Characterizing Work Zone Configurations and Effects

A Project for
The Alabama Department of Transportation

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Life-cycle cost analysis (LCCA) uses economic principles to compare competing investment alternatives. It is used by the Alabama Department of Transportation (ALDOT) to help select between asphalt and concrete alternatives for large paving projects. The purpose of this University Transportation Center for Alabama research project was to collect data that will assist ALDOT in determining the user costs or vehicle queue lengths that may result from a highway work zone. This project was the second phase of a multi-phase project to update the LCCA process. The researchers investigated the following areas:
Project/Work zone duration data for typical Interstate reconstruction and rehabilitation activities.
Investigation of typical work zone configurations (i.e. lane closure scenarios) for Interstate rehabilitation activities.
Investigation of two software packages capable of calculating vehicle queue lengths.
Evaluating the effectiveness of calculating user costs with FHWA’s RealCost v.2.1 software.
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Executive Summary

State departments of transportation use pavement Life-Cycle Cost Analysis (LCCA) as a factor to help make choices between asphalt pavement and concrete pavement for the design of major highways. Most states have good databases for construction costs but do not have quality databases for construction duration, which is useful for calculating the user costs of the proposed facility.

This report determined several useful values for the duration of asphalt and concrete highway reconstruction and major rehabilitation activities modeled in a pavement LCCA such as asphalt resurfacing, concrete rehabilitation, concrete rubblization, and concrete pavement removal and replacement. Researchers gathered duration data from nine state Departments of Transportation (DOTs), construction contractors, national agencies, and state agencies. Data acquired from the state DOTs consisted of the time the agency allotted to the contractor to complete the construction after the work began date. This data represents the maximum amount of time needed to complete a specific rehabilitation task and the maximum time that motorists can expect a reduced speed limit for the length of the project:

- Asphalt resurfacing: 7 calendar days per lane mile
- Concrete rehabilitation: 6 calendar days per lane mile
- Concrete pavement remove and replace: 18 calendar days per lane mile
- Concrete pavement rubblization plus asphalt overlay: 17 calendar days per lane mile

The data acquired from the contractors and agencies consisted of the actual production rates for the construction tasks. These production rates assume that contractor crews work on the project 12 hours each day until the project is completed. These values may be considered the minimum time needed to complete the work. They also represent the time that a lane closure might be in place:

- Asphalt resurfacing: one work day per lane mile (3 inch lift)
- Concrete rehabilitation: 1.5 work days per lane mile
- Concrete pavement remove and replace: two work days per lane mile
- Concrete pavement rubblization plus asphalt overlay: two work days per lane mile

The researchers used the Federal Highway Administration (FHWA) LCCA software program RealCost v.2.1 to calculate the user costs resulting from a typical Interstate rehabilitation activity using the duration data listed above to portray the expected work zone duration. The results (and results from a previous research effort) led researchers to conclude that the software program may not be appropriate for calculating ALDOT project user costs at this time:

- RealCost v.2.1 cannot easily portray real-life work zone conditions. Separate user cost analyses must be made and then added together to get reasonably accurate modeling of work zone situations and their associated user costs.
- RealCost v.2.1 gives very large user costs that may overshadow agency costs.

Even if user costs are not used as an input to LCCA studies, the duration data is still useful in LCCA comparisons. Software programs are available that calculate vehicle queue lengths at work zones. The presence and length of queues is different for different paving alternatives. The duration data will reveal how long drivers must cope with queues, which can act as a deciding factor when agency costs for the paving alternatives are very similar.

The queue programs can also be useful in determining when lane closures can be used on a project. If the program indicates that excessive queues will develop during daylight hours, lane closures may be scheduled at night.

The researchers performed a limited comparison of two software programs used to calculate vehicle queue lengths: a program from the Oklahoma Department of Transportation and FHWA's RealCost v.2.1. Four common traffic scenarios were used to compare the two programs. The Oklahoma DOT program was identified as more useful to ALDOT at this time for two reasons:

- It is easier to use than the FHWA program
- It calculates higher queue length values than those of the FHWA program, providing a more conservative to queue estimation.

Section 1
Introduction

Problem Identification

Life-cycle cost analysis (LCCA) is a technique that utilizes economic principles to evaluate and compare competing investment alternatives. An LCCA incorporates initial and discounted future costs over the useful lives of the alternatives to identify the best value, i.e., the lowest long-term cost. An LCCA is often used as a tool to help select the most appropriate design for a project. A highway department often performs a pavement LCCA to compare an asphalt pavement design versus a concrete pavement design.

Many highway departments are concerned only with the agency costs when performing a pavement LCCA. Agency costs are costs directly incurred by the highway agency, such as labor, equipment, and materials used in construction or major maintenance. Some highway departments are also interested in the user costs of the proposed facility. If the demand on the roadway becomes greater than the capacity, a queue of vehicles will develop upstream of the work zone, causing extra user costs as vehicles wait in traffic, perform extra accelerations and decelerations, etc. In many cases, the highway department may need to determine the length of such a queue, because excessive queue lengths may be used to disqualify one of the design alternatives. Queue length becomes increasingly important if the results of an LCCA do not yield substantial differences in cost between the design alternatives.

The University Transportation Center for Alabama (UTCA) conducted a research project for the Alabama Department of Transportation (ALDOT), Research Project 930-562, from August 2002 – May 2003. The purpose of that project was to evaluate changes that may be incorporated into ALDOT's LCCA procedures and to identify a schedule to implement the potential changes. The project was the scoping phase of a potential multi-phase project to update the LCCA process. Researchers investigated potential queue lengths at work zones and the effect of user costs on typical ALDOT LCCAs. The UTCA research team concluded that ALDOT must obtain better data for project durations and work zone configurations before queue lengths may be determined or user costs reliably may be added to LCCA calculations.

Objectives

This project was the second phase of the multi-phase project to update the LCCA process. The purpose of this research was to collect data that will assist ALDOT in calculating the length of queued vehicles and in determining the user costs that may result from a highway work zone. Establishing usable values for the duration of typical reconstruction or rehabilitation activities and the associated daily production rates for major divided highways was the primary focus of this report. The work also compared queue length results from two computer programs to help ALDOT assess their applicability in Alabama situations.

Report Organization

The remainder of this report is divided into the following major headings and sub-headings:

- Section 2 - Literature review – This chapter discusses typical LCCA procedures, current ALDOT LCCA practices, user costs, queue lengths, and common work zone strategies.
- Section 3 – Methodology and Results – This chapter gives a detailed account of the steps involved in the collection of relevant data. This chapter also displays data collected in three investigations:
    - Project duration data collection
    - Work zone configuration data collection
    - Production rates data collection
- Section 4 - Data analysis – This chapter analyzes the data collected for project duration and production rates. The chapter concludes with a comparison of queue lengths calculated by the Federal Highway Administration (FHWA) LCCA software and a capacity spreadsheet from the Oklahoma Department of Transportation (DOT).
- Section 5 - Conclusions and Future Work – This chapter presents the conclusions derived from this research and gives suggestions for enhancements to this research.

Section 2
Background

Introduction

The following review of literature provides background information concerning effective pavement life-cycle cost procedures and current ALDOT LCCA practices. The review describes methods for calculating user costs at a highway work zone and determining the length of queued vehicles that may develop upstream of the work zone. In addition, the literature review provides information concerning typical work zone strategies for various Interstate rehabilitation activities.

LCCA Basics

LCCA is a technique that utilizes economic principles to evaluate and compare competing investment alternatives (FHWA, 2002, Primer). An LCCA incorporates initial and discounted future costs over the useful lives of the alternatives to identify the best value, i.e., the lowest long term cost. It may be used as a tool to help select the most appropriate design for the particular project. For example, an LCCA may be conducted to help decide whether a rigid pavement design or a flexible pavement design should be used. An LCCA is typically performed during the design stage of a project.

The Alabama Department of Transportation (ALDOT) performs life-cycle cost analyses to compare alternative pavement designs and reconstruction strategies for the following situations:

- New construction projects, flexible pavement reconstruction projects, and projects involving the addition of a separate roadway to an existing roadway when the pavement design structural number equals or exceeds 6.00.
- Any project involving the reconstruction of concrete pavement.

Several methods are used for performing a life-cycle cost analysis, including net present value (NPV), equivalent uniform annual costs (EUAC), rate of return (ROR), break even analysis, and benefit-cost (B/C) ratios (FHWA, 2002, Primer). The FHWA recommends the NPV method for performing an LCCA, and ALDOT utilizes NPV in its calculations.

The designer must choose between using nominal dollars or real dollars when performing a life-cycle cost analysis via the NPV method. Real dollars reflect a constant purchasing power, while nominal dollars reflect fluctuations in purchasing power as a function of time. For example, the price for a ton of hot-mix asphalt may be $35 today, and is also represented as $35 in twenty years using real dollars. If nominal dollars are used for this same example, the designer considers inflation and represents the price of a ton of hot mix asphalt as $65 in the future. Real dollars are more widely used in an LCCA. Real dollars and nominal dollars should not be mixed in the same analysis (FHWA, 2002, Primer). ALDOT uses real dollars in its life-cycle cost analyses.

The discount rate, or interest rate, is necessary to complete an LCCA utilizing the NPV method. FHWA suggests using a discount rate between 3 and 5 percent (Smith and Walls, 1998). ALDOT currently uses a 4 percent discount rate on its life-cycle cost analyses.

The analysis period is the length of time selected for the life-cycle cost analysis. The analysis period for two competing alternatives should be the same. FHWA recommends an analysis period of at least 35 years but acknowledges that 20 to 30 year analysis periods are frequently used. In general, the analysis period should be longer than the initial pavement performance period and long enough to incorporate at least one rehabilitation activity (FHWA, 2002, Primer). The Alabama Department of Transportation currently uses a 28-year analysis period.

Performance Period

The designer conducting an LCCA must define performance periods for the initial pavement design and for subsequent rehabilitation activities, and they have a major impact on LCCA results. They are determined by analyzing pavement management historical data.

Figure 2-1 shows a diagram of performance period (service life) vs. pavement condition. This figure illustrates that the pavement condition deteriorates during the service life of a pavement. The pavement deteriorates faster as the pavement condition worsens, as shown by an increasing slope of the curve during one service life. The pavement is then rehabilitated, and the pavement deterioration cycle begins again.

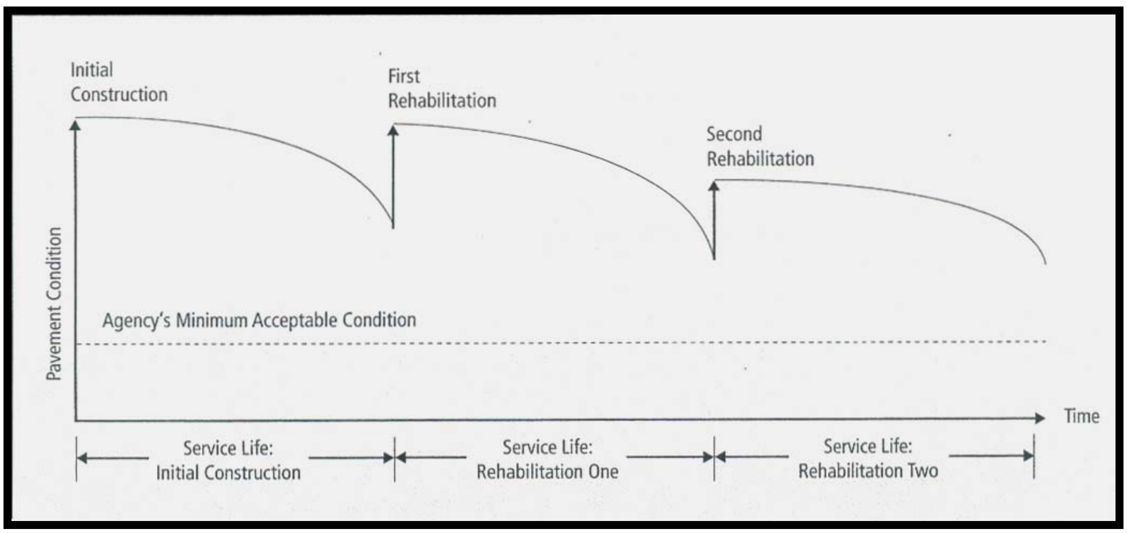

Figure 2-1. Pavement service life (FHWA, 2002, Primer)

Due to the effects of discounting in an LCCA, the timing of the rehabilitation activities has a major impact on the results. A change of one year in rehabilitation timing, in either direction, for either pavement alternate can change the LCCA results. Timing is even more critical with early rehabilitation activities because they are discounted less and have a greater impact on LCCA results than later activities (ACPA, 2002). ALDOT currently uses a 12-year initial performance period for flexible pavements and a 20-year initial performance period for rigid pavements.

ALDOT uses an 8-year performance period for all subsequent rehabilitation activities for both flexible and rigid pavements.

Agency Costs vs. User Costs

An LCCA does not require that all costs associated with each alternative be included, but only the costs that demonstrate differences between alternatives. Agency costs refer to costs directly incurred by the highway agency. These include initial construction costs, periodic maintenance costs, and major rehabilitation activities. User costs are the costs incurred by the traveling public such as vehicle operating costs, travel time costs, and crash costs. User costs arise from the timing, duration, and scope of construction work zones, because work zones usually restrict the normal capacity of the facility (Smith and Walls, 1998). ALDOT currently performs life-cycle cost analyses utilizing only agency costs.

The highway designer may develop an expenditure stream diagram to help visualize the timing and quantity of expenditures to assist in the NPV calculation. The diagram can be created by carefully selecting the performance periods and assigning each activity its appropriate cost. An example of an expenditure stream diagram is shown in Figure 2-2 (FHWA, 2002, Primer).

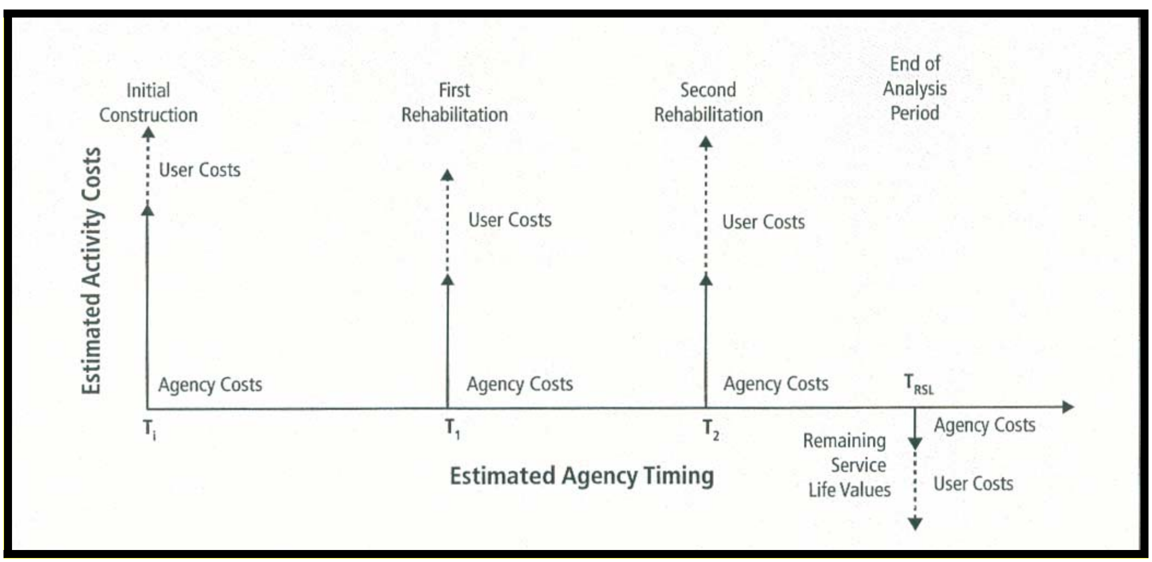

Figure 2-2. Expenditure stream diagram (FHWA, 2002, Primer)

Deterministic Analysis vs. Probabilistic Analysis

There are two approaches to performing a life-cycle cost analysis: deterministic and probabilistic. These methods differ in the way they deal with uncertainty associated with input parameters such as activity costs and timing. The deterministic approach assigns each input variable a distinct fixed cost (discrete value). This discrete value is usually the average of historical data or is simply based on engineering judgment. Assigning discrete values to input variables yields a discrete value for the LCCA estimate. A deterministic approach does not recognize the uncertainty associated with the various inputs (FHWA, 2002, Primer). ALDOT currently conducts life-cycle cost analyses using the deterministic approach.

