To the Graduate Council:

I am submitting herewith a thesis written by Dwight Anthony Allen entitled " Predictive Time Estimate Formulation for Bridge Deck Rehabilitation." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Civil Engineering.

Hal Deatherage, Major Professor

We have read this thesis
and recommend its acceptance:

Edwin G. Burdette

Kang C. Chon

Accepted for the Council:

Associate Vice Chancellor and
Dean of the Graduate School

PREDICTIVE TIME ESTIMATE FORMULATION FOR BRIDGE DECK REHABILITATION

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Dwight Anthony Allen
May 1998

Copyright © by Dwight Anthony Allen, 1998
All rights reserved

DEDICATION

This thesis is dedicated in the loving memory of my grandfather, William Bush, who spent endless hours instructing me in how to rig and construct a multitude of objects. I shall never forget the visit to my grandparents when I chose to forgo watching television and instead spent it with my grandfather in his wood shed. That day forever changed my life. I am eternally grateful for the hours I spent in the presence of my grandfather; he has to be undoubtedly the most intelligent man I have ever known. It is from this uneducated man who could not read or write that I have inherited my intellectual and creative capabilities. It was he who taught me the fine art of creative problem solving. I am eternally indebted to you Daddy Willie.

ACKNOWLEDGEMENTS

I believe it only befitting that I thank my grandmother, James Etta Bush, for the exceptional parental example that she set along with my grandfather, William Bush. It was from such an example that my mother and I have benefited. I thank my mother, Beatrice Allen, for her dedicated relationship to my father, Odean Allen, and for their combined effort to provide a loving and stable family environment for my brothers, my sister, and myself. It has been from that stable environment that I have gained the support to achieve all the things I have achieved and have yet to achieve in my life. I would like to thank my older brother Marcus and my sister Janice for the exceptional example they have left for me and my younger brother, Phil, for as the younger siblings we have benefited greatly from the paths they have paved. And I thank Phil for his adventurous spirit and his insatiable work ethic. If I were to die today I would die a very rich and happy man due to my family. Last but not least I acknowledge the supreme grace that has been granted to me from above for the abundant blessing that I have received as a citizen of this country and the peace of mind that can only come from knowing the source of eternal love.

ABSTRACT

This research develops a methodology for the establishment of project time estimates for bridge deck rehabilitation. By providing a method for the development of production rates critical to the completion of bridge deck rehabilitation, it also provides a consistent method for evaluation of contractor claims that may arise during a bridge deck rehabilitation project. To date, this is the most comprehensive research effort devoted to the topic of predictive time estimates for bridge deck rehabilitation. While this research is not definitive, it provides an unprecedented compilation of introductory information, practical application of existing data collection and analysis procedures, the development of an innovative historical record analysis technique, and the development of predictive time estimate formulas. The effectiveness of these predictive formulas lies in the accuracy of the estimated material quantities related to the rehabilitation work and the relevancy of the production rates. The production rates provided by this research are reflective of both first-hand field observation and historical record analyses. These production rates represent a preliminary effort toward the establishment of production rates that model typical production rates achieved in the field. The rates and formulas presented in this research serve as benchmarks for future research and their augmentation has the potential to dramatically increase the effective use of predictive time estimate formulas.

TABLE OF CONTENTS

CHAPTER PAGE

1. INTRODUCTION 1
   - Problem Statement 5
   - Research Objectives 6
   - Preliminary Research Methodology 7
   - Final Research Methodology 8

2. LITERATURE REVIEW: NEW TECHNOLOGY IN BRIDGE DECK INSPECTION 11
   - Infrared Thermography 12
     - *Infrared Thermography Case Studies* 13
     - *Limitations of Infrared Thermography* 14
   - Ground-Penetrating Radar 15
   - Conclusion 16

3. TDOT HISTORICAL PERFORMANCE SURVEY 17

4. RESEARCH DEVELOPMENT 25
   - Types of Bridge Deck Rehabilitation 25
   - The Identification of Bridge Deck Rehabilitation Work Activities 29
   - Establishing Critical Activities for Bridge Deck Rehabilitation 32
   - Establishing Production Rates 34
   - Observation-Based Production Analysis 36
     - *Obtaining TDOT Job Site Locations* 37
     - *The Use of Method Production Delay Models* 38
       - *Preliminary Information* 38
       - *Data Collection* 39
       - *Cycle Information* 44
       - *Delay Information* 42
       - *Productivity and Productivity Analysis* 45
   - Historical-Record Based Production Analysis 45
     - *Obtaining TDOT Historical Documentation* 46
     - *The Development of the Constant Path Distribution Method* 47

CHAPTER PAGE

5. PREDICTIVE TIME ESTIMATE FORMULA....54
Basic Formula Concept....54
General Prediction Formula....56
Formula Features....56
Equation Constants....57
Formula Expansion....58

6. PRODUCTION RATE ANALYSES....63
Production Rate Features....63
Concrete Repair Material Quantity Determination....65
Production Rates....66
Sample Calculations....66
Production Rate Test....71

7. CONCLUSIONS AND RECOMMENDATIONS....73
Continued Monitoring of Production Rates....73
Preliminary Production Rates....74
Calendar Day verse Working Day Contracts....75
Research Continuance....76

BIBLIOGRAPHY....77

APPENDICES....80

VITA....178

LIST OF TABLES

Table 1. An Example of Work Activity Identification Via Bidsheet Analyses 30

Table 2. Identified Work Categories and Associated Work Activities 31

Table 3. The Critical Work Categories and Associated Work Activities 35

Table 4. A Project's Event Table as Obtained Through Historical Record Analyses 48

Table 5. Material Quantities Specified for a Typical Projects as Obtained through Historical Records 49

Table 6. Bridge Deck Spot Patching Production Rates 67

Table 7. Bridge Deck Overlay Production Rates 68

Table 8. Bridge Deck Replacement Production Rates 69

Table 9. Production Rate Test 70

LIST OF FIGURES

Figure 1. Overall Estimating Survey 19

Figure 2. Project Size Cost Estimating Survey 20

Figure 3. Project Size Time Estimating Survey 21

Figure 4. Regional Cost Estimating Survey 22

Figure 5. Regional Time Estimating Survey 23

Figure 6. Distinguishing the Difference Between Full and Partial Depth Deck Repair 28

Figure 7. The General Gantt Chart for Bridge Deck Rehabilitation Projects 33

Figure 8. The Data Collection Report Sheet 40

Figure 9. The Method Productivity Delay Method Worksheet 43

Figure 10. Constant Path Distribution Method (CPDM) 53

Figure 11. Bridge Deck Spot Patching Time Estimate Formula 60

Figure 12. Bridge