+50	Union Gore	6/18-19/2005	60
	120+40	115+55	James Street LT & Gore	6/19/2005	334
7524-H	123+67	115+48	Shoulder	6/19/2005	178
Stage III					
8049-P	101+17	106+00	Slipform C1 Line	6/25/2005	189
	106+00	115+80	Slipform C1 Line	6/25/2005	619
8049-H	101+26	101+86	Slipform C1 Line	6/26/2005	39
			2 Panels replaced	6/26/2005	5
	106+25	114+00	Shoulder	6/26/2005	249
	106+00	110+05	Handwork C1 Line	6/26/2005	195
Stage IV					
8049-P	101+35	160+25	SBCD/C1 Line	7/16/2005	540
8049-H	101+60	160+25	SBCD/C1 Line	7/17/2005	253
		121+00	Dearborn & S. Union	7/16/2005	81
			Union St	7/15/2005	30
				Job Total	5642.5
				Engineers Est.	5151

Appendix E: Probabilistic and Deterministic CA4PRS Estimation Reports For The I-5 James to Olive Case Study Analyses 1, 2, 3 and 4



Constructability and Productivity Analysis for LLPRS

Project Details

Project Identifier: 1st Analysis: Deterministic Scoping Level Estimation
Project Description: The following productivity estimate does not differentiate between hand and slipform paving quantities. The resource profile inputs are based upon the inputs from the I-15 Ontario weekend closure.
Location: Southbound I-5 through downtown Seattle Washington
Project Notes: -HMA is treated as CTB

Analyst Name: Brett Ozolin
Route Name: I-5 James to Olive
Width of Outside Truck Lane (ft): 12
Construction Start Date: 6/14/2006
Mobilization (Hours): 3

Analysis Date: 6/14/2006
Objective (lane-miles): 2.22
Width of Inside Truck Lane (ft): 12

Demobilization (Hours): 13

Resource Profile

Resource Description	Capacity Characteristics
Demolition Hauling Truck	Rated Capacity: 24.3 ton Trucks per Hour per Team: 10 Efficiency: 0.50 Number of Team: 2 Team Efficiency: 0.90
Base Delivery Truck	Rated Capacity: 13.1 cu. yd Trucks per Hour: 6 Efficiency: 1.00
Batch Plant	Capacity: 200 cu. yd/hour Number of Plants: 1
Concrete Delivery Truck	Rated Capacity: 7.8 cu. yd Trucks per Hour: 12 Efficiency: 1.00
Paver	Speed: 44 ft/min Number of Pavers: 1

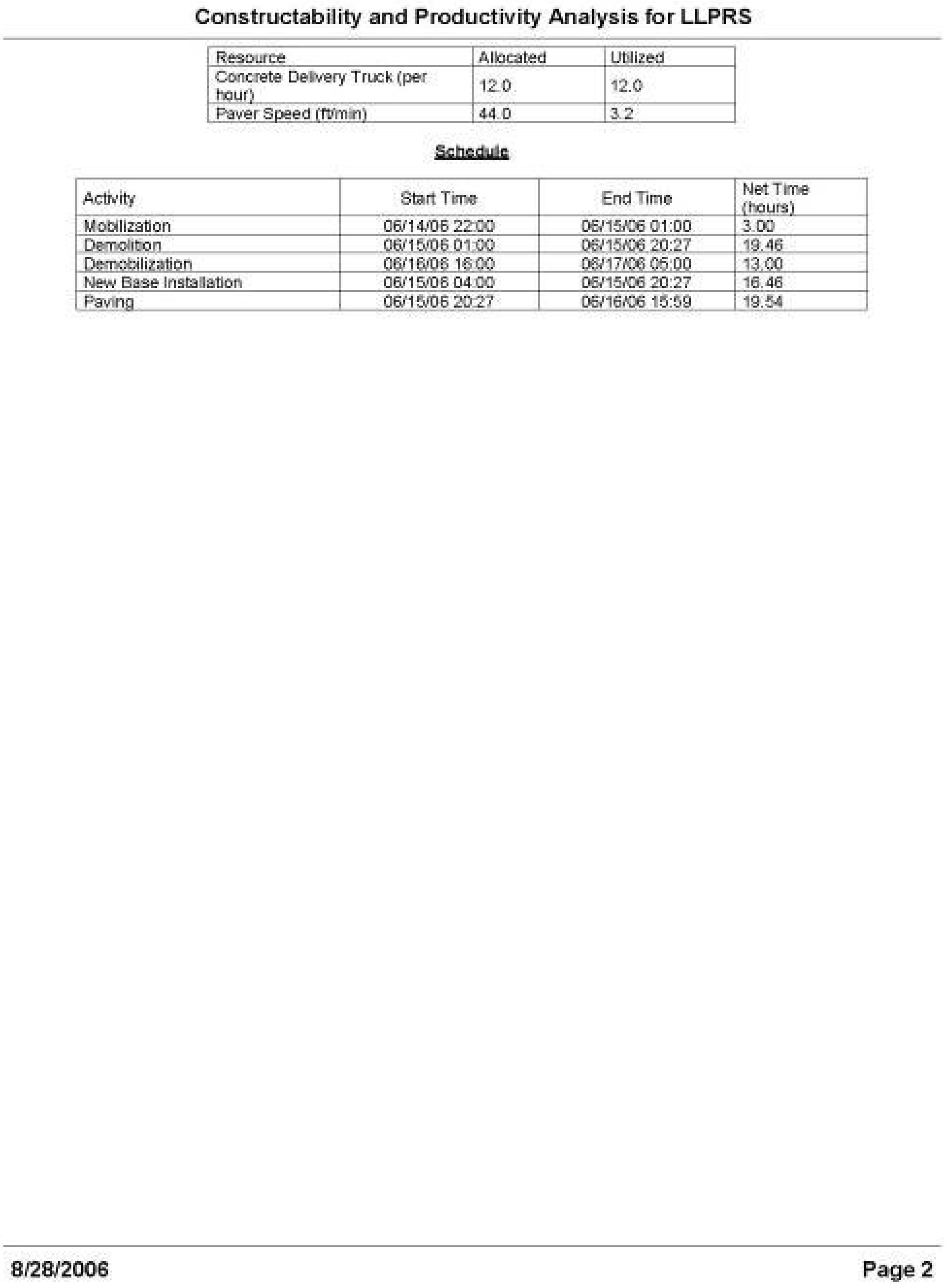
Analysis Options and Results

Construction Window:	Weekend Closure (55 Hours/Weekend)
Working Method:	Sequential Single Lane (T2)
Section Profile:	PCCP: 13.0 inches, New Base: 3.0 inches
Curing Time:	8-Hours
Objective (lane-miles):	2.22
Maximum Possible (lane-miles):	0.72
Maximum Possible (c/l-miles):	0.72
Construction Windows Needed To Meet Objective:	3.09
Demolition Quantity (cu. yd):	2251.4
New Base Quantity (cu. yd):	422.1
Concrete Quantity (cu. yd):	1829.3
Constraint Resource:	Demolition Hauling Truck, Concrete Delivery Truck
Demolition to Paving:	1:1.00
Demolition Hours:	19.5
Paving Hours:	19.5

Resource Utilization

Resource	Allocated	Utilized
Demolition Hauling Truck (per hour per team)	10.0	10.0
Base Delivery Truck (per hour)	6.0	2.0
Batch Plant (cu-yd/hour)	200.0	93.6

8/28/2006 **Page 1**

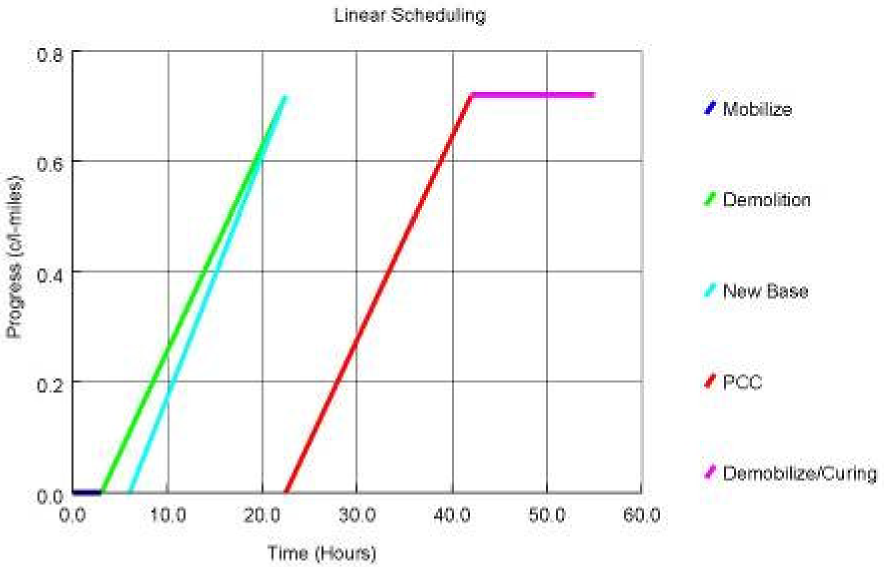


Constructability and Productivity Analysis for LLPRS

Resource	Allocated	Utilized
Concrete Delivery Truck (per hour)	12.0	12.0
Paver Speed (ft/min)	44.0	3.2

Schedule

Activity	Start Time	End Time	Net Time (hours)
Mobilization	06/14/06 22:00	06/15/06 01:00	3.00
Demolition	06/15/06 01:00	06/15/06 20:27	19.46
Demobilization	06/16/06 16:00	06/17/06 05:00	13.00
New Base Installation	06/15/06 04:00	06/15/06 20:27	16.46
Paving	06/15/06 20:27	06/16/06 15:59	19.54


Linear Scheduling
Progress (cl-miles)
0.8
0.6
0.4
0.2
0.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
Time (Hours)
Mobilize
Demolition
New Base
PCC
Demobilize/Curing

Constructability and Productivity Analysis for LLPRS

Project Details

Project Identifier: 1st Analysis: Probabilistic Scoping Level Estimation
Project Description: The following productivity estimate does not differentiate between hand and slipform paving quantities. The resource profile inputs are based upon the inputs from the I-15 Ontario weekend closure.
Location: Southbound I-5 through downtown Seattle Washington
Project Notes: -HMA is treated as CTB

Analyst Name: Brett Ozolin
Route Name: I-5 James to Olive
Width of Outside Truck Lane (ft): 12
Construction Start Date: 6/14/2006
Mobilization (Hours): 3

Analysis Date: 6/14/2006
Objective (lane-miles): 2.22
Width of Inside Truck Lane (ft): 12
Demobilization (Hours): 13

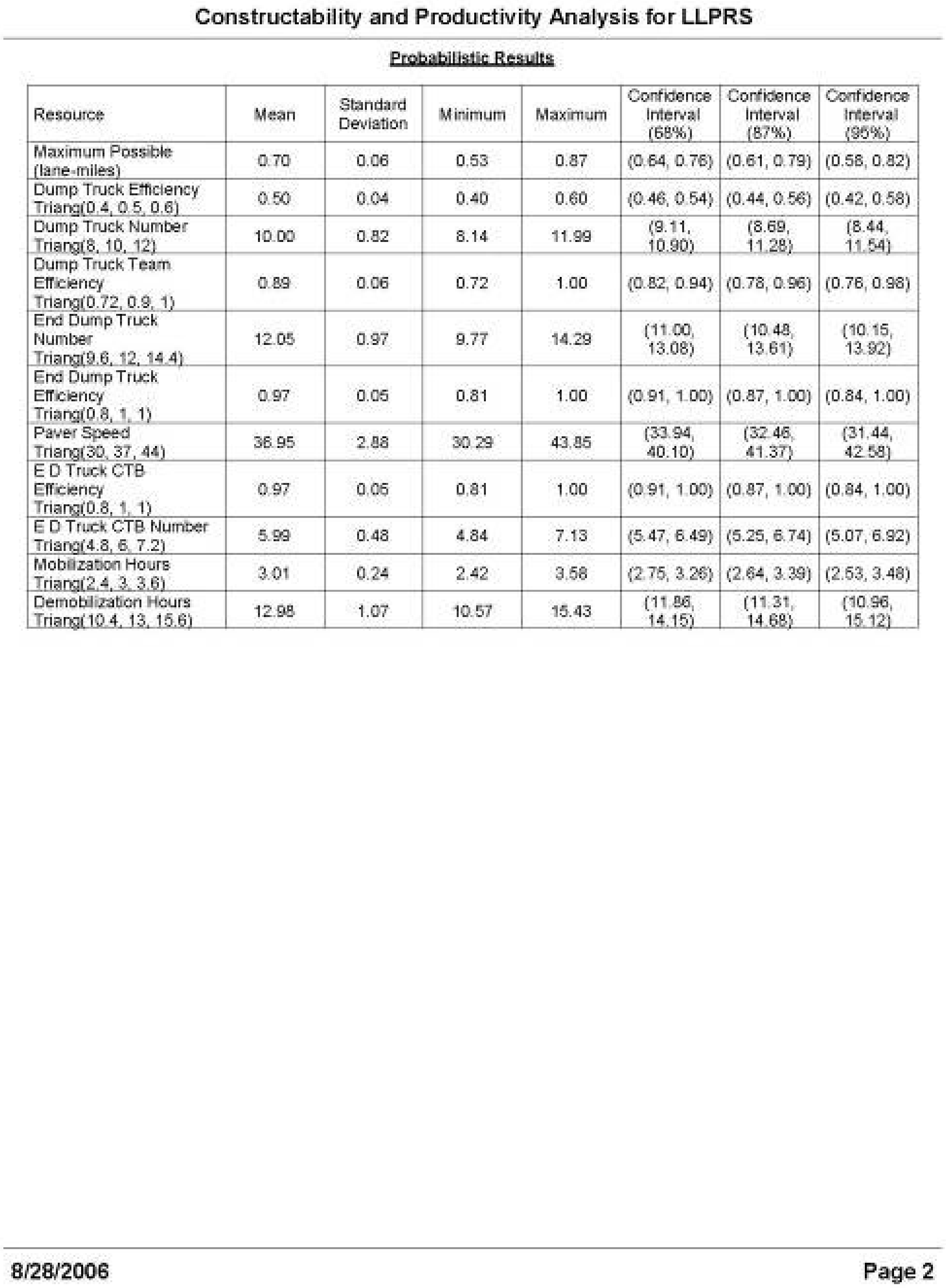
Resource Profile

Resource Description	Capacity Characteristics
Demolition Hauling Truck	Rated Capacity: 24.3 ton Trucks per Hour per Team: 10 Efficiency: 0.50 Number of Team: 2 Team Efficiency: 0.87
Base Delivery Truck	Rated Capacity: 13.1 cu. yd Trucks per Hour: 6 Efficiency: 0.93
Batch Plant	Capacity: 200 cu. yd/hour Number of Plants: 1
Concrete Delivery Truck	Rated Capacity: 7.8 cu. yd Trucks per Hour: 12 Efficiency: 0.93
Paver	Speed: 37 ft/min Number of Pavers: 1

Analysis Options and Results

Construction Window:	Weekend Closure (55 Hours/Weekend)
Working Method:	Sequential Single Lane (T2)
Section Profile:	PCCP: 13.0 inches, New Base: 3.0 inches
Curing Time:	8-Hours
Objective (lane-miles):	2.22
Maximum Possible (lane-miles):	0.70
Maximum Possible (c/l-miles):	0.70
Construction Windows Needed To Meet Objective:	3.18

8/28/2006 **Page 1**

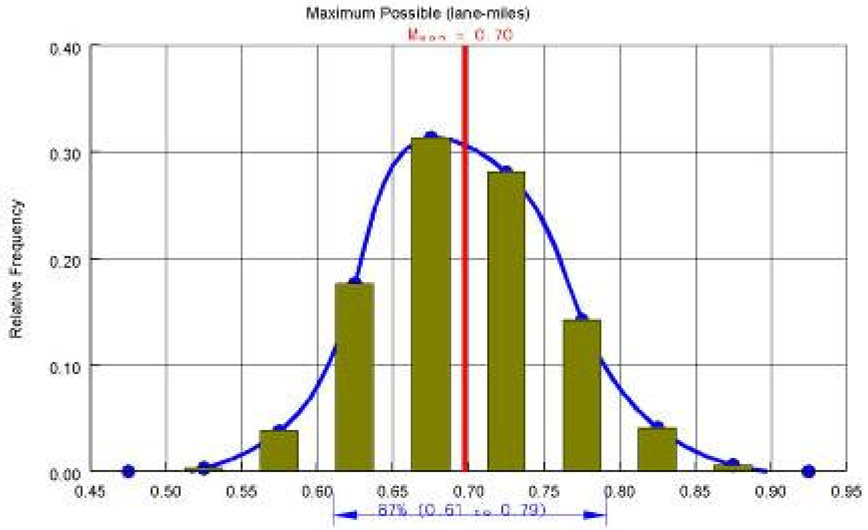


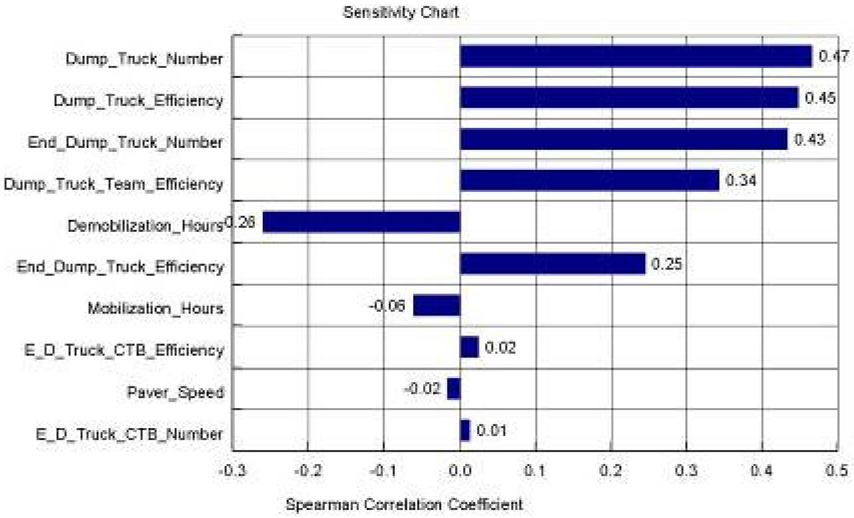
Constructability and Productivity Analysis for LLPRS

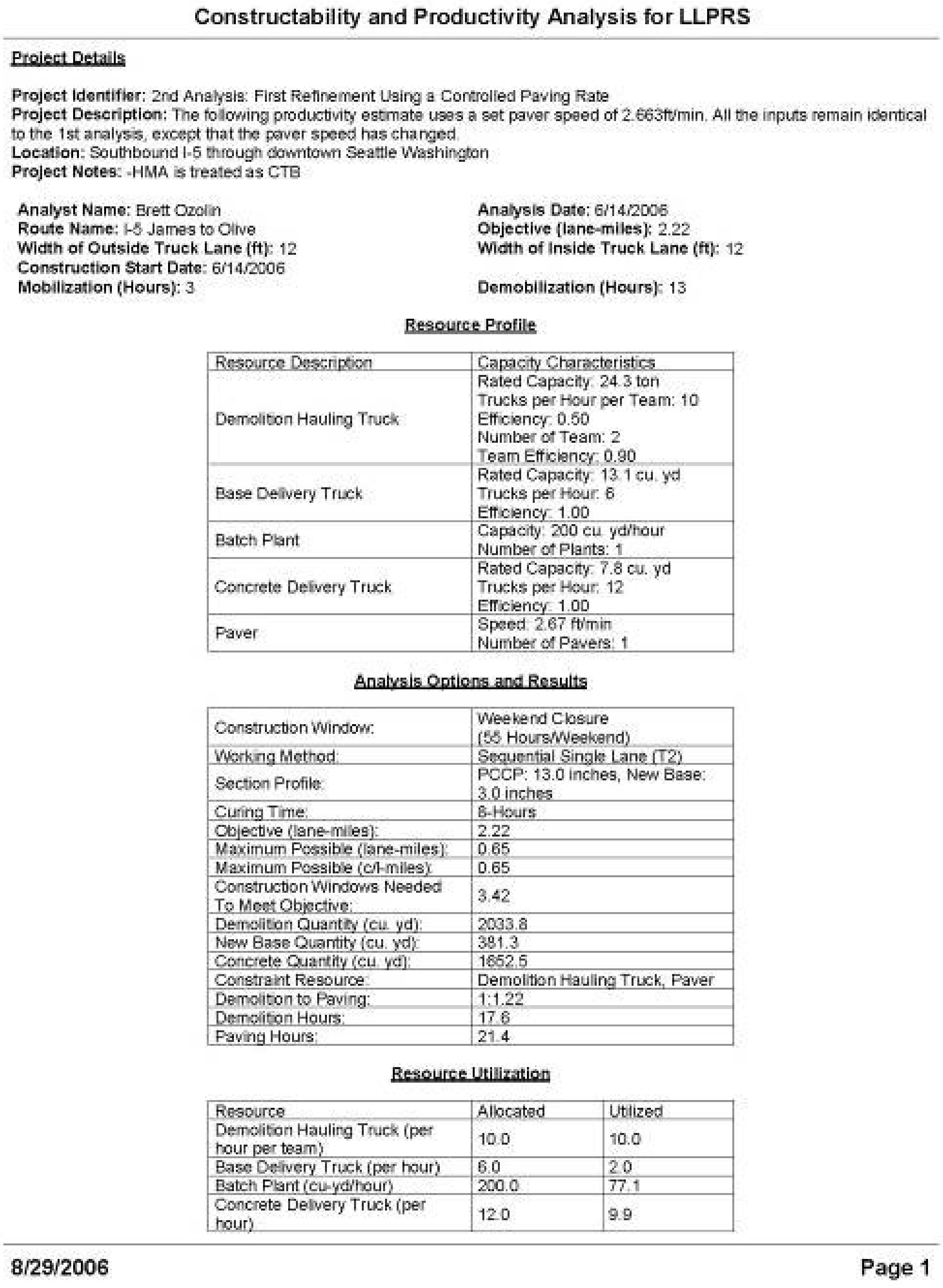
Probabilistic Results

Resource	Mean	Standard Deviation	Minimum	Maximum	Confidence Interval (68%)	Confidence Interval (87%)	Confidence Interval (95%)
Maximum Possible (lane-miles)	0.70	0.06	0.53	0.87	(0.64, 0.76)	(0.61, 0.79)	(0.58, 0.82)
Dump Truck Efficiency Triang(0.4, 0.5, 0.6)	0.50	0.04	0.40	0.60	(0.46, 0.54)	(0.44, 0.56)	(0.42, 0.58)
Dump Truck Number Triang(8, 10, 12)	10.00	0.82	8.14	11.99	(9.11, 10.90)	(8.69, 11.28)	(8.44, 11.54)
Dump Truck Team Efficiency Triang(0.72, 0.9, 1)	0.89	0.06	0.72	1.00	(0.82, 0.94)	(0.78, 0.96)	(0.76, 0.98)
End Dump Truck Number Triang(9.6, 12, 14.4)	12.05	0.97	9.77	14.29	(11.00, 13.08)	(10.48, 13.61)	(10.15, 13.92)
End Dump Truck Efficiency Triang(0.8, 1, 1)	0.97	0.05	0.81	1.00	(0.91, 1.00)	(0.87, 1.00)	(0.84, 1.00)
Paver Speed Triang(30, 37, 44)	36.95	2.88	30.29	43.85	(33.94, 40.10)	(32.46, 41.37)	(31.44, 42.58)
E D Truck CTB Efficiency Triang(0.8, 1, 1)	0.97	0.05	0.81	1.00	(0.91, 1.00)	(0.87, 1.00)	(0.84, 1.00)
E D Truck CTB Number Triang(4.8, 6, 7.2)	5.99	0.48	4.84	7.13	(5.47, 6.49)	(5.25, 6.74)	(5.07, 6.92)
Mobilization Hours Triang(2.4, 3, 3.6)	3.01	0.24	2.42	3.58	(2.75, 3.26)	(2.64, 3.39)	(2.53, 3.48)
Demobilization Hours Triang(10.4, 13, 15.6)	12.98	1.07	10.57	15.43	(11.86, 14.15)	(11.31, 14.68)	(10.96, 15.12)

8/28/2006 **Page 2**


Maximum Possible (lane-miles)
Mean = 0.70
Relative Frequency
0.40
0.30
0.20
0.10
0.00
0.45
0.50
0.55
0.60
0.65
0.70
0.75
0.80
0.85
0.90
0.95
87% (0.61 to 0.79)


Sensitivity Chart
Dump_Truck_Number
Dump_Truck_Efficiency
End_Dump_Truck_Number
Dump_Truck_Team_Efficiency
Demobilization_Hours
End_Dump_Truck_Efficiency
Mobilization_Hours
E_D_Truck_CTB_Efficiency
Paver_Speed
E_D_Truck_CTB_Number
0.47
0.45
0.43
0.34
-0.26
0.25
-0.06
0.02
-0.02
0.01
-0.3
-0.2
-0.1
0.0
0.1
0.2
0.3
0.4
0.5
Spearman Correlation Coefficient



Constructability and Productivity Analysis for LLPRS

Project Details

Project Identifier: 2nd Analysis: First Refinement Using a Controlled Paving Rate
Project Description: The following productivity estimate uses a set paver speed of 2.663ft/min. All the inputs remain identical to the 1st analysis, except that the paver speed has changed.
Location: Southbound I-5 through downtown Seattle Washington
Project Notes: -HMA is treated as CTB

Analyst Name: Brett Ozolin
Route Name: I-5 James to Olive
Width of Outside Truck Lane (ft): 12
Construction Start Date: 6/14/2006
Mobilization (Hours): 3

Analysis Date: 6/14/2006
Objective (lane-miles): 2.22
Width of Inside Truck Lane (ft): 12

Demobilization (Hours): 13

Resource Profile

Resource Description	Capacity Characteristics
Demolition Hauling Truck	Rated Capacity: 24.3 ton Trucks per Hour per Team: 10 Efficiency: 0.50 Number of Team: 2 Team Efficiency: 0.90
Base Delivery Truck	Rated Capacity: 13.1 cu. yd Trucks per Hour: 6 Efficiency: 1.00
Batch Plant	Capacity: 200 cu. yd/hour Number of Plants: 1
Concrete Delivery Truck	Rated Capacity: 7.8 cu. yd Trucks per Hour: 12 Efficiency: 1.00
Paver	Speed: 2.67 ft/min Number of Pavers: 1

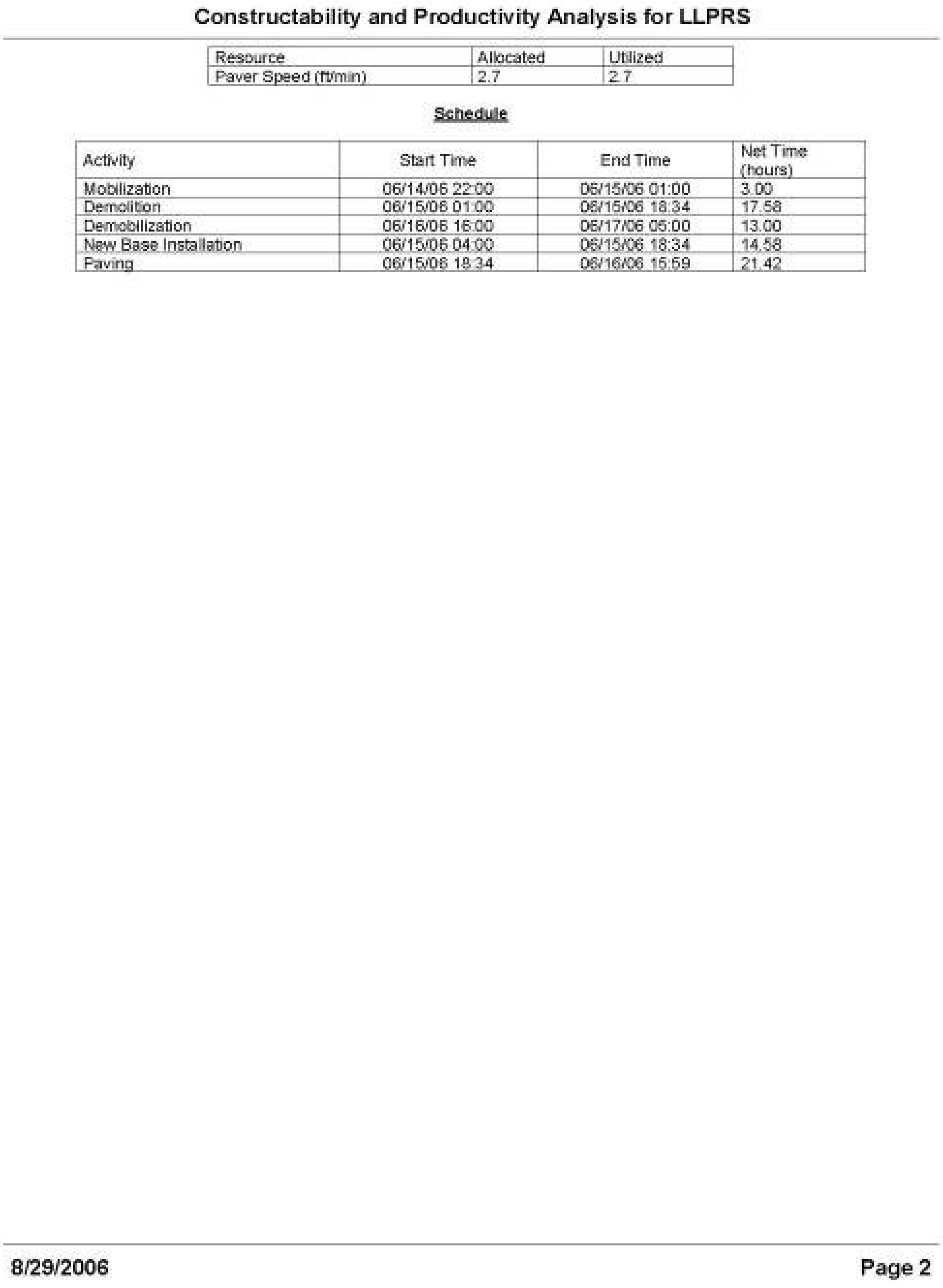
Analysis Options and Results

Construction Window:	Weekend Closure (55 Hours/Weekend)
Working Method:	Sequential Single Lane (T2)
Section Profile:	PCCP: 13.0 inches, New Base: 3.0 inches
Curing Time:	8-Hours
Objective (lane-miles):	2.22
Maximum Possible (lane-miles):	0.65
Maximum Possible (c/l-miles):	0.65
Construction Windows Needed To Meet Objective:	3.42
Demolition Quantity (cu. yd):	2033.8
New Base Quantity (cu. yd):	381.3
Concrete Quantity (cu. yd):	1652.5
Constraint Resource:	Demolition Hauling Truck, Paver
Demolition to Paving:	1:1.22
Demolition Hours:	17.6
Paving Hours:	21.4