To account for the uncertainties in life-cycle cost analysis, FHWA recommends performing an LCCA using the probabilistic or risk analysis approach, rather than the deterministic approach. Risk comes from the uncertainty associated with future events. Risk analysis is performed to estimate what event might happen in the future, how likely that event is to happen, and the consequences of that event happening (Smith and Walls, 1998). In the case of a pavement LCCA, one event that an analyst is concerned with would be the overall net-present value (NPV) agency cost of a project.

Risk analysis results are usually presented in the form of a probability distribution, which shows the range of possible values and the probability of their occurrence. This allows the decision maker to weigh the probability of an outcome occurring (Smith and Walls, 1998). The probabilistic approach to conducting an LCCA allows the designer to define the values of individual inputs by a probability distribution (frequency distribution). One or more uncertain input parameters must be identified for each project alternative. The designer identifies project parameters for which a frequency distribution can be identified, and then develops a distribution for those parameters. A computerized simulation technique known as Monte Carlo simulation draws values from the probability distributions entered for each uncertain input variable, and uses these values to compute a single NPV output value. This sampling process is repeated thousands of times to generate a probability distribution for the net present value (NPV). The resulting NPV distribution can be compared to other alternatives' NPV distributions to determine the most economical option for any given risk level (Smith and Walls, 1998).

Probabilistic Approach Strengths

A majority of input variables in a pavement LCCA are uncertain, such as the initial cost, future cost, and performance period of the pavement. Addressing these uncertainties makes the results more relevant to the real world (Tighe, 2001). A probabilistic LCCA addresses these uncertainties by allowing ranges of inputs (probability distributions) to be entered rather than a single mean value, as is entered in the deterministic approach. The probabilistic results are also in the form of a probability distribution. This allows the analyst to decide what the NPV for an alternative is at a specified level of probability. For example, an analyst using the probabilistic approach to an LCCA might find out that there is a 90 percent probability that the NPV for alternative number 1 is $4 million or less, and there is only a 20 percent probability that the NPV for alternative number 2 is $4 million or less. Figure 2-3 shows how the NPV probability distribution is generated (Smith and Walls, 1998).

LCCA Peer Review

The Federal Highway Administration conducted an LCCA peer review in January 2002 to identify positive ALDOT life-cycle cost analysis practices (ALDOT, 2002). ALDOT provided the FHWA with its LCCA procedures and also provided an example of a past LCCA. The FHWA peer review team confirmed that ALDOT's stated procedures were used in its analyses and found the following good LCCA practices:

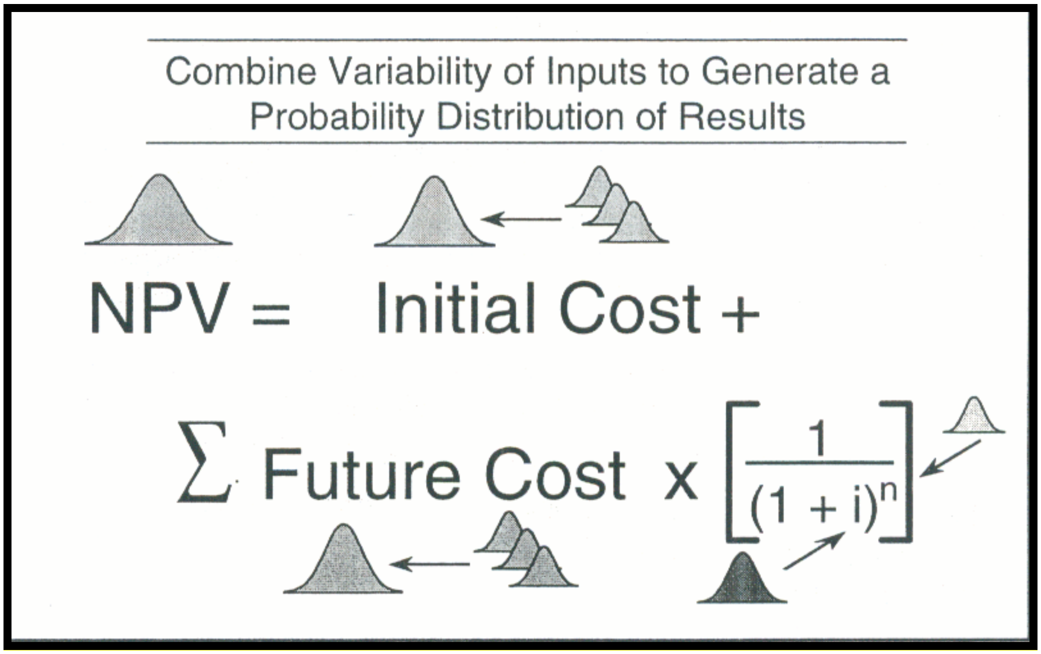

Figure 2-3. NPV distribution generation (Smith and Walls, 1998)

- ALDOT LCCA procedures use the following current national FHWA recommended procedures:
  - Use of a 4 percent discount rate
  - Use of an analysis period that includes at least one rehabilitation
  - Use of the NPV method to compare discounted costs
- A well documented history of the evolution of LCCA procedures.
- A good working relationship between the FHWA Division and State DOT.
- Good use of available cost data.

The FHWA peer review team listed areas in which ALDOT's LCCA procedures could be refined:

- Use pavement management system information to evaluate the cost effectiveness of new paving materials/procedures such as Superpave, stone matrix asphalt (SMA), modified asphalts, and tied concrete shoulders.
- Develop a formal policy statement that addresses factors for not selecting the lowest life-cycle alternative such as excessive queues and user delays during rehabilitation.
- Incorporate reliability into pavement life estimates.
- Begin to assemble data on the variability of LCCA inputs to be prepared for the implementation of the anticipated new edition of AASHTO's Guide for Design of Pavement Structures (AASHT0, 1993).
- Evaluate the effect of proposed out-year rehabilitations on users of the facility such as the analysis of queue lengths and user delays.

UTCA Report 02409 (Lindly and Clark, 2003) was published in June 2003, and addressed those areas. One of the UTCA research team's conclusions was that better data for asphalt and concrete work zone lengths, configurations, and durations must be obtained before reliable queue lengths or user costs may be added to LCCA calculations. This research deals primarily with this issue (last bullet above).

LCCA Software

The Federal Highway Administration recently released its newest RealCost version 2.1 software. This software is able to perform an LCCA utilizing either the probabilistic approach or the deterministic approach. The FHWA software can also calculate user costs, if the designer chooses. This software is modeled after the method presented in the FHWA publication "Life-Cycle Cost Analysis in Pavement Design – In Search of Better Investment Decisions" (Smith and Walls, 1998). A more thorough description of the FHWA software is provided in the UTCA research report (Lindly and Clark, 2003).

ALDOT currently performs LCCA's utilizing AASHTO's Darwin software to calculate agency construction and rehabilitation costs. Darwin is only capable of performing a deterministic analysis. The designer is not able to factor in the variability of inputs. Darwin is also only used to calculate agency costs in an LCCA; it does not calculate user costs or queue length.

User Cost Calculation and Queue Length Determination

Even if a highway agency does not assign a distinct dollar value to user costs, most agencies are concerned with the travel delay. Delay may be quantified by determining the length of the queue of backed-up drivers that results from a work zone in place during the construction or rehabilitation of a roadway. This section will address the basics of how user costs are incurred, how they can be calculated, and how the length of the queue may be calculated.

Origins of User Costs

There are seven possible user cost components that the traveling public can incur while traversing a work zone (ACPA, 2002). Three of these components are associated with a free flow condition, and four are associated with the forced-flow condition. The forced flow condition refers to the situation in which a queue forms upstream of the work zone, while there is no queue that forms while the work zone is in the free flow condition.

In the case of the free-flow condition, cars must slow to the posted work zone speed limit, but there is no major impediment, so no queue develops. The three user cost components that arise from vehicles traversing a work zone in free-flow conditions are 1) *speed change delay*, 2) *speed change vehicle operating costs (VOC),* and 3) *reduced speed delay*. *Speed change delay* is the additional time required to decelerate from the upstream speed to the work zone speed, and to accelerate back to the initial upstream speed after traversing the work zone. The *speed change VOC* is the additional vehicle operating cost associated with decelerating from the upstream approach speed to the work zone speed and then accelerating back to the approach speed. The *reduced speed delay* is defined as the additional time required to traverse the work zone at the lower posted speed. *Reduced speed delay* is dependant on the upstream and work zone speed differential and the length of the work zone (Smith and Walls, 1998). *Speed change delay* and *reduced speed delay* are travel time costs; *speed change VOC* is a vehicle operating cost. Figure 2-4 shows a work zone in free-flow condition and the user cost components associated with it (Smith and Walls, 1998).

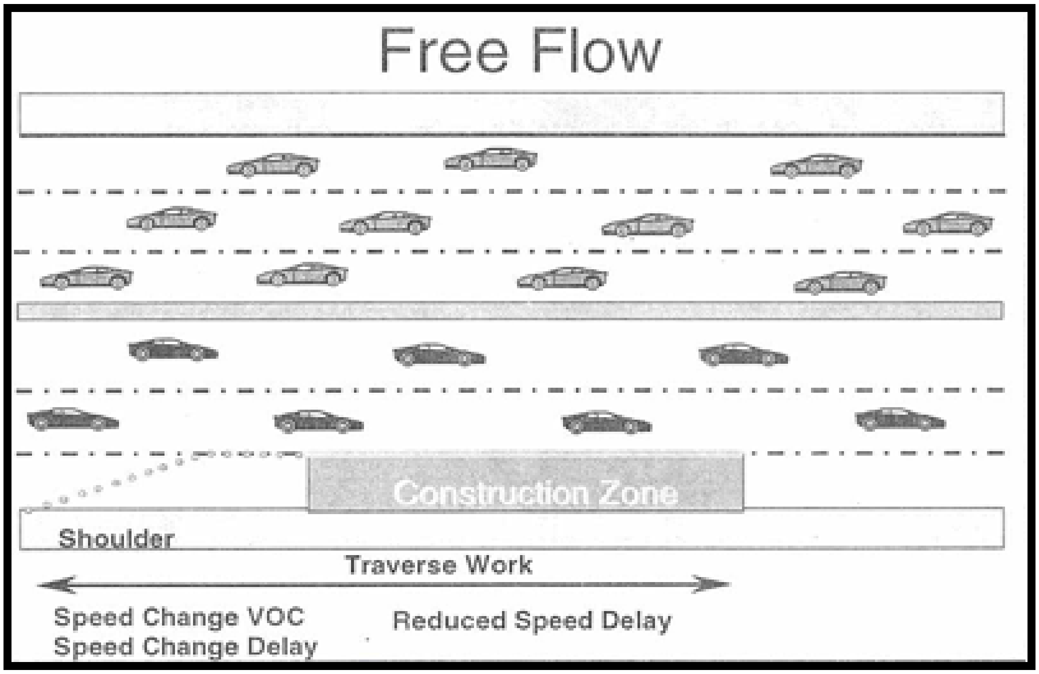

Figure 2-4. Free flow conditions (Smith and Walls, 1998)

In the case of forced flow, the hourly traffic demand exceeds the work zone capacity. As a result, a queue forms upstream of the work zone. The forced flow condition imposes four user cost components: 1) *stopping delay*, 2) *Stopping VOC*, 3) *Queue Delay*, and 4) *Idling VOC*. The *stopping delay* is the additional time necessary to come to a complete stop from the upstream approach speed and the additional time necessary to accelerate back to the approach speed after leaving the work zone. The *stopping VOC* is the vehicle operating cost associated with stopping from the upstream approach speed and accelerating back to the approach speed. The *queue delay* is defined as the time necessary to pass through the queue under forced-flow conditions. Lastly, the *Idling VOC* is the vehicle operating cost associated with stop-and-go driving while traversing the queue (Smith and Walls, 1998). Figure 2-5 shows a work zone under forced flow conditions and the user costs associated with it.

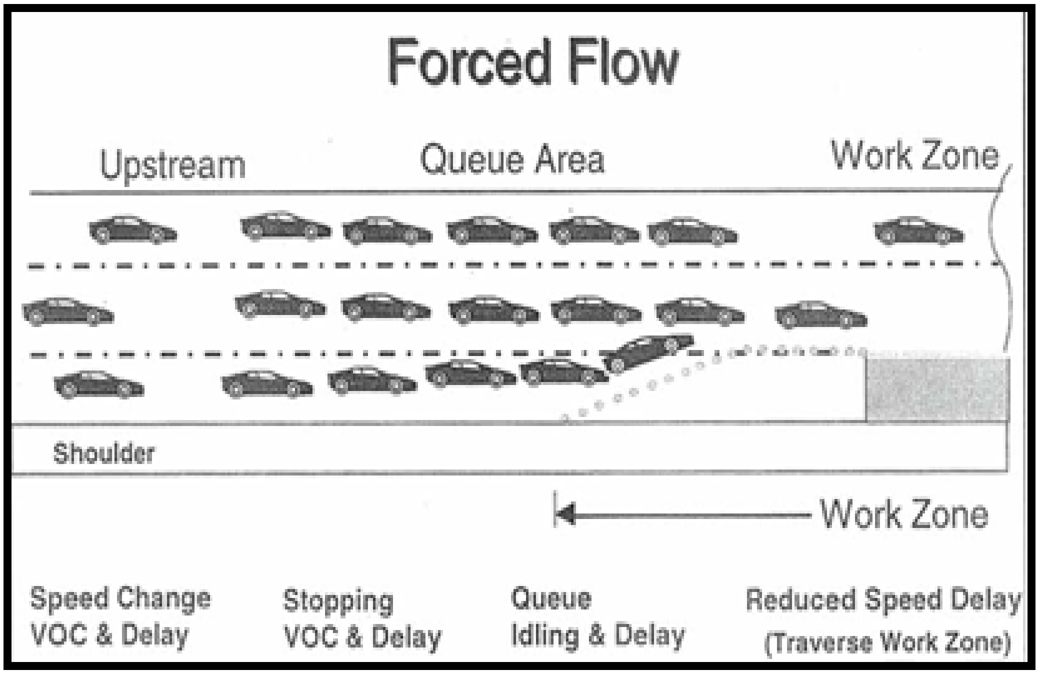

Figure 2-5. Forced flow conditions (Smith and Walls, 1998)

Calculating User Costs

A designer must have specific knowledge of the work zone characteristics and the traffic characteristics to calculate the user costs at a work zone. Each work zone established over the analysis period affects the traffic flow, and thus the user costs. The user costs are calculated by analyzing the hourly demand of the work zone versus the hourly capacity of the work zone. Several specific characteristics of the work zone must be acquired for each major construction or rehabilitation activity (FHWA, 2002, Draft):

- Projected year the work zone occurs
- Number of days the work zone will be in place
- Specific hours of each day the work zone will be in place (e.g., 10 pm – 6 am)
- Work zone length
- Work zone speed limit (mph)
- Number of lanes available during construction activity (Note: if shoulder is used for vehicle travel, it counts as a lane)

The specific traffic data to be acquired to calculate work zone related user costs in the FHWA LCCA computer program follows: (FHWA, 2002, Draft)

- AADT (Average Annual Daily Traffic)
- Single unit trucks as percent of AADT
- Combination unit trucks as percent of AADT
- Traffic hourly distribution (hour by hour)
- Annual growth rate of traffic (percent)
- Speed limit under normal operating conditions (mph)
- Free flow capacity (vphpl)

- Class-by-class values of travel time ($/vehicle-hr)

FHWA report SA-98-079 (Smith and Walls, 1998) provides a step-by-step method for calculating user costs by hand or with Microsoft Excel. The hand method is labor intensive. The easiest way to calculate work zone related user costs is to use an Excel-based spreadsheet program. The new *FHWA RealCost version 2.1* is a program of this type that is capable of calculating the user costs given the required work zone and traffic data. The FHWA program is explained more thoroughly in (Lindly and Clark, 2003). The program does an hour-by-hour comparison of the roadway capacity and traffic demand. From this comparison, the program determines the number of vehicles per hour that traverse the work zone and how many vehicles traverse a possible queue. Class-by-class vehicle operating cost (VOC) rates and delay cost rates are then applied to calculate each of the seven possible user cost components described previously. FHWA includes recommended values for the VOC rates and delay cost rates in (Smith and Walls, 1998). Each of the user cost components is summed to calculate the user cost incurred by the driving public for one day's work zone. The total user cost associated with the reconstruction or rehabilitation activity is calculated by multiplying the total number of days the work zone is in place by the user cost incurred during one day.

Calculating Queue Lengths

Many state DOTs that do not directly consider user costs when performing a LCCA are still interested in determining the queue lengths that might develop in the construction/rehabilitation activities modeled. Software capable of calculating hour-by-hour queue lengths include *FHWA RealCost version 2.1* and a Microsoft Excel based spreadsheet created by the Oklahoma Department of Transportation. This report will refer to the second program as the ODOT capacity spreadsheet. Essentially the same data needed to calculate user costs is also needed to calculate queue lengths, except that construction and rehabilitation costs are not required. The FHWA software program calculates the length of queue during each hour by dividing the average number of queued vehicles for that hour by the change in traffic density during that hour. This method is explained thoroughly in (Smith and Walls, 1998), Section 3. The Oklahoma spreadsheet calculates queue lengths in much the same way. Details on calculating queue lengths with the two different types of software are provided in Section 4, "Data Analysis and Application."

Work Zone/Project Duration

Dr. Karl Wunderlich and Dawn Hardesty published a report in 2003 titled "A Snapshot of Summer Work Zone Activity" (Wunderlich and Hardesty, 2003). This report presented work zone data that was collected from 13 states' DOT websites in the summer of 2001. The work zone data was listed for only major construction projects during that summer. One of the work zone statistics that was researched was duration, defined as the number of days between the reported start and end dates of the project.

Wunderlich and Hardesty found that the average work zone duration was 125 days and the median work zone duration was 65 days. The researchers did not categorize the duration data by project type, but instead grouped all projects together. UA researchers decided to collect work zone/project duration data for specific project types.

Work Zone Strategies

An analyst that wishes to calculate user costs in an LCCA must choose an appropriate work zone configuration for each of the construction activities being modeled. A work zone is the general location of a work activity on a highway. The Manual on Uniform Traffic Control Devices (MUTCD) (FHWA, 1998) refers to a work zone as a "temporary traffic control zone." This report will call it simply a "work zone." The general purpose of work zone traffic control is to "provide for the safe and efficient movement of vehicles, bicycles, and pedestrians through or around work zones while reasonably protecting workers and equipment." (FHWA, 1998)

The duration of the construction activity is a major factor in determining the overall configuration of a work zone. Work zone duration is defined as the length of time a work activity occupies a certain location. The MUTCD divides work duration into the following five categories:

1. *Long-term* – work that occupies a location for several days or more
2. *Intermediate-term* – work that occupies a location for at least one day, and up to several days
3. *Short-term* – work that occupies a location for no more than 12 hours
4. *Short duration* – work that occupies a location for up to one hour
5. *Mobile work* – work that moves intermittently or continuously

There are several physical work zone features that must be identified to better understand the layout of a highway work zone, including the *advanced warning area*, *transition area*, *activity area*, and *termination area*. The *advanced warning area* is the region where drivers are informed about the upcoming work activity and lane closures. The *transition area* is the region where traffic is diverted from its normal path to a new path utilizing channelization devices such as barrels and cones. The *activity area* is the region where construction activity takes place and traffic is restricted (Dixon & Hummer, 1996). The *termination area* is the final portion of the work zone that begins downstream of the activity area. This area is used to allow traffic to clear the activity area and return to normal traffic operations. It is usually followed by END ROAD WORK signs (Lewis, 1989). Figure 2-6 illustrates these work zone components.

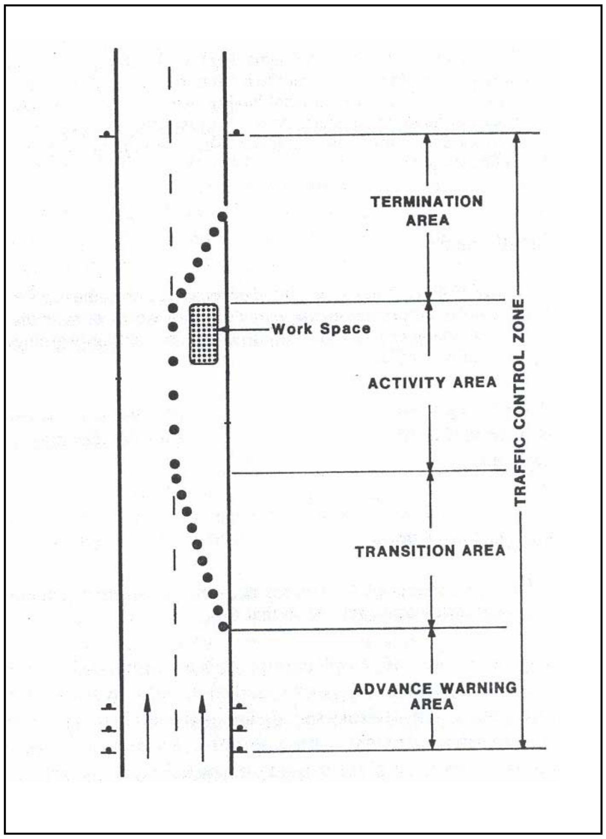

Figure 2-6. Work zone components (Lewis, 1989)

Two types of work zone lane closure strategies are often employed for reconstruction or rehabilitation of Interstates or multi-lane divided highways: *partial closure* and *crossover*. The *partial closure*, often referred to as a "single-lane closure," is one in which one lane in one direction is closed. Closures of this type result in no disruption of traffic in the opposite direction. Single-lane closures are the most common types of lane closures. A *crossover*, also known as "two-lane, two-way traffic operation," is a closure scenario where one direction of the highway is closed. The traffic that normally uses that roadway is crossed over the median, and two-way traffic is maintained on the other roadway (Jiang, 1999). Figure 2-7 illustrates the two lane closure scenarios.

Strategies for Concrete Pavement Projects

This section discusses typical traffic control strategies for the most common types of concrete pavement rehabilitation activities. This discussion will concentrate on traffic control strategies for multi-lane divided highways because they are the focus of this research.

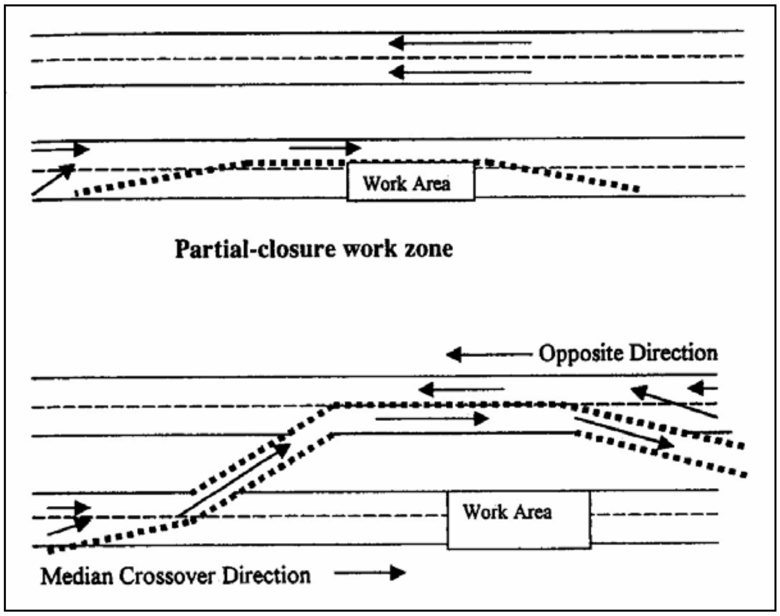

Figure 2-7. Lane closure types (Jiang, 1999)

The most common concrete pavement rehabilitation activities include joint repair, full and partial-depth repair, grinding, slab stabilization, and crack sealing or resealing. These types of rehabilitation activities can be accomplished by the traffic control strategies named below and described in subsequent paragraphs (ACPA, 2000):

1. Full-length single lane closure
2. Alternating lane closures
3. Multiple work areas

The simplest form of traffic control for concrete pavement rehabilitation is to close one lane the entire length of the project where work is required. This generally gives the contractor more flexibility in his operations; however, it may penalize the driving public by making the length of lane closure longer than necessary. Some of the basic advantages of the *full-length lane closure* follow (ACPA, 2000):

- Entire lane to be worked on is available to contractor
- Traffic controls do not have to be moved after they are installed
- Traffic only has to travel through one transition

Some of the disadvantages of the full-length lane closure work zone follow:

- Traffic delays due to slow vehicles may be excessive
- Drivers may see long stretches of lane closures with little to no work activity
- Not easily adapted to heavy directional peaks
- Disabled vehicles may have major impacts on traffic

Another approach to traffic control for concrete rehabilitation activities on a multi-lane highway is *alternating lane closures*. This strategy consists of closing one lane from point A to point B, and then closing the other lane from point A to point B. Typically the work proceeds down one lane in the morning, and comes back down the other lane in the afternoon. One method for accomplishing this strategy is by using moveable concrete barriers (MCB) (ACPA, 2000). Some advantages of this method follow:

- Flexibility to adjust to traffic and work
- Can be scheduled to eliminate drop-offs between lanes (by paving down one lane in the A.M. and back the other lane in the P.M.)

The *alternating lane closure* method also has the following basic disadvantages:

- Must be able to open lanes to traffic on same work day
- Traffic control must change when a lane closure is changed
- Traffic operates close to workers
- Traffic may be confused by frequent changes

The *multiple work areas* strategy is a third common type of traffic control strategy for concrete rehabilitation activities. This type of method is usually best for work that takes place at several isolated spots. It typically calls for a number of sets of traffic control devices. This strategy may also be confusing to drivers because they do not expect several work areas in close proximity. One advantage of having multiple work areas is that traffic control is necessary only where work is taking place, rather than the entire length of the project (ACPA, 2000).

Resurfacing Strategies

This section discusses the two typical traffic control strategies for the resurfacing of multi-lane divided highways, usually involving asphalt overlays or unbonded concrete overlays (ACPA, 2000):

1. Advancing limited closure in one lane
2. Lane shifts onto shoulder or median

During *advancing limited closure in one lane*, a single lane closure is instituted and then lengthened or shortened according to traffic or construction. A common example involves a paving operation when a short length of lane is closed and then expanded as the paving operation moves downstream. Some advantages to this strategy follow:

1. Work area may be shortened when traffic is heavy
2. Easier to adjust to schedule changes than a full-length closure

A disadvantage to this strategy is that the traffic control devices must be moved whenever the lane closure expands or contracts.

One of the most common types of traffic control strategies for the resurfacing of multi-lane divided highways is the *lane shift onto the shoulder or median.* This strategy is an excellent choice when lane closures of any duration result in unacceptable delay. In this strategy, the same number of lanes is kept open by shifting a lane of traffic onto the shoulder or median. Some of the basic advantages of this type of traffic control strategy follow (ACPA, 2000):

- Maintains original number of lanes
- Facilitates the maintenance of traffic by limiting the section of the highway affected
- Reduces the burden on adjacent communities in terms of emergency services and businesses

The basic disadvantages of using lane shifts during resurfacing operations follow:

- More time must be provided for construction
- Construction phasing and traffic control plans are more complicated
- Limited areas for contractor to work and move equipment
- Requires phasing of construction operations
- Restricted lane widths may result in traffic delays and/or crashes

Section 3
Methodology and Results

Introduction

The purpose of this research was to quantify certain typical attributes for the reconstruction or major rehabilitation activities concerned with Interstate highways or other major multi-lane highways. Attributes such as the project duration, work zone length, and lane closure scenarios are needed to calculate the user costs or potential vehicle queue lengths of projects. This chapter provides a detailed description of the methodology employed for this research and presents the data collected.

The following tasks were performed as part of this research:

1. Project duration data collection
2. Work zone configuration investigation
3. Production rates data collection

Project Duration Data Collection

The authors collected data concerning Interstate reconstruction and rehabilitation project durations from a variety of sources. First, researchers consulted with ALDOT's Construction and Planning Bureaus. Next, researchers examined the websites and consulted with the construction divisions within five other Southeastern state departments of transportation. In most cases, UA researchers obtained a construction progress report detailing all current construction projects or recently finished construction projects. In other cases, state engineers simply provided average durations for specific reconstruction or rehabilitation activities on a per lane mile basis. Last, The authors examined the websites for over 30 other state DOT's within the continental United States. Some of the state DOT websites contained detailed information on construction projects, while others were not as helpful. UA researchers obtained project status reports from the helpful websites such as the North Dakota and Oklahoma DOT websites. The sections below detail the project duration and project length data that were successfully obtained from each state.

Alabama

Data concerning typical highway construction project durations and lengths for the state of Alabama was acquired from the Alabama Department of Transportation's most recent Construction Status Report (ALDOT, 2003) through the ALDOT Construction Bureau. It contains detailed information about all current highway construction projects, as well as some recently completed projects. Researchers tabulated data for Interstate reconstruction and rehabilitation activities. Projects were omitted if they contained bridge repair or other miscellaneous time-consuming construction activities that might skew the road construction data.