Resource Utilization

Resource	Allocated	Utilized
Demolition Hauling Truck (per hour per team)	10.0	10.0
Base Delivery Truck (per hour)	6.0	2.0
Batch Plant (cu-yd/hour)	200.0	77.1
Concrete Delivery Truck (per hour)	12.0	9.9

8/29/2006 **Page 1**



Constructability and Productivity Analysis for LLPRS

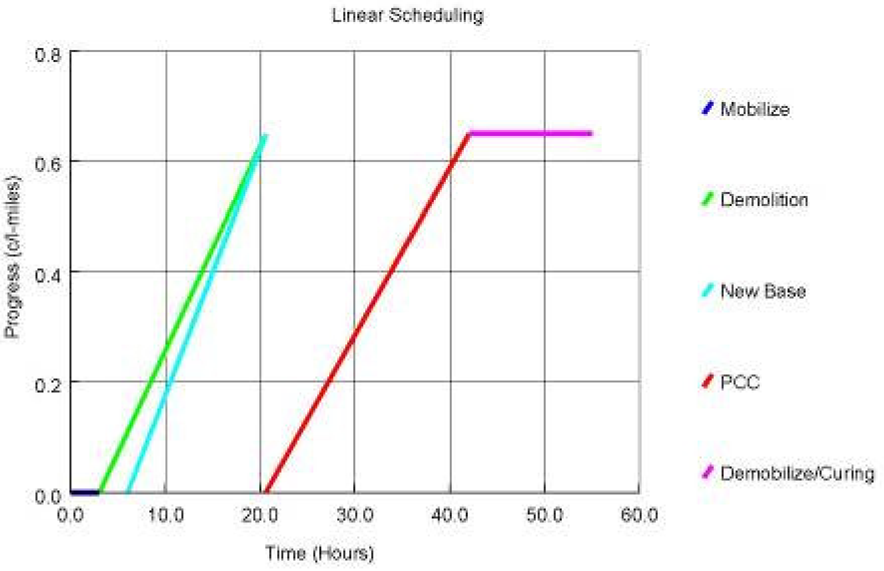
Resource	Allocated	Utilized
Paver Speed (ft/min)	2.7	2.7

Schedule

Activity	Start Time	End Time	Net Time (hours)
Mobilization	06/14/06 22:00	06/15/06 01:00	3.00
Demolition	06/15/06 01:00	06/15/06 18:34	17.58
Demobilization	06/16/06 16:00	06/17/06 05:00	13.00
New Base Installation	06/15/06 04:00	06/15/06 18:34	14.58
Paving	06/15/06 18:34	06/16/06 15:59	21.42

8/29/2006 **Page 2**

Constructability and Productivity Analysis for LLPRS



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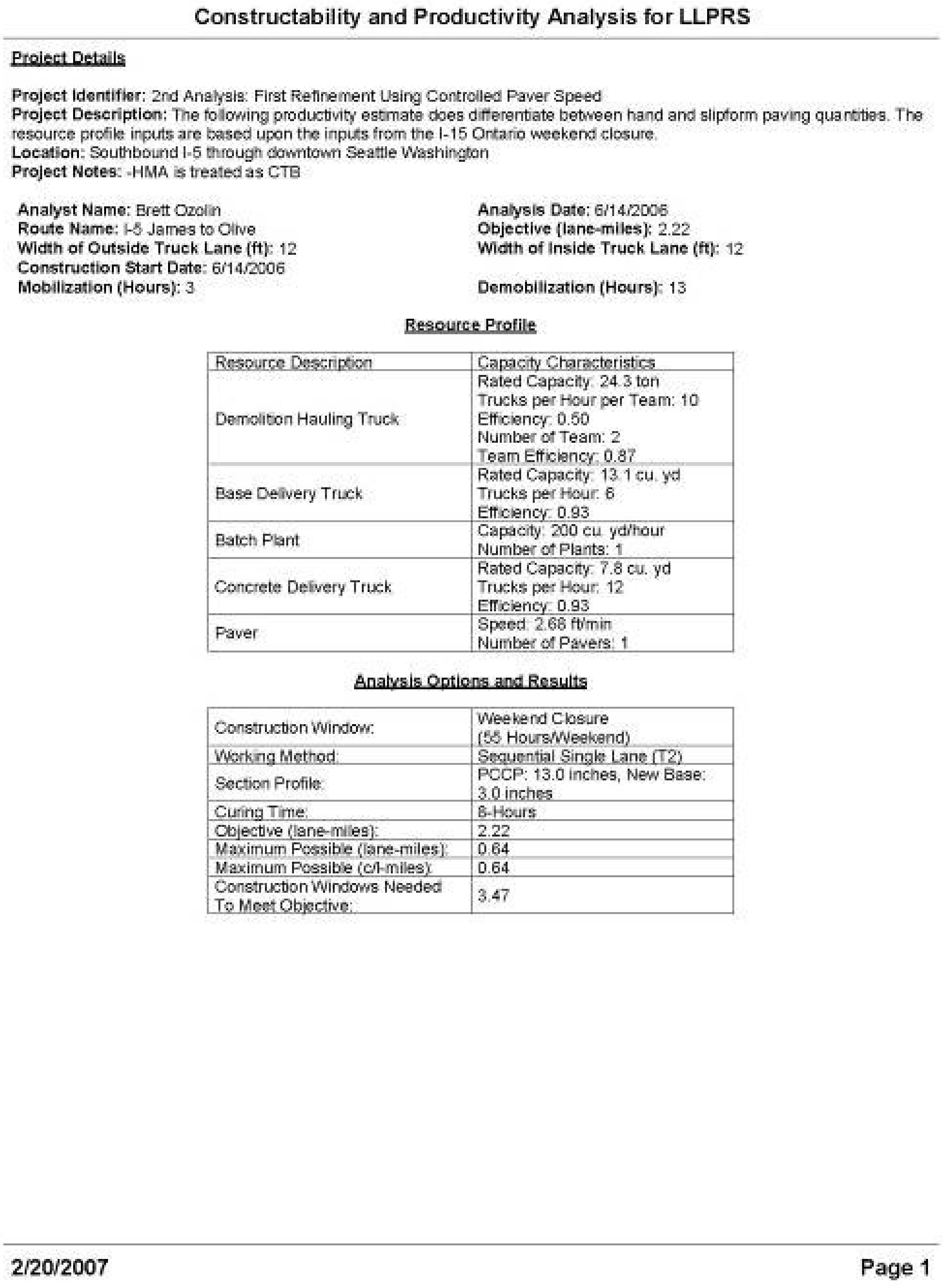


Constructability and Productivity Analysis for LLPRS

Project Details

Project Identifier: 2nd Analysis: First Refinement Using Controlled Paver Speed
Project Description: The following productivity estimate does differentiate between hand and slipform paving quantities. The resource profile inputs are based upon the inputs from the I-15 Ontario weekend closure.
Location: Southbound I-5 through downtown Seattle Washington
Project Notes: -HMA is treated as CTB

Analyst Name: Brett Ozolin
Route Name: I-5 James to Olive
Width of Outside Truck Lane (ft): 12
Construction Start Date: 6/14/2006
Mobilization (Hours): 3

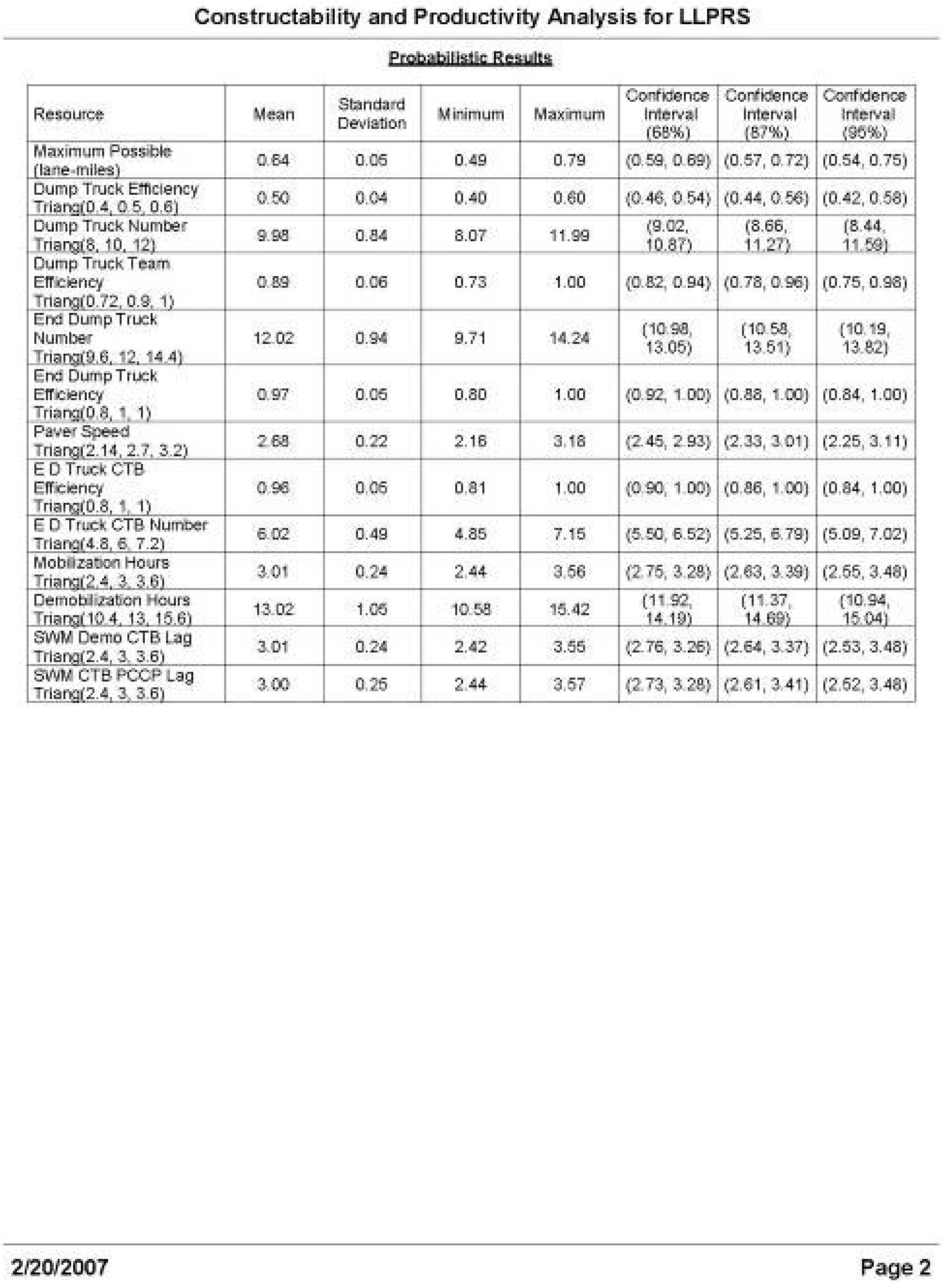
Analysis Date: 6/14/2006
Objective (lane-miles): 2.22
Width of Inside Truck Lane (ft): 12
Demobilization (Hours): 13

Resource Profile

Resource Description	Capacity Characteristics
Demolition Hauling Truck	Rated Capacity: 24.3 ton Trucks per Hour per Team: 10 Efficiency: 0.50 Number of Team: 2 Team Efficiency: 0.87
Base Delivery Truck	Rated Capacity: 13.1 cu. yd Trucks per Hour: 6 Efficiency: 0.93
Batch Plant	Capacity: 200 cu. yd/hour Number of Plants: 1
Concrete Delivery Truck	Rated Capacity: 7.8 cu. yd Trucks per Hour: 12 Efficiency: 0.93
Paver	Speed: 2.68 ft/min Number of Pavers: 1

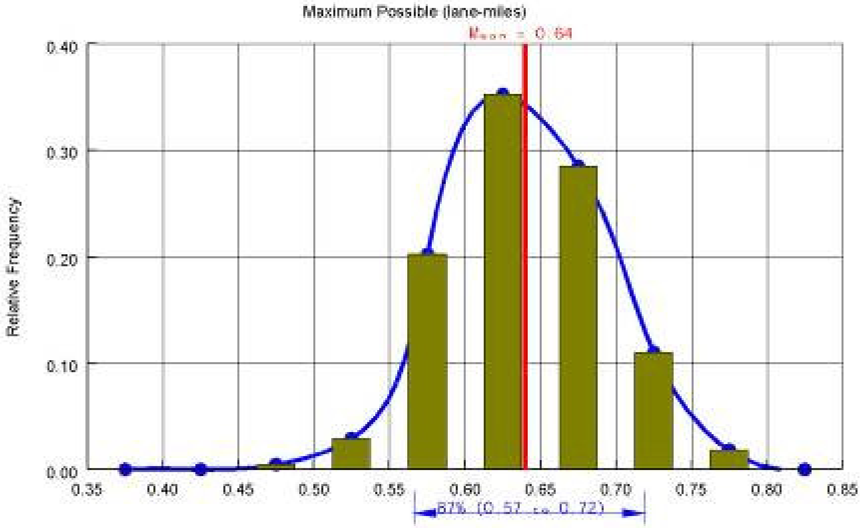
Analysis Options and Results

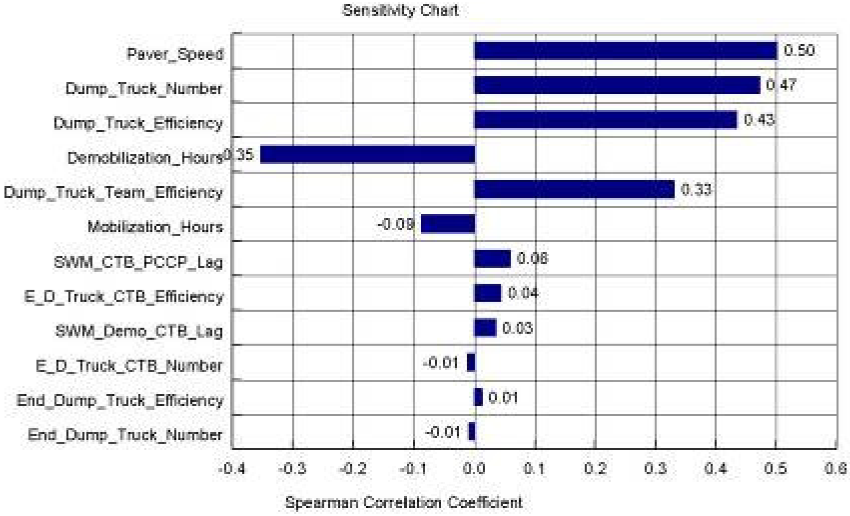
Construction Window:	Weekend Closure (55 Hours/Weekend)
Working Method:	Sequential Single Lane (T2)
Section Profile:	PCCP: 13.0 inches, New Base: 3.0 inches
Curing Time:	8-Hours
Objective (lane-miles):	2.22
Maximum Possible (lane-miles):	0.64
Maximum Possible (c/l-miles):	0.64
Construction Windows Needed To Meet Objective:	3.47

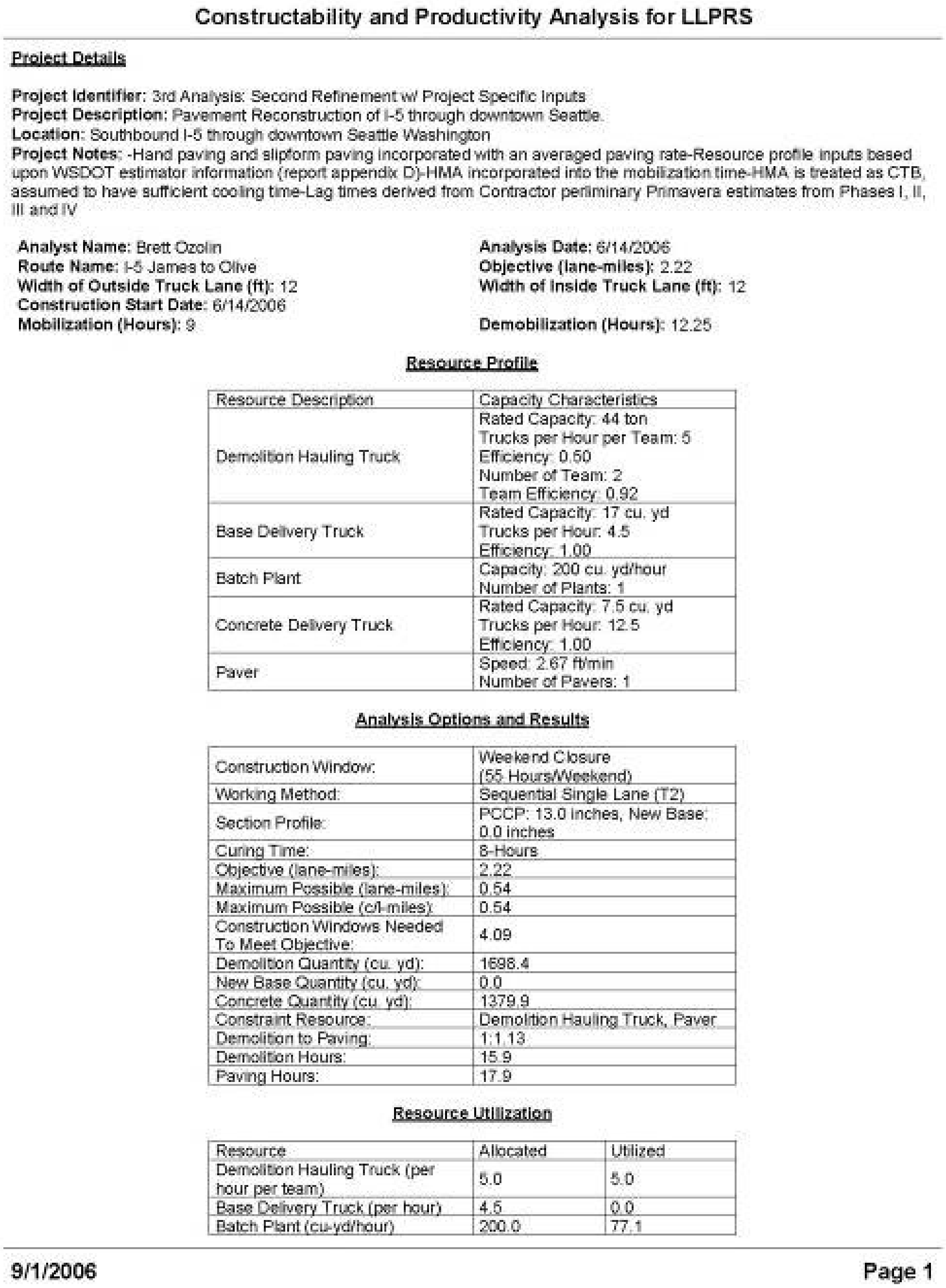


Probabilistic Results

Resource	Mean	Standard Deviation	Minimum	Maximum	Confidence Interval (68%)	Confidence Interval (87%)	Confidence Interval (95%)
Maximum Possible (lane-miles)	0.64	0.05	0.49	0.79	(0.59, 0.69)	(0.57, 0.72)	(0.54, 0.75)
Dump Truck Efficiency Triang(0.4, 0.5, 0.6)	0.50	0.04	0.40	0.60	(0.46, 0.54)	(0.44, 0.56)	(0.42, 0.58)
Dump Truck Number Triang(8, 10, 12)	9.98	0.84	8.07	11.99	(9.02, 10.87)	(8.66, 11.27)	(8.44, 11.59)
Dump Truck Team Efficiency Triang(0.72, 0.9, 1)	0.89	0.06	0.73	1.00	(0.82, 0.94)	(0.78, 0.96)	(0.75, 0.98)
End Dump Truck Number Triang(9.6, 12, 14.4)	12.02	0.94	9.71	14.24	(10.98, 13.05)	(10.58, 13.51)	(10.19, 13.82)
End Dump Truck Efficiency Triang(0.8, 1, 1)	0.97	0.05	0.80	1.00	(0.92, 1.00)	(0.88, 1.00)	(0.84, 1.00)
Paver Speed Triang(2.14, 2.7, 3.2)	2.68	0.22	2.16	3.18	(2.45, 2.93)	(2.33, 3.01)	(2.25, 3.11)
E D Truck CTB Efficiency Triang(0.8, 1, 1)	0.96	0.05	0.81	1.00	(0.90, 1.00)	(0.86, 1.00)	(0.84, 1.00)
E D Truck CTB Number Triang(4.8, 6, 7.2)	6.02	0.49	4.85	7.15	(5.50, 6.52)	(5.25, 6.79)	(5.09, 7.02)
Mobilization Hours Triang(2.4, 3, 3.6)	3.01	0.24	2.44	3.56	(2.75, 3.28)	(2.63, 3.39)	(2.55, 3.48)
Demobilization Hours Triang(10.4, 13, 15.6)	13.02	1.06	10.58	15.42	(11.92, 14.19)	(11.37, 14.69)	(10.94, 15.04)
SWM Demo CTB Lag Triang(2.4, 3, 3.6)	3.01	0.24	2.42	3.55	(2.76, 3.26)	(2.64, 3.37)	(2.53, 3.48)
SWM CTB PCCP Lag Triang(2.4, 3, 3.6)	3.00	0.25	2.44	3.57	(2.73, 3.28)	(2.61, 3.41)	(2.52, 3.48)


Maximum Possible (lane-miles)
Mean = 0.64
Relative Frequency
0.40
0.30
0.20
0.10
0.00
0.35
0.40
0.45
0.50
0.55
0.60
0.65
0.70
0.75
0.80
0.85
87% (0.57 to 0.72)


Sensitivity Chart
Paver_Speed
Dump_Truck_Number
Dump_Truck_Efficiency
Demobilization_Hours
Dump_Truck_Team_Efficiency
Mobilization_Hours
SWM_CTB_PCCP_Lag
E_D_Truck_CTB_Efficiency
SWM_Demo_CTB_Lag
E_D_Truck_CTB_Number
End_Dump_Truck_Efficiency
End_Dump_Truck_Number
0.50
0.47
0.43
-0.35
0.33
-0.09
0.06
0.04
0.03
-0.01
0.01
-0.01
-0.4
-0.3
-0.2
-0.1
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Spearman Correlation Coefficient



Constructability and Productivity Analysis for LLPRS

Project Details

Project Identifier: 3rd Analysis: Second Refinement w/ Project Specific Inputs
Project Description: Pavement Reconstruction of I-5 through downtown Seattle.
Location: Southbound I-5 through downtown Seattle Washington
Project Notes: -Hand paving and slipform paving incorporated with an averaged paving rate-Resource profile inputs based upon WSDOT estimator information (report appendix D)-HMA incorporated into the mobilization time-HMA is treated as CTB, assumed to have sufficient cooling time-Lag times derived from Contractor perliminary Primavera estimates from Phases I, II, III and IV

Analyst Name: Brett Ozolin
Route Name: I-5 James to Olive
Width of Outside Truck Lane (ft): 12
Construction Start Date: 6/14/2006
Mobilization (Hours): 9

Analysis Date: 6/14/2006
Objective (lane-miles): 2.22
Width of Inside Truck Lane (ft): 12

Demobilization (Hours): 12.25

Resource Profile

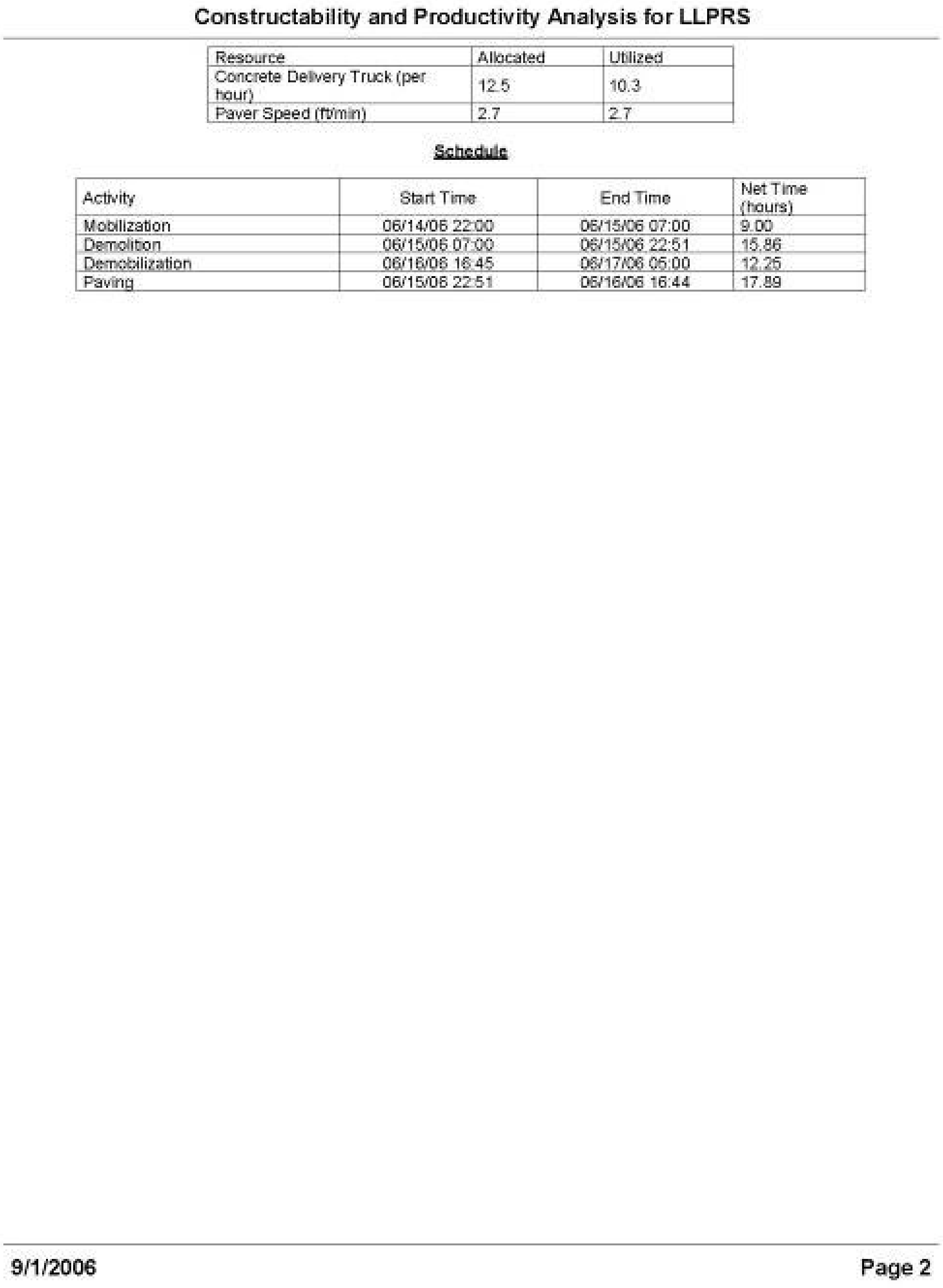
Resource Description	Capacity Characteristics
Demolition Hauling Truck	Rated Capacity: 44 ton Trucks per Hour per Team: 5 Efficiency: 0.50 Number of Team: 2 Team Efficiency: 0.92
Base Delivery Truck	Rated Capacity: 17 cu. yd Trucks per Hour: 4.5 Efficiency: 1.00
Batch Plant	Capacity: 200 cu. yd/hour Number of Plants: 1
Concrete Delivery Truck	Rated Capacity: 7.5 cu. yd Trucks per Hour: 12.5 Efficiency: 1.00
Paver	Speed: 2.67 ft/min Number of Pavers: 1

Analysis Options and Results

Construction Window:	Weekend Closure (55 Hours/Weekend)
Working Method:	Sequential Single Lane (T2)
Section Profile:	PCCP: 13.0 inches, New Base: 0.0 inches
Curing Time:	8-Hours
Objective (lane-miles):	2.22
Maximum Possible (lane-miles):	0.54
Maximum Possible (c/l-miles):	0.54
Construction Windows Needed To Meet Objective:	4.09
Demolition Quantity (cu. yd):	1698.4
New Base Quantity (cu. yd):	0.0
Concrete Quantity (cu. yd):	1379.9
Constraint Resource:	Demolition Hauling Truck, Paver
Demolition to Paving:	1:1.13
Demolition Hours:	15.9
Paving Hours:	17.9