The specific information the authors obtained from this report included the project number, project description, project length, and the total number of "working days" after the work began date allotted to the contractor by ALDOT to complete the project. The Construction Status Report also identified the percentage of total work the contractor had performed up to the date of the report, as well as the percentage of time used by the contractor.

In general, ALDOT assumes approximately 180 working days per year and 15 working days per month. Table 3-1 lists the 29 projects acquired from the ALDOT Construction Status Report and their corresponding description, county, length, number of lanes, and number of working days allotted. If a project was 100 percent completed, the recorded number of working days was determined by multiplying the percent time used by the contractor times the total number of working days allotted to the contractor. The completed projects are indicated with an asterisk next to the project number.

Table 3-1. Major highway projects in Alabama

Project #	Project Description	County	Project Length (mi)	Normal No. Lanes (Each Direction)	Duration (WDs)
IM-59-1 (207)	Asphalt pavement planing and resurfacing	Tuscaloosa	13.623	2	260
IM-59-2 (108) and (109)	Rehab of PCC pavement	DeKalb	23.506	2	254
IM-59-1 (210)	Asphalt pavement planing and resurfacing	Greene	10.020	2	250
IM-65-1 (220)	PCC pavement rubblization and asphalt overlay	Butler	8.890	2	366
IM-65-1 (239)	PCC pavement rubblization and asphalt overlay	Montgomery	6.462	2	255
NHF-0020 (501)	Asphalt pavement resurfacing	Lawrence	4.567	2	50
MGF-209 (31)	Asphalt pavement resurfacing	Montgomery	7.570	2	268
IM-565-5 (78)	Asphalt pavement planing and resurfacing	Madison	7.921	4	82
STPSA-CN00 (7) *	Asphalt pavement resurfacing	Madison	0.230	2	3
ACIM-I065 (306) *	Asphalt pavement planing and resurfacing	Limestone	12.040	2	78
NHF-0102 (517) *	Asphalt pavement planing and resurfacing	Marshall	4.225	2	55
IM-DBAAF-65-3 (143) *	PCC rubblization and asphalt overlay, ADD lanes	Jefferson	4.527	2	539
IM-65-2 (140) *	Asphalt pavement resurfacing and planing	Shelby	7.538	3	180
IM-NHF-I20 (314)	Additional asphalt lanes	St. Clair	1.392	2	225
IM-NHF-I059 (214)	Additional asphalt lanes	Jefferson	5.056	3	365
IM-I085 (310) *	Asphalt resurface and superelev correction	Lee	8.062	2	296 Cal. Days
IM-65-2 (148)	Asphalt planing and resurfacing	Chilton	9.396	2	175
IM-I059 (316)	Asphalt planing and resurfacing	Greene	10.180	2	245
NHF-I059 (307)	Additional asphalt lanes	Tuscaloosa	5.033	2	445 Cal days
NHF-I059 (315)	Additional asphalt lanes	Tuscaloosa	5.130	2	395 Cal days
IM-65-1 (254) *	Asphalt resurface	Autauga	7.979	2	161
ACIM-I065 (325) *	Rehab of PCC pavement	Butler	9.061	2	40
IM-85-1 (136) *	Asphalt pavement planing and resurfacing	Macon	14.628	2	220
IM-65-1 (260) *	Asphalt pavement planing and resurfacing	Baldwin	7.325	2	181
IM-65-1 (261) *	Asphalt pavement planing and resurfacing	Baldwin	8.520	2	181
IM-65-1 (257) *	Asphalt pavement planing and resurfacing	Conecuh	22.529	2	220
IM-10-1 (118) *	Asphalt pavement planing and resurfacing	Mobile	16.155	2	225
IM-10-1 (120) *	Asphalt pavement planing and resurfacing	Mobile	3.739	3	75

UA researchers also determined the number of through lanes on each facility where the projects occurred, either by physical inspection or with the help of the ALDOT Assistant Materials Engineer. With this data, The authors determined how many working days were allotted to the contractor for each lane mile of work for each project.

The following is a list of the general types of Interstate or major divided highway construction jobs for which the UA researchers collected data:

1. Asphalt planing and resurfacing
2. Rehabilitation of portland cement concrete (PCC) pavement
3. PCC pavement rubblization plus a hot mix asphalt overlay
4. Additional lane plus asphalt overlay

Tables 3-2 through 3-5 show the projects grouped according to the type of work being performed. Each table lists the project number, number of lanes in each direction, number of working days, and the amount of working days allotted for a given lane mile of the project. The bottom of each table also shows the average and standard deviation for the total number of working days allotted per lane mile of the project. The concrete pavement rehabilitation projects took the least amount of time to complete with an average of 1.9 working days per lane mile, while the construction of additional lanes took the most time to complete with an average of 18.3 working days per lane mile.

Table 3-2. Asphalt resurfacing projects in AL

Project Number	# Lanes (each direction)	Length	Work Days	WDs per lane mile
IM-59-1 (207)	2	13.623	260	4.771
IM-59-1 (210)	2	10.02	250	6.238
NHF-0020 (501)	2	4.567	50	2.737
MGF-209 (31)	2	7.570	268	8.851
IM-565-5 (78)	2	7.921	82	2.588
STPSA-CN00 (7)	2	0.230	3	3.261
ACIM-I065 (306)	2	12.040	78	1.620
NHF-0102 (517)	2	4.225	55	3.254
IM-65-2 (140)	3	7.538	180	3.980
IM-I085 (310)	2	8.062	148	4.589
IM-65-2 (148)	2	9.396	175	4.656
IM-I059 (316)	2	10.180	245	6.017
IM-65-1 (254)	2	7.979	161	5.044
IM-85-1 (136)	2	14.628	220	3.760
IM-65-1 (260)	2	7.325	181	6.177
IM-65-1 (261)	2	8.520	181	5.311
IM-65-1 (257)	2	22.529	220	2.441
IM-10-1 (118)	2	16.155	225	3.482
IM-10-1 (120)	3	3.739	75	3.343
			AVE	**4.322**
			STDEV	1.718

Table 3-3. Concrete rehabilitation projects in AL

Project Number	# Lanes (each direction)	Length	Work Days	WDs per lane mile
IM-59-2 (108) and (109)	2	23.506	254	2.701
ACIM-I065 (325)	2	9.061	40	1.104
			AVE	**1.903**
			STDEV	1.130

Table 3-4. Rubblization projects in AL

Project Number	# Lanes (each direction)	Length	Work Days	WDs per lane mile
IM-65-1 (220)	2	8.89	366	10.292
IM-65-1 (239)	2	6.462	255	9.865
IM-DBAAF-65-3 (143)	2	4.527	539	29.766
			AVE	**16.641**
			STDEV	11.368

Table 3-5. Construction of additional lanes in AL

Project Number	# Lanes (each direction)	Length	Work Days	WDs per lane mile
IM-NHF-I20 (314)	2	1.392	225	40.409
IM-NHF-I059 (214)	3	5.056	365	12.032
NHF-I059 (307)	2	5.033	223	11.077
NHF-I059 (315)	2	5.13	198	9.649
			AVE	**18.292**
			STDEV	14.778

Georgia

UA researchers acquired data concerning the length and duration of typical Interstate rehabilitation and reconstruction projects from the Georgia Department of Transportation's Contract Status Reports (GADOT, 2003). The Media Relations Coordinator for the Georgia DOT provided the UA research team with the most recent Contract Status Report for each county in Georgia. The reports contain information on every highway project being conducted or recently finished in Georgia counties. The status reports list the following data for each project:

1. Contract number
2. Job description
3. Project length
4. Project location
5. Work began date
6. Current speculated completion date
7. Percentage of work completed to date
8. Percentage of allotted time used

Researchers tabulated data for every Interstate rehabilitation or reconstruction job. Projects were omitted if they contained bridge repair or other miscellaneous time-consuming construction activities. Similar job types were then grouped. The Media Relations Coordinator for the Georgia DOT also provided the UA research team with the number of travel lanes available for each project. This data made it possible to determine the total number of calendar days per lane mile of roadway that were required for the project to be completed. The following is a list of the three types of Interstate rehabilitation jobs for which the UA research collected data:

1. Asphalt planing and resurfacing
2. Additional lane plus asphalt overlay
3. Concrete pavement (PCC) rehabilitation (grinding, joint cleaning and resealing, full-depth repairs)

Tables 3-6 through 3-8 show the highway construction projects grouped by job type. Each table lists the project number, number of lanes in each direction, project length, total number of calendar days required for project completion, and the total number of calendar days per lane mile for project completion. The averages and standard deviations for the total number of calendar days per lane mile are shown at the bottom of each table. The asphalt resurfacing projects were allotted the least amount of time to complete with an average of 6.74 calendar days per lane mile. The projects consisting of the construction of additional lanes plus an asphalt overlay were allotted the most time to complete with an average of 19.83 calendar days per lane mile.

Table 3-6. Asphalt resurfacing projects in GA

Project Number	# Lanes (each direction)	Length	Cal Days	CDs per lane mile
NHS-M000-00 (502)	3	6.011	156	4.33
NHS-M001-00 (027)	2	23.970	307	3.20
NHS-M001-00 (007)	3	4.080	180	7.35
NHS-M000-00 (459)	2	8.810	425	12.06
			AVE =	**6.74**
			StDEV =	**3.96**

Table 3-7. Asphalt resurfacing and widening projects in GA

Project Number	# Lanes (each direction)	Length	Cal Days	CDs per lane mile
NH-75-1 (157)	2	14.530	780	13.42
NH-IM-75-1 (158)	3	8.000	840	17.50
NH-IM-95-1 (122)	2	7.911	768	24.27
NH-IM-95-1 (119)	2	8.048	926	28.76
NH-75-1 (203)	3	13.655	1162	14.18
NHS-M000-00 (437)	3	1.502	360	39.95
NH-IM-95-1 (125)	3	6.896	745	18.01
IM-95-1 (123)	3	7.404	880	19.81
NH-IM-95-1 (155)	3	7.850	880	18.68
NHS-M000-00 (542)	3	21.690	485	3.73
			AVE =	**19.83**
			StDEV =	**9.70**

Table 3-8. Concrete rehabilitation projects in GA

Project Number	# Lanes	Length	Cal Days	CDs per lane mile
IM-75-2 (204)	3	17.516	760	7.23
NHS-M001-00 (691)	3 to 4*	10.302	360	5.82 to 4.37
NHS-M000-00 (48)	3	21.300	270	2.11
			AVE =	**4.88**
			StDEV =	2.19

* This project varies from a total of 6 lanes to a total of 8 lanes

Mississippi

The Mississippi Department of Transportation (MDOT) does not produce construction status reports that contain enough information to calculate reliable project durations and lengths. Therefore, MDOT supplied limited data for typical project durations. The MDOT Construction Division provided the UA research team with average construction durations in workdays for the following typical Interstate rehabilitation jobs:

1. Full-Depth PCC pavement repair
2. Diamond grinding
3. Asphalt milling and overlay

Table 3-9 lists the Interstate rehabilitation activities and their expected construction durations for the state of Mississippi.

Table 3-9. Mississippi project durations

Job Description	Ave Duration (WDs)	Length (mi)	# Lanes	WDs per lane mile
Full-Depth PCC pavement repair	4	0.5	2	4.00
Diamond Grinding	2	1	1	2.00
HMAC Milling and Overlay	2	1	1	2.00

Texas

The authors obtained data concerning Texas Interstate project durations and lengths from the Texas Department of Transportation (TXDOT) web site. Most of the data was taken directly from the TXDOT's State Let Construction Recapitulation (TXDOT, 2004). The following data items were recorded for each Interstate rehabilitation or reconstruction project found within the Construction Recapitulation:

1. Project number
2. Project description
3. Facility
4. Project length (miles)
5. Project duration (days)

If the project had not been completed, the data recorded for project duration was the total number of contract working days awarded to that contract after the work began. If the project was completed, the project duration was the total number of working days charged by the contractor after the work began. Projects that contained bridge repair or other miscellaneous time-consuming construction activities were omitted from the data.

The TXDOT Construction Division provided the UA researchers with a digital copy of the plan sets for each project researched. From this data, UA researchers determined the total number of travel lanes on each facility for each project. This data was used to calculate the total number of working days per lane mile required to perform the given reconstruction or rehabilitation activity. For some of the projects, the number of lanes varied throughout the project. The authors used the average number of lanes for each of these projects to determine the total number of working days charged per lane mile. Tables 3-10 through 3-14 show data for each of the projects grouped by the following construction project types:

1. Asphalt resurfacing
2. Full-depth PCC pavement repair
3. PCC pavement rehabilitation (clean and seal joints, grinding, etc.)
4. Construction of two new PCC lanes
5. PCC pavement remove and replace

For each project listed in Tables 3-10 through 3-14, the project number, total number of working days charged, total number of lanes, and the total number of working days charged by the contractor per lane mile of the project is listed. The averages and standard deviation for the total amount of working days charged per lane mile are listed at the bottom of each table. The projects consisting of full-depth concrete repair took the least amount of time to complete, with an average duration of 0.6 working days per lane mile. As expected, the construction of additional concrete lanes took the greatest amount of time to complete with an average of 55 working days per lane mile.

Table 3-10. Asphalt resurfacing projects in TX

Project Number	Project Length (mi)	WDs Allotted	# Lanes	WDs per lane mile
IM 30-4(88)	20.184	167	6	1.379
IMD 20-4(257)	9.262	426	4	11.499
IM 20-1(154)	16.406	120	4	1.829
IM 10-3(100)	19.974	170	4	2.128
IM 35-4(215)	12.445	98	4	1.969
IM 10-4(317)	4.406	77	4	4.369
IM 410-4(316)	6.818	149	4	5.463
IM 10-4(334)	20.061	130	4	1.620
IM 37-1(123)	16.56	150	8	1.132
IM 35E-6(367)	25.813	317	6	2.047
IM 20-1(151)	16.207	194	4	2.993
			AVE =	**3.312**
			StDev =	**3.020**

Table 3-11. Full-depth concrete repair projects in TX

Project Number	Project Length (mi)	WDs Allotted	# Lanes	WDs per lane mile
IM 45-1(316)	21.515	75	6	0.581
IM 45-1(318)	16.463	60	6	0.607
C 9-11-195	25.985	94	4, 6, 8	0.603
			AVE =	**0.597**
			StDev =	**0.014**

Table 3-12. Concrete rehabilitation projects in TX

Project Number	Project Length (mi)	WDs Allotted	# Lanes	WDs per lane mile
IM 45-1(320)	13.940	297	8	2.663
IM 10-1(231)	16.327	480	4	7.350
			AVE =	5.006
			StDev =	3.314

Table 3-13. Construction of additional concrete lanes in TX

Project Number	Project Length (mi)	WDs Allotted	# Lanes	WDs per lane mile
I 35-3(222)	2.835	600	4 to 6	52.910
NH 2000(25)	2.835	651	4 to 6	57.407
			AVE =	55.159
			StDev =	3.180

Table 3-14. Concrete pavement remove and replace in TX

Project Number	Project Length (mi)	WDs Allotted	# Lanes	WDs per lane mile
IM 40-1(181)	6.240	420	4	16.827

Louisiana

The UA research team collected project length and duration data for 15 recently completed Louisiana Interstate rehabilitation projects from the Louisiana Department of Transportation, Construction Division. Each project contained the following information:

1. Project number
2. Project description
3. Route number
4. Number of actual calendar days the project charged after work began
5. Number of lanes

UA obtained data for five types of projects:

1. Asphalt resurfacing
2. PCC pavement rubblization plus asphalt overlay
3. Remove and replace existing PCC pavement
4. PCC pavement rehab and/or repair
5. Patch and seal joints

Tables 3-15 and 3-16 show the project data categorized by project type. The tables show the project number, total number of lanes, project length, total number of charged calendar days after construction began, and the total number of calendar days per lane mile required to complete each project. The average and standard deviation for the total number of calendar days per lane mile for each project type is shown at the bottom of each category in Tables 3-15 and 3-16. The projects consisting of patching and the sealing of joints required the least amount of time to complete with an average of 2.58 calendar days per lane mile. The projects that consisted of removing and replacing the existing concrete pavement required the most amount of time to complete with an average of 46.96 calendar days per lane mile.

North Carolina

The authors obtained data for North Carolina Interstate reconstruction and rehabilitation projects from the North Carolina Department of Transportation (NCDOT) web site. The Construction Progress Report (NCDOT, 2004), located within the NCDOT's web site, contains detailed information on each highway project currently under construction or recently finished. UA researchers collected the following data from NCDOT's Construction Progress Report:

Table 3-15. Asphalt Interstate projects in LA

Asphalt Resurfacing Project Number	Total # Lanes	Length	Charged CDs	CDs per lane-mile
455-05-0098	4	7.9	180	5.70
450-13-0023	4	7.7	56	1.82
455-06-0044	4	4.8	86	4.48
450-90-0160	6	1.8	23	2.13
451-07-0051	4	6.9	130	4.71
454-04-0067	4	5.3	48	2.26
450-18-0089	4	3.6	115	7.99
			AVE =	**4.15**
			StDev =	**2.26**
Rubblization/Overlay Project Number	**Total # Lanes**	**Length**	**Charged CDs**	**CDs per lane-mile**
454-02-0028	4	6.2	80	3.23
450-03-0037	4	10.7	175	4.09
450-91-0076	4	7.9	282	8.92
			AVE =	**5.41**
			StDev =	**3.07**

Table 3-16. Concrete Interstate projects in LA

PCC Remove and Replace Projects	Total # Lanes	Length	Charged CDs	CDs per lane-mile
451-03-0055	4	1.5	374	62.33
451-08-0061	4	1.9	240	31.58
			AVE =	**46.96**
			StDev =	**21.75**
PCC Pavement Rehab Projects	**Total # Lanes**	**Length**	**Charged CDs**	**CDs per lane-mile**
454-01-0067	6	4.1	220	8.94
455-05-0096	4	28.7	186	1.62
			AVE =	**5.28**
			StDev =	**5.18**
Patch and Seal Joints Projects	**Total # Lanes**	**Length**	**Charged CDs**	**CDs per lane-mile**
451-05-0096	4	13.3	137	**2.58**

1. Project number
2. Project length
3. Project description
4. Work began date
5. Revised completion date
6. Percent completed
7. Resident engineer name and telephone number

Data from approximately 24 Interstate reconstruction and/or rehabilitation projects was collected. Projects that contained extensive bridge repair or other miscellaneous time-consuming construction activities were omitted. The resident engineer for each project was contacted to obtain a more detailed job description as well as the total number of travel lanes present on the facility. UA researchers obtained data for the following project types:

1. New asphalt construction
2. Remove and replace existing PCC pavement, add 2 lanes in each direction
3. Asphalt resurfacing
4. Asphalt resurfacing, add two lanes in each direction
5. Bonded concrete overlay, add one PCC lane in each direction

Tables 3-17 through 3-21 group similar projects and show the project number, project length, calendar days allotted after construction began, and total number of calendar days per lane mile of project allotted by the NCDOT to complete the project. The average and standard deviations for the total number of calendar days per lane mile for each project type is shown at the bottom of each category in Tables 3-17 and 3-18. The total number of lanes after construction was used to calculate the total number of calendar days per lane mile required to complete the project for any activity that involved the addition of one or more travel lanes. The projects that involved the reconstruction of existing pavement took the greatest amount of time to complete, such as the removal and replacement of concrete pavement plus additional lanes with an average of 60.1 calendar days allotted per lane mile. The projects consisting of asphalt resurfacing took the least amount of time to complete with an average of 10.1 calendar days per lane mile.

Table 3-17. New asphalt Interstate construction in NC

Project Number	Project Length (mi)	CDs Allotted	Tot # lanes	CDs per lane mile
C105262	4.456	1460	6	54.608
C105272	3.727	1305	6	58.358
C105298	6.447	1490	6	38.519
C200357	2.299	1305	6	94.606
C200475	4.591	1185	6	43.019
			AVE =	**57.822**
			StDev =	**22.110**

Table 3-18. Remove and replace concrete pavement and add additional lanes in NC

Project Number	Project Length (mi)	CDs Allotted	Tot # lanes	CDs per lane mile
C104952	3.125	1395	8	55.800
C105213	1.736	1640	8	118.088
C105216	3.559	1425	8	50.049
C105239	4.848	1425	8	36.742
C105369	4.611	1395	8	37.817
C105556	3.468	1060	8	38.206
C105600	2.543	1335	8	65.621
C200693	2.123	1335	8	78.603
			AVE =	**60.116**
			StDev =	**27.714**

Table 3-19. Asphalt resurfacing projects in NC

Project Number	Project Length (mi)	CDs Allotted	Tot # lanes	CDs per lane mile
C200429	10.246	455	4	11.102
C200584	8.190	300	4	9.158
			AVE =	**10.130**
			StDev =	**1.375**

Table 3-20. Asphalt resurfacing plus construction of four additional lanes in NC

Project Number	Project Length (mi)	CDs Allotted	Tot # lanes	CDs per lane mile
C104975	4.753	1245	8	32.742
C105064	5.800	1395	8	30.065
			AVE =	**31.404**
			StDev =	**1.894**

Table 3-21. Bonded concrete overlay plus construction of additional lanes in NC

Project Number	Project Length (mi)	CDs Allotted	Tot # lanes	CDs per lane mile
C200242	10.837	723	6	11.119

Oklahoma

The authors collected project length and project duration data for Interstate rehabilitation projects from the Oklahoma Department of Transportation (ODOT) web site. The “Award Notices, Highway Construction Contracts” (ODOT, 2004) within the ODOT website contains detailed information on every highway construction job let by ODOT since 2002. The authors gathered data on only the following types of Interstate construction jobs:

1. Asphalt resurfacing
2. Concrete pavement remove and replace
3. Unbonded concrete overlay
4. Concrete pavement rehabilitation

Rehabilitation projects that contained bridge repair or other miscellaneous time-consuming construction activities were purposely omitted. The Award Notices contained the following useful data on each project:

1. Project number
2. Project description
3. Project length
4. Project location
5. Total number of calendar days allotted after the work began

The ODOT Planning Division provided UA researchers with the appropriate number of travel lanes available for each project. This data was used to calculate the total number of calendar days allotted to the contractor per lane mile of Interstate. Tables 3-22 through 3-25 show the project data grouped together by project type. Each table lists the project's number, length, number of calendar days allotted, total number of lanes, and the number of calendar days allotted per lane mile. The tables also show the average value and standard deviation for the number of calendar days per lane mile for each project type. The projects consisting of concrete pavement rehabilitation took the least amount of time to complete with an average of 4.17 calendar days per lane mile. The unbonded concrete overlay projects consumed the greatest amount of time, with an average of 15.99 calendar days per lane mile.

Table 3-22. Asphalt resurfacing projects in OK

Project Number	Project Length (mi)	CDs Allotted	# lanes	CDs per lane mile
IMY-40-1 (65)	4.489	120	4	6.683
IMY-35-2 (277)	4.900	100	6	3.401
IMY-35-2 (278)	6.042	75	4	3.103
IMY-40-6 (285)	8.000	180	4	5.625
IMY-40-2 (115)	7.030	270	4	9.602
IMY-40-1 (68)	5.023	150	4	7.466
IMY-40-3 (63)	1.894	150	4	19.799
NHIY-35-4 (196)	6.159	330	4	13.395
IMY-0040-5 (372)	4.740	195	4	10.285
			AVE =	**8.818**
			StDev =	**5.278**

Table 3-23. Concrete pavement remove and replace projects in OK

Project Number	Project Length (mi)	CDs Allotted	# lanes	CDs per lane mile
IMY-40-4 (381)	6.273	300	4	11.956
IMY-35-1 (101)	7.044	360	4	12.777
IMY-35-1 (100)	7.087	360	4	12.699
IMY-40-6 (286)	6.417	300	4	11.688
			AVE =	**12.280**
			StDev =	**0.541**

Table 3-24. Unbonded concrete overlay projects in OK

Project Number	Project Length (mi)	CDs Allotted	# lanes	CDs per lane mile
IMY-40-4 (382)	3.093	210	4	16.974
NHIY-0035-1 (126)	3.484	215	4	15.428
IMY-35-4 (151)	4.015	250	4	15.567
			AVE =	**15.989**
			StDev =	**0.855**

Table 3-25. Concrete pavement rehabilitation projects in OK

Project Number	Project Length (mi)	CDs Allotted	# lanes	CDs per lane mile
IMC-155N (333)	7.200	60	4	2.083
IMC-167N (84)	6.000	150	4	6.250
			AVE =	**4.167**
			StDev =	**2.946**

North Dakota

UA researchers collected a limited amount of project duration and length data from North Dakota. North Dakota was selected because of the large amount of concrete roadways located within the state. UA collected the data from North Dakota's Project Status Report (NDDOT, 2004), located within the North Dakota DOT's website. The status report supplied brief descriptions of every major highway construction project let within the last four years. The status report contains brief information on each project such as the project number, description, location, and important dates such as the project start and end date.

The authors found data for six concrete reconstruction or rehabilitation projects on North Dakota Interstates. Researchers also contacted the North Dakota DOT Construction Division, which provided the authors with the project length and the total number of lanes on the facility. Table 3-26 shows the project numbers, a description of work, project length, total number of lanes, total number of calendar days after construction began to complete the project, and the total number of calendar days per lane mile to complete the project. The North Dakota DOT

Construction Division provided researchers with a very detailed description of the type of concrete pavement work that was completed. Each project had slight differences in the type of work that was done; therefore, all of the concrete projects are listed in the same table.

Table 3-26. Concrete Interstate projects in North Dakota

Project No.	Type of Work	Length (miles)	No. of Lanes (Total)	Total CDs	CDs per Lane Mile
AC-IM-1-094(069)128	Pavement Reconstruction w/Continuously Reinforced Concrete, Selective Grading	8.9	4	165	4.63
AC-IM-1-094(067)128	Pavement Reconstruction w/Continuously Reinforced Concrete, Selective Grading	8.9	4	190	5.34
IM-2-094(047)240	Pavement Reconstruction w/Jointed Concrete and Dowel Bar Ties, Grading	7.9	4	90	2.85
IM-2-094(055)305	Pavement Reconstruction w/Jointed Concrete and Dowel Bar Ties, Grading, Interchange Ramps HBP Mill & Overlay	9.8	4	443	11.30
IM-2-094(059)248	Concrete Pavement Repair, Dowel Bar Retrofit, Diamond Grinding, Joint Sealing, Safety Improvements	10.5	4	140	3.33
IM-2-094(057)209	Concrete Pavement Repair, Dowel Bar Retrofit, Diamond Grinding, Joint Sealing, Selective Pavement Replacement, Selective HBP Mill & Overlay	18.4	4	73	0.99

Iowa

The UA research team obtained reliable information on project duration determination for highway rehabilitation activities from the Iowa Department of Transportation "Bid Letting Guidelines" (IADOT, 1998). This document contained helpful information for estimating contract periods. The contract period is defined as the "time period allowed in the contract for completion of all work contained in the contract documents" (IADOT, 1998). This is essentially the number of working days the agency allots to the contractor to fully complete the work after the work began date. Type of work, traffic volumes, staging requirements, and project complexity all affect contract period, as do environmental constraints, availability of materials, and coordination with other construction projects.

The Iowa Bid Letting Guidelines also contained tables that presented average daily (12-hr workday) construction rates for many different types of activities. Table 3-27 lists Iowa's suggested daily construction rates for asphalt resurfacing, longitudinal joint repair, full-depth PCC repair, new PCC pavement, and pavement removal.

Table 3-27. Iowa construction rates

Construction Activity	Rate
Asphalt resurfacing	1500 tons/day
Longitudinal joint repair	3000 LF/day
Full-depth PCC patches	110 SY/day
New PCC pavement	4000 SY/day
Removal of pavement (<20,000 SY)	1000 SY/day
Removal of pavement (>20,000 SY)	4000 SY/day

Work Zone Configuration Investigation

The authors investigated the feasibility of collecting data related to work zone configurations such as specific lane-closure scenarios (single-lane closure, median crossover, etc.), work zone schedules (night time work, entire roads closed for a weekend, reduced hours of work, etc.), and work zone lengths for Interstate construction projects. UA researchers and the Project Advisory Committee met and decided that data concerning work zone schedules and lane-closure scenarios should not be researched. The group decided that work zone configurations and schedules are changing so rapidly that they cannot be predicted for projects 12 or more years in the future, such as those being modeled when performing a LCCA. Specific information regarding work zones can only be acquired on a project-by-project basis and only acquired shortly before work begins. Work zone hours and lane closure scenarios are determined by examining traffic demand, construction phasing, weather, and other local factors. As such, it was concluded that the ALDOT employee performing the LCCA should consult with the ALDOT Design group, then make an informed estimate regarding work zone configuration on a project-by-project basis. A discussion of common work zone configurations for various construction activities is provided in Section 2.10 of Section 2, "Literature Review."

UA researchers consulted with the ALDOT Construction Division and ST Bunn Construction Company concerning typical work zone lengths for Interstate reconstruction and rehabilitation activities. It was determined that almost all Interstate projects set up a work zone the entire length of the project. The authors also determined that ALDOT prohibits a single-lane closure longer than three miles on any section of Interstate for a given direction. Other lane closure restrictions are made on a project-by-project basis.

Production Rates Data Collection

AL Asphalt Paving Association Data

The authors met with the Executive Director of the Alabama Asphalt Pavement Association to discuss production rates for asphalt pavement rehabilitation activities such as milling and asphalt overlays. He provided UA researchers with valuable information on production rates, factors that may affect production rates, and contacts at construction companies that provided additional insight into these matters.

ALDOT uses two major types of asphalt Interstate rehabilitation activities:

- Asphalt overlay
- Planing (milling) plus an asphalt overlay

Milling may be required prior to an asphalt overlay, depending upon the extent of pavement deterioration. In these cases, the milling machine starts working on the roadway one to two hours before the asphalt overlay work begins. The roadway is first milled to a specified depth and then swept clean. Next, a tack coat is applied, and the road is ready for the overlay.