Resource Utilization

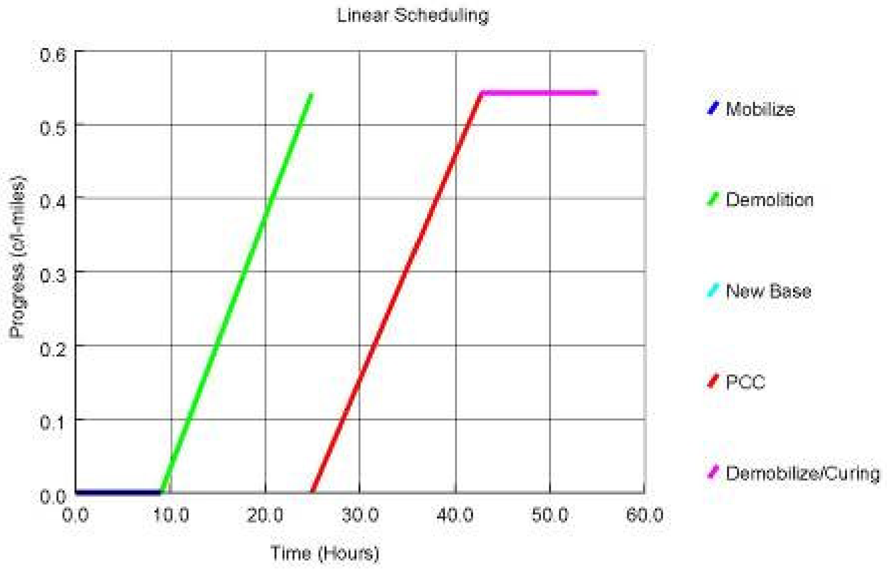
Resource	Allocated	Utilized
Demolition Hauling Truck (per hour per team)	5.0	5.0
Base Delivery Truck (per hour)	4.5	0.0
Batch Plant (cu-yd/hour)	200.0	77.1

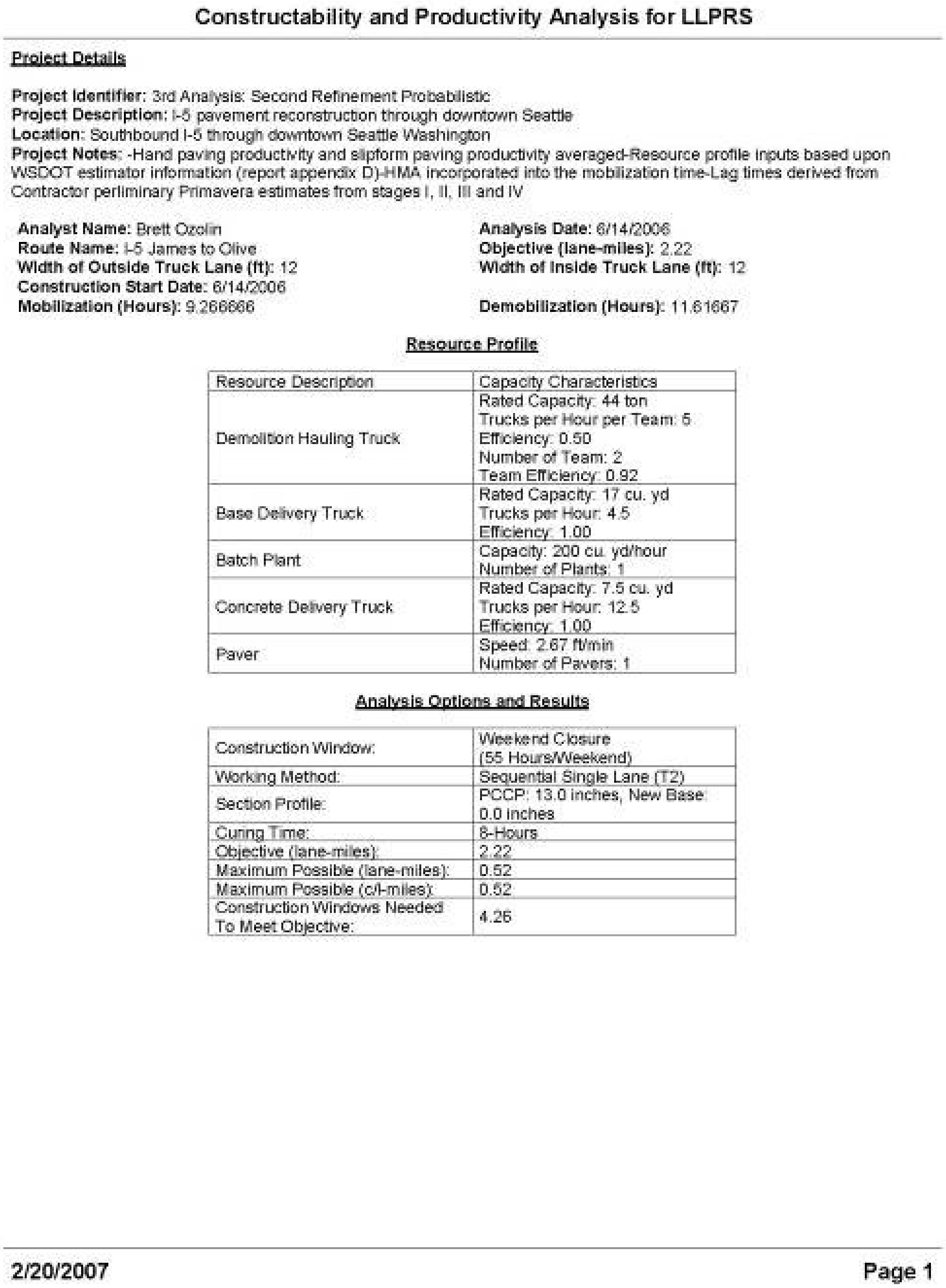


Resource	Allocated	Utilized
Concrete Delivery Truck (per hour)	12.5	10.3
Paver Speed (ft/min)	2.7	2.7

Schedule

Activity	Start Time	End Time	Net Time (hours)
Mobilization	06/14/06 22:00	06/15/06 07:00	9.00
Demolition	06/15/06 07:00	06/15/06 22:51	15.86
Demobilization	06/16/06 16:45	06/17/06 05:00	12.25
Paving	06/15/06 22:51	06/16/06 16:44	17.89


Linear Scheduling
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Progress (cl-miles)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
Time (Hours)
Mobilize
Demolition
New Base
PCC
Demobilize/Curing



Constructability and Productivity Analysis for LLPRS

Project Details

Project Identifier: 3rd Analysis: Second Refinement Probabilistic
Project Description: I-5 pavement reconstruction through downtown Seattle
Location: Southbound I-5 through downtown Seattle Washington
Project Notes: -Hand paving productivity and slipform paving productivity averaged-Resource profile inputs based upon WSDOT estimator information (report appendix D)-HMA incorporated into the mobilization time-Lag times derived from Contractor perliminary Primavera estimates from stages I, II, III and IV

Analyst Name: Brett Ozolin
Route Name: I-5 James to Olive
Width of Outside Truck Lane (ft): 12
Construction Start Date: 6/14/2006
Mobilization (Hours): 9.266666

Analysis Date: 6/14/2006
Objective (lane-miles): 2.22
Width of Inside Truck Lane (ft): 12

Demobilization (Hours): 11.61667

Resource Profile

Resource Description	Capacity Characteristics
Demolition Hauling Truck	Rated Capacity: 44 ton Trucks per Hour per Team: 5 Efficiency: 0.50 Number of Team: 2 Team Efficiency: 0.92
Base Delivery Truck	Rated Capacity: 17 cu. yd Trucks per Hour: 4.5 Efficiency: 1.00
Batch Plant	Capacity: 200 cu. yd/hour Number of Plants: 1
Concrete Delivery Truck	Rated Capacity: 7.5 cu. yd Trucks per Hour: 12.5 Efficiency: 1.00
Paver	Speed: 2.67 ft/min Number of Pavers: 1

Analysis Options and Results

Construction Window:	Weekend Closure (55 Hours/Weekend)
Working Method:	Sequential Single Lane (T2)
Section Profile:	PCCP: 13.0 inches, New Base: 0.0 inches
Curing Time:	8-Hours
Objective (lane-miles):	2.22
Maximum Possible (lane-miles):	0.52
Maximum Possible (c/l-miles):	0.52
Construction Windows Needed To Meet Objective:	4.26

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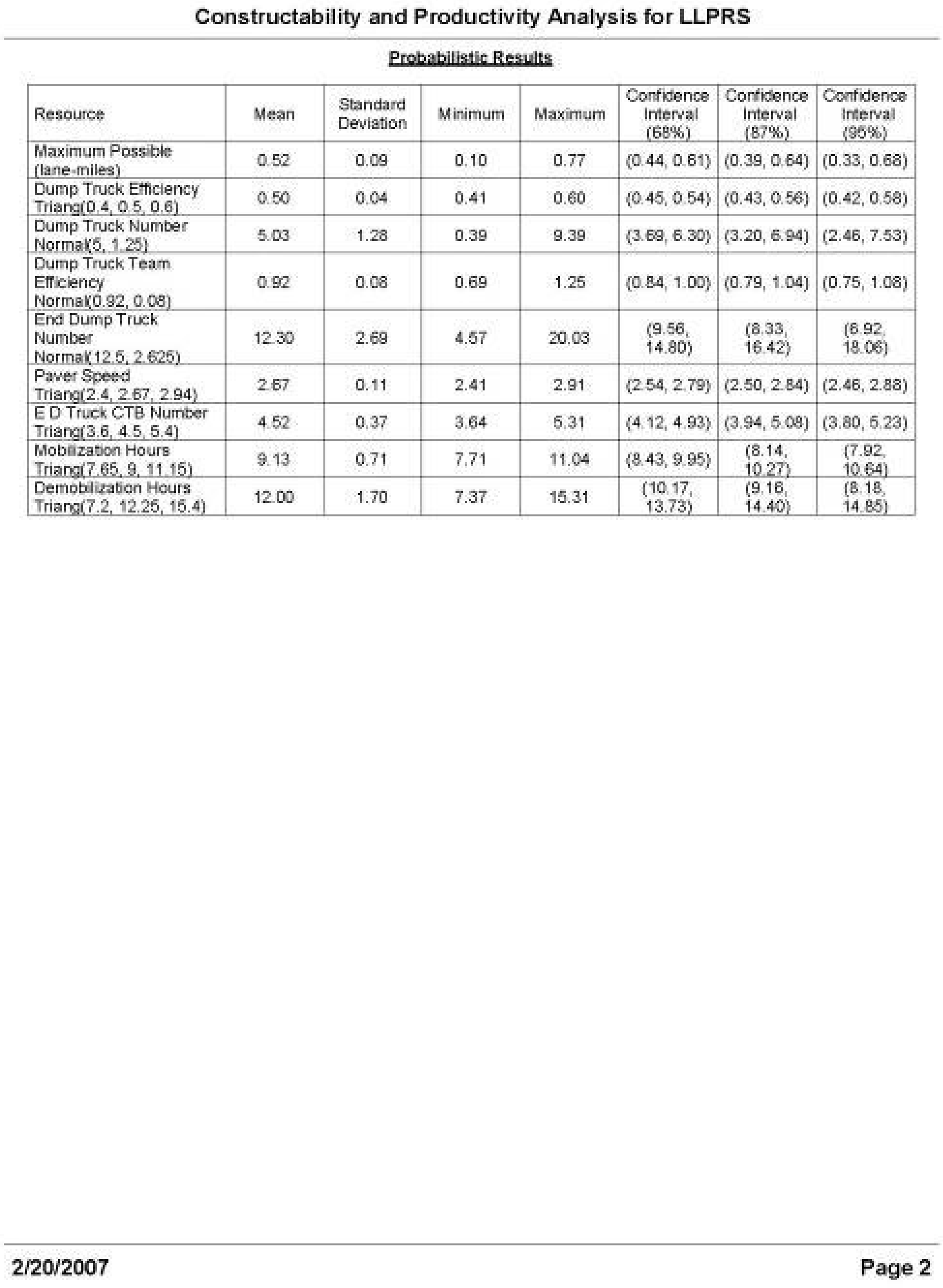
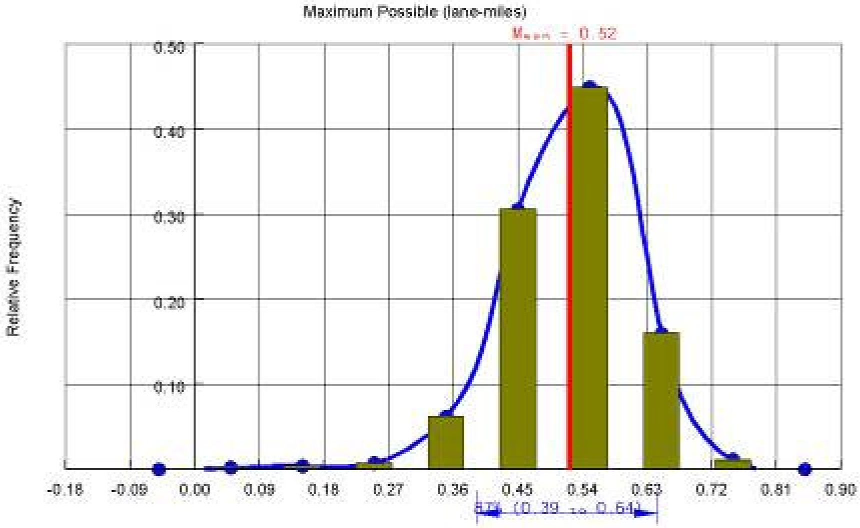


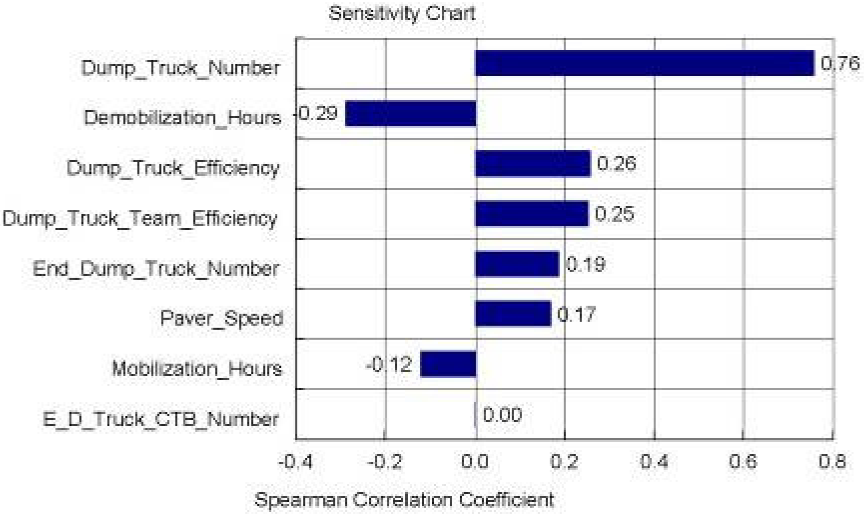
Constructability and Productivity Analysis for LLPRS

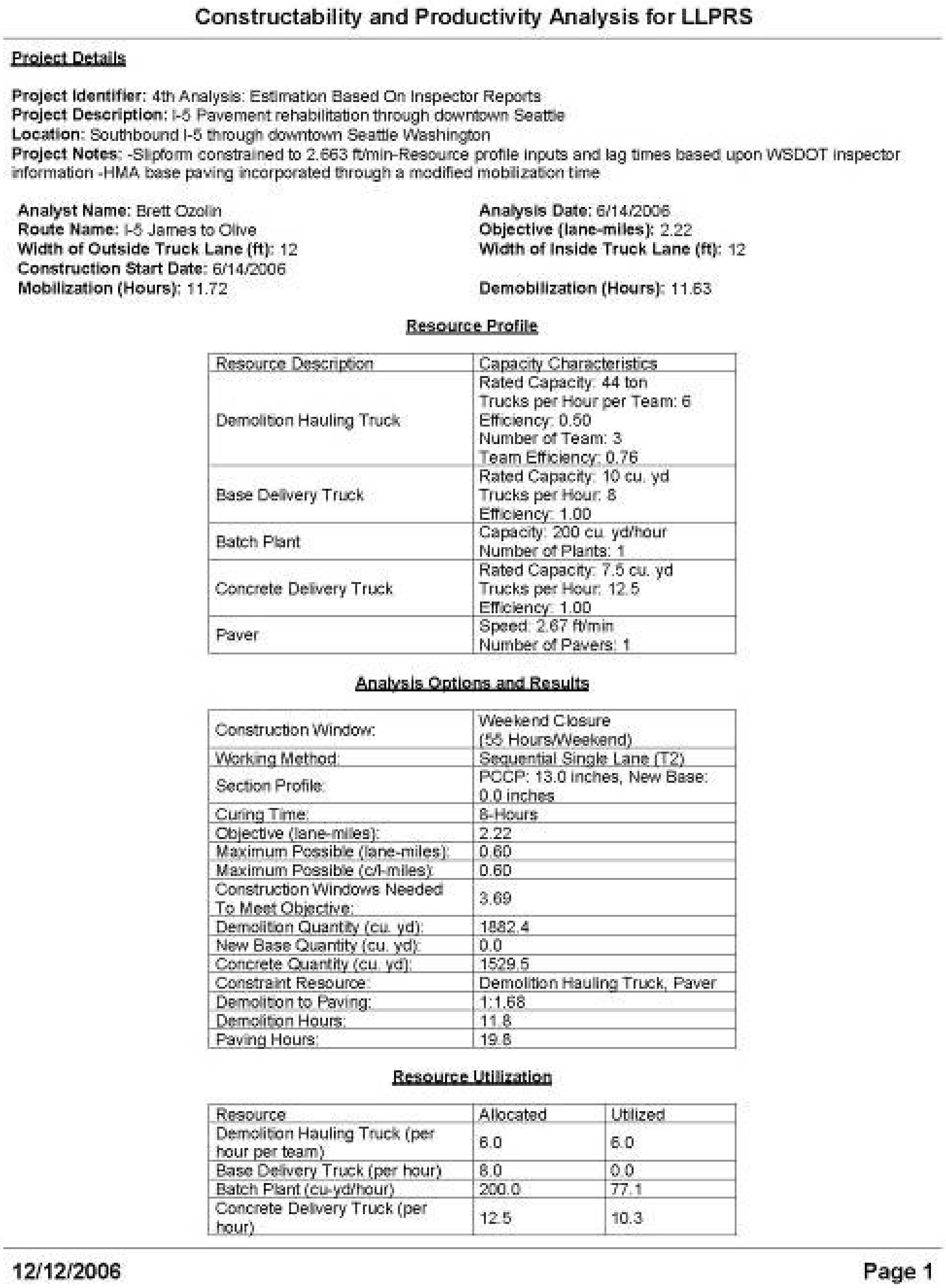
Probabilistic Results

Resource	Mean	Standard Deviation	Minimum	Maximum	Confidence Interval (68%)	Confidence Interval (87%)	Confidence Interval (95%)
Maximum Possible (lane-miles)	0.52	0.09	0.10	0.77	(0.44, 0.61)	(0.39, 0.64)	(0.33, 0.68)
Dump Truck Efficiency Triang(0.4, 0.5, 0.6)	0.50	0.04	0.41	0.60	(0.45, 0.54)	(0.43, 0.56)	(0.42, 0.58)
Dump Truck Number Normal(5, 1.25)	5.03	1.28	0.39	9.39	(3.69, 6.30)	(3.20, 6.94)	(2.46, 7.53)
Dump Truck Team Efficiency Normal(0.92, 0.08)	0.92	0.08	0.69	1.25	(0.84, 1.00)	(0.79, 1.04)	(0.75, 1.08)
End Dump Truck Number Normal(12.5, 2.625)	12.30	2.69	4.57	20.03	(9.56, 14.80)	(8.33, 16.42)	(6.92, 18.06)
Paver Speed Triang(2.4, 2.67, 2.94)	2.67	0.11	2.41	2.91	(2.54, 2.79)	(2.50, 2.84)	(2.46, 2.88)
E D Truck CTB Number Triang(3.6, 4.5, 5.4)	4.52	0.37	3.64	5.31	(4.12, 4.93)	(3.94, 5.08)	(3.80, 5.23)
Mobilization Hours Triang(7.65, 9, 11.15)	9.13	0.71	7.71	11.04	(8.43, 9.95)	(8.14, 10.27)	(7.92, 10.64)
Demobilization Hours Triang(7.2, 12.25, 15.4)	12.00	1.70	7.37	15.31	(10.17, 13.73)	(9.16, 14.40)	(8.18, 14.85)

Constructability and Productivity Analysis for LLPRS







Constructability and Productivity Analysis for LLPRS

Project Details

Project Identifier: 4th Analysis: Estimation Based On Inspector Reports
Project Description: I-5 Pavement rehabilitation through downtown Seattle
Location: Southbound I-5 through downtown Seattle Washington
Project Notes: -Slipform constrained to 2.663 ft/min-Resource profile inputs and lag times based upon WSDOT inspector information -HMA base paving incorporated through a modified mobilization time

Analyst Name: Brett Ozolin
Route Name: I-5 James to Olive
Width of Outside Truck Lane (ft): 12
Construction Start Date: 6/14/2006
Mobilization (Hours): 11.72

Analysis Date: 6/14/2006
Objective (lane-miles): 2.22
Width of Inside Truck Lane (ft): 12

Demobilization (Hours): 11.63

Resource Profile

Resource Description	Capacity Characteristics
Demolition Hauling Truck	Rated Capacity: 44 ton Trucks per Hour per Team: 6 Efficiency: 0.50 Number of Team: 3 Team Efficiency: 0.76
Base Delivery Truck	Rated Capacity: 10 cu. yd Trucks per Hour: 8 Efficiency: 1.00
Batch Plant	Capacity: 200 cu. yd/hour Number of Plants: 1
Concrete Delivery Truck	Rated Capacity: 7.5 cu. yd Trucks per Hour: 12.5 Efficiency: 1.00
Paver	Speed: 2.67 ft/min Number of Pavers: 1

Analysis Options and Results

Construction Window:	Weekend Closure (55 Hours/Weekend)
Working Method:	Sequential Single Lane (T2)
Section Profile:	PCCP: 13.0 inches, New Base: 0.0 inches
Curing Time:	8-Hours
Objective (lane-miles):	2.22
Maximum Possible (lane-miles):	0.60
Maximum Possible (c/l-miles):	0.60
Construction Windows Needed To Meet Objective:	3.69
Demolition Quantity (cu. yd):	1882.4
New Base Quantity (cu. yd):	0.0
Concrete Quantity (cu. yd):	1529.5
Constraint Resource:	Demolition Hauling Truck, Paver
Demolition to Paving:	1:1.68
Demolition Hours:	11.8
Paving Hours:	19.8

Resource Utilization

Resource	Allocated	Utilized
Demolition Hauling Truck (per hour per team)	6.0	6.0
Base Delivery Truck (per hour)	8.0	0.0
Batch Plant (cu-yd/hour)	200.0	77.1
Concrete Delivery Truck (per hour)	12.5	10.3

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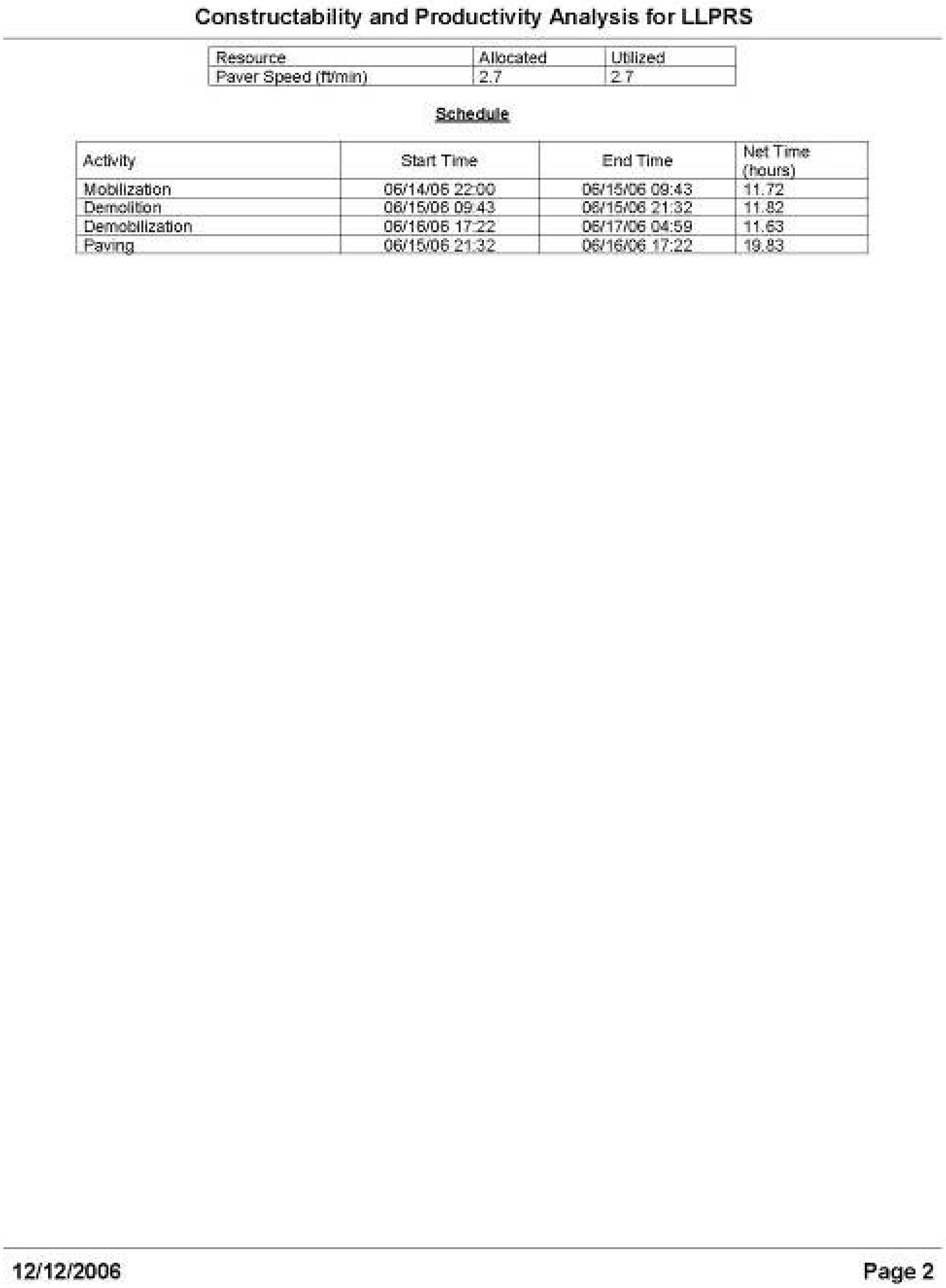

Constructability and Productivity Analysis for LLPRS

Resource	Allocated	Utilized
Paver Speed (ft/min)	2.7	2.7

Schedule

Activity	Start Time	End Time	Net Time (hours)
Mobilization	06/14/06 22:00	06/15/06 09:43	11.72
Demolition	06/15/06 09:43	06/15/06 21:32	11.82
Demobilization	06/16/06 17:22	06/17/06 04:59	11.63
Paving	06/15/06 21:32	06/16/06 17:22	19.83