The asphalt overlay operation consists of dump trucks continuously loading asphalt pavement into the paving machine/spreader as it spreads the new asphalt on the roadway at a specified thickness. In most cases, approximately 2000 tons of asphalt can be applied per day by each spreader. At this production rate with standard 12-foot lanes and an asphalt density of about 2.0 tons per cubic yard, it is possible to apply three inches of asphalt to almost two lane miles per day. Production rates often vary depending on the trucking capacity, because usually the asphalt plants produce more asphalt than the trucks can carry. Thus, trucking capacity often determines the production speed. Once the asphalt has been laid and thoroughly rolled, core samples are taken to verify that the asphalt has been sufficiently compacted. The roadway is able to carry traffic within three or four hours after paving. However, most contractors do not open any of the newly paved roadway until at least one mile has been completed.

National Highway Institute

UA researchers contacted Pave Tech, which prepared two pavement rehabilitation courses for the National Highway Institute (NHI), to obtain duration data for various concrete Interstate reconstruction and rehabilitation activities. Pave Tech could not provide production data. Instead, it recommended contacting the American Concrete Pavement Association for specific information on production rates or project durations.

American Concrete Pavement Association Data

The authors met with the Alabama Director of the American Concrete Pavement Association (ACPA), Southeast Chapter, to discuss production rates for typical concrete pavement rehabilitation activities for Alabama Interstates. A list of the major concrete pavement rehabilitation activities that are currently performed on Alabama Interstates or have been modeled in an ALDOT LCCA follows:

1. Full-depth repair
2. Diamond grinding
3. Joint cleaning and resealing
4. Remove and replace existing pavement
5. Unbonded concrete overlay

ACPA supplied the UA research team with reliable average production rate values for each of the above activities. The information came from other ACPA representatives as well as various Southeastern concrete contractors. Concrete rehabilitation production rates may vary due to weather, contactor's incentive, traffic demand, amount of existing pavement distresses, and other factors.

Full-Depth Repair

Full-depth concrete repair involves the repairing or replacing of severely distressed sections of concrete pavement. The full-depth repair is essentially a patch that extends from the surface down to the aggregate base. On average, 80 cubic yards of PCC pavement can be full-depth repaired per 12-hour workday.

Grinding

Diamond grinding is a procedure used to restore or improve pavement rideability. Diamond grinding can remove bumps from new pavements as well as reprofile rough lanes. It is often performed to remove the following conditions: faulting, surface deformations, inadequate slope for drainage, and excessive surface polishing (ACPA, 1990). Grinding is usually performed one lane at a time with three four-foot wide machines working simultaneously. Each machine is equipped with many diamond saw blades gang mounted on a cutting head. Three machines working together can grind approximately 1.5 lane-miles per 12-hour workday.

Joint Cleaning and Resealing

All concrete pavements on Alabama Interstates contain both transverse and longitudinal joints. The joints must be periodically cleaned and resealed to prevent water and foreign objects from entering the pavement structure. Contractors in Alabama can clean and seal transverse joints at a rate of approximately 5000 linear feet per 12-hour shift. Longitudinal joints can be cleaned and sealed at an average rate of 10,000 linear feet per 12-hour shift. Both of these activities are usually done simultaneously. Many times, concrete roadways have asphalt shoulders. In these cases, the joint between the concrete lane and asphalt shoulder can be cleaned and sealed about 5 miles per 12-hour shift.

Remove and Replace

Sometimes the original pavement condition has deteriorated to the extent that the entire concrete pavement must be removed and replaced. On average, 3000 linear feet of 12-foot wide slabs of jointed plain concrete pavement (JPCP) can be removed and replaced per 12-hour shift. Alabama only uses JPCP for concrete roadways.

Unbonded Concrete Overlay

An unbonded concrete overlay is an effective solution for cases when the existing concrete pavement is in the advanced stages of deterioration. An unbonded concrete overlay is one alternative to rubblizing the pavement and overlaying it with asphalt. An unbonded concrete overlay is nothing more than placing new concrete pavement on top of the old, deteriorated concrete pavement, except that there is an inner layer (unbonding layer) of asphalt between the two concrete layers. The inner asphalt layer is usually two inches thick. During construction, contractors make sure not to line up the joints of the two concrete layers. Most unbonded concrete overlay projects require minimal pre-overlay repairs. On average, unbonded concrete overlays can be constructed at the rate of one lane mile per 12-hour workday.

Contractor Data

The authors interviewed seven contractors to get further input on typical production rates for Interstate reconstruction and rehabilitation activities.

ST Bunn Construction

UA researchers consulted with ST Bunn Construction Company concerning typical production rates for asphalt Interstate milling and overlay operations. ST Bunn Construction was responsible for several of the construction projects presented in Section 3.2. The company lays approximately 1200 tons of asphalt per 12-hour workday for most Interstate asphalt overlay projects. At this production rate with standard 12-foot lanes and an asphalt density of 2.0 tons per cubic yard, it is possible to apply three inches of asphalt to over one and a half lane miles per day.

Racon Incorporated

UA researchers contacted Racon Inc. to inquire about typical production rates for asphalt Interstate overlays. Racon indicated that for most asphalt overlays on Interstates in Alabama, about 1500 to 2000 tons of asphalt can be applied per 12-hour work day. The thickness of the asphalt layer being applied determines how many lane miles can be accomplished per day.

Mobile Asphalt Company

The authors consulted with the Mobile Asphalt Company concerning typical production rates for asphalt Interstate overlays. The Mobile Asphalt Company can lay approximately 1500 tons of asphalt per work day, assuming that the asphalt plant is within about 20 miles of the project and there is a sufficient number of trucks delivering the asphalt to the site. Their representative indicated that with an average production rate of 1500 tons per day, a one-inch thick wearing surface can be applied to about 3.5 lane miles per day. If the owner wishes to apply a 3-inch thick layer of asphalt, Mobile Asphalt can expect to complete over one lane mile per day. The Company indicated that sometimes asphalt overlay work is performed only at night, especially in heavily populated urban areas. For these cases, it is possible to apply about 1000 tons of asphalt per night shift. A typical night shift may be from 9:00 PM to 6:00 AM.

Resonant Machines, Inc.

Rubblization is the process of fracturing concrete pavement into small pieces. The fractured pieces of concrete range in size from a fraction of an inch on top to almost nine inches on the bottom of the slab. The fractured pieces have an angular interlock, making the rubblized concrete pavement a very strong base layer for an asphalt overlay. Rubblization followed with an asphalt overlay is the alternative to removing and replacing a deteriorated concrete pavement at the end of its useful life.

The authors consulted with Resonant Machines Inc. about typical production rates for the rubblization of concrete Interstates or major divided highways. Resonant Machines Inc. performs most of the rubblizing projects throughout the United States, and they indicated that one rubblizing machine can fully rubblize about one lane mile per workday, or about 7000 square yards per work day. If the agency wishes to spend additional money and use two machines, two lane miles can be completed per 12-hour workday.

Uretek USA, Inc.

Slab stabilization, also known as undersealing or pressure grouting, is the pressure insertion of a material beneath a concrete slab of PCC pavement for the purpose of filling voids beneath the slab and to provide a thin layer that reduces deflections and resists pumping. The material used for slab stabilization may be cement grout or polymer resin. Uretek uses a high-density polymer resin material to underseal and also lift and realign the affected concrete slab. Uretek indicated that they underseal jointed plain PCC pavement at the average rate of one half a lane mile per workday. Uretek also indicated that if a cement grout is used, only 250 linear feet could be completed per workday.

Scruggs Company

Researchers consulted with Scruggs Company about production rates for typical concrete pavement rehabilitation activities. The construction activities and their expected production rates obtained from the Scruggs Company representative follow:

- Remove and replace concrete pavement: 2000 SY / workday (12 hr)
- Full-depth concrete repair: 225 CY / workday (12 hr)
- Joint cleaning and resealing: 3500 LF / workday (12 hr)

Gilbert Texas Construction

The author consulted with Gilbert Texas Construction about the typical production rate for removing and replacing existing concrete pavement on Interstate highways. Their representative indicated that it is possible to remove and replace about 4000 square yards of concrete pavement per 12-hour workday.

Section 4
Duration Data Analysis

Collecting data concerning the duration of Interstate reconstruction and rehabilitation activities was the focus of this research. Project duration is a key factor involved in calculating user costs or in simply quantifying the amount of time the user will be affected by the construction activity. Calculating user costs often helps analysts eliminate a project alternative if the LCCA agency costs are very close. Comparison of vehicle queue lengths also may affect the selection of construction alternatives.

This chapter analyses the data collected and presented in Section 3, “Methodology and Results.” It also compares the queue lengths calculated by RealCost v. 2.1 and the Oklahoma DOT capacity spreadsheet.

Project Duration Comparisons

State comparisons

UA researchers consulted several state departments of transportation to obtain project durations for Interstate reconstruction and rehabilitation activities. In most cases, researchers obtained construction progress reports detailing all current or recently completed highway construction projects in their respective states.

Each state’s construction progress reports, with the exception of Alabama and Texas, listed the project durations in calendar days. Both ALDOT and the Texas Department of Transportation presented the project duration within their construction status reports as “working days.” For the sake of comparison, UA researchers converted the total amount of working days to calendar days by multiplying the working days by two because ALDOT assumes that there are approximately 180 working days in a typical year. Although this conversion may not be the same in every state, the author used this value lacking precise conversion data for every state.

Table 4-1 displays the average and standard deviation for the total number of calendar days allotted and/or charged per lane mile for typical asphalt resurfacing projects in each state. The table also shows the total number of asphalt resurfacing projects researched for each state and the weighted average for the number of calendar days allotted (7.55 CDs per lane mile). North Carolina had the highest duration at 10.13 calendar days per lane mile, while Alabama showed the greatest variation in data. Louisiana allotted the least amount of time to complete resurfacing projects at 4.16 calendar days per lane mile.

Table 4-1. Asphalt resurfacing project durations

State	Ave CDs per Lane Mile	Standard Deviation of CDs	Number of Projects
Alabama*	8.64	7.70	19
Georgia	6.74	3.96	4
Texas*	6.62	6.04	11
Louisiana	4.16	2.26	7
North Carolina	10.13	1.38	2
Oklahoma	8.82	5.28	9

Weighted Average = 7.55 CDs / lane mile; *data converted from WDs to CDs

Table 4-2 shows the average and standard deviation for the total number of calendar days allotted per lane mile by each state for typical concrete rehabilitation activities such as diamond grinding and cleaning and resealing joints. The table also shows the total number of concrete rehabilitation projects researched from each state and the weighted average for the number of calendar days allotted (5.51 CDs per lane mile). There is wide variation in the average number of calendar days allotted. Alabama had the least with 3.81 calendar days per lane mile, while Texas had the most with 10.01 calendar days per lane mile. This large variation may be due to the wide variety of projects that can fall under the heading of "concrete pavement rehabilitation" and the limited number of concrete rehab projects collected.

Table 4-2. Concrete pavement rehabilitation project durations

State	Ave CDs per Lane Mile	Standard Deviation of CDs	Number of Projects
Alabama*	3.81	2.26	2
Georgia	4.88	5.06	4
Texas*	10.01	6.63	2
Louisiana	5.28	5.18	2
Oklahoma	4.17	2.95	2

Weighted Average = 5.51 CDs / lane mile; *data converted from WDs to CDs

Table 4-3 displays the average and standard deviations of the number of calendar days allotted per lane mile for full-depth concrete pavement repairs by each state. The table also lists the number of projects researched for each state. Unfortunately, The authors were only able to collect data from the states of Mississippi and Texas. Mississippi allots about eight calendar days per lane mile for full-depth concrete repair, while Texas averaged 1.19 calendar days per lane mile. Researchers recommend allotting about 4.5 calendar days per lane mile for full-depth concrete repairs. This value is the average of the two values listed in Table 4-3. It should be noted that the actual duration of full-depth concrete repairs is dependent on the number of deteriorated sections per lane mile.

Table 4-3. Full-depth concrete pavement repair durations

State	Average CDs per Lane Mile	Standard Deviation of CDs	Number of Projects
Mississippi	8.00	N/A	N/A
Texas*	1.19	0.028	3

*data converted from WDs to CDs

Table 4-4 shows the average and standard deviations for the number of calendar days allotted to the contractor to remove and replace existing concrete pavement. The table also displays the number of projects researched from each state and the weighted average for the number of calendar days allotted (18.26 CDs per lane mile). Louisiana allotted the longest amount of time with an average of 46.96 calendar days per lane mile, while North Dakota allotted only 6.03 calendar days per lane mile.

Table 4-4. Concrete pavement remove and replace durations

State	Average CDs per Lane Mile	Standard Deviation of CDs	Number of Projects
Texas*	33.65	N/A	1
Louisiana	46.96	21.75	2
Oklahoma	12.28	0.54	4
North Dakota	6.03	3.67	4

Weighted Average = 18.26 CDs / lane mile; *data converted from WDs to CDs

Agency time allotted vs. contractors data

The authors collected project duration data for various Interstate reconstruction and rehabilitation activities from two sources: state departments of transportation (DOTs) and construction companies. As discussed previously, project duration data from the DOTs came primarily from highway construction progress reports, which contain the amount of time the agency allotted to the contractor to complete the work. In most cases, the agency allotted a rather conservative (large) window of time to complete the project. The production rates at the work site acquired from contractors and national agencies was generally less than the amount of time allotted to the contractor by the agency. For example, the average number of calendar days allotted to the contractor to complete a typical asphalt Interstate resurfacing project was 7.55 calendar days per lane mile. This value is the average number of calendar days calculated for all of the states combined. However, data acquired from construction companies showed that if a three-inch layer of asphalt is applied, at least 1.5 lane miles could be completed per 12-hour workday.

Table 4-5 compares the average project durations, calculated from all of the states combined, to the average expected production rates collected from the construction companies and agencies for the following activities:

- Asphalt resurfacing
- Concrete pavement rehabilitation (grinding and/or joint cleaning and resealing)
- Concrete pavement remove and replace
- Concrete pavement rubblization plus an asphalt overlay

Full-depth concrete repair is omitted from Table 4-5 because the actual production rates are dependent on the number of square yards of pavement to be repaired. The value of two workdays per lane mile for the production rate of the concrete pavement rubblization plus an asphalt overlay was determined by adding one workday per lane mile for the rubblization plus one workday per lane mile for the asphalt overlay. The two work days per lane mile value is conservative in that it assumes that the rubblization and resurfacing activities do not take place concurrently.

Table 4-5. Project duration comparisons

Construction Activity	Average Time Allotted to Contractor by DOTs	Actual Expected Production Rate by Contractors
Asphalt resurfacing	7.55 CDs / lane mile	0.67 workdays / lane mile (3" lift)
Concrete rehabilitation	5.51 CDs / lane mile	1.5 workdays / lane mile
Concrete remove and replace	18.26 CDs / lane mile	2 workdays / lane mile
Concrete rubblization + asphalt overlay	16.58 CDs / lane mile	2 workdays / lane mile

Table 4-5 confirms that the agency typically allots more time to complete a project than the on-site construction time needed to complete the construction task.

UA researchers determined that the time the DOT allots to the contractor (middle column of Table 4-5) may be used as the maximum amount of time needed to complete a specific construction task, i.e., the total number of days that motorists can expect a reduced speed limit for the length of the project. The actual production rates for construction tasks (far right column of Table 4-5) may be considered the minimum time needed to complete such work, i.e., the time that a lane closure will be in place.

Project Duration Statistics

UA researchers gathered enough data for the allotted duration of asphalt Interstate resurfacing to produce a probability plot to yield estimates of the Weibull distribution parameters. The probability plot also provides a graphical picture and a quantitative estimate of how well the distribution fits the collected data. Researchers also produced probability plots yielding the estimates of the Normal and Lognormal distribution parameters, but chose to present the Weibull probability plot because the data fit the Weibull distribution more accurately. The authors used the asphalt resurfacing duration data from the Alabama, Georgia, Louisiana, North Carolina, Texas, and Oklahoma Departments of Transportation. The duration data obtained from Alabama and Texas was converted from the number of workdays per lane mile to the approximate number of calendar days per lane mile.

The authors employed the "least squares" method of probability plotting to determine the two parameters of the Weibull distribution using E.E. Lewis's, "Introduction to Reliability Engineering," (Lewis, 1994). The method consists of transforming the equation for the cumulative distribution function (CDF) to a form that can be plotted as: $y = ax + b$, where a is the slope and b is the y-axis intercept. A straight line can be constructed through the data, and the distribution parameters can be determined in terms of the slope and the intercept.

UA researchers fit the data for the total amount of calendar days allotted per lane mile of asphalt resurfacing to the Weibull distribution. First, the data was listed in rank order. Next, F(t) was estimated via the mean rank method from (Lewis, 1994),

$$F(t) = i / N+1,$$

where i = data point number and N = total number of data points.

Next, UA researchers utilized the least squares method to fit the data to the Weibull distribution. The CDF with respect to time is given by (Lewis, 1994):

$$F(t) = 1 - \exp[-(t/\theta)^m], \ \ 0 \le t \le \infty.$$

The distribution was then put in a form for probability plotting by solving for 1 / (1 – F(t)) and then taking the natural logarithm twice to obtain,

$$\ln[\ln[1/ 1\text{-}F(t)]] = m\ln t - m\ln\theta.$$

This can be set into the form of y = ax + b if,

$$y = \ln[\ln[1/ 1\text{-}F(t)]]$$

and

$$x = \ln(t).$$

Once the data is plotted, the shape parameter of the Wiebull distribution, m, is equal to the slope

$$m = a,$$

and the scale parameter, θ, is estimated in terms of the slope and the y intercept by

$$\theta = \exp(-b/a).$$

Table 4-6 shows the spreadsheet for the Wiebull probability plot for the total number of calendar days allotted per lane mile as described above. The values with the asterisk represent data converted from workdays to calendar days. Figure 4-1 shows the probability plot of the Weibull distributed asphalt resurfacing duration data. The equation of the regression line is shown:

$$y = 2.0146x - 4.2218$$

The regression line has an R squared value of 0.9692, which indicates a very good fit to the Weibull distribution.

Table 4-6. Weibull probability plot for calendar days per lane mile

i	t	F(t)=(i/(N+1))	x = LN(t)	y=LN(LN(1/(1-F)))
1	1.8182	0.0196	0.5978	-3.9219
2	2.1296	0.0392	0.7559	-3.2187
3	2.2642	0.0588	0.8172	-2.8031
4*	2.2645	0.0784	0.8174	-2.5050
5*	2.7580	0.0980	1.0145	-2.2712
6	3.1033	0.1176	1.1325	-2.0781
7	3.2019	0.1373	1.1638	-1.9130
8*	3.2392	0.1569	1.1753	-1.7683
9*	3.2401	0.1765	1.1756	-1.6391
10	3.4014	0.1961	1.2242	-1.5221
11*	3.6572	0.2157	1.2967	-1.4149
12*	3.9373	0.2353	1.3705	-1.3158
13*	4.0935	0.2549	1.4094	-1.2234
14*	4.2555	0.2745	1.4482	-1.1366
15	4.3254	0.2941	1.4645	-1.0547
16	4.4792	0.3137	1.4994	-0.9769
17	4.7101	0.3333	1.5497	-0.9027
18*	4.8826	0.3529	1.5857	-0.8317
19*	5.1761	0.3725	1.6441	-0.7634
20*	5.4741	0.3922	1.7000	-0.6975
21	5.6250	0.4118	1.7272	-0.6337
22	5.6962	0.4314	1.7398	-0.5718
23*	5.9851	0.4510	1.7893	-0.5115
24*	6.5089	0.4706	1.8732	-0.4526
25*	6.5217	0.4902	1.8751	-0.3949
26	6.6830	0.5098	1.8996	-0.3383
27*	6.6863	0.5294	1.9001	-0.2827
28*	6.9638	0.5490	1.9407	-0.2277
29	7.3529	0.5686	1.9951	-0.1734
30	7.4657	0.5882	2.0103	-0.1196
31*	7.5198	0.6078	2.0175	-0.0660
32*	7.9597	0.6275	2.0744	-0.0127
33	7.9861	0.6471	2.0777	0.0406
34*	8.7381	0.6667	2.1677	0.0940
35	9.1575	0.6863	2.2146	0.1478
36*	9.3125	0.7059	2.2314	0.2019
37*	9.5427	0.7255	2.2558	0.2568
38	9.6017	0.7451	2.2619	0.3125
39*	10.0890	0.7647	2.3114	0.3694
40	10.2848	0.7843	2.3307	0.4278
41*	10.6221	0.8039	2.3629	0.4881
42*	10.9270	0.8235	2.3912	0.5508
43	11.1019	0.8431	2.4071	0.6165
44*	12.0334	0.8627	2.4877	0.6861
45	12.0602	0.8824	2.4899	0.7608
46*	12.3549	0.9020	2.5141	0.8426
47*	12.4750	0.9216	2.5237	0.9343
48	13.3950	0.9412	2.5949	1.0414
49*	17.7015	0.9608	2.8736	1.1752
50	19.7994	0.9804	2.9856	1.3691

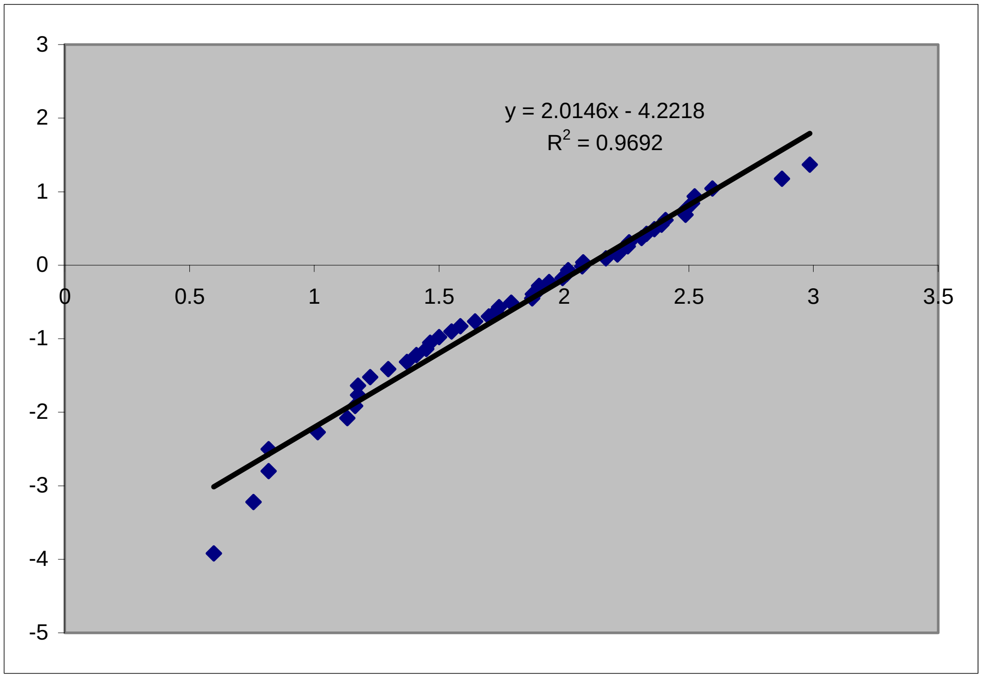

Figure 4-1. Probability plot of Weibull distributed data

The equation of the regression line was used to determine the two parameters for the Weibull distributed data. The shape parameter, m, was determined to be 2.0146. The scale parameter, θ, was calculated to be 8.1303. Given that the total number of calendar days allotted to finish the asphalt resurfacing project is distributed as a Weibull, the shape and scale parameters can be used to estimate the duration of a given resurfacing project at a certain probability. For example, with the given parameters, there is a 31% chance that the DOT will allot 5 or fewer calendar days per lane mile, and a 78% chance that the DOT will allot 10 or fewer calendar days per lane mile for a typical asphalt Interstate resurfacing job.

The Weibull distribution parameters, θ and m, can also be used to determine the expected value, or mean value for the number of calendar days allotted per lane mile. The equation for the expected value follows:

$$E(x) = \theta\Gamma(1 + 1/m)$$

The authors calculated the expected number of calendar days allotted per lane mile for asphalt resurfacing projects to be 7.20 calendar days. Thus, Weibull analysis recommends allotting approximately 7 calendar days per lane mile to complete asphalt resurfacing projects. This value is very similar to the value of 7.55 calendar days per lane mile from Table 4-5.

UA researchers did not produce similar statistical results for the concrete pavement rehabilitation activities because there were insufficient data points to perform viable statistical research.

Section 5
Queue Length Calculator Comparison

Many state DOTs consider the length of the queue that develops under forced-flow conditions at a work zone as part of their decision criteria when conducting a life-cycle cost analysis or formulating a traffic control plan. To calculate if a queue will be present and then find the length of the queue, the analyst must have the following inputs:

- AADT
- Percent trucks
- Traffic hourly distribution
- Hours of lane closure(s)
- Total number of lanes
- Number of closed lanes
- Free flow speed
- Lane capacity
- Directional distribution (% outbound vs. % inbound)

The authors examined and compared two software programs that are capable of calculating hour-by-hour queue lengths:

- RealCost v.2.1
- Oklahoma Department of Transportation (ODOT) capacity spreadsheet. ALDOT uses this program to perform its queue analysis.

Both programs are Microsoft Excel based spreadsheet programs that provide an hour-by-hour listing of potential queue lengths. Both programs require the input data described in the bullets above. Directions for operating RealCost v.2.1 and determining where the queue lengths are displayed are given in (Lindly and Clark, 2003). The ODOT capacity spreadsheet is a simple spreadsheet program containing only three worksheets. Two worksheets contain shaded input spaces that are clearly marked, while the third worksheet contains only the outputs. Appendix 1 shows an example of the worksheet that contains the queue lengths calculated by the ODOT capacity spreadsheet.

UA researchers compared the queue lengths calculated by both software programs for the following four scenarios using the default hourly distributions and the default directional factors from FHWA's RealCost v.2.1 in both programs:

1. Urban 6-lane Interstate (outbound direction)
    a. AADT = 75,000
    b. 12% trucks
    c. Single lane closure from 6 AM to 6 PM
    d. 70 mph free-flow speed
    e. 2400 passenger cars per-hour-per-lane (pcphpl) normal capacity

2. Urban 6-lane Interstate (inbound direction)
    a. AADT = 75,000
    b. 12% trucks
    c. Single lane closure from 6 AM to 6 PM
    d. 70 mph free-flow speed
    e. 2400 passenger cars per-hour-per-lane (pcphpl) normal capacity
3. Rural 4-lane Interstate (outbound direction)
    a. AADT = 45,000
    b. 12% trucks
    c. Single lane closure from 6 AM to 6 PM
    d. 70 mph free-flow speed
    e. 2400 passenger cars per-hour-per-lane (pcphpl) normal capacity
4. Rural 4-lane Interstate (inbound direction)
    a. AADT = 45,000
    b. 12% trucks
    c. Single lane closure from 6 AM to 6 PM
    d. 70 mph free-flow speed
    e. 2400 passenger cars per-hour-per-lane (pcphpl) normal capacity

Table 5-1 compares the queue lengths calculated by both software programs for the first scenario listed above. Both programs showed that queues developed between the hours of 4 PM and 7 PM. The longest queue calculated was by the ODOT program at 2.4 miles, between the hours of 5 PM and 6 PM. The shortest queue displayed by RealCost was 0.4 miles, between the hours of 4 PM and 5 PM.

Table 5-1. Outbound Urban Queue Comparisons

Time	RealCost Queue Length (mi)	ODOT Queue Length (mi)
4 PM – 5 PM	0.4	0.8
5 PM – 6 PM	2.1	2.4
6 PM – 7 PM	1.9	1.4

Table 5-2 shows the queue lengths determined by both programs for the second scenario described above: 6-lane Interstate with inbound directional factors. The queue lengths calculated by both programs were similar, though the ODOT program gave consistently higher results. Significant queues developed between the morning rush hours of 7 AM and 11 AM.

Table 5-2. Inbound Urban Queue Comparisons

Time	RealCost Queue Length (mi)	ODOT Queue Length (mi)
7 AM – 8 AM	0.8	1.1
8 AM – 9 AM	1.2	1.3
9 AM – 10 AM	0.5	1.1
10 AM – 11 AM	0.0	0.2

Table 5-3 compares the queue lengths that were calculated by both software programs for the third scenario discussed above: 4-lane rural Interstate with the outbound directional factors. The ODOT capacity spreadsheet calculated significantly longer queues than RealCost v.2.1. The ODOT program also estimated that queues would form between the hours of 11 AM and 2 PM, while the FHWA program did not.

Table 5-3. Outbound Rural Queue Comparisons

Time	RealCost Queue Length (mi)	ODOT Queue Length (mi)
11 AM – 12 PM	0.0	0.1
12 PM – 1 PM	0.0	0.2
1 PM – 2 PM	0.0	0.6
2PM – 3 PM	0.0	1.2
3 PM – 4 PM	0.1	1.9
4 PM – 5 PM	1.5	3.9
5 PM – 6 PM	3.4	5.1
6 PM – 7 PM	2.6	4.1

Table 5-4 displays the queue lengths calculated by both programs for the fourth scenario described above: 4-lane rural Interstate with inbound directional factors. Both programs showed extensive queues between 2 PM and 7 PM. However, the ODOT capacity spreadsheet calculated longer queue lengths each hour than FHWA's RealCost v.2.1. Also, the ODOT program calculated queues that developed between noon and 2 PM, while the FHWA program did not.

Table 5-4. Inbound Rural Queue Comparisons

Time	RealCost Queue Length (mi)	ODOT Queue Length (mi)
12 PM – 1 PM	0.0	0.4
1 PM- 2 PM	0.0	1.0
2 PM – 3 PM	0.2	1.8
3 PM – 4 PM	0.8	2.9
4 PM – 5 PM	2.4	4.7
5 PM – 6PM	3.2	5.0
6 PM – 7 PM	1.9	3.9

Both software programs calculated similar queue lengths for the urban scenarios, but queue lengths were quite different for the rural scenarios. In all cases, the ODOT capacity spreadsheet calculated longer queues than the FHWA computer program. UA researchers recommend that ALDOT continue evaluating queue lengths with the ODOT capacity spreadsheet for two reasons: 1) it is easier to use than the FHWA program, and 2) the ODOT queue length values are higher than those of the FHWA program, providing a more conservative approach.