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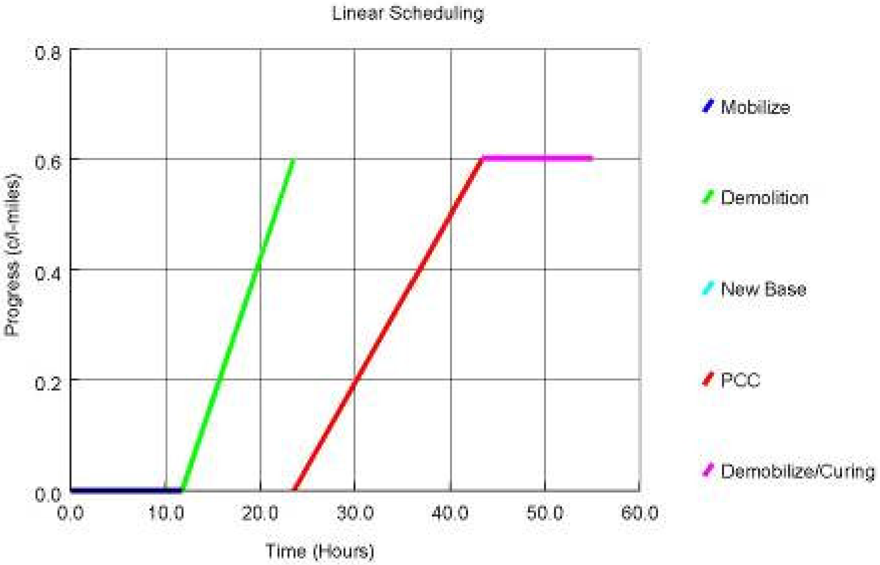
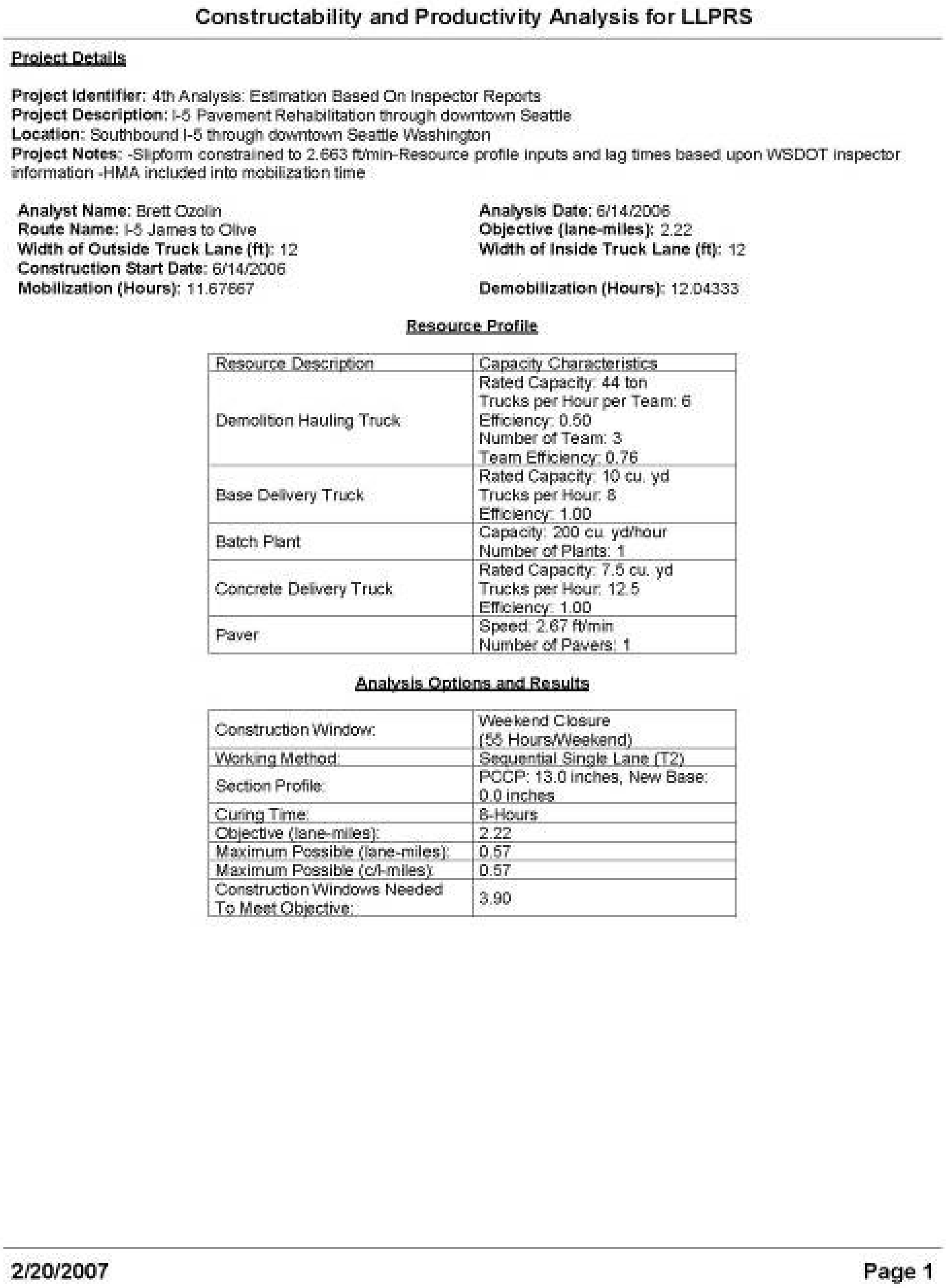

Linear Scheduling
0.8
0.6
0.4
0.2
0.0
Progress (cl-miles)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
Time (Hours)
Mobilize
Demolition
New Base
PCC
Demobilize/Curing



Constructability and Productivity Analysis for LLPRS

Project Details

Project Identifier: 4th Analysis: Estimation Based On Inspector Reports
Project Description: I-5 Pavement Rehabilitation through downtown Seattle
Location: Southbound I-5 through downtown Seattle Washington
Project Notes: -Slipform constrained to 2.663 ft/min-Resource profile inputs and lag times based upon WSDOT inspector information -HMA included into mobilization time

Analyst Name: Brett Ozolin
Route Name: I-5 James to Olive
Width of Outside Truck Lane (ft): 12
Construction Start Date: 6/14/2006
Mobilization (Hours): 11.67667

Analysis Date: 6/14/2006
Objective (lane-miles): 2.22
Width of Inside Truck Lane (ft): 12

Demobilization (Hours): 12.04333

Resource Profile

Resource Description	Capacity Characteristics
Demolition Hauling Truck	Rated Capacity: 44 ton Trucks per Hour per Team: 6 Efficiency: 0.50 Number of Team: 3 Team Efficiency: 0.76
Base Delivery Truck	Rated Capacity: 10 cu. yd Trucks per Hour: 8 Efficiency: 1.00
Batch Plant	Capacity: 200 cu. yd/hour Number of Plants: 1
Concrete Delivery Truck	Rated Capacity: 7.5 cu. yd Trucks per Hour: 12.5 Efficiency: 1.00
Paver	Speed: 2.67 ft/min Number of Pavers: 1

Analysis Options and Results

Construction Window:	Weekend Closure (55 Hours/Weekend)
Working Method:	Sequential Single Lane (T2)
Section Profile:	PCCP: 13.0 inches, New Base: 0.0 inches
Curing Time:	8-Hours
Objective (lane-miles):	2.22
Maximum Possible (lane-miles):	0.57
Maximum Possible (c/l-miles):	0.57
Construction Windows Needed To Meet Objective:	3.90

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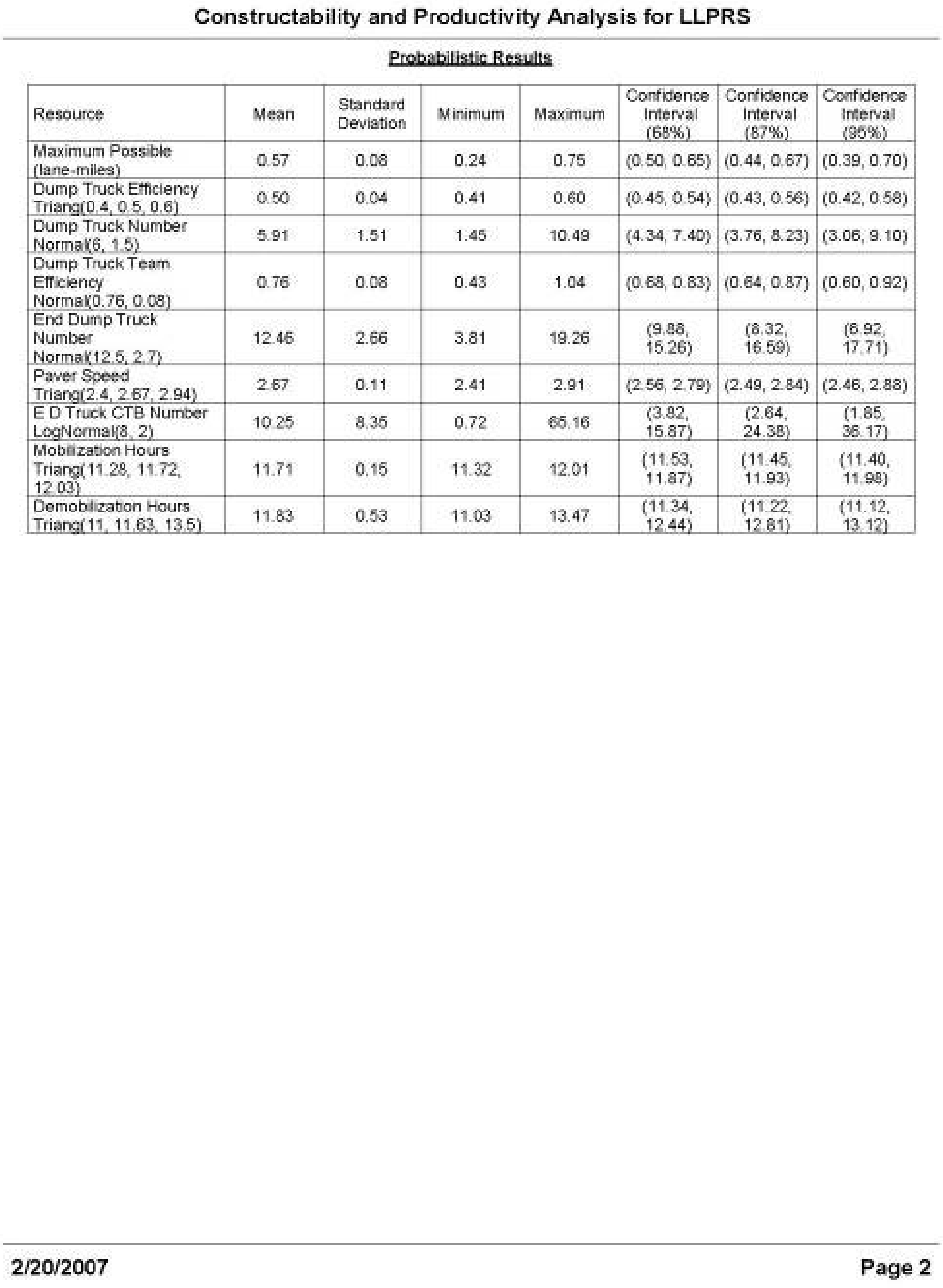
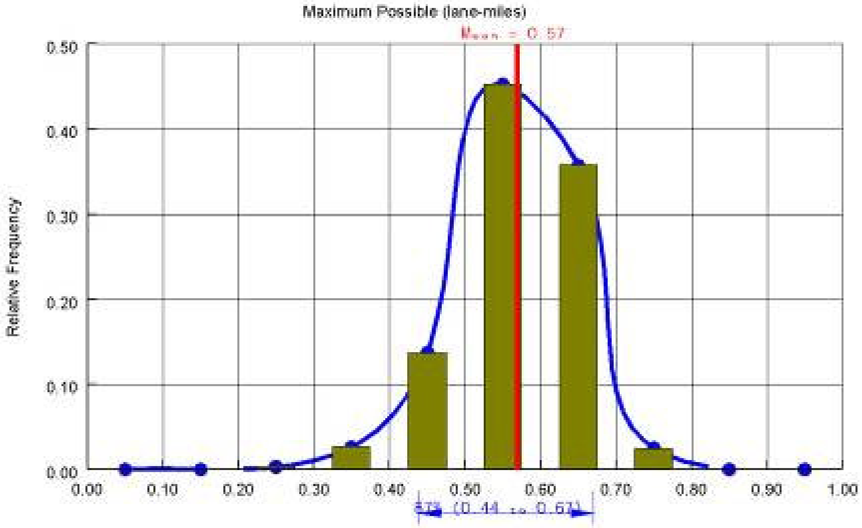
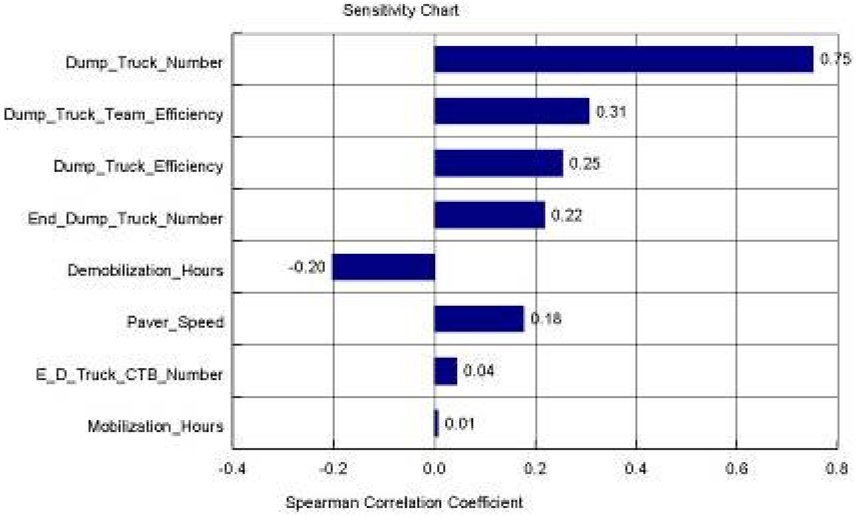


Constructability and Productivity Analysis for LLPRS

Probabilistic Results

Resource	Mean	Standard Deviation	Minimum	Maximum	Confidence Interval (68%)	Confidence Interval (87%)	Confidence Interval (95%)
Maximum Possible (lane-miles)	0.57	0.08	0.24	0.75	(0.50, 0.65)	(0.44, 0.67)	(0.39, 0.70)
Dump Truck Efficiency Triang(0.4, 0.5, 0.6)	0.50	0.04	0.41	0.60	(0.45, 0.54)	(0.43, 0.56)	(0.42, 0.58)
Dump Truck Number Normal(6, 1.5)	5.91	1.51	1.45	10.49	(4.34, 7.40)	(3.76, 8.23)	(3.06, 9.10)
Dump Truck Team Efficiency Normal(0.76, 0.08)	0.76	0.08	0.43	1.04	(0.68, 0.83)	(0.64, 0.87)	(0.60, 0.92)
End Dump Truck Number Normal(12.5, 2.7)	12.46	2.66	3.81	19.26	(9.88, 15.26)	(8.32, 16.59)	(6.92, 17.71)
Paver Speed Triang(2.4, 2.67, 2.94)	2.67	0.11	2.41	2.91	(2.56, 2.79)	(2.49, 2.84)	(2.46, 2.88)
E D Truck CTB Number LogNormal(8, 2)	10.25	8.35	0.72	65.16	(3.82, 15.87)	(2.64, 24.38)	(1.85, 36.17)
Mobilization Hours Triang(11.28, 11.72, 12.03)	11.71	0.15	11.32	12.01	(11.53, 11.87)	(11.45, 11.93)	(11.40, 11.98)
Demobilization Hours Triang(11, 11.63, 13.5)	11.83	0.53	11.03	13.47	(11.34, 12.44)	(11.22, 12.81)	(11.12, 13.12)


Maximum Possible (lane-miles)
Mean = 0.57
Relative Frequency
0.50
0.40
0.30
0.20
0.10
0.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
87% (0.44 to 0.67)


Sensitivity Chart
Dump_Truck_Number
Dump_Truck_Team_Efficiency
Dump_Truck_Efficiency
End_Dump_Truck_Number
Demobilization_Hours
Paver_Speed
E_D_Truck_CTB_Number
Mobilization_Hours
0.75
0.31
0.25
0.22
-0.20
0.18
0.04
0.01
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
Spearman Correlation Coefficient

Appendix F: Truck Ticket Information Used to Derive a Weighted Paver Speed

Slipform Truck Ticket Data Used for Deriving Weighted Paver Speed

The data contained in this appendix section was used to determine slipform paving productivity.

Mix Design 8049-P 4000 PSI -12 HR Slipform Partial Information For 4/24/05

Truck No.	Batch Record	Time Between Batches (hr:min:sec)	Batch #	Mix ID	Quantity (CY)	Job Total (CY)
155	5:54:00 AM		100	8049-P	7.5	742.5
142	5:58:00 AM	0:04:00	101	8049-P	7.5	750
148	6:01:00 AM	0:03:00	102	8049-P	7.5	757.5
152	6:05:00 AM	0:04:00	103	8049-P	7.5	765
-	6:08:00 AM	0:03:00	104	8049-P	7.5	772.5
140	6:14:00 AM	0:06:00	105	8049-P	7.5	780
-	6:18:00 AM	0:04:00	106	8049-P	7.5	787.5
-	6:20:00 AM	0:02:00	107	8049-P	7.5	795
-	6:24:00 AM	0:04:00	108	8049-P	7.5	802.5
-	6:27:00 AM	0:03:00	109	8049-P	7.5	810
-	6:31:00 AM	0:04:00	110	8049-P	7.5	817.5
-	6:36:00 AM	0:05:00	111	8049-P	7.5	825
-	6:48:00 AM	0:12:00	112	8049-P	7.5	832.5
-	6:52:00 AM	0:04:00	113	8049-P	7.5	840
142	7:11:00 AM	0:19:00	114	8049-P	7.5	847.5
-	7:16:00 AM	0:05:00	115	8049-P	7.5	855
-	7:19:00 AM	0:03:00	116	8049-P	7.5	862.5
-	7:24:00 AM	0:05:00	117	8049-P	7.5	870
148	7:26:00 AM	0:02:00	118	8049-P	7.5	877.5
-	7:31:00 AM	0:05:00	119	8049-P	7.5	885
140	7:36:00 AM	0:05:00	120	8049-P	7.5	892.5
-	7:39:00 AM	0:03:00	121	8049-P	7.5	900
-	7:44:00 AM	0:05:00	122	8049-P	7.5	907.5
-	7:47:00 AM	0:03:00	123	8049-P	7.5	915
157	7:51:00 AM	0:04:00	124	8049-P	7.5	922.5
-	7:54:00 AM	0:03:00	125	8049-P	7.5	930
159	7:57:00 AM	0:03:00	126	8049-P	7.5	937.5

Mix Design 8049-P 4000 PSI -12 HR Slipform Partial Information For 4/24/05

Truck No.	Batch Record	Time Between Batches (hr:min:sec)	Batch #	Mix ID	Quantity (CY)	Job Total (CY)
449	8:08 AM	0:11:00	128	8049-P	11	948.5
446	8:13 AM	0:05:00	130	8049-P	11	959.5
444	8:22 AM	0:09:00	132	8049-P	11	970.5
438	8:25 AM	0:03:00	134	8049-P	11	981.5
448	8:52 AM	0:27:00	136	8049-P	11	992.5
441	8:56 AM	0:04:00	138	8049-P	11	1003.5
439	9:00 AM	0:04:00	140	8049-P	11	1014.5
419	9:05 AM	0:05:00	141	8049-P	10	1024.5
443	9:13 AM	0:08:00	143	8049-P	11	1035.5
422	9:18 AM	0:05:00	144	8049-P	10	1045.5
434	9:28 AM	0:10:00	145	8049-P	11	1056.5
436	9:32 AM	0:04:00	146	8049-P	11	1067.5
423	9:39 AM	0:07:00	145	8049-P	10	1077.5
449	9:42 AM	0:03:00	-	8049-P	11	1088.5
444	10:16 AM	0:34:00	103	8049-P	11	1099.5

Mix Design 8049-P 4000 PSI - 12 HR Slipform Partial Information For 6/18/2005

Truck No.	Batch Time	Arrival Time	Time Between Truck Arrivals (hr:min)	Quantity (yd^3)	Batch Number
23	5:42 PM	6:15 PM	-	7.5	4
13	5:44 PM	6:19 PM	0:04	7.5	5
22	5:50 PM	6:28 PM	0:09	7.5	6
25	5:56 PM	6:35 PM	0:07	7.5	8
201	6:03 PM	6:42 PM	0:07	7.5	10
24	6:27 PM	6:58 PM	0:16	7.5	9
21	6:29 PM	7:12 PM	0:14	7.5	10
19	6:42 PM	7:14 PM	0:02	7.5	11
20	6:46 PM	7:20 PM	0:06	7.5	12
3	6:56 PM	7:24 PM	0:04	7.5	13
202	6:59 PM	7:28 PM	0:04	7.5	14
13	7:05 PM	7:34 PM	0:06	7.5	15
22	7:07 PM	7:38 PM	0:04	7.5	16
45	7:20 PM	7:44 PM	0:06	7.5	17
201	7:22 PM	7:48 PM	0:04	7.5	18
24	7:25 PM	7:52 PM	0:04	7.5	19
19	7:39 PM	8:04 PM	0:12	7.5	20
21	7:44 PM	8:09 PM	0:05	7.5	21
20	7:47 PM	8:14 PM	0:05	7.5	22
3	7:50 PM	8:16 PM	0:02	7.5	23
23	8:05 PM	8:29 PM	0:13	7.5	24
13	8:07 PM	8:33 PM	0:04	7.5	25
22	8:11 PM	8:37 PM	0:04	7.5	26
25	8:14 PM	8:39 PM	0:02	7.5	27
201	8:34 PM	8:59 PM	0:20	7.5	28
24	8:38 PM	9:02 PM	0:03	7.5	29
21	8:40 PM	9:07 PM	0:05	7.5	30
20	8:55 PM	9:17 PM	0:10	7.5	31
10	8:57 PM	9:19 PM	0:02	7.5	32
3	9:00 PM	9:24 PM	0:05	7.5	33
23	9:13 PM	9:34 PM	0:10	7.5	34
13	9:16 PM	9:39 PM	0:05	7.5	35
22	9:18 PM	9:43 PM	0:04	7.5	36
25	9:20 PM	9:48 PM	0:05	7.5	37
201	9:34 PM	10:01 PM	0:13	7.5	38
24	9:37 PM	10:03 PM	0:02	7.5	39

	Average Time Between Truck Deliveries (hr:min:sec)	Average Truckload (CY)	Average Producitivity (CY/Hr)
Mix 8049-P Slipform Partial Information For 4/24/05 Phase I	0:04:44	7.5	95.07
Mix 8049-P Slipform Partial Information For 4/24/05 Phase I	0:07:30	10.8	86.40
Mix 8049-P Slipform Partial Information From 7/16/05 Phase IV	0:04:13	7.5	106.72
	Unweighted Average of Productivity (CY/Hr)		96.06
	Rounded Average Used for Analysis (CY/Hr)		95

Hand Paving Truck Ticket Data Used for Deriving Weighted Paver Speed

The data contained in this appendix section was used to derive a hand paving productivity rate.

BI #18 Mix #7524-H 30 HR Paving Mix 1 1/2" (Ramp) 4/23/05 Salinas

Truck Driver	Jobsite Arrival Time	Time Between Batches (hr:min:sec)	Batch #	Mix ID	Quantity (CY)	Job Total (CY)
John Reid	1:12:00 PM	-	-	-	11	22
Doug White	1:20:00 PM	0:08:00	45	7524-H	10	42
John Lewis	1:36:00 PM	0:16:00	44	7524-H	10	32
Ken Dawson	1:47:00 PM	0:11:00	46	7524-H	10	42
Bob Labrash	1:56:00 PM	0:09:00	48	7524-H	11	53
Ron Henke	2:04:00 PM	0:08:00	49	7524-H	11	64
Wayne Bradford	2:10:00 PM	0:06:00	50	7524-H	10	74
Sean Bradley	2:30:00 PM	0:20:00	51	7524-H	11	85
John Reid	2:40:00 PM	0:10:00	53	7524-H	11	96
Doug White	2:55:00 PM	0:15:00	54	7524-H	10	106
Tonely Melewski	3:05:00 PM	0:10:00	56	7524-H	11	117
Mike Butterworth	3:20:00 PM	0:15:00	57	7524-H	10	127
John Lewis	3:35:00 PM	0:15:00	58	7524-H	10	137
Bob Labrash	3:45:00 PM	0:10:00	59	7524-H	11	148
Ron Henke	4:00:00 PM	0:15:00	61	7524-H	11	159
Harry Hansen	4:10:00 PM	0:10:00	62	7524-H	11	170
Tim Doane	4:25:00 PM	0:15:00	63	7524-H	11	181
Sean Bradley	4:35:00 PM	0:10:00	64	7524-H	10	191
Doug White	5:00:00 PM	0:25:00	66	7524-H	10	201
Mike Butterworth	5:15:00 PM	0:15:00	67	7524-H	10	211
John Lewis	5:35:00 PM	0:20:00	69	7524-H	10	221
Ken Dawson	5:46:00 PM	0:11:00	70	7524-H	10	231
Harry Hansen	5:55:00 PM	0:09:00	71	7524-H	11	242
Tim Doane	6:33:00 PM	0:38:00	73	7524-H	2	244

BI #18 Mix #7524-H 30 HR Paving Mix 1 1/2" 4/24/05 Salinas

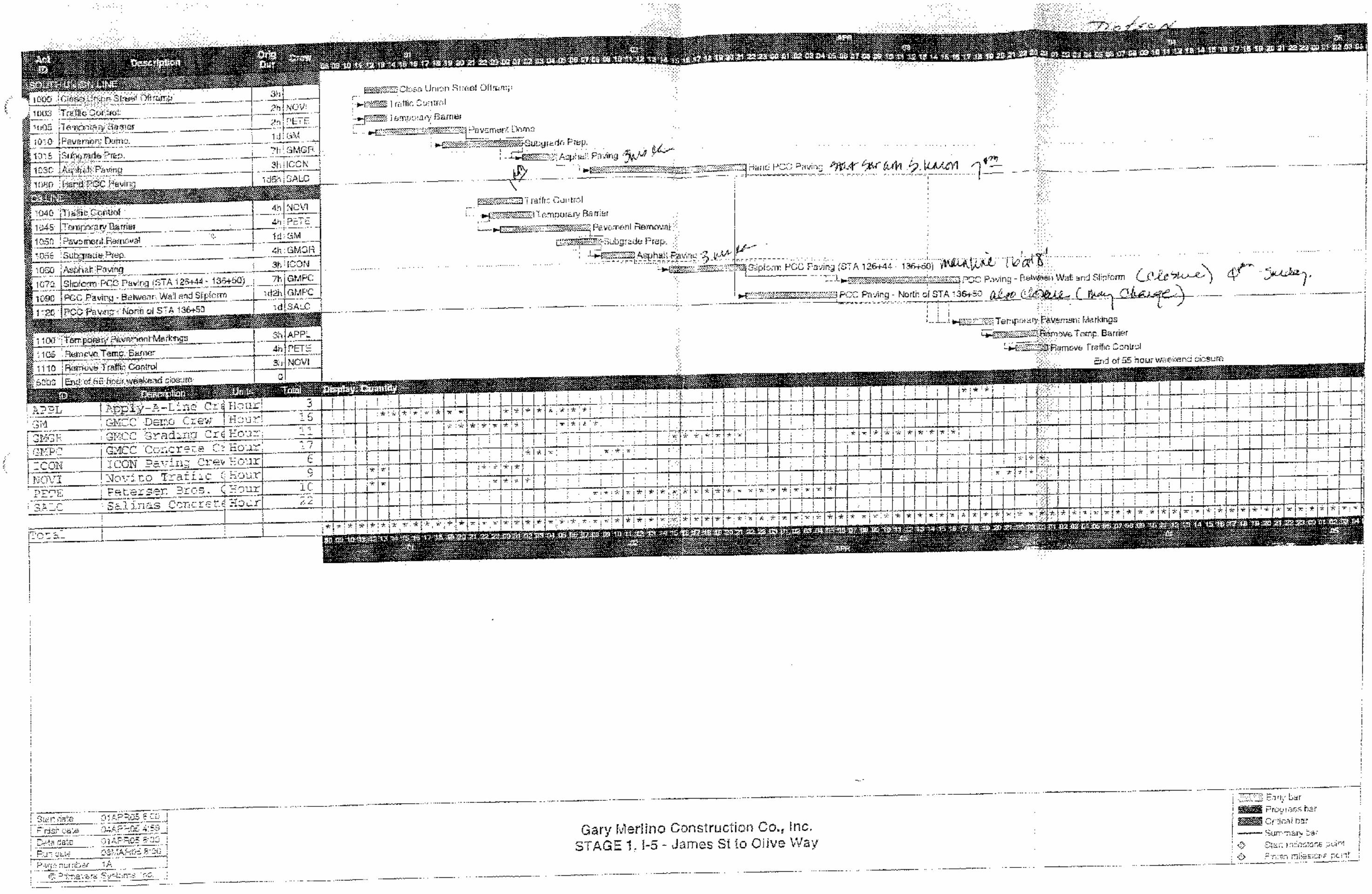
Truck Driver	Jobsite Arrival Time	Time Between Batches (hr:min:sec)	Batch #	Mix ID	Quantity (CY)	Job Total (CY)
Bob Labrash	11:00:00 AM	-	154	7524-H	11	11
-	11:13:00 AM	0:13:00	155	7524-H	11	22
Ron Henke	11:23:00 AM	0:10:00	156	7524-H	11	33
Tony Melewski	11:49:00 AM	0:26:00	157	7524-H	11	44
Dan Leenhouts	12:02:00 PM	0:13:00	158	7524-H	11	55
Mark Stout	12:15:00 PM	0:13:00	159	7524-H	10	65
Mark Bergman	12:28:00 PM	0:13:00	160	7524-H	11	76
Wayne Bradford	12:39:00 PM	0:11:00	161	7524-H	10	86
John Reid	12:55:00 PM	0:16:00	162	7524-H	11	97
Marty Bjornstad	1:06:00 PM	0:11:00	163	7524-H	11	108
Paul Mayo	1:18:00 PM	0:12:00	164	7524-H	11	119
Ron Hills	1:31:00 PM	0:13:00	165	7524-H	11	130
Bob Labrash	1:40:00 PM	0:09:00	166	7524-H	11	141
Tony Melewski	1:50:00 PM	0:10:00	167	7524-H	11	152
Ron Henke	2:05:00 PM	0:15:00	168	7524-H	11	163
Mark Stout	2:16:00 PM	0:11:00	169	7524-H	10	173
Dan Leenhouts	2:27:00 PM	0:11:00	170	7524-H	11	184
Wayne Bradford	2:44:00 PM	0:17:00	171	7524-H	10	194
John Reid	2:57:00 PM	0:13:00	172	7524-H	11	205
Marty Bjornstad	3:09:00 PM	0:12:00	173	7524-H	11	216
Ron Hills	3:34:00 PM	0:25:00	174	7524-H	11	227
Ron Henke	4:10:00 PM	0:36:00	177	7524-H	11	238
Mark Stout	4:20:00 PM	0:10:00	180	7524-H	10	248
Wayne Bradford	4:35:00 PM	0:15:00	181	7524-H	10	258
John Reid	4:50:00 PM	0:15:00	184	7524-H	11	269
Ron Hills	5:34:00 PM	0:44:00	187	7524-H	11	280
Mark Stout	6:20:00 PM	0:46:00	196	7524-H	10	290
Wayne Bradford	6:38:00 PM	0:18:00	194	7524-H	10	300
Dan Leenhouts	6:51:00 PM	0:13:00	195	7524-H	11	311
Bob Labrash	7:00:00 PM	0:09:00	196	7524-H	11	322
John Reid	7:05:00 PM	0:05:00	197	7524-H	11	333
Ron Hills	7:20:00 PM	0:15:00	198	7524-H	11	344
Mark Stout	7:41:00 PM	0:21:00	199	7524-H	10	354
Wayne Bradford	7:50:00 PM	0:09:00	200	7524-H	10	364

Mix ID 8049-H 6/26/05

Truck Driver	Truck No.	Jobsite Arrival Time	Time Between Batches (hr:min:sec)	Batch #	Mix ID	Quantity (CY)	Job Total (CY)
Randy Laukala	438	7:52:00 AM	-	10	8049-H	11	11
Tony Melewski	441	8:06:00 AM	0:14:00	12	8049-H	11	22
Dan Leenhouts	439	8:25:00 AM	0:19:00	6	8049-H	11	33
Mark Bergman	443	8:40:00 AM	0:15:00	14	8049-H	11	44
Tony Guilian	437	9:04:00 AM	0:24:00	17	8049-H	11	55
Robert Dobosh	432	9:25:00 AM	0:21:00	20	8049-H	11	66
Ron Henke	448	9:50:00 AM	0:25:00	32	8049-H	11	77
Randy Laukala	438	10:06:00 AM	0:16:00	34	8049-H	11	88
Wayne Bradford	422	10:25:00 AM	0:19:00	36	8049-H	10	98
Tony Melewski	441	10:36:00 AM	0:11:00	40	8049-H	11	109
Dan Leenhouts	439	10:53:00 AM	0:17:00	42	8049-H	11	120
Mark Bergman	443	11:06:00 AM	0:13:00	46	8049-H	11	131
Robert Dobosh	432	11:16:00 AM	0:10:00	54	8049-H	11	142
Ron Henke	448	11:34:00 AM	0:18:00	58	8049-H	11	153
Rich Geraghty	415	11:46:00 AM	0:12:00	59	8049-H	10	163
Randy Laukala	438	11:55:00 AM	0:09:00	63	8049-H	11	174
Sean Stott	435	12:10:00 PM	0:15:00	65	8049-H	11	185
Wayne Bradford	422	12:25:00 PM	0:15:00	66	8049-H	10	195
Paul Mayo	436	12:40:00 PM	0:15:00	68	8049-H	11	206
Robert Dobosh	432	12:56:00 PM	0:16:00	70	8049-H	11	217
Tony Guilian	437	1:03:00 PM	0:07:00	72	8049-H	11	228
Ron Henke	448	1:10:00 PM	0:07:00	74	8049-H	11	239
Bob Labrash	446	1:20:00 PM	0:10:00	76	8049-H	11	250
Sean Stott	435	1:30:00 PM	0:10:00	78	8049-H	11	261
John Reid	434	1:40:00 PM	0:10:00	80	8049-H	11	272
Wayne Bradford	422	1:50:00 PM	0:10:00	81	8049-H	10	282
Tony Guilian	437	2:05:00 PM	0:15:00	83	8049-H	11	293

	Average Time Between Truck Deliveries (hr:min:sec)	Average Truckload (yd^3)	Average Producitivity (yd^3/hr)
Mix #7524-H Hand Pave 4/23/05 Stage 1	0:13:57	10.13	53.37
Mix #7524-H Hand Pave 4/24/05 Stage 1	0:16:04	10.70	45.95
Mix #8049-H Hand Pave 6/26/05 Stage 3	0:14:19	10.85	45.35
	Average Productivity (yd^3/hr)		48.22
	Average Used for Analysis (yd^3/hr)		50.00

Appendix G: Preliminary Contractor Primavera Schedules



Act ID	Description	Orig Dur	Crew
SOUTH UNION LINE			
1000	Close Union Street Offramp	3h	
1003	Traffic Control	2h	NOVI
1005	Temporary Barrier	2h	PETE
1010	Pavement Demo.	1d	GM
1015	Subgrade Prep.	7h	GMGR
1030	Asphalt Paving	3h	ICON
1080	Hand PCC Paving	1d5h	SALC
CLINE			
1040	Traffic Control	4h	NOVI
1045	Temporary Barrier	4h	PETE
1050	Pavement Removal	1d	GM
1055	Subgrade Prep.	4h	GMGR
1060	Asphalt Paving	3h	ICON
1070	Slipform PCC Paving (STA 126+44 - 136+50)	7h	GMPC
1090	PCC Paving - Between Wall and Slipform	1d2h	GMPC
1120	PCC Paving - North of STA 136+50	1d	SALC
1100	Temporary Pavement Markings	3h	APPL
1105	Remove Temp. Barrier	4h	PETE
1110	Remove Traffic Control	3h	NOVI
6000	End of 55 hour weekend closure	0	

ID	Description	Units	Total
APPL	Apply-A-Line Cr	Hour	3
GM	GMCC Demo Crew	Hour	15
GMGR	GMCC Grading Cre	Hour	11
GMPC	GMCC Concrete C	Hour	17
ICON	ICON Paving Crew	Hour	6
NOVI	Novito Traffic (	Hour	9
PETE	Petersen Bros. (	Hour	10
SALC	Salinas Concrete	Hour	22
TOTAL			

(closure) 4th Sunday.

also closure (may change)

Start date	01APR05 8:00
Finish date	04APR05 4:59
Data date	01APR05 8:00
Run date	03MAR05 8:50
Page number	1A

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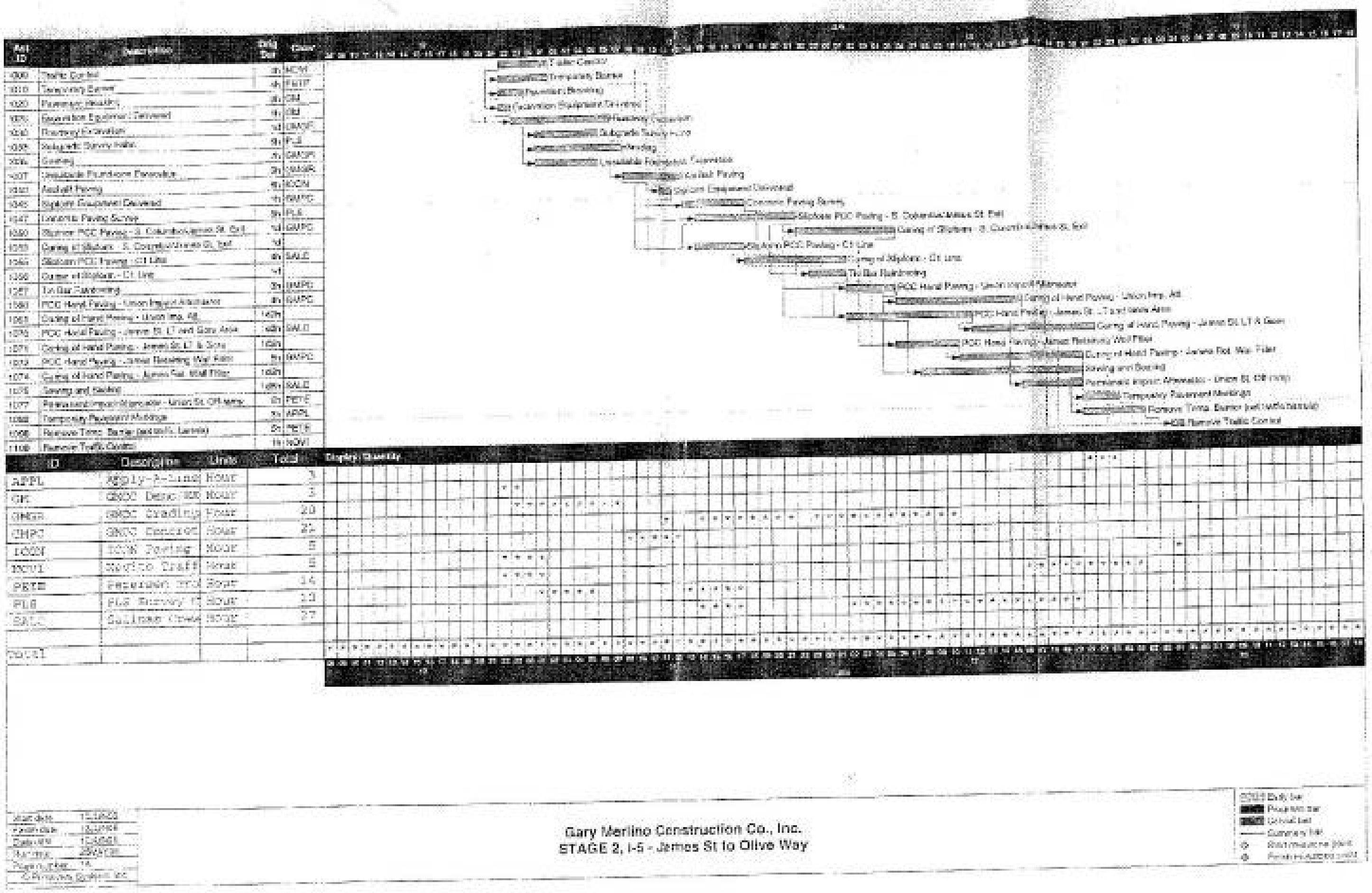
Gary Merlino Construction Co., Inc.
STAGE 1, I-5 - James St to Olive Way

▨	Early bar
■	Progress bar
▨	Critical bar
—	Summary bar
◇	Start milestone point
◇	Finish milestone point



Act ID	Description	Orig Dur	Crew
1000	Traffic Control	3h	NOVI
1010	Temporary Barrier	4h	PETE
1020	Pavement Breaking	3h	GK
1025	Excavation Equipment Delivered	1h	GK
1030	Roadway Excavation	1d	GMGR
1035	Subgrade Survey Hubs	5h	PLS
1036	Grading	2h	GMGR
1037	Unsuitable Foundation Excavation	2h	GMGR
1040	Asphalt Paving	4h	ICON
1045	Slipform Equipment Delivered	1h	GMPC
1047	Concrete Paving Survey	5h	PLS
1050	Slipform PCC Paving - S. Columbia/James St. Exit	1d	GMPC
1055	Curing of Slipform - S. Columbia/James St. Exit	7d	
1060	Slipform PCC Paving - C1 Line	4h	SALC
1065	Curing of Slipform - C1 Line	7d	
1067	Tie Bar Reinforcing	2h	GMPC
1068	PCC Hand Paving - Union Impact Attenuator	4h	GMPC
1069	Curing of Hand Paving - Union Imp. Att.	168h	
1070	PCC Hand Paving - James St. LT and Gore Area	48h	SALC
1071	Curing of Hand Paving - James St. LT & Gore	168h	
1072	PCC Hand Paving - James Retaining Wall Filler	5h	GMPC
1074	Curing of Hand Paving - James Ret. Wall Filler	168h	
1075	Sawing and Sealing	16h	SALC
1077	Permanent Impact Attenuator - Union St. Off ramp	6h	PETE
1080	Temporary Pavement Markings	3h	APPL
1090	Remove Temp. Barrier (add traffic Lanes)	2h	PETE
1100	Remove Traffic Control	1h	NOVI

ID	Description	Units	Total	Display: Quantity
APPL	Apply-A-Line	Hour	3	
GK	GMCC Demo. [illegible]	Hour	3	
GMGR	GMCC Grading	Hour	20	
GMPC	GMCC Concrete	Hour	22	
ICON	ICON Paving	Hour	5	
NOVI	Novico Craft	Hour	5	
PETE	Petersen Bro	Hour	14	
PLS	PLS Survey	Hour	13	
SALC	Salinas Crew	Hour	27	
Total				

Start date [illegible]
Finish date [illegible]
Data date [illegible]
Run date [illegible]
Page number 1A
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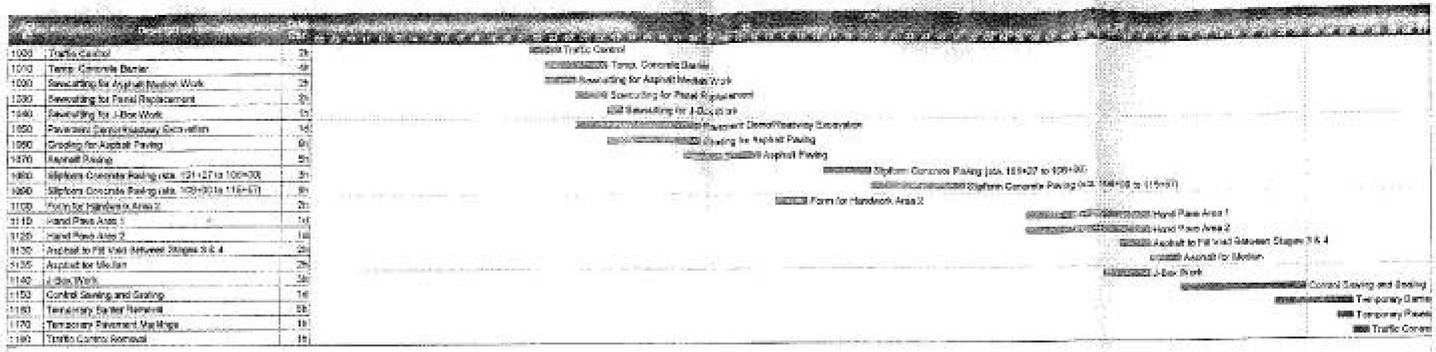
STAGE 2, I-5 - James St to Olive Way

- Early bar
- Progress bar
- Critical bar
- Summary bar
- ◇ Start milestone point
- ◇ Finish milestone point



1000	Traffic Control	2h
1010	Temp. Concrete Barrier	4h
1020	Sawcutting for Asphalt Median Work	2h
1030	Sawcutting for Panel Replacement	2h
1040	Sawcutting for J-Box Work	1h
1050	Pavement Demo/Roadway Excavation	14h
1060	Grading for Asphalt Paving	9h
1070	Asphalt Paving	5h
1080	Slipform Concrete Paving (sta. 101+27 to 106+00)	3h
1090	Slipform Concrete Paving (sta. 106+00 to 115+67)	8h
1100	Form for Handwork Area 2	3h
1110	Hand Pave Area 1	1d
1120	Hand Pave Area 2	1d
1130	Asphalt to Fill Void Between Stages 3 & 4	2h
1135	Asphalt for Median	2h
1140	J-Box Work	3h
1150	Control Sawing and Sealing	1d
1160	Temporary Barrier Removal	5h
1170	Temporary Pavement Markings	1h
1180	Traffic Control Removal	1h

Start date	24JUN05
Finish date	27JUN05
Data date	24JUN05
Run date	22JUN05
Page number	1A

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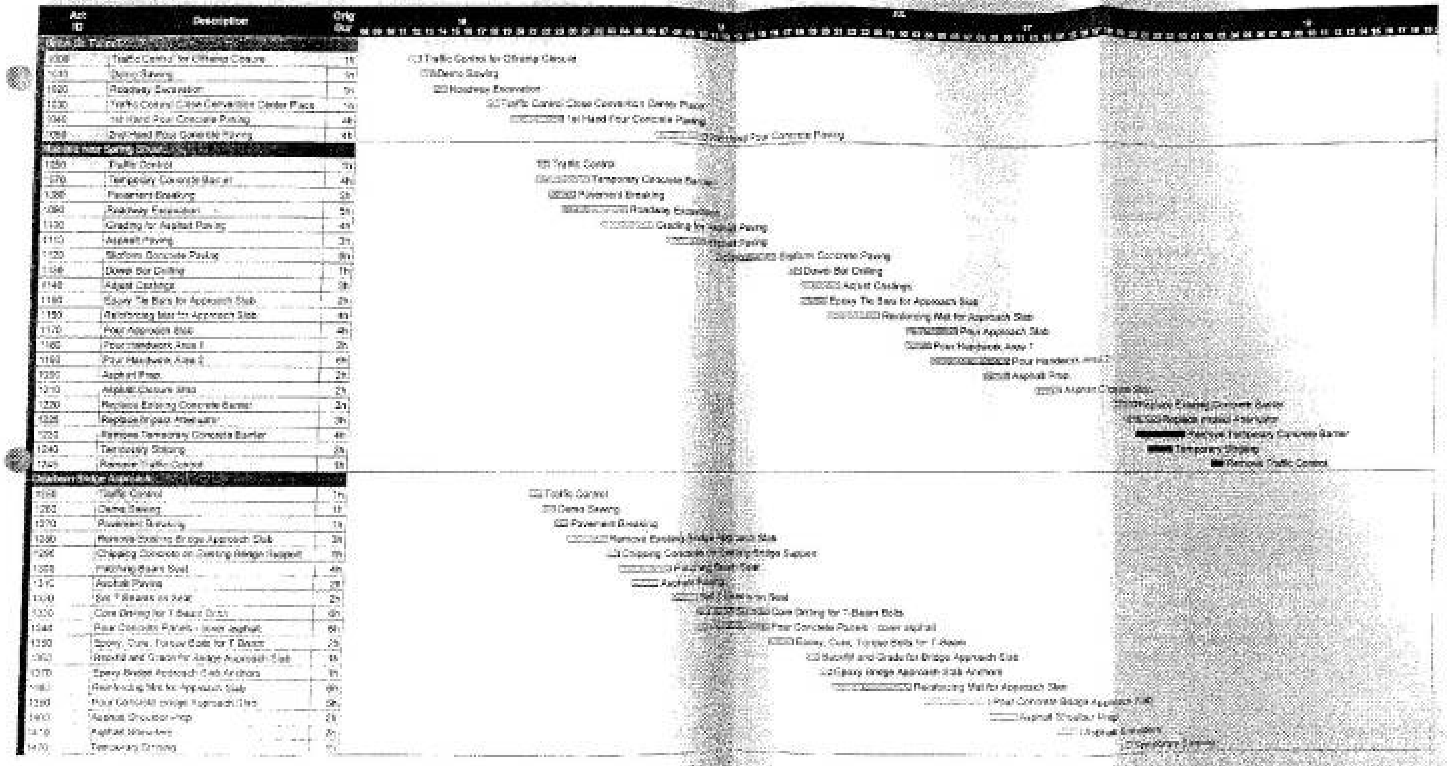
Gary Merlino Construction Co., Inc.
STAGE 3 - 55 hour weekend closure

▨	Early bar
■	Progress bar
▨	Critical bar
—	Summary bar
◆	Start milestone point
◆	Finish milestone point



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STAGE 4 - 55 hour weekend closure

Appendix H: Recorded Inspector Scheduling Information for Construction Stages 1, 2, 3 & 4

STAGE 1: S-UNION ST 120+96 TO 124+70.59
C3 124+70.59 TO 138+45.79

Production rate for S-Union off ramp

Pavement Demo Including Excavation

Date	Start time	Finish date	Finish time	Duration (hr:mm)	Volume (CY)	Rate (cy/hr)	Crews	Labor	Operators	Trucks	Equipment
4/22/2005	12:10	4/22/2005	23:25	11:15	706.3	62.78	2	6	4	8	see lists

Subgrade Preparation

Date	Start time	Finish date	Finish time	Duration (hr:mm)	Area (SY)	Rate (sy/hr)	Crews	Labor	Operators	Trucks	Equipment
4/22/2005	23:25	4/23/2005	5:15	18:10	897	49.38	1	6	4	8	see lists

HMA Paving

Date	Start time	Finish date	Finish time	Duration (hr:mm)	Tons	Rate (ton/hr)	Crews	Labor	Operators	Trucks	Equipment
4/23/2005	5:30	4/23/2005	9:30	4:00	195	48.75	1	6	3	9	see lists

Hand PCCP Paving

Date	Start time	Finish date	Finish time	Duration (hr:mm)	Volume (CY)	Rate (cy/hr)	Crews	Labor	Operators	Trucks	Equipment
4/23/2005	11:00	4/23/2005	18:50	7:50	338	43.15	1	25			see lists

Production rate for C3 line

Install Temporary Barrier

Date	Start time	Finish date	Finish time	Duration (hr:mm)	LF	Rate (lf/hr)	Crews	Labor	Operators	Trucks	Equipment
4/22/2005	22:00	4/23/2005	1:20	3:20	1,400	420.00	2	4	2		see lists

Pavement Demo Including Excavation

Date	Start time	Finish date	Finish time	Duration (hr:mm)	Volume (CY)	Rate (cy/hr)	Crews	Labor	Operators	Trucks	Equipment
4/22/2005	22:30	4/23/2005	18:40	20:10	1,495	74.13	2	7	5	20	see lists

Subgrade Preparation

Date	Start time	Finish date	Finish time	Duration (hr:mm)	Area (SY)	Rate (sy/hr)	Crews	Labor	Operators	Trucks	Equipment
4/23/2005	4:30	4/23/2005	23:25	18:55	3372	178.26	1	4	5		see lists

HMA Paving

Date	Start time	Finish date	Finish time	Duration (hr:mm)	Tons	Rate (ton/hr)	Crews	Labor	Operators	Trucks	Equipment
4/23/2005	11:10	4/23/2005	15:20	4:10	650	156.00	1	6	3		see lists

Hand PCCP Paving

Date	Start time	Finish date	Finish time	Duration (hr:mm)	Volume (CY)	Rate (cy/hr)	Crews	Labor	Operators	Trucks	Equipment
4/24/2005	11:00	4/24/2005	20:30	9:30	372	39.16	1	18			see lists

Slipform PCCP Paving

Date	Start time	Finish date	Finish time	Duration (hr:mm)	Volume (CY)	Rate (cy/hr)	Crews	Labor	Operators	Trucks	Equipment
4/23/2005	23:00	4/24/2005	11:50	12:50	1099.5	85.68	1	9	4	8	see lists

Remove Temporary Barrier

Date	Start time	Finish date	Finish time	Duration (hr:mm)	LF	Rate (lf/hr)	Crews	Labor	Operators	Trucks	Equipment
4/24/2005	21:15	4/25/2005	1:30	4:15	1,400	329.41	2	5	3		see lists

STAGE 2: C1 115+48.55 to C2 124+71.45

Install Temporary Barrier

Date	Start time	Finish date	Finish time	Duration (hr:mm)	LF	Rate (lf/hr)	Crews	Labor	Operators	Trucks	Equipment
6/17/2005	22:38	6/18/2005	3:15	4:37	1,200	259.93	2	7	2	see lists	see lists

Pavement Demo Including Excavation

Date	Start time	Finish date	Finish time	Duration (hr:mm)	Volume (CY)	Rate (cy/hr)	Crews	Labor	Operators	Trucks	Equipment
6/17/2005	23:00	6/18/2005	10:37	11:37	1,801	155.04	3	8	7	see lists	see lists

Subgrade Preparation

Date	Start time	Finish date	Finish time	Duration (hr:mm)	Area (SY)	Rate (sy/hr)	Crews	Labor	Operators	Trucks	Equipment
6/18/2005	2:30	6/18/2005	13:00	10:30	4062	386.86	2	12	4	see lists	see lists

HMA Paving

Date	Start time	Finish date	Finish time	Duration (hr:mm)	Tons	Rate (ton/hr)	Crews	Labor	Operators	Trucks	Equipment
6/18/2005	11:10	6/18/2005	15:22	4:12	700	166.67	1	6	3	see lists	see lists

Hand PCCP Paving

Date	Start time	Finish date	Finish time	Duration (hr:mm)	Volume (CY)	Rate (cy/hr)	Crews	Labor	Operators	Trucks	Equipment
6/19/2005	6:00	6/19/2005	14:00	8:00	360	45.00	1	18		see lists	see lists

Slipform PCCP Paving

Date	Start time	Finish date	Finish time	Duration (hr:mm)	Volume (CY)	Rate (cy/hr)	Crews	Labor	Operators	Trucks	Equipment
6/18/2005	17:55	6/19/2005	2:05	8:10	665	81.43	2	14	2	see lists	see lists

Remove Temporary Barrier

Date	Start time	Finish date	Finish time	Duration (hr:mm)	LF	Rate (lf/hr)	Crews	Labor	Operators	Trucks	Equipment
6/19/2005	22:15	6/20/2005	1:00	2:45	1,200	436.36	2	8	3	see lists	see lists

STAGE 3: C1 101+23.80 to C1 115+48.55

Install Temporary Barrier

Date	Start time	Finish date	Finish time	Duration (hr:mm)	LF	Rate (lf/hr)	Crews	Labor	Operators	Trucks	Equipment
6/24/2005	22:30	6/25/2005	4:00	5:30	1,600	290.91	2	8	2	see lists	see lists

Pavement Demo Including Excavation

Date	Start time	Finish date	Finish time	Duration (hr:mm)	Volume (CY)	Rate (cy/hr)	Crews	Labor	Operators	Trucks	Equipment
6/24/2005	23:00	6/25/2005	7:15	8:15	1,496	181.33	3	6	6	see lists	see lists

Subgrade Preparation

Date	Start time	Finish date	Finish time	Duration (hr:mm)	Area (SY)	Rate (sy/hr)	Crews	Labor	Operators	Trucks	Equipment
6/25/2005	3:15	6/25/2005	10:40	7:25	3375	455.06	2	12	4	see lists	see lists

HMA Paving

Date	Start time	Finish date	Finish time	Duration (hr:mm)	Tons	Rate (ton/hr)	Crews	Labor	Operators	Trucks	Equipment
6/25/2005	10:30	6/25/2005	14:45	4:15	580	136.47	1	6	3	see lists	see lists

Hand PCCP Paving for C1 105+98 TO C1 110+10

Date	Start time	Finish date	Finish time	Duration (hr:mm)	Volume (CY)	Rate (cy/hr)	Crews	Labor	Operators	Trucks	Equipment
6/26/2005	6:45	6/26/2005	12:05	5:20	195	36.56	1	13	4	see lists	see lists

Hand PCCP Paving for shoulder 105+98 to 114+00

Date	Start time	Finish date	Finish time	Duration (hr:mm)	Volume (CY)	Rate (cy/hr)	Crews	Labor	Operators	Trucks	Equipment
6/26/2005	9:05	6/26/2005	14:40	5:35	250	44.78	1	13	2	see lists	see lists

Slipform PCCP Paving for C1 101+27 to 106+00

Date	Start time	Finish date	Finish time	Duration (hr:mm)	Volume (CY)	Rate (cy/hr)	Crews	Labor	Operators	Trucks	Equipment
6/25/2005	15:39	6/25/2005	18:21	2:42	180	66.67	1	14	3	see lists	see lists

Slipform PCCP Paving for C1 106+00 to C1 115+58

Date	Start time	Finish date	Finish time	Duration (hr:mm)	Volume (CY)	Rate (cy/hr)	Crews	Labor	Operators	Trucks	Equipment
6/25/2005	17:30	6/26/2005	2:50	7:20	620	84.55	1	14	3	see lists	see lists

Remove Temporary Barrier

Date	Start time	Finish date	Finish time	Duration (hr:mm)	LF	Rate (lf/hr)	Crews	Labor	Operators	Trucks	Equipment
6/26/2005	21:45	6/27/2005	1:30	3:45	1,600	426.67	2	8	3	see lists	see lists

STAGE 4: SBCD 100+98.8 TO C1 106+25 AND

APPROACH SLAB: SBCD 2158+03.29 TO SBCD 2158+28.29

Install Temporary Barrier

Date	Start time	Finish date	Finish time	Duration (hr:mm)	LF	Rate (lf/hr)	Crews	Labor	Operators	Trucks	Equipment
7/16/2005	23:10	7/17/2005	1:15	2:15	620	275.56	2	8	2	see lists	see lists

Pavement Demo Including Excavation

Date	Start time	Finish date	Finish time	Duration (hr:mm)	Volume (CY)	Rate (cy/hr)	Crews	Labor	Operators	Trucks	Equipment
7/16/2005	23:15	7/17/2005	5:30	5:15	966	184.00	3	6	6	see lists	see lists

Subgrade Preparation

Date	Start time	Finish date	Finish time	Duration (hr:mm)	Area (SY)	Rate (sy/hr)	Crews	Labor	Operators	Trucks	Equipment
7/16/2005	3:00	7/17/2005	9:00	6:00	2179	363.17	2	12	4	see lists	see lists

HMA Paving

Date	Start time	Finish date	Finish time	Duration (hr:mm)	Tons	Rate (ton/hr)	Crews	Labor	Operators	Trucks	Equipment
7/17/2005	9:35	7/17/2005	14:00	4:25	380	86.04	1	6	3	see lists	see lists

Hand PCCP Paving for SBCD 104+05 TO 106+25 (SHOULDER)

Date	Start time	Finish date	Finish time	Duration (hr:mm)	Volume (CY)	Rate (cy/hr)	Crews	Labor	Operators	Trucks	Equipment
7/17/2005	7:15	7/17/2005	12:50	5:35	180	32.24	1	8	3	see lists	see lists

Hand PCCP Paving for shoulder SBCD 101+23.80 to 106+00.00

Date	Start time	Finish date	Finish time	Duration (hr:mm)	Volume (CY)	Rate (cy/hr)	Crews	Labor	Operators	Trucks	Equipment
7/17/2005	6:30	7/17/2005	11:45	5:15	80	15.24	1	7	2	see lists	see lists

Slipform PCCP Paving for C1 101+27 to 106+00

Date	Start time	Finish date	Finish time	Duration (hr:mm)	Volume (CY)	Rate (cy/hr)	Crews	Labor	Operators	Trucks	Equipment
7/16/2005	16:35	7/16/2005	21:20	4:45	502	105.68	1	14	3	see lists	see lists

Remove Temporary Barrier

Date	Start time	Finish date	Finish time	Duration (hr:mm)	LF	Rate (lf/hr)	Crews	Labor	Operators	Trucks	Equipment
7/17/2005	20:00	7/18/2005	0:30	4:30	620	137.78	2	8	3	see lists	see lists

Appendix I: Truck Ticket Data

6/18 4000 psi Slipform

Truck No.	Arrival Time	Time Between Truck Arrivals (hr:min)	Mix ID	Quantity (yd^3)	Truck No.	Arrival Time	Time Between Batch Arrivals (hr:min)	Mix ID	Quantity (yd^3)
13	6:15 PM	-	8049-P	7.5	23	8:29 PM	0:13	8049-P	7.5
23	6:19 PM	0:04	8049-P	7.5	13	8:33 PM	0:04	8049-P	7.5
22	6:28 PM	0:09	8049-P	7.5	22	8:37 PM	0:04	8049-P	7.5
25	6:35 PM	0:07	8049-P	7.5	25	8:39 PM	0:02	8049-P	7.5
201	6:42 PM	0:07	8049-P	7.5	201	8:59 PM	0:20	8049-P	7.5
24	6:58 PM	0:16	8049-P	7.5	24	9:02 PM	0:03	8049-P	7.5
21	7:12 PM	0:14	8049-P	7.5	21	9:07 PM	0:05	8049-P	7.5
19	7:14 PM	0:02	8049-P	7.5	20	9:17 PM	0:10	8049-P	7.5
20	7:19 PM	0:05	8049-P	7.5	19	9:19 PM	0:02	8049-P	7.5
3	7:24 PM	0:05	8049-P	7.5	3	9:24 PM	0:05	8049-P	7.5
202	7:28 PM	0:04	8049-P	7.5	23	9:34 PM	0:10	8049-P	7.5
13	7:34 PM	0:06	8049-P	7.5	13	9:39 PM	0:05	8049-P	7.5
22	7:38 PM	0:04	8049-P	7.5	22	9:43 PM	0:04	8049-P	7.5
45	7:44 PM	0:06	8049-P	7.5	25	9:48 PM	0:05	8049-P	7.5
201	7:48 PM	0:04	8049-P	7.5	201	10:01 PM	0:13	8049-P	7.5
24	7:52 PM	0:04	8049-P	7.5	24	10:03 PM	0:02	8049-P	7.5
19	8:04 PM	0:12	8049-P	7.5	21	10:06 PM	0:03	8049-P	7.5
21	8:09 PM	0:05	8049-P	7.5	20	10:09 PM	0:03	8049-P	7.5
20	8:14 PM	0:05	8049-P	7.5	19	10:24 PM	0:15	8049-P	7.5
3	8:16 PM	0:02	8049-P	7.5					

4/23 4000 psi Slipform Mainline Merlino

Truck No.	Batch Time	Arrival Time	Time Between Truck Arrivals (hr:min)	Quantity (yd^3)	Batch Number	Truck No.	Batch Time	Arrival Time	Time Between Truck Arrivals (hr:min)	Quantity (yd^3)	Batch Number
1	10:26 PM	11:01 PM	-	7.5	2	6	11:40 PM	12:09 AM	0:10	7.5	6
2	10:40 PM	11:14 PM	0:13	7.5	3	7	11:46 PM	12:14 AM	0:05	7.5	7
3	10:54 PM	11:24 PM	0:10	7.5	3	8	11:52 AM	12:24 AM	0:10	7.5	8
4	11:11 PM	11:45 PM	0:21	7.5	4	9	11:57 AM	12:27 AM	0:03	7.5	9
5	11:32 PM	11:59 PM	0:14	7.5	5	10	11:59 AM	12:33 AM	0:06	7.5	10

4/23 4000 psi Slipform Mainline Merlino

Truck No.	Batch Time	Arrival Time	Time Between Truck Arrivals (hr:min)	Quantity (yd^3)	Batch Number	Truck No.	Batch Time	Arrival Time	Time Between Truck Arrivals (hr:min)	Quantity (yd^3)	Batch Number
16	12:15 AM	12:59 AM	-	7.5	17	54	3:15 AM	3:43 AM	0:03	7.5	55
17	12:18 AM	1:02 AM	0:03	7.5	18	55	3:21 AM	3:49 AM	0:06	7.5	56
18	12:21 AM	1:04 AM	0:02	7.5	19	56	3:23 AM	3:54 AM	0:05	7.5	57
19	12:24 AM	1:11 AM	0:07	7.5	20	57	3:29 AM	3:59 AM	0:05	7.5	58
20	12:27 AM	1:07 AM	-0:04	7.5	21	58	3:32 AM	4:03 AM	0:04	7.5	59
21	12:29 AM	12:16 AM	-	7.5	22	59	3:36 AM	4:04 AM	0:01	7.5	60
22	12:32 AM	1:17 AM	1:01	7.5	23	60	3:38 AM	4:09 AM	0:05	7.5	61
23	12:36 AM	1:23 AM	0:06	7.5	24	61	3:41 AM	4:13 AM	0:04	7.5	62
24	12:37 AM	1:29 AM	0:06	7.5	25	62	3:44 AM	4:16 AM	0:03	7.5	63
25	12:39 AM	1:32 AM	0:03	7.5	26	63	3:46 AM	4:18 AM	0:02	7.5	64
26	1:05 AM	1:36 AM	0:04	7.5	27	64	3:49 AM	4:21 AM	0:03	7.5	65
27	1:17 AM	1:42 AM	0:06	7.5	28	65	3:52 AM	4:22 AM	0:01	7.5	66
28	1:24 AM	1:53 AM	0:11	7.5	29	66	3:57 AM	4:31 AM	0:09	7.5	67
29	1:26 AM	1:57 AM	0:04	7.5	30	67	4:04 AM	4:33 AM	0:02	7.5	68
30	1:31 AM	2:00 AM	0:03	7.5	31	68	4:07 AM	4:37 AM	0:04	7.5	69
31	1:36 AM	2:07 AM	0:07	7.5	32	69	4:11 AM	4:41 AM	0:04	7.5	70
32	1:41 AM	2:10 AM	0:03	7.5	33	70	4:13 AM	4:44 AM	0:03	7.5	71
33	1:47 AM	2:16 AM	0:06	7.5	34	71	4:17 AM	4:48 AM	0:04	7.5	72
34	1:53 AM	2:24 AM	0:08	7.5	35	72	4:20 AM	4:52 AM	0:04	7.5	73
35	1:57 AM	2:28 AM	0:04	7.5	36	73	4:22 AM	4:56 AM	0:04	7.5	74
36	2:00 AM	2:32 AM	0:04	7.5	37	74	4:26 AM	4:59 AM	0:03	7.5	75
37	2:02 AM	2:36 AM	0:04	7.5	38	75	4:28 AM	5:03 AM	0:04	7.5	76
38	2:06 AM	2:39 AM	0:03	7.5	39	76	4:31 AM	5:07 AM	0:04	7.5	77
39	2:09 AM	2:42 AM	0:03	7.5	40	77	4:33 AM	5:11 AM	0:04	7.5	78
40	2:12 AM	2:46 AM	0:04	7.5	41	78	4:41 AM	5:13 AM	0:02	7.5	79
41	2:16 AM	2:53 AM	0:07	7.5	42	79	4:44 AM	5:16 AM	0:03	7.5	80
42	2:18 AM	2:56 AM	0:03	7.5	43	80	4:48 AM	5:21 AM	0:05	7.5	81
43	2:21 AM	3:00 AM	0:04	7.5	44	81	4:51 AM	5:23 AM	0:02	7.5	82
44	2:24 AM	3:04 AM	0:04	7.5	45	82	4:55 AM	5:27 AM	0:04	7.5	83
45	2:26 AM	3:09 AM	0:05	7.5	46	83	4:58 AM	5:38 AM	0:11	7.5	84
46	2:41 AM	3:13 AM	0:04	7.5	47	84	5:00 AM	5:33 AM	-0:05	7.5	85
47	2:43 AM	3:17 AM	0:04	7.5	48	85	5:06 AM	5:36 AM	0:03	7.5	86
48	2:49 AM	3:19 AM	0:02	7.5	49	86	5:08 AM	5:43 AM	0:07	7.5	87
49	2:53 AM	3:22 AM	0:03	7.5	50	87	5:12 AM	5:47 AM	0:04	7.5	88
50	2:56 AM	3:25 AM	0:03	7.5	51	88	5:16 AM	5:51 AM	0:04	7.5	89
51	3:00 AM	3:30 AM	0:05	7.5	52	89	5:19 AM	5:59 AM	0:08	7.5	90
52	3:03 AM	3:32 AM	0:02	7.5	53	90	5:22 AM	6:02 AM	0:03	7.5	90
53	3:11 AM	3:40 AM	0:08	7.5	54						

7/16/2005 Group 2 BI #18 SBCD/C1 Line 160-25 to

Truck No.	Batch Time	Arrival Time	Time Between Truck Arrivals (hr:min)	Quantity (yd^3)	Batch Number	Truck No.	Batch Time	Arrival Time	Time Between Truck Arrivals (hr:min)	Quantity (yd^3)	Batch Number
1	4:00 PM	4:35 PM	-	7.5	57	14	4:58 PM	5:23 PM	0:04	7.5	70
2	4:09 PM	4:42 PM	0:07	7.5	58	15	5:02 PM	5:25 PM	0:02	7.5	71
3	4:13 PM	4:45 PM	0:03	7.5	59	16	5:04 PM	5:30 PM	0:05	7.5	72
6	4:25 PM	4:50 PM	0:05	7.5	62	17	5:14 PM	5:42 PM	0:12	7.5	73
4	4:16 PM	4:54 PM	0:09	7.5	60	18	5:16 PM	5:44 PM	0:02	7.5	74
5	4:20 PM	4:58 PM	0:08	7.5	61	19	5:21 PM	5:48 PM	0:04	7.5	75
7	4:28 PM	5:00 PM	0:02	7.5	63	20	5:23 PM	5:50 PM	0:02	7.5	76
8	4:32 PM	5:04 PM	0:04	7.5	64	21	5:25 PM	5:54 PM	0:04	7.5	77
9	4:38 PM	5:08 PM	0:04	7.5	65	22	5:29 PM	5:57 PM	0:03	7.5	79
10	4:42 PM	5:10 PM	0:02	7.5	66	23	5:34 PM	6:02 PM	0:05	7.5	81
11	4:46 PM	5:14 PM	0:04	7.5	67	24	5:38 PM	6:07 PM	0:05	7.5	82
12	4:50 PM	-	-	7.5	68	25	5:41 PM	6:10 PM	0:03	7.5	83
13	4:54 PM	5:19 PM	-	7.5	69						

6/25 4000 psi Slipform

Truck No.	Batch Time	Arrival Time	Time Between Truck Arrivals (hr:min)	Quantity (yd^3)	Batch Number	Truck No.	Batch Time	Arrival Time	Time Between Truck Arrivals (hr:min)	Quantity (yd^3)	Batch Number
2	7:10 PM	7:46 PM	-	7.5	28	41	10:21 PM	10:54 PM	0:06	7.5	67
1	7:07 PM	7:53 PM	0:07	7.5	27	42	10:23 PM	10:55 PM	0:01	7.5	68
3	7:12 PM	7:56 PM	0:03	7.5	29	43	10:27 PM	11:00 PM	0:05	7.5	69
5	7:18 PM	8:01 PM	0:05	7.5	31	45	10:42 PM	11:09 PM	0:09	7.5	70
4	7:15 PM	8:04 PM	0:03	7.5	30	46	10:44 PM	11:14 PM	0:05	7.5	71
6	7:20 PM	8:09 PM	0:05	7.5	32	44	10:40 PM	11:21 PM	0:07	7.5	72
7	7:23 PM	8:12 PM	0:03	7.5	33	47	10:48 PM	11:25 PM	0:04	7.5	73
8	7:25 PM	8:17 PM	0:05	7.5	34	48	10:51 PM	11:31 PM	0:06	7.5	74
9	7:28 PM	8:19 PM	0:02	7.5	35	49	10:53 PM	11:35 PM	0:04	7.5	75
10	7:31 PM	8:24 PM	0:05	7.5	36	50	10:57 PM	11:40 PM	0:05	7.5	76
11	7:33 PM	8:29 PM	0:05	7.5	37	51	11:01 PM	11:44 PM	0:04	7.5	77
12	7:36 PM	8:33 PM	0:04	7.5	38	52	11:04 PM	11:48 PM	0:04	7.5	78
13	7:38 PM	8:38 PM	0:05	7.5	39	53	11:06 PM	11:53 PM	0:05	7.5	79
14	7:40 PM	8:43 PM	0:05	7.5	40	54	11:09 PM	11:57 PM	0:04	7.5	80
15	8:01 PM	8:46 PM	0:03	7.5	41	55	11:12 PM	12:01 AM	0:04	7.5	81
16	8:06 PM	8:51 PM	0:05	7.5	42	56	11:15 PM	12:07 AM	0:06	7.5	82
17	8:09 PM	8:56 PM	0:05	7.5	43	57	11:19 PM	12:11 AM	0:04	7.5	83
18	8:13 PM	9:01 PM	0:05	7.5	44	58	11:21 PM	12:16 AM	0:05	7.5	84
19	8:20 PM	9:04 PM	0:03	7.5	45	59	11:24 PM	12:18 AM	0:02	7.5	85
20	8:23 PM	9:09 PM	0:05	7.5	46	60	11:43 PM	12:24 AM	0:06	7.5	86
21	8:25 PM	9:14 PM	0:05	7.5	47	61	12:05 AM	12:29 AM	0:05	7.5	87
22	8:30 PM	9:16 PM	0:02	7.5	48	62	12:06 AM	12:33 AM	0:04	7.5	88
23	8:35 PM	9:21 PM	0:05	7.5	49	63	12:09 AM	12:41 AM	0:08	7.5	89
24	8:38 PM	9:26 PM	0:05	7.5	50	64	12:12 AM	12:46 AM	0:05	7.5	90
25	8:44 PM	9:29 PM	0:03	7.5	51	65	12:14 AM	12:51 AM	0:05	7.5	91
26	8:47 PM	9:36 PM	0:07	7.5	52	66	12:17 AM	12:56 AM	0:05	7.5	92
27	9:00 PM	9:39 PM	0:03	7.5	53	67	12:20 AM	12:58 AM	0:02	7.5	93
28	9:06 PM	9:42 PM	0:03	7.5	54	68	12:23 AM	1:03 AM	0:05	7.5	94
29	9:17 PM	9:46 PM	0:04	7.5	55	69	12:26 AM	1:08 AM	0:05	7.5	95
30	9:22 PM	9:51 PM	0:05	7.5	56	70	12:29 AM	1:12 AM	0:04	7.5	96
31	9:31 PM	9:58 PM	0:07	7.5	57	71	12:34 AM	1:17 AM	0:05	7.5	97
32	9:39 PM	10:04 PM	0:06	7.5	58	72	12:42 AM	1:22 AM	0:05	7.5	98
33	9:43 PM	10:12 PM	0:08	7.5	59	73	12:49 AM	1:24 AM	0:02	7.5	99
34	9:46 PM	10:15 PM	0:03	7.5	60	74	12:56 AM	1:28 AM	0:04	7.5	100
35	9:53 PM	10:19 PM	0:04	7.5	61	75	12:59 AM	1:32 AM	0:04	7.5	101
36	9:59 PM	10:23 PM	0:04	7.5	62	76	1:13 AM	1:39 AM	0:07	7.5	102
37	10:06 PM	10:31 PM	0:08	7.5	63	77	1:18 AM	1:44 AM	0:05	7.5	103
38	10:10 PM	10:38 PM	0:07	7.5	64	78	-	1:49 AM	0:05	7.5	104
39	10:15 PM	10:44 PM	0:06	7.5	65	79	1:24 AM	1:54 AM	0:05	7.5	105
40	10:18 PM	10:48 PM	0:04	7.5	66	80	1:32 AM	1:56 AM	0:02	7.5	105

6/28/2005 4000 PSI Slipform

Truck No.	Batch Time	Arrival Time	Time Between Truck Arrivals (hr:min)	Quantity (yd^3)	Batch Number	Truck No.	Batch Time	Arrival Time	Time Between Truck Arrivals (hr:min)	Quantity (yd^3)	Batch Number
1	5:17 PM	6:05 PM	-	7.5	1	45	9:31 PM	10:05 PM	0:08	7.5	80
2	5:27 PM	5:50 PM	-0:15	7.5	2	46	9:45 PM	10:13 PM	0:08	7.5	85
3	5:37 PM	6:10 PM	0:20	7.5	3	47	9:48 PM	10:18 PM	0:05	7.5	86
4	5:53 PM	-	-	7.5	4	49	9:50 PM	10:24 PM	0:06	7.5	87
5	5:59 PM	6:31 PM	-	7.5	9	50	9:55 PM	10:26 PM	0:02	7.5	88
6	6:06 PM	6:45 PM	0:14	7.5	11	63	10:45 PM	10:35 PM	0:09	7.5	105
7	6:10 PM	6:48 PM	0:03	7.5	12	64	10:50 PM	10:40 PM	0:05	7.5	106
8	6:14 PM	6:50 PM	0:02	7.5	13	51	10:02 PM	10:40 PM	0:14	7.5	90
9	6:18 PM	6:54 PM	0:04	7.5	14	65	11:03 PM	10:45 PM	0:05	7.5	108
10	6:21 PM	6:57 PM	0:03	7.5	15	13	10:05 PM	10:46 PM	0:06	7.5	91
11	6:23 PM	7:02 PM	0:05	7.5	16	66	11:05 PM	10:48 PM	0:03	7.5	109
12	6:35 PM	7:09 PM	0:07	7.5	19	22	10:08 PM	10:50 PM	0:04	7.5	92
13	6:37 PM	7:15 PM	0:06	7.5	20	51	10:12 PM	10:42 PM	-0:08	7.5	93
14	6:40 PM	7:09 PM	-0:06	7.5	21	52	10:15 PM	10:53 PM	0:11	7.5	94
15	6:48 PM	7:19 PM	0:10	7.5	24	53	10:18 PM	10:56 PM	0:03	7.5	95
16	6:51 PM	-	-	7.5	25	54	10:19 PM	10:58 PM	0:02	7.5	96
17	6:53 PM	7:24 PM	-	7.5	26	55	10:22 PM	11:05 PM	0:07	7.5	97
18	7:03 PM	7:32 PM	0:08	7.5	29	57	10:28 PM	11:04 PM	-0:01	7.5	99
19	7:10 PM	7:38 PM	0:06	7.5	32	56	10:24 PM	11:15 PM	0:11	7.5	98
20	7:12 PM	7:43 PM	0:05	7.5	33	58	10:31 PM	11:18 PM	0:03	7.5	100
21	7:14 PM	7:45 PM	0:02	7.5	34	59	10:33 PM	11:21 PM	0:03	7.5	101
22	7:17 PM	7:47 PM	0:02	7.5	35	60	10:36 PM	-	-	7.5	102
23	7:27 PM	7:53 PM	0:06	7.5	39	61	10:39 PM	11:28 PM	-	7.5	103
24	7:30 PM	7:57 PM	0:04	7.5	40	62	10:42 PM	11:32 PM	0:04	7.5	104
25	7:33 PM	8:04 PM	0:07	7.5	41	67	11:10 PM	11:50 PM	1:02	7.5	110
26	7:36 PM	8:10 PM	0:06	7.5	42	68	11:19 PM	11:53 PM	0:03	7.5	112
27	7:53 PM	8:15 PM	0:05	7.5	47	69	11:23 PM	11:56 PM	0:03	7.5	113
28	7:55 PM	8:20 PM	0:05	7.5	48	71	11:35 PM	12:02 AM	0:06	7.5	116
29	7:58 PM	8:25 PM	0:05	7.5	49	72	11:39 PM	12:08 AM	0:06	7.5	117
30	8:02 PM	8:26 PM	0:01	7.5	50	73	11:43 PM	12:11 AM	0:03	7.5	118
31	8:19 PM	8:43 PM	0:17	7.5	55	74	11:45 PM	12:15 AM	0:04	7.5	119
32	8:22 PM	8:47 PM	0:04	7.5	56	75	11:50 PM	12:22 AM	0:07	7.5	120
33	8:25 PM	8:59 PM	0:12	7.5	57	76	11:53 PM	12:27 AM	0:05	7.5	121
34	8:31 PM	9:05 PM	0:06	7.5	58	77	11:56 PM	12:30 AM	0:03	7.5	122
35	8:43 PM	9:11 PM	0:06	7.5	62	78	12:00 AM	12:35 AM	0:05	7.5	123
36	8:46 PM	-	-	7.5	63	79	12:06 AM	12:38 AM	0:03	7.5	124
37	8:48 PM	9:16 PM	-	7.5	64	80	12:08 AM	12:42 AM	0:04	7.5	125
38	8:53 PM	9:20 PM	0:04	7.5	65	82	12:15 AM	12:45 AM	0:03	7.5	127
39	9:03 PM	9:29 PM	0:09	7.5	69	81	12:11 AM	12:47 AM	0:05	7.5	126
40	9:05 PM	9:32 PM	0:03	7.5	70	83	12:19 AM	12:49 AM	0:04	7.5	128
41	9:08 PM	9:36 PM	0:04	7.5	71	84	12:23 AM	12:51 AM	0:02	7.5	129
42	9:10 PM	9:42 PM	0:06	7.5	75	85	12:25 AM	12:55 AM	0:04	7.5	130
43	9:26 PM	9:55 PM	0:13	7.5	78	86	12:33 AM	1:00 AM	0:05	7.5	131
44	9:28 PM	9:57 PM	0:02	7.5	79						

7/16/2005 Group 2 BI #18 SBCD/C1 Line 160-25 to

Truck No.	Batch Time	Arrival Time	Time Between Truck Arrivals (hr:min)	Quantity (yd^3)	Batch Number	Truck No.	Batch Time	Arrival Time	Time Between Truck Arrivals (hr:min)	Quantity (yd^3)	Batch Number
1	4:00 PM	4:35 PM	-	7.5	57	14	4:58 PM	5:23 PM	0:04	7.5	70
2	4:09 PM	4:42 PM	0:07	7.5	58	15	5:02 PM	5:25 PM	0:02	7.5	71
3	4:13 PM	4:45 PM	0:03	7.5	59	16	5:04 PM	5:30 PM	0:05	7.5	72
6	4:25 PM	4:50 PM	0:05	7.5	62	17	5:14 PM	5:42 PM	0:12	7.5	73
4	4:16 PM	4:54 PM	0:09	7.5	60	18	5:16 PM	5:44 PM	0:02	7.5	74
5	4:20 PM	4:58 PM	0:08	7.5	61	19	5:21 PM	5:48 PM	0:04	7.5	75
7	4:28 PM	5:00 PM	0:02	7.5	63	20	5:23 PM	5:50 PM	0:02	7.5	76
8	4:32 PM	5:04 PM	0:04	7.5	64	21	5:25 PM	5:54 PM	0:04	7.5	77
9	4:38 PM	5:08 PM	0:04	7.5	65	22	5:29 PM	5:57 PM	0:03	7.5	79
10	4:42 PM	5:10 PM	0:02	7.5	66	23	5:34 PM	6:02 PM	0:05	7.5	81
11	4:46 PM	5:14 PM	0:04	7.5	67	24	5:38 PM	6:07 PM	0:05	7.5	82
12	4:50 PM	-	-	7.5	68	25	5:41 PM	6:10 PM	0:03	7.5	83
13	4:54 PM	5:19 PM	-	7.5	69						

7/16/2005 Group 2 BI #18 SBCD/C1 Line

Truck No.	Batch Time	Arrival Time	Time Between Truck Arrivals (hr:min)	Quantity (yd^3)	Batch Number
50	7:17 PM	7:38 PM	-	7.5	114
51	7:19 PM	7:41 PM	0:03	7.5	115
52	7:22 PM	7:44 PM	0:03	7.5	116
53	7:30 PM	7:51 PM	0:07	7.5	118
54	7:33 PM	7:55 PM	0:04	7.5	119
55	7:36 PM	-	-	7.5	119
56	7:38 PM	8:01 PM	-	7.5	121
57	7:41 PM	8:06 PM	0:05	7.5	122
58	7:45 PM	8:11 PM	0:05	7.5	123
59	7:48 PM	8:15 PM	0:04	7.5	124
60	7:51 PM	8:18 PM	0:03	7.5	125
61	7:53 PM	8:21 PM	0:03	7.5	126
62	7:57 PM	8:23 PM	0:02	7.5	127
63	7:59 PM	8:26 PM	0:03	7.5	128
64	8:02 PM	8:32 PM	0:06	7.5	129
65	8:06 PM	8:36 PM	0:04	7.5	130
66	8:10 PM	8:39 PM	0:03	7.5	131
67	8:13 PM	8:41 PM	0:02	7.5	132
68	8:16 PM	8:43 PM	0:02	7.5	133
69	8:20 PM	8:46 PM	0:03	7.5	134
70	8:24 PM	8:48 PM	0:02	7.5	135
71	8:29 PM	8:52 PM	0:04	7.5	136
72	8:33 PM	8:57 PM	0:05	7.5	137

Appendix J: Probabilistic Estimation

Probabilistic estimation is an important feature of CA4PRS that treats the input parameters in the resource and scheduling profiles as variables. In contrast, deterministic estimation treats all of the input parameters as constants, which does not capture the variations frequently seen during construction. In reality, the CA4PRS input parameters used to predict construction productivity will likely vary. Probabilistic estimation provides a more accurate representation of construction because input parameters are modeled with a probability distribution. The probability distribution predicts the likely behavior of an input parameter over a range of potential input parameter values. Probabilistic estimation is the preferred means of CA4PRS analysis because this type of estimation can define and incorporate the uncertainty associated with determining each scheduling or resource input parameter. Probabilistic analysis also yields a more comprehensive estimate than deterministic analysis by providing a range of likely construction productivity, but requires more information about expected variable behavior and the likely variable probability distributions. Included in this documentation is a general description and guide on selecting and using the appropriate distribution functions. The I-5 James to Olive Project is used as a case study for determining and assigning probability distributions.

11.1 Introduction

CA4PRS probabilistic estimation requires users to assign a probability distribution function to the input parameters in the scheduling and resource profiles. Probability distributions are statistical functions that describe the probable behavior of an input parameter. Input parameters assigned a probabilistic function will not have one precise value, but rather a range of possible or potential values. The probability distribution function describes the probability of an input parameter being assigned a particular value in this range of potential values. Probability distributions are commonly described using graphical representation. Figure 44 depicts the behavior of an unknown input parameter over a range of possible values. For this example, a normal distribution is depicted. Normal distributions are defined through two statistical parameters: the mean (μ) and the standard deviation (σ). The mean value is the most likely or probable value in the probability distribution being modeled. The standard deviation describes the width of the distribution and how far values are likely to be from the mean. Standard deviations can be used for assigning the probability of a value for being within a range. For instance, for a normal distribution, 68.2 percent of the area under the curve is within one standard deviation whereas 95.4 percent of the area under the curve is within two standard deviations. Other distributions will have different shapes and descriptive parameters but are used for describing the probability of an input parameter having different values within a specified range.

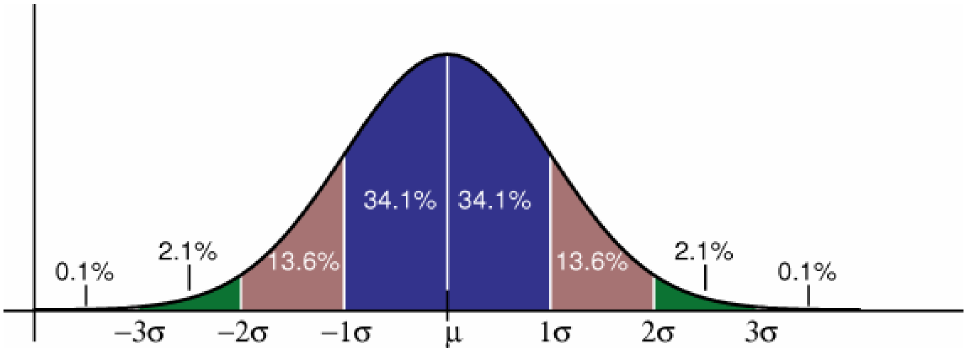


Figure 44 - Typical graphical representation of a productivity distribution (Wikipedia contributors, 2006).

In a probabilistic analysis, CA4PRS combines probability distribution functions with Monte Carlo simulation. Monte Carlo simulations refer to a stochastic problem-solving process that is used for solving complex problems. The process is referred to as stochastic because it is dependent upon the use of random numbers. Modeling construction productivity is suited to Monte Carlo simulation because construction productivity is based upon input parameters that will likely vary within a range of values. A Monte Carlo simulation is composed of multiple iterations. During one simulation iteration, random values are assigned to each input parameter according to their specified probability distribution function. The random input parameters generated during one Monte Carlo simulation iteration are placed into a CA4PRS estimate. This estimate generates a contractor productivity estimate in lane-miles for that specific iteration. By running up to as many as several thousand iterations during a Monte Carlo simulation, CA4PRS produces an overall figure for the most likely production rate in lane-miles given input parameter variability.

11.2 Simulation Settings

Users can change how CA4PRS operates the Monte Carlo simulation and arrives at an estimate by modifying the simulation settings. The simulation settings are found under the Options pull down menu on any CA4PRS probabilistic estimate.

The first operating parameter users can define is the sampling scheme. The sampling scheme can be set to either random results or reproducible results. A Monte Carlo analysis generates a random stream of numbers from which input parameters are produced from their probability distributions. Checking the random results box causes the program to select input parameters from anywhere within the number stream. In contrast, the reproducible results function uses a seed value which tells the simulation where to begin in the random number stream. Because random numbers are still generated but start at a specific point, number generation is considered pseudo random (Lee, 2000).

After setting the sampling scheme, users have the option of setting the number of sampling iterations. A greater number of iterations utilizes a larger number of samples and runs additional construction scenarios. The number of iterations ran for a CA4PRS analysis should be large enough to generate a representative number of productivity estimation results. CA4PRS has a default value of 2000 for number of iterations. The default value of 2000 appears to be sufficiently large enough for representative results. All of the probabilistic simulations performed on the I-5 James to Olive case study converged before the 2000th iteration.

During simulation iterations, CA4PRS will monitor simulation outputs and look for sample convergence. Convergence is determined by examining the statistical parameters such as the standard deviation, mean, 10th , 25th , 75th and 90th percentiles for each output. If the statistical parameters are within the convergence tolerance between monitored simulation iterations, the simulation will stop. Choosing a convergence tolerance simply defines the extent to which the statistical parameters have to vary between trials to continue the simulation. Convergence is only monitored after a specified number of iterations. Checking for convergence requires time and computation, so multiple iterations should be run between convergence checks. The CA4PRS default values for the simulation settings appeared to produce accurate results and not require too much computational effort for generating estimates on the I-5 James to Olive project and should be applied on future estimates. After setting the simulation operation parameters, the scheduling and resource profile inputs are assigned distributions.

11.3 Types of Distribution

The probabilistic behavior of the scheduling and resource input parameters are modeled through the use of an assigned distribution function. Assigning a distribution to an input parameter is dependent upon what information is known about the input parameter being modeled or how confidently a user can predict input parameter behavior. While developing an estimate for a new project, most users will only have an expected mean rate or approximate input parameter value. This information can be paired with a distribution data from documented previous CA4PRS projects, such as the I-10 Pomona and I-15 Devore projects, as well a logical user assumptions about input parameter variability and behavior. If less information is known about an input, it can be easily modeled by using assumptions with triangular, normal and log normal distributions. If additional information such as a maximum and a minimum value are known for an input, users can begin applying truncated normal, truncated log normal and beta distributions. The geometric and uniform distributions do not appear to have as much relevance for modeling input behavior as the previously mentioned distributions. The following information provides a brief description about each of the available distributions in CA4PRS. These descriptions contain provide recommendations for when and how to apply the distributions and what type of inputs are commonly modeled by each distribution.

11.3.1 Deterministic Distribution

Within the probabilistic functions, users can select the option of modeling input parameters as deterministic. During the development of an estimate, some input parameters for a project may not vary and are best held as constants. For instance, number of batch plants may not vary and would best be represented deterministically.

11.3.2 Uniform Distribution

A uniform distribution (Figure 45) defines a discrete set of values that are all equally probable. In CA4PRS this distribution is utilized by specifying a minimum and maximum value for any input. During the iterative simulation process, CA4PRS will assign equal probability to the input values being equal to or between the established limits. For instance, if demolition truck arrival rates were assigned a uniform distribution with a maximum of five and a minimum or three, the potential for three, four or five demolition trucks arriving per hour will have equal probability. This type of distribution would be of limited use for most to the existing CA4PRS inputs.

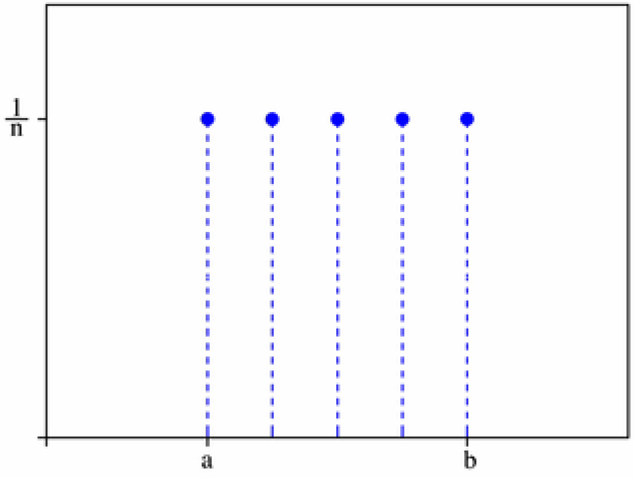


Figure 45 – A uniform distribution (Wikipedia contributors, 2006)

11.3.3 Normal Distribution

Normal distributions are one of the most frequently used forms of distribution and are commonly known as bell curves (Weisstein, 2004). A normal distribution is a distribution that is symmetric about the mean. The distribution of values around the mean is described by the standard deviation of the sample data being represented. Assigning a normal distribution to any of the CA4PRS inputs requires input of both the mean and the standard deviation for the input being modeled. Normal distributions typically arise where a large number of small effects act additively or independently upon a variable (Wikipedia contributors, 2006).

For a CA4PRS probabilistic estimate, team efficiency in the demolition window is one factor that could potentially be represented as a normal distribution. Demolition is influenced by a variety of factors including truck arrival rates, operator and laborer breaks, pavement quality, operating room, weather and even time of day. Team efficiency will have an operating mean, but will likely vary symmetrically around the mean as the factors that impact efficiency vary. In using this type of distribution, users are required to identify an appropriate standard deviation that will describe how the team efficiency will vary. If team efficiency is predicted to be fairly consistent, then a smaller standard deviation should be used. At greater levels of uncertainty, the standard deviation should be increased for CA4PRS input parameters. A recommended starting point for unknown data is to assume the value of the standard deviation will be 10-20 percent of the expected input parameter mean.

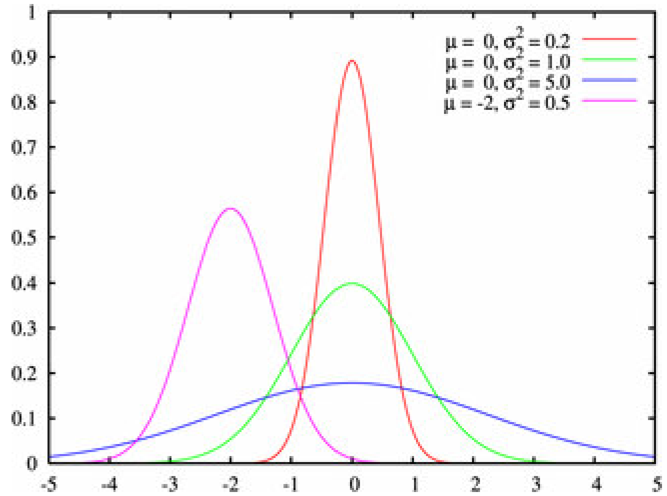


Figure 46 - Normal distribution (Wikipedia contributors, 2006)

11.3.4 Log Normal Distribution

A log-normal probability distribution is the probability distribution of a variable whose logarithm is normally distributed. Lognormal distributions arise when a random input parameter is multiplicatively influenced by a small number of independent variables (Wikipedia contributors, 2006). With this type of distribution the value of the input parameter changes logarithmically in relation to the probability function. Demolition truck loading times and the arrival rate of material trucks are activities that can be represented by this type of distribution. On the I-10 project in California, analysis of demolition truck loading and end dump truck arrival both produced distributions that were interpreted to be log normal distributions (Lee et al., 2001).

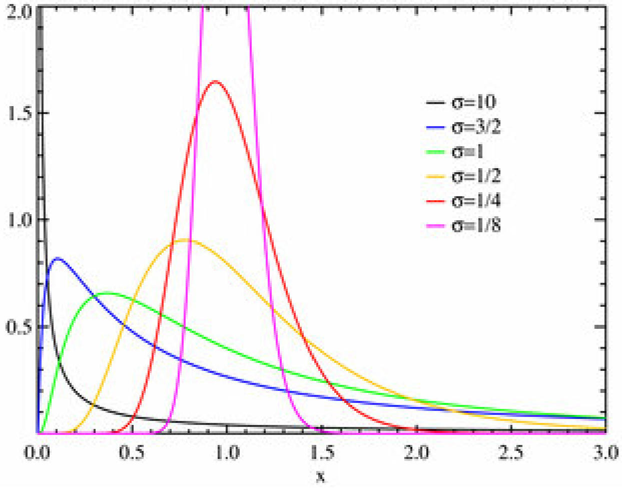


Figure 47 - Log normal distribution (Wikipedia contributors, 2006)

11.3.5 Triangular Distribution

A triangular distribution is a continuous probability distribution that can be used when relatively little information exists about the behavior of an input parameter (Wikipedia contributors, 2006). To use this type of distribution, only the maximum and minimum values for a range of potential input parameters values need to be known or approximated. This type of distribution can be used with almost any construction input as long as the user has a reasonable estimate for maximum and minimum input parameter values.

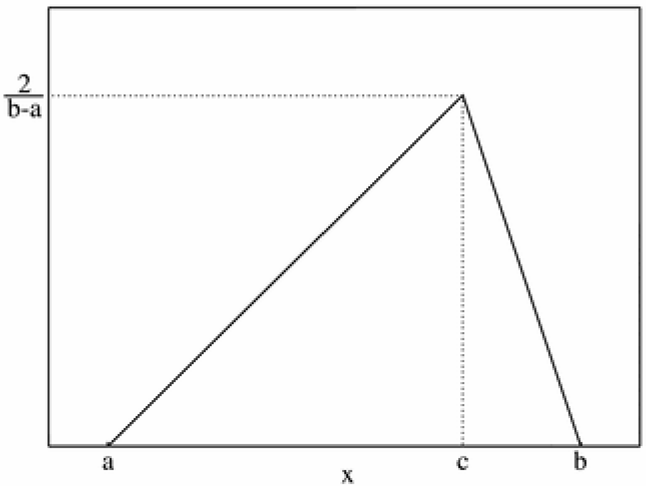


Figure 48 - Triangular distribution (Wikipedia contributors, 2006)

11.3.6 Beta Distribution

Beta distributions are most commonly used to describe intervals defined by the maximum and minimum value of a variable. Beta distributions can be used to describe the relationship between two variables, commonly referred to as the α variable and β variable. Modeling this type of distribution in CA4PRS requires inputting values for both α and β. Because of its complexity and potential for different shapes, the beta distribution in CA4PRS should only be used where necessary and if the more commonly used normal, lognormal and triangular distributions do not apply.

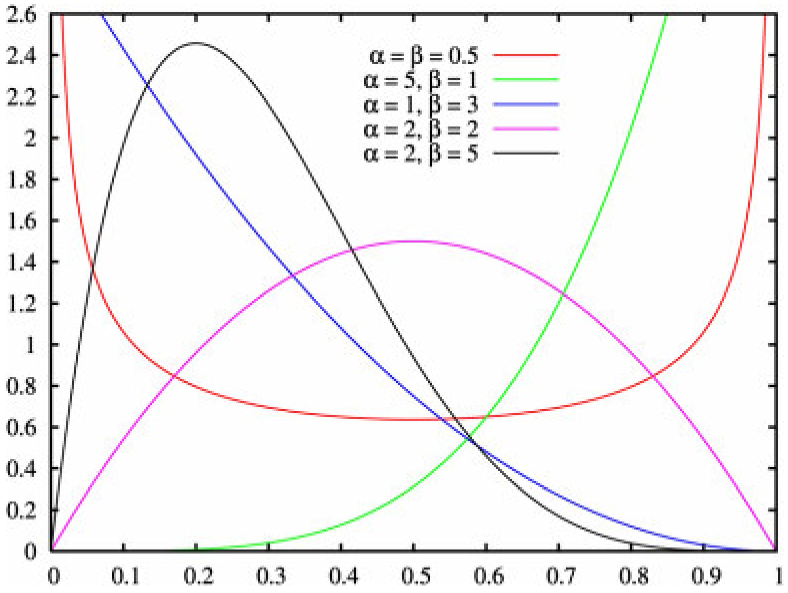


Figure 49 - Beta distribution (Wikipedia contributors, 2006)

11.3.7 Geometric Distribution

A geometric distribution refers to a unique type of distribution that is modeled with the statistical equation:

$$P(X=n) = (1-p)^{n-1}p$$

This equation describes the probability of achieving a success or outcome "*p*", for a statistical event on the nth attempt. The probability of a failure on the first try would be 1-*p*. The probability of a failure on n-1 trials would be $(1-p)^{n-1}$. Accordingly, the probability of a success on the nth attempt would be *p*, leading to the distribution described by the previously depicted equation. This distribution is commonly described through a coin flip analogy. The probability of flipping heads on any trial is ½, so $p = 0.5$. A success P will be defined as flipping the coin with the head up. The probability of a success P on the first trial is 0.5. The probability of seeing a success on the second trial is:

$$P = (1-0.5)^{(2-1)} \times 0.5.$$

The probability of a success on the third trial would be:

$$P= (1-0.5)^{(3-1)} \times 0.5.$$

The probability for achieving a success on trials one through six are displayed in Table 61. Input parameters that display this type of behavior can be graphically modeled with the distribution shape shown in Figure 50. None of the CA4PRS input parameters will likely be modeled by this type of distribution.

Table 61 - Geometric Distribution Probability Distribution For A Coin Toss

n*th* Trial	Probability of a Success on nth trial
1	0.5
2	0.25
3	0.125
4	0.0625
5	0.0313
6	0.0156

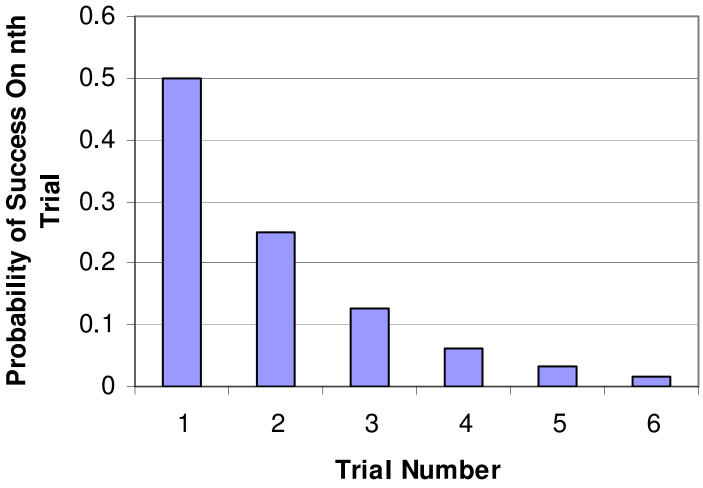


Figure 50 - Graphical representation of a geometric distribution.

11.3.8 Truncated Normal Distribution

A truncated normal distribution is very similar to a normal distribution, but is confined between an upper and a lower limit. To use this type of distribution CA4PRS requires inputting the mean, standard deviation, maximum and minimum values for an input parameter. This type of distribution could be used to describe an input parameter such as truck arrival rates when a minimum or maximum number of truck arrivals is known, or for input parameters that are based on a percentage and should not be assigned values greater than 100 percent or less than 0.

11.3.9 Truncated Log Normal Distribution

A truncated log normal distributions is very similar to a log normal distribution, but is confined between an upper and a lower limit. The value of a variable will change logarithmically according to the probability function, but input parameter values will be confined to an upper and lower limit.

11.4 Interpreting the CA4PRS Output Reports

A CA4PRS probabilistic productivity estimate report provides valuable information in the form of a distribution for maximum productivity and an input sensitivity chart. The following analysis provides users with information about how to interpret the CA4PRS reports of a probabilistic analysis.

11.4.1 Maximum Productivity Distribution Chart and Confidence Intervals

During a Monte Carlo simulation, CA4PRS records the maximum possible productivity in lane-miles for all simulation iterations. CA4PRS uses the stored productivity calculations to produce a histogram which shows the relative frequency of achievable productivity. Figure 51 shows a typical productivity distribution plot from a generic CA4PRS probabilistic estimate. The productivity results are divided into bins, which are groups of analysis results which have similar estimates for the maximum attainable productivity. For the estimate shown in Figure 51, the bins distinguish productivity estimates based upon five-hundredths of a mile. With this distribution CA4PRS provides a mean, or expected productivity, as well as a confidence interval. A confidence interval is a statistical tool that assigns a probability of finding an input parameter within a range of likely values. A confidence can be assigned to any interval, but CA4PRS uses a confidence interval of 87 percent. With the given CA4PRS probabilistic productivity distribution, users can infer that 87 percent of the probabilistic construction scenarios will have a productivity that falls within the established range.

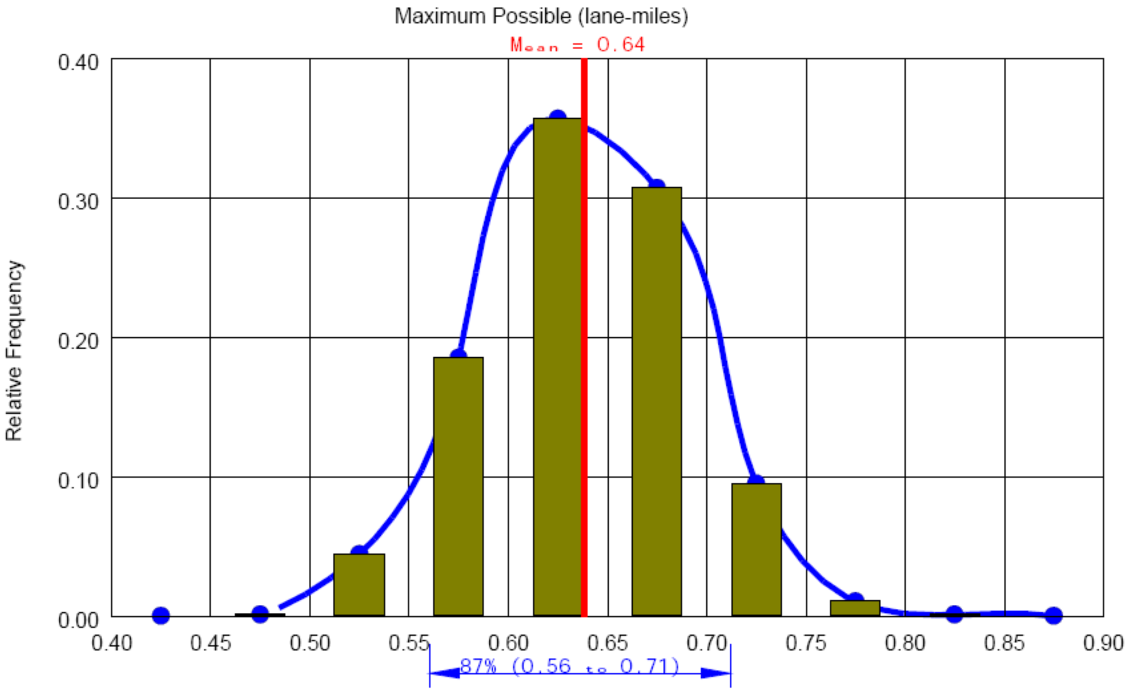


Figure 51 - A typical productivity distribution output chart from a probabilistic CA4PRS estimate.

11.4.2 The Tornado Chart and the Spearman Coefficient

Correlation coefficients are used to describe the relationship between two variables. In CA4PRS one of the variables is construction productivity, while the other variable is one of the resource or scheduling input parameters. The Spearman coefficient does not assume a linear relationship between two variables and is often used with ordinal data, such as ranks, to measure the degree of association between two variables (Weisstein, 2006). Because it uses ranks, the Spearman correlation coefficient is a type of correlation coefficient that is commonly used where it is not convenient or possible to assign actual values to the variables being modeled (Easton and McColl, 2006). If the relationship between two variables is positive, then the correlation coefficient will be positive. The larger the coefficient is, the stronger the positive relationship between the variables. Negative relationships are indicated by a negative correlation coefficient. Larger negative coefficients indicate stronger negative relationships (Easton and McColl, 2006).

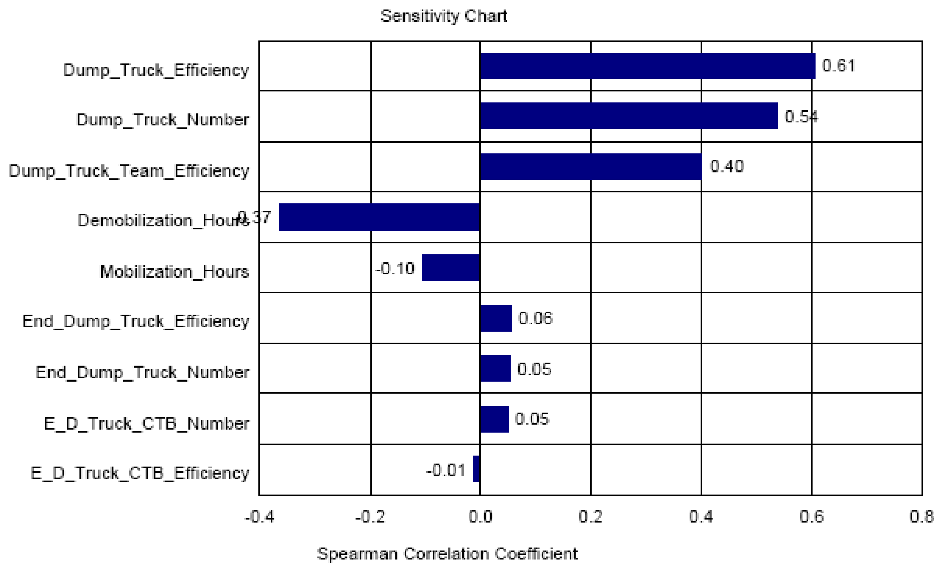


Figure 52 -A typical productivity and input parameter sensitivity output chart from a probabilistic CA4PRS estimate.

11.5 CA4PRS Probabilistic Estimation: Assigning Distributions for Scheduling and Resource Input Parameters Using the I-5 James to Olive Case Study

The estimates completed for the I-5 James to Olive case study use information from truck tickets, preliminary construction schedules, inspector reports and user assumptions to determine and assign probabilistic functions to the scheduling and resource input parameters. The preliminary construction schedules and inspector reports are contained in Appendices G and H, respectively. These reports can be used to ascertain the distribution and variability of activity lag times, mobilization and demobilization times for construction stages 1, 2, 3 and 4. Distributions for HMA and PCC truck arrival rates and packing efficiency have been determined from the truck ticket data depicted in Appendix I from the following stages:

<u>Slipform PCC Truck Tickets</u>

- Stage 1 4/23/05: 85 truck tickets
- Stage 2 6/18/05: 39 truck tickets
- Stage 3 6/25/05: 80 truck tickets
- Stage 3 6/28/05: 87 truck tickets

- Stage 4 7/16/05: 48 truck tickets

HMA Base Trucks

- Stage 1 4/23/05: 6 truck tickets
- Stage 2 6/18/05: 19 truck tickets
- Stage 3 6/25/05: 45 truck tickets
- Stage 4 7/16/05: 56 truck tickets

The following analysis from this data describes which distributions should be used to represent each input parameter, what distribution parameters such as a standard deviations, maximums and minimums should applied to the distribution.

11.5.1 Scheduling Profile Input Parameter Distributions

Probabilistic distributions can be assigned to the input parameters for a CA4PRS estimate in the scheduling window based upon the information that is available to program users at the time of estimation. Distribution information can be obtained from existing documentation such as this report, as well as several of the referenced papers about improvement projects completed in California (Ibbs and Lee, 2001). In addition to prior documentation, new users can assign probabilistic distributions and distribution parameters using logical assumptions. The following discussion describes the resources and methods used to assign the probabilistic distributions and distribution parameters for the four completed CA4PRS analyses.

11.5.1.1 1st and 2nd Analysis: Scheduling Input Parameter Distributions for the Design Report and the First Estimate Refinement

Both of the estimates produced for the first two CA4PRS analyses use scheduling input parameters that have been taken from the I-15 Ontario weekend closure CA4PRS database project. In the CA4PRS database for this project, there is no documentation that outlines or describes the probabilistic distributions that were used on this project. In developing these two estimates, probabilistic distributions and distribution parameters were assigned using user assumptions. Due to the uncertainty associated with assigning probability distributions, the scheduling input parameters were modeled with triangular distributions. For the I-5 James to Olive project, the I-15 Ontario parameter inputs were treated as the mean or most likely values within the triangular distributions. Maximum and minimum values were set by increasing or decreasing the mean by a factor of 20 percent. The modification factor of 20 percent was selected to establish a factor that would provide a range of possible values over which the input parameter values could vary.

11.5.1.2 3rd Analysis: Scheduling Input Parameter Distributions for the Second Estimate Refinement

For the third CA4PRS analysis completed for the I-5 James to Olive case study, scheduling input parameter distributions have been based upon four preliminary contractor Primavera schedules. These Primavera reports were submitted by the contractor to WSDOT prior to the start of construction. The combined preliminary schedules provide only four values for determining appropriate scheduling input parameter distributions. A sample size of four does not provide enough information to confidently determine the distribution or distribution parameters that would be accurate and representative of input parameter behavior. In order to develop a more comprehensive and representative distribution, the number of available input parameter values should be greater. Because of the uncertainty associated with input parameter behavior, triangular distributions have been applied. The mean or most likely value for each input parameter has been determined by averaging the four input parameter values obtained from each Primavera schedule. The distribution maximum and minimum values have been set based upon the maximum and minimum input parameter values contained within the Primavera schedules. These values were then increased or decreased by a factor of 20 percent in order to achieve the distribution maximum and minimum. This factor has been applied due to the smaller sample size of four values. In this smaller sample, the potential maximum and minimum values are not likely to be represented.

The 20 percent factor was arbitrarily used in order to provide a greater range of potential input parameter values.

11.5.1.3 4th Analysis: Scheduling Input Parameter Distributions for the Estimate Based on Observed Construction Productivity

For the fourth analysis based on construction records, the scheduling input parameter distributions have been based upon inspector reports from the four construction stages. Due to changing construction conditions and the availability of only four values for each input parameter, a high degree of uncertainty exists for applying representative scheduling input parameter. Consequently, the scheduling input parameters were assigned triangular distributions. As mentioned in section 11.3.5, triangular distributions can be applied in situations where minimal information is known about an input parameter. Maximum and minimum values have been set based upon the maximum and minimum input parameter values observed in inspector reports.

11.5.2 Resource Profile Input Parameter Distributions

Probabilistic distributions will be assigned to the resource profile inputs based upon the amount of information that is available to users at the time the estimate is developed. Users developing estimates for new projects will have two main options for assigning distributions: past project distribution documentation and user assumptions. The following sections describe the assumptions and documentation used for developing the input parameter distributions used for the four estimation analyses completed on the I-5 James to Olive case study.

11.5.2.1 1st and 2nd Analysis: Resource Input Parameter Distributions for the Design Report and the First Estimate Refinement

At the design report or early 30 percent submittal estimation levels, little or no data will likely exist about the expected distribution or behavior for resource inputs. Assigning specific distributions requires significant knowledge of a project and the factors that will impact productivity and productivity variability. Without detailed distribution information, program users will have to assume a probability distribution function. For generating estimates at lower levels of planning, normal distributions and triangular distributions are recommended. Normal distributions are one of the most common distribution types and random variables are frequently assumed to be normally distributed (Weisstein, 2004). During early estimate development for the I-10 project in Pomona, researchers assumed the resource input profiles were normally distributed (Lee et al., 2001). Although common, using a normal distribution requires some approximation for the standard deviation of each input. Due to the uncertainty of assigning an accurate standard deviation for each input, the first two estimates developed for the I-5 James to Olive case study used triangular distributions rather than normal distributions. Assigning triangular distributions to input parameters in CA4PRS requires establishing a mean, maximum and minimum value. For the I-5 James to Olive case study, the mean, or most likely, values for triangular distributions were set to the resource input parameter values used on the I-15 Ontario weekend closure database project. The maximum and minimum values for the triangular distribution were arbitrarily set at 20 percent greater or less than the used inputs. For instance, demolition truck arrival rate is assumed to be ten trucks per hour. Applying a 20 percent factor to this expected mean created a range of probable arrival rates with a minimum of eight trucks per hour and a maximum of twelve trucks per hour. Setting the maximum and minimum values at 20 percent of the observed input appeared to provide a reasonable range that would allow input variation within probable limits.

11.5.2.2 3rd Analysis: Resource Input Parameter Distributions for the Second Estimate Refinement

The third CA4PRS estimate uses project specific resource input parameters that have been obtained from a collection of early productivity rates estimated by WSDOT construction personnel. Early estimation efforts by WSDOT used the productivity assumptions depicted in Appendix C. These productivity rates can be modeled within CA4PRS by developing resource input parameters as outlined in section 4.2.4.2. The scheduling input parameters have been assigned probability distributions based upon the I-10 Pomona project documentation and user assumptions (Lee et al., 2002). I-10 documentation has been used to develop distributions for:

- Demolition truck arrival rates
- Demolition truck team efficiency
- PCC delivery truck arrival rates

User assumptions have been applied to the following input parameters:

- Demolition packing efficiency
- Base truck arrival rates
- PCC paver speed

The resource input parameters not listed either cannot be assigned a distribution, or have been assigned deterministic distributions.

11.5.2.2.1 Demolition Truck Arrival Rates

The distribution of demolition truck arrivals is based on the research results from the I-10 project in Pomona, California. During construction for the I-10 project, researchers found that an average of nine demolition trucks arrived to the job site per hour (Lee et al., 2001). Truck arrival rates are approximately symmetric around the mean and depict a normal distribution with a standard deviation of 2.3 trucks per hour (Figure 53). Demolition truck arrival rates for the second refinement to the I-5 James to Olive case study have been assigned a normal distribution. For the I-10 project, the standard deviation of 2.3 trucks per hour is approximately 25 percent of the mean value. The estimate generated for this case study uses a truck arrival rate of six demolition trucks per hour. The truck arrival rate will have a corresponding deviation of 25 percent of the mean value, which is equivalent to 1.5 trucks per hour.

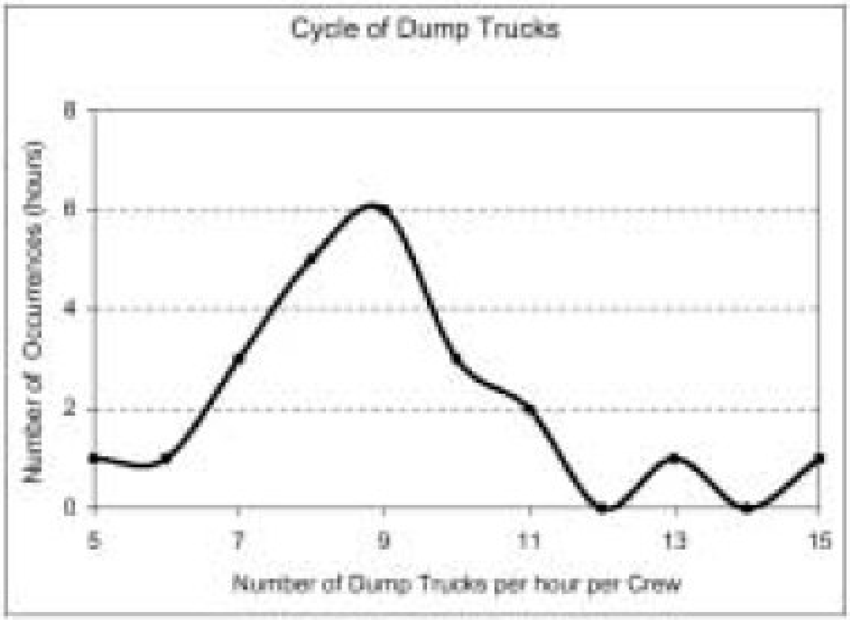


Figure 53 –The distribution associated with demolition truck arrivals for the I-10 Pomona project (Lee et al., 2001).

11.5.2.2.2 Demolition Truck Team Efficiency

On the I-10 Pomona project, researchers calculated team efficiency based upon the rate at which demolition trucks were loaded. Researchers found that the average loading time of a demolition truck to be 5.5 minutes, or correspondingly, 10.9 trucks per hour. In contrast, the average number of trucks loaded per hour was found to be nine. Dividing the average arrival rate by the potential maximum arrival rate resulted in a demolition team efficiency of 82 percent (Lee et al., 2001).

$$82\%\,Team\,Efficiency = \frac{9\frac{trucks}{hr}}{11\frac{trucks}{hr}}$$

Where:

9 = Average number of demolition trucks loaded per hour

11 = Maximum number of demolition trucks loaded in one hour

Documentation of the I-10 Pomona project shows how team efficiency was calculated, but does not provide information about team efficiency distribution or distribution factors. On the I-5 James to Olive case study, team efficiency was thought to be influenced by a variety of factors and vary symmetrically around a mean productivity. Due to this anticipated symmetric distribution, team efficiency was assumed to be distributed normally. Mean team efficiency was found to be 92 percent, as calculated in section 4.2.4.3.1. The normal distribution for this analysis was arbitrarily given a standard deviation of 8 percent in order to limit team efficiency to 100 percent.

11.5.2.2.3 PCC Delivery Truck Arrival Rate

I-10 project documentation depicts PCC delivery trucks having a normal arrival distribution with a mean arrival rate of ten trucks per hour and a standard deviation of 2.1 trucks per hour (Lee et al., 2001). The recorded standard deviation has a value 21 percent of the mean value. The second refinement for the I-5 James to Olive case study uses a PCC truck arrival rate of 12.5 trucks per hour. For a probabilistic analysis, PCC truck arrivals are assigned a normal distribution with a standard deviation 21 percent of the mean value, or 2.6 trucks per hour.

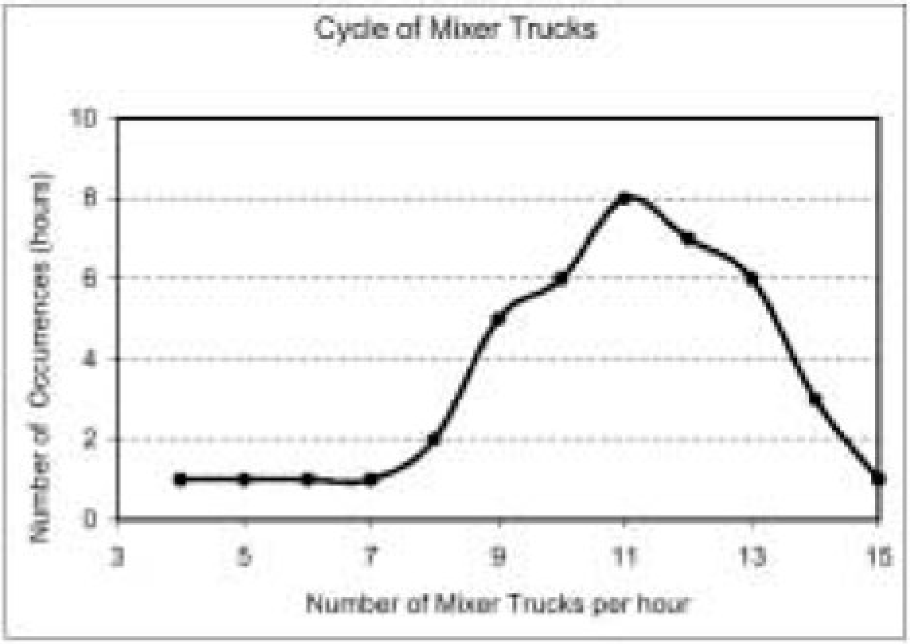


Figure 54 - Distribution of PCC mix truck arrival rates per hour (Lee et al., 2001).

11.5.2.2.4 Demolition Packing Efficiency and Base Truck Arrival Rates

Triangular distributions have been applied to both the demolition packing efficiency and base truck arrival rates based on user assumption. No prior documentation exists that describes the distribution and distribution parameters for these two input parameters. Due to the uncertainty of the exact distribution and distribution parameters, triangular distributions have been applied. The mean, or most likely, values for the triangular distributions are the same scheduling input parameters used in the deterministic estimate. Maximum and minimum values of the input parameter have been set at 20 percent greater than and less than the most likely values. Again, a factor of 20 percent was arbitrarily used in order to establish a range for input parameter variation.

11.5.2.2.5 PCC Paver Speed

For the purposes of this estimate, the paver speed has been set to a rate of 2.67 ft/min in order to accommodate different hand and machine paving productivities. For users developing future estimates on projects that contain hand and machine paving, PCC paver speed should be represented by a deterministic rate or a probabilistic distribution with a small standard deviation. Paving machines produces the best ride and pavement quality in terms of a roughness index when they maintain a consistent speed (B. Dotson, personal interview, April 22, 2006). In effort to deliver a high quality project, most contractors will try to maintain a constant paver speed. No information is available about the distribution of paver speeds, so a triangular distribution with a maximum and minimum 10 percent above and below the mean expected rate have been used for this analysis.

11.5.2.3 4th Analysis: Resource Input Parameter Distributions for the Estimate Based on Observed Construction Productivity

The distributions applied to the resource input parameters for the fourth analysis have been based upon observed construction productivity and truck ticket information. The scheduling resource input parameters can be grouped into five categories:

- Demolition trucks
- HMA base paving
- PCC paving
- PCC batch plant
- PCC Paver

11.5.2.3.1 Demolition Trucks

No truck ticket information is provided for demolition packing efficiency or truck arrival rates. The distributions and distribution parameters for these input parameters have been derived similar to the methods used in the previous analysis.

11.5.2.3.1.1 Packing Efficiency

For the I-5 James to Olive project, packing efficiency has been set to 50 percent in accordance with a standard packing efficiency figure used by a local concrete recycling facility (Gretchen, personal interview, July 29, 2006). No prior documentation exists that describes the distribution and distribution parameters for packing efficiency. The distribution is assumed to be triangular and is assigned distribution parameters similar to the methods described in section 11.5.2.2.4.

11.5.2.3.1.2 Truck Arrival Rates

No truck ticket data has been obtained for deriving the observed demolition truck arrival rate distribution. Demolition truck arrival rates will be assigned a normal distribution and distribution parameters according to section 11.5.2.2.1.

11.5.2.3.2 Demolition Team Efficiency

For the purposes of this estimate, team efficiency has been assigned a normal distribution and distribution parameters according to section 11.5.2.2.2. As described in section 4.2.5.3.1, the derivation of team efficiency is based upon achieving a demolition productivity rate and not the actual team efficiency.

11.5.2.3.3 HMA Base Delivery Trucks

For paving activities, multiple HMA delivery trucks entered and left the I-5 James to Olive jobsite per construction closure. Information about each truck trip is depicted Appendix I and has been used to identify the distributions associated with:

- HMA base truck packing efficiency
- HMA base truck arrivals

11.5.2.3.3.1 HMA Base Truck Packing Efficiency

The HMA truck ticket receipts from the I-5 James to Olive Project contain HMA truck load information that is widely distributed. The tonnage of HMA hauled per truck load varies between fifteen to thirty-four tons. The distribution of load size using 66 truck tickets data from construction stages 1 and 4 have been used to produce Figure 55. This distribution of data points shows that the contractor utilized three different types of trucks to haul HMA loads. The three different truck sizes can be approximated by 15 ton, 27 ton and 33 ton loads. This distribution shows that a contractor used the equipment that was available and not necessarily one type of truck. In order to use the largest data sample, distribution analysis will use truck ticket information from the trucks that hauled loads of 31.9 tons or more of HMA.

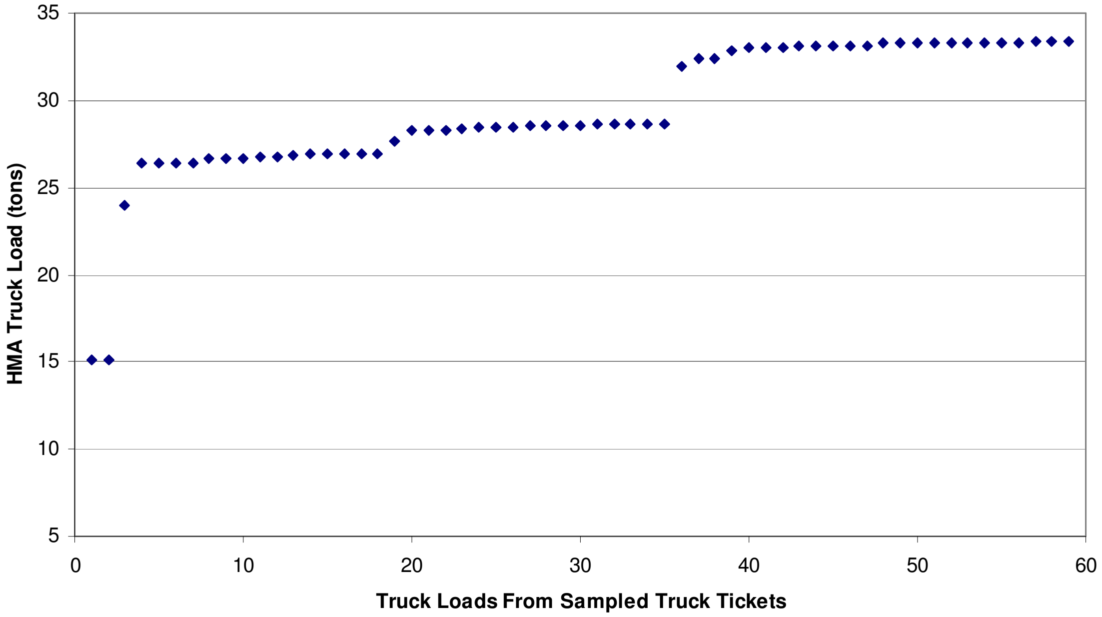


Figure 55- The HMA load size distribution taken from truck tickets.

Twenty-four truck tickets for the HMA trucks that carried between 31.9 tons and 33.4 tons of HMA have been used to produce Figure 56. There is no obvious distribution for load size and the differences in load size appear negligible. The difference between the average load and the maximum load is 0.2 tons. For HMA trucks carrying 31.9 to 33.5 tons of HMA, truck load sizes are consistent and by correlation, packing efficiencies should also be consistent. The tight clustering of HMA loads can be explained by the fact that trucks are probably loaded close to the legal axle weight limit permissible on Washington State roads. For the purposes of this productivity estimate, the distribution information has been used to assume that trucks are loaded to their maximum capacity for each trip. Because of the minimal variation, HMA packing efficiency is assigned a deterministic distribution with a mean value of 100 percent.

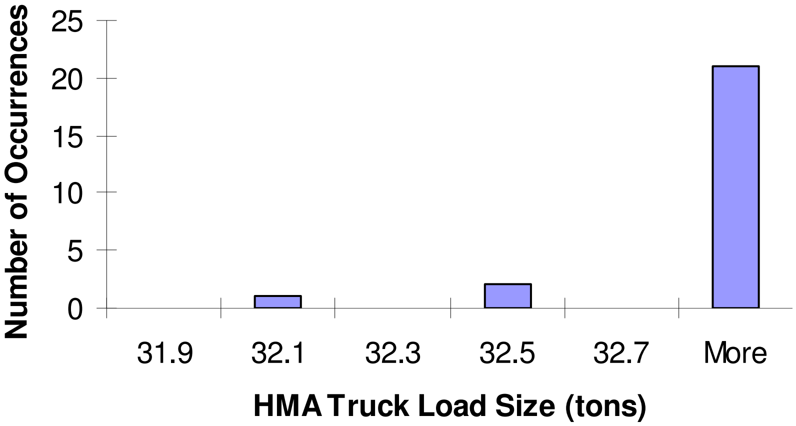


Figure 56 - Distribution of HMA truck load size.

11.5.2.3.3.2 HMA Base Truck Arrival Rate

The distribution of HMA truck arrival times has been determined by using the truck tickets for trucks using trailers with a total load capacity between 26.5 and 33.5 tons. According to inspector reports from the I-5 James to Olive Project, HMA base installation was typically completed within three or four hours. HMA paving was completed relatively quickly and with far less material in comparison to PCC paving. Because of the fast paving operations and the use of if trucks with varying capacities, truck arrival rates have been determined from a relatively small data sample set. Truck ticket information from construction stages 1 and 4 provide a sample size of fifty-eight truck tickets. Because HMA paving does not take place over longer periods of time and did not provide a large sample of truck ticket data, HMA truck arrival rates have been modeled using minutes between truck arrivals as opposed to truck arrivals per hour. Truck arrivals should exhibit the same arrival distribution regardless if arrival rates are considered using either minutes or hours. Figure 57 depicts the minutes between truck arrivals for HMA trucks with load a load capacity between 26.5 and 33.5 tons.

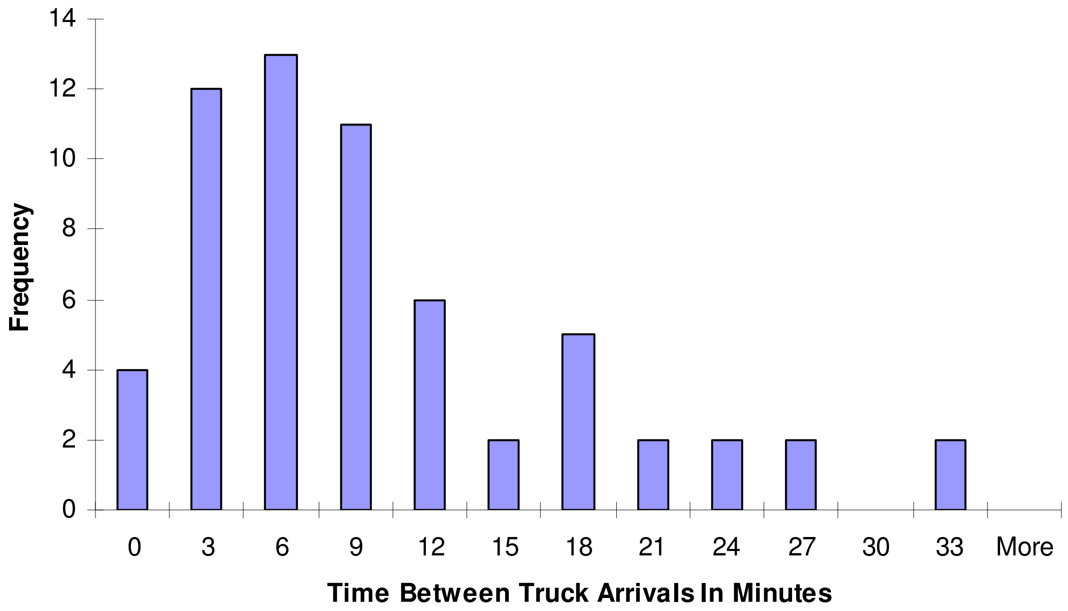


Figure 57 -HMA truck arrival rates for trucks carrying 26.5 to 33.5 tons of HMA.

HMA truck arrival behavior depicts a distinctly lognormal distribution. The distribution seen in Figure 57 has a mean time of nine minutes between truck arrivals with a standard deviation of about eight minutes. If the distribution could be accurately calculated on an hourly basis, the standard deviation would not likely be as large. On an hourly basis, the extremes in fast or slow arrival times would probably be more balanced with one another. The high deviation associated with truck arrivals in minutes will be ignored and HMA truck arrivals will be assigned an arrival standard deviation similar to demolition truck arrivals outlined in section 11.5.2.2.1. For the estimate completed based on observed construction productivity, the HMA truck arrival rate input parameter will be modeled with a lognormal distribution and a standard deviation 25 percent of the mean value. The mean truck arrival rate input parameter for the probabilistic distribution is equivalent to truck arrival rate input parameter used for the deterministic estimate.

11.5.2.3.4 PCC Delivery Trucks

WSDOT engineers predicted that the amount of concrete paving material delivered to the I-5 James to Olive project would require 700 truckloads (WSDOT I-5 James to Olive Pavement Rehab: By the Numbers, 2005). The large number of truck deliveries produced a substantial amount of information for load batch time, load arrival time and load quantity. Data from this large sample of truck tickets have been used to determine the distribution for:

- PCC packing efficiency and volume capacity
- PCC truck arrival rates

11.5.2.3.4.1 PCC Truck Packing Efficiency and Volume Capacity

Derivations of distributions for PCC packing efficiency are based on a representative sample of thirty-seven truck tickets. The truck tickets are from June 18th, 2005 during construction stage 2. Ticket information from the entire sample shows that all PCC trucks contained 7.5cy^3 of PCC material with no variations in load size. Truck load size variation appears negligible and PCC dump trucks will are assigned a deterministic packing efficiency of 100 percent and a deterministic 7.5cy^3 volume capacity.

11.5.2.3.4.2 PCC Truck Arrival Rate

On the I-5 James to Olive Project, PCC paving took place over extended periods of time, producing a large data set of truck tickets. The large collection of truck ticket data facilitated the calculation of truck arrival rates on an hourly basis from multiple construction stages (Table 62). The hourly arrival rates in Table 62 have been used to create a graphical representation for the distribution of truck arrival rates (Figure 58). The distribution in Figure 58 shows a distinct normal distribution. The modeled distribution has a mean of 12.5 truck arrivals per hour and a standard deviation of 2.7 trucks per hour. For the probabilistic estimate based upon observed construction productivity, PCC truck arrival rates are assumed to be distributed normally and have a mean arrival rate of 12.5 trucks per hour and a standard deviation of 2.7 trucks per hour.

Table 62 - PCC Truck Arrival Rates Per Hour Based Upon Truck Ticket Information

6/28/2005	1:00AM - 2:00AM	2:00AM - 3:00AM	3:00AM - 4:00AM	4:00AM - 5:00AM	5:00AM - 6:00AM
Trucks Per Hour	12	13	15	17	15

6/18/2005	7:00PM - 8:00PM	8:00PM - 9:00PM	9:00PM - 10:00PM
Trucks Per Hour	10	9	9

6/25/2005	8:00PM - 9:00PM	9:00PM - 10:00PM	10:00PM - 11:00PM	11:00PM - 12:00AM	12:00AM - 1:00AM	1:00AM - 2:00AM
Trucks Per Hour	14	14	11	12	13	13

6/28/2005	6:00PM - 7:00PM	7:00PM - 8:00PM	8:00PM - 9:00PM	9:00PM - 10:00AM	10:00AM - 11:00AM	11:00AM - 12:00PM	12:00PM - 1:00PM
Trucks Per Hour	8	14	9	11	16	11	15

7/16/2005	5:00PM - 6:00PM	8:00PM - 9:00PM
Trucks Per Hour	16	17

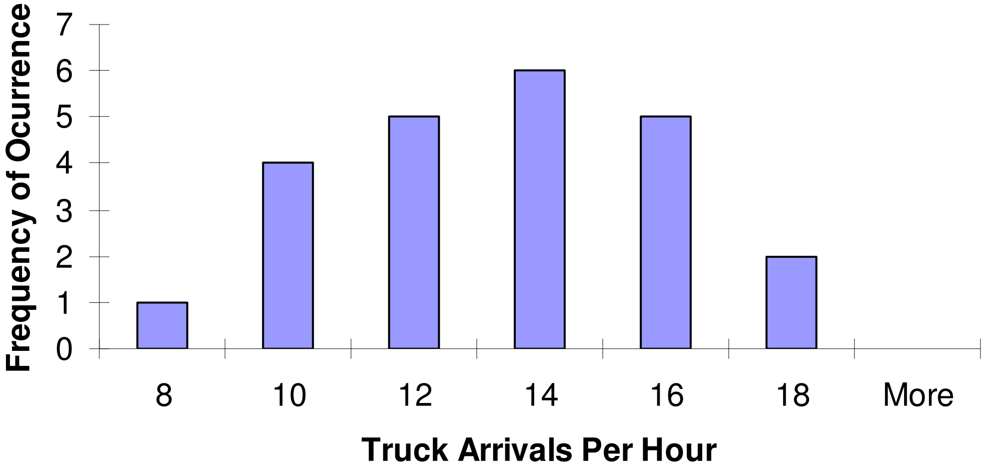
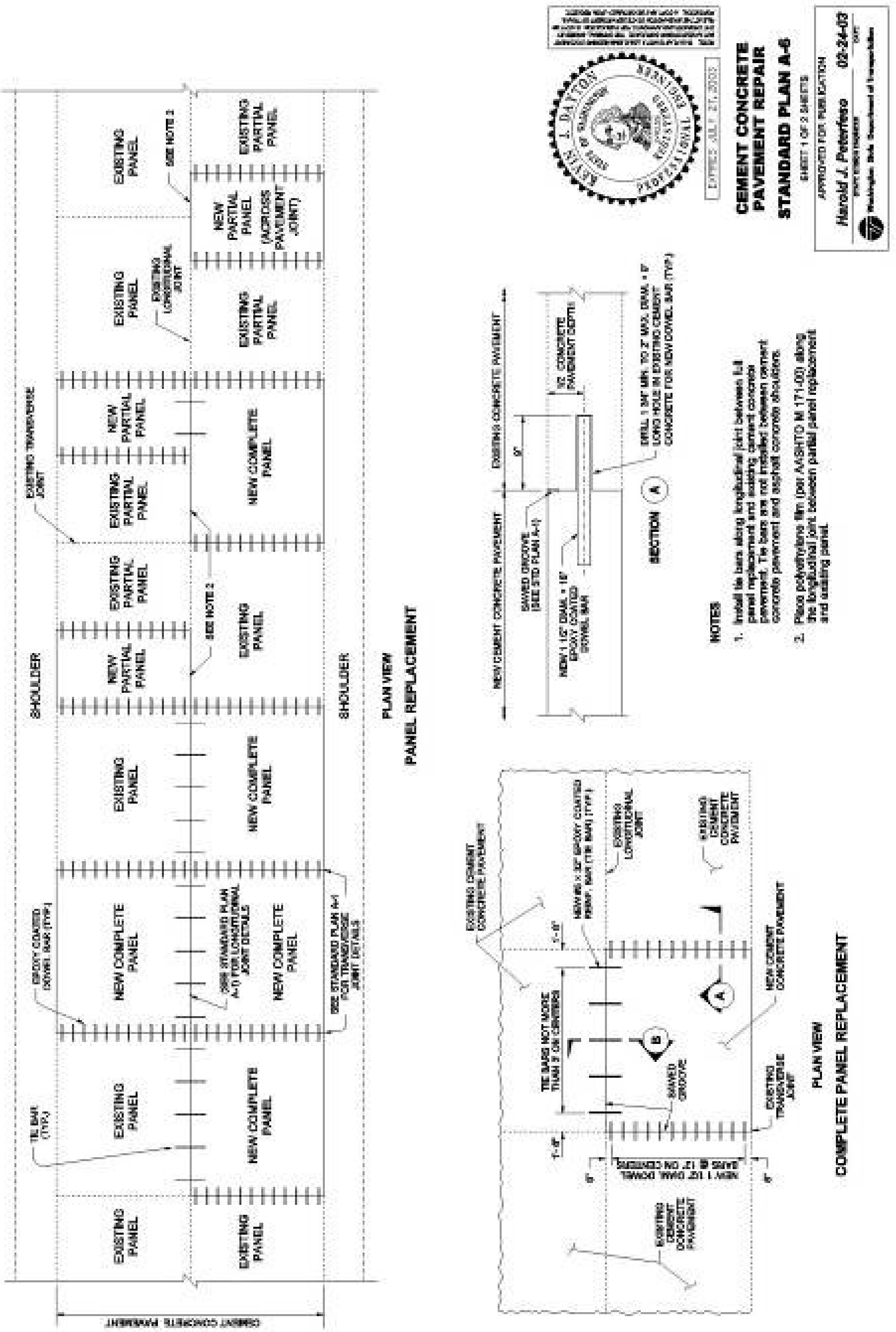


Figure 58 - The distribution of hourly arrival rates for PCC delivery trucks.

11.5.2.3.5 Probabilistic Paver Speed Inputs

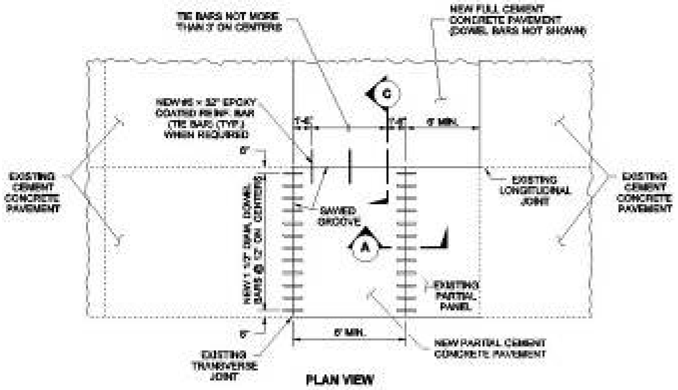
For the estimate based on observed productivity, the paver speed has been assigned a triangular distribution with an expected paving rate of 2.67 ft/min in order to accommodate different hand and machine paving productivities. Maximum and minimum values have been established at 10 percent higher or lower, respectively, than the expected paving rate.

Appendix K: WSDOT Standard Plan A-6

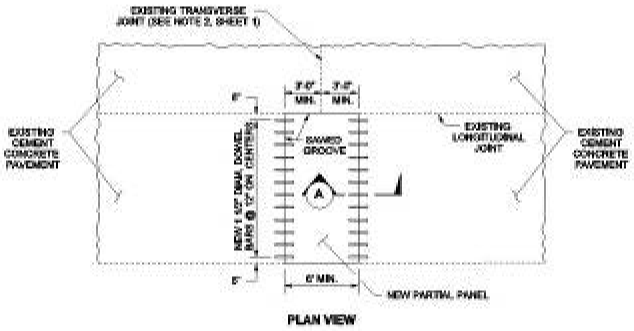


NOTES

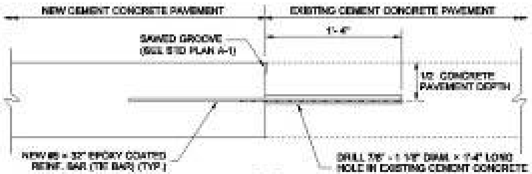
1. Install tie bars along longitudinal joint between full panel replacement and existing cement concrete pavement. Tie bars are not installed between cement concrete pavement and asphalt concrete shoulders.
2. Place polyethylene film (per AASHTO M 171-00) along the longitudinal joint between partial panel replacement and existing panel.



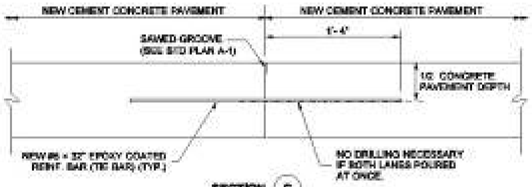
PARTIAL PANEL REPLACEMENT
WITH TIE BARS



PARTIAL PANEL REPLACEMENT
WITHOUT TIE BARS



SECTION B



SECTION C

KEVIN J. DAYTON

EXPIRES JULY 27, 2003

CEMENT CONCRETE PAVEMENT REPAIR

STANDARD PLAN A-6

SHEET 2 OF 2 SHEETS

APPROVED FOR PUBLICATION

Harold J. Peterfeso 02-24-03

STATE DESIGN ENGINEER DATE

Washington State Department of Transportation

Appendix L: Current WSDOT Polymer Bridges Overlays