Section 6
User Cost Example

Much of this report has focused on collecting project duration data for Interstate reconstruction and rehabilitation activities. Researchers also used the data to calculate the user costs that result from one typical rehabilitation activity. The example calculation used RealCost v.2.1 to model the first major rehabilitation activity for the asphalt alternative of ALDOT project number IM-65-1 (264), the reconstruction of the 1.4-mile section of Interstate 65 from Fairview Avenue to the Alabama River in Montgomery, AL. The example calculation was performed using only deterministic inputs rather than probabilistic inputs because of the inherent limitations with the FHWA LCCA software described below.

RealCost v. 2.1 Limitations

The authors determined that it is not possible to obtain completely accurate results for the determination of user costs when performing a probabilistic LCCA with FHWA's RealCost v.2.1. An analyst using the FHWA program must enter the following work zone information for the initial construction and all subsequent rehabilitation activities for each alternative:

- Work zone duration (days)
- Number of lanes open
- Work zone length (miles)
- Work zone speed limit (mph)
- Work zone capacity (vehicles per hour per lane)
- Time of day of lane closures (ex. 6 AM to 6 PM)

If an analyst indicates that the work zone duration is 20 days and enters a single-lane closure between 6 AM and 6 PM, then the FHWA program assumes that the 12-hour single lane closure is in effect for each of the 20 days. In reality, the work zone might be in place for 20 days, but there probably will not be a lane closure in place within the work zone for each of the 20 days. This situation leads RealCost v.2.1 to calculate inflated user costs.

Section 4 described two kinds of project duration data collected by the UA research team:

- Time allotted to contractor
- Actual production rates

The time allotted to the contractor typically describes the total time that the work zone is in place with reduced speed limit signs. The actual production rate describes the time when, in addition to reduced speed limits, there is a lane closure of some kind. Consider the asphalt overlay of two lane miles of a 4-lane Interstate. The agency will allot approximately 14 calendar days to complete the task, but the work will only require a lane closure for two 12-hour workdays. As such, a work zone may be in place for two weeks with a reduction in speed, but a lane will be closed for only two 12-hour workdays. RealCost v.2.1 does not allow this type of work zone modeling when performing a probabilistic LCCA.

If user costs are desired, the authors suggest calculating them deterministically using RealCost v.2.1 by calculating the user costs for the "speed reduction only" and the "work zone in place" scenarios separately, then adding them as described below.

User Cost Example for the Montgomery Project

UA researchers calculated the user costs and compared them to the agency costs for the asphalt overlay of the 1.4-mile, 3-lane, outbound section of I-65 in Montgomery, AL. All construction costs were acquired from the ALDOT Assistant Materials Engineer. Traffic data such as ADT, percent trucks, and hourly distribution used to calculate user costs was acquired from the ALDOT Transportation Planning Bureau. UA researchers assumed that there would be a single-lane closure between the hours of 6 AM and 6 PM. The work zone duration values used for the user cost calculation were obtained from the data described in Sections 3 and 4 and consisted of five work days involving a lane closure and a total of 30 calendar days when only work zone signs would be present and a reduced speed limit would be in place.

The deterministic total user costs for the asphalt overlay were determined by adding the user costs calculated by RealCost v.2.1 for the following separate scenarios:

- 5 days of single lane closures between 6 AM and 6 PM (only 2 of 3 lanes open)
- 25 days where all 3 lanes are open, but a reduced speed limit (from 70 mph to 55 mph) is in place for 24 hours each day

Table 6-1 shows the individual user cost components calculated for the single lane closure scenario described above. Most of the user costs are attributed to the added travel time required by the queues that developed.

Table 6-1. Single-lane closure for 5 days

Cost Component	Cost	Percent
WZ Speed Change VOC	$6,306	3%
WZ Speed Change Delay	$6,193	3%
WZ Reduced Speed Delay	$10,343	5%
Queue Stopping Delay	$7,857	4%
Queue Stopping VOC	$9,775	5%
Queue Added Travel Time	$148,201	75%
Queue Idle Time	$8,210	4%
Total Cost	$196,886	100%

Table 6-2 shows each of the user cost components from the reduced speed limit only scenario described above. No queue developed because all of the lanes remained open. However, user costs developed as a result of slowing the traffic from 70 mph to 55 mph the length of the project for 25 days. The costs are all attributed to the actions of slowing for the work zone and re-accelerating after it.

Table 6-2. Three lanes open with reduced speed

Cost Component	Cost	Percent
WZ Speed Change VOC	$57,792	30%
WZ Speed Change Delay	$56,754	30%
WZ Reduced Speed Delay	$75,229	40%
Queue Stopping Delay	$0	0%
Queue Stopping VOC	$0	0%
Queue Added Travel Time	$0	0%
Queue Idle Time	$0	0%
Total Cost	$189,775	100%

Table 6-3 compares the agency cost for resurfacing that particular 1.4-mile, outbound section of Interstate 65 to the total user cost for the activity. The total user cost is only $59,012 less than the total agency cost for the asphalt overlay.

Table 6-3. Agency cost vs. user cost

Type	Amount
Agency Cost	$445,673
User Cost	$386,661

The total user cost for each of the major activities modeled in an LCCA can be calculated by the method described above. RealCost v.2.1 can only do this type of analysis deterministically. However, the analyst may still choose to perform a probabilistic LCCA analyzing only the agency costs, and then use the deterministically calculated user costs as a supplement to the LCCA results.

The authors performed several sample LCCAs in (Lindly and Clark, 2003). Results from those analyses indicated that user costs are often similar to and can be larger than agency costs.

Section 7

Conclusions and Recommendations

This section provides a summary of the work conducted during the course of this research and the conclusions drawn from that work. Opportunities for future work are also identified.

Summary of Work and Conclusions

LCCA uses economic principles to compare competing investment alternatives. An LCCA is typically used by a state DOT to help select the most appropriate design for a construction project, such as selecting between asphalt and concrete alternatives for a paving project. The LCCA is designed to identify the most cost effective alternative, but it may not be the only decision making tool.

ALDOT performs LCCAs to compare alternative pavement designs for the following situations:

- New construction projects, flexible pavement reconstruction projects, and projects involving the addition of a separate roadway to an existing roadway when the pavement design structural number equals or exceeds 6.00.
- Any project involving the reconstruction of concrete pavement

The purpose of this research project was to collect data that will assist ALDOT in determining the potential user costs or user impacts that may result from a highway work zone. This project was the second phase of a multi-phase project to update the LCCA process and focused on the duration of typical reconstruction and rehabilitation activities for major divided highways. UTCA researchers also investigated two software packages that calculate vehicle queue lengths upstream of highway work zones.

Data Collection

Data for this project was gathered from sources listed below:

- Alabama Department of Transportation (DOT)
- Georgia DOT
- Mississippi DOT
- Texas DOT
- Louisiana DOT
- North Carolina DOT
- Oklahoma DOT
- North Dakota DOT
- Iowa DOT
- Alabama Asphalt Paving Association
- National Highway Institute
- American Concrete Pavement Association
- S.T. Bunn Construction Company

- Racon, Inc.
- Mobile Asphalt Company
- Resonant Machines, Inc.
- Uretek USA, Inc.
- Scruggs Company
- Gilbert Texas Construction

Project duration data for various Interstate reconstruction and rehabilitation activities was acquired from the state DOTs. If the project was not yet completed, researchers recorded the time the DOT allotted to the contractor in calendar days after work begins to complete the specific project. If the project was already completed, researchers recorded the calendar days the contractor charged the DOT. UA researchers gathered this data from each of the DOT construction divisions' contract status reports. Most contract status reports are produced either quarterly or monthly by the construction division and contain specific information on each highway project currently under construction or recently completed, such as the project's description, location, time allotted to contractor, and percent completed. Extra data such as the number of lanes or clarification of the activity was acquired by consulting with DOT engineers.

The time allotted to the contractor to complete a project is typically very conservative. Thus, UA researchers recommend that this value be used as the maximum amount of time needed to complete a specific construction task, i.e., the total number of days that motorists can expect a reduced speed limit for the length of the project. The authors recommend using the following rounded values for maximum calendar days after work begins for each of the following common Interstate construction activities:

- Asphalt resurfacing: 7 calendar days per lane mile
- Concrete rehabilitation: 6 calendar days per lane mile
- Concrete pavement remove and replace: 18 calendar days per lane mile
- Concrete pavement rubblization plus asphalt overlay: 17 calendar days per lane mile

UA researchers consulted federal and state agencies as well as local and national contractors to determine specific production rates for Interstate reconstruction and rehabilitation activities. The typical production rates obtained from these sources indicate that projects can be completed in far less time than the calendar days that DOTs allot to the contractor to complete the work. The actual production rates may be considered the minimum time needed to complete such work, i.e., the time when a lane closure will be in place. The authors recommend using the following values for the average minimum time needed to complete common Interstate construction activities. The values are given in terms of workdays involving 12-hour shifts. Please note that "concrete rehabilitation" lumps several types of rehabilitation activities into a single value because all state DOTs contacted record data as "concrete rehabilitation" rather than as individual activities.

- Asphalt resurfacing: one work day per lane mile (3" lift)
- Concrete rehabilitation: 1.5 work days per lane mile
- Concrete pavement remove and replace: two work days per lane mile
- Concrete pavement rubblization plus asphalt overlay: two work days per lane mile

If an analyst does not wish to calculate user costs directly, the production rates may be used to predict the time the highway users will be impacted by a lane closure.

Table 7-1 shows the actual construction times needed to complete various reconstruction and rehabilitation activities. The values listed in the table came from a variety of production rate data presented in Section 3. The researchers present the more conservative of these values in Table 7-1. The conservative rates represent sustainable production rates rather than maximum production rates. The data in this table is presented in the units that were indicated by the contractors and agencies, as opposed to the data converted to work days per lane mile described above.

Table 7-1. Actual construction times/rates

Activity	Rate
Asphalt resurfacing	1500 tons / work day
Full-depth concrete repair	80 cubic yards / work day
Diamond grinding	1.5 lane miles / work day
Joint cleaning and resealing	3000 – 4000 LF / work day
Remove and replace concrete pavement (<20,000 SY)	1000 square yards / work day
Remove and replace concrete pavement (>20,000 SY)	2000 – 4000 square yards / work day
Concrete pavement rubblization	1 lane mile / work day
Unbonded concrete overlay	1 lane mile / work day
Underseal PCC pavement	0.5 lane miles / work day

Queue Calculation Software

Researchers examined and compared two software programs capable of calculating hour-by-hour queue lengths:

- FHWA RealCost v.2.1
- Microsoft Excel based spreadsheet created by ODOT and currently used by ALDOT

Researchers compared the queue lengths calculated by both software programs for four common scenarios using the default hourly distributions and directional factors from RealCost v.2.1. Results from the four cases indicated that the two programs predict similar hours of the day when significant queues will occur. However, the ODOT capacity spreadsheet calculated longer queues than the FHWA computer program for all cases. Until more detailed comparisons can be performed, UA researchers recommend that ALDOT continue evaluating queue lengths with the ODOT capacity spreadsheet as opposed to RealCost v.2.1 for two reasons:

- The ODOT spreadsheet is easier to use
- ODOT queue values are more conservative

User Cost Calculation

The authors used RealCost v.2.1 to calculate the user costs resulting from the asphalt overlay of a 1.4-mile section of I-65 in Montgomery. The researchers used the duration data described in this report to portray the actual work zone conditions that can be expected for this type of work.

Researchers concluded that RealCost v.2.1 may not be appropriate for calculating ALDOT project user costs for the following reasons:

- RealCost v.2.1 cannot easily portray real-life work zone conditions. Separate user cost analyses must be made and then added together to get reasonably accurate modeling of work zone situations and their associated user costs.
- RealCost v.2.1 gives very large user costs that may overshadow agency costs.

The authors concluded that the best use of the software programs described in this report may be to predict queue lengths that result from lane closures. The analysis of queue lengths can be used to schedule lane closures (full day vs. night vs. non-rush hours, etc.) that are necessary to complete major reconstruction and rehabilitation activities often modeled in an LCCA.

The duration data collected in this report will help to predict how long the work zones will remain in place. The duration data will make it possible to determine how many days to expect queues resulting from the lane closure.

Future Work

In addition to the work completed during the course of this research, two areas of future research work are suggested:

- Research on the accuracy of various queue calculators may be performed to recommend a particular software package for the calculation of vehicle queues upstream of highway work zones. UA researchers performed a comparison of two programs without the benefit of knowing “ground truth.” Thus, these and other programs must be investigated and compared to actual queue conditions before it is possible to identify the most appropriate queue calculator for ALDOT.
- Research should be performed to evaluate the cost effectiveness of new paving materials/procedures such as Superpave, stone matrix asphalt (SMA), modified asphalts, and tied concrete shoulders. Researchers could not perform such work at this time because too few projects using these new materials have been constructed to date.

Section 8
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Appendix 1
Example of ODOT Capacity Spreadsheet Output

		User Defined – Factors								
Hour	No. Lanes Closed (1)	AADT Factor (K)	Direction Factor (D)	Volume (2)	Limiting Capacity	Max Cars in Queue	Delay Cost	Fuel Cost	Total Costs	Max Queue (mi.)
Mid.-1am	0	1.200	0.47	474	7,200	0	0	0	0	0.0
1am-2am	0	0.800	0.43	289	7,200	0	0	0	0	0.0
2am-3am	0	0.700	0.46	270	7,200	0	0	0	0	0.0
3am-4am	0	0.500	0.48	202	7,200	0	0	0	0	0.0
4am-5am	0	0.700	0.57	335	7,200	0	0	0	0	0.0
5am-6am	0	1.700	0.58	828	7,200	0	0	0	0	0.0
6am-7am	1	5.100	0.63	2,699	3,029	0	0	84	84	0.0
7am-8am	1	7.800	0.60	3,931	3,029	901	5,406	580	5,986	1.1
8am-9am	1	6.300	0.59	3,122	3,029	992	11,358	927	12,285	1.3
9am-10am	1	5.200	0.55	2,402	3,029	887	8,130	619	8,749	1.1
10am-11am	1	4.700	0.46	1,816	3,029	161	685	80	765	0.2
11am-Noon	1	5.300	0.49	2,181	3,029	0	0	68	68	0.0
Noon-1pm	1	5.600	0.50	2,352	3,029	0	0	73	73	0.0
1pm-2pm	1	5.700	0.50	2,394	3,029	0	0	75	75	0.0
2pm-3pm	1	5.900	0.49	2,428	3,029	0	0	76	76	0.0
3pm-4pm	1	6.500	0.46	2,512	3,029	0	0	78	78	0.0
4pm-5pm	1	7.900	0.45	2,986	3,029	0	0	93	93	0.0
5pm-6pm	1	8.500	0.40	2,856	3,029	0	0	89	89	0.0
6pm-7pm	0	5.900	0.46	2,280	7,200	0	0	0	0	0.0
7pm-8pm	0	3.900	0.48	1,572	7,200	0	0	0	0	0.0
8pm-9pm	0	3.300	0.47	1,303	7,200	0	0	0	0	0.0
9pm-10pm	0	2.800	0.47	1,105	7,200	0	0	0	0	0.0
10pm-11pm	0	2.300	0.48	927	7,200	0	0	0	0	0.0
11pm-Mid.	0	1.700	0.45	643	7,200	0	0	0	0	0.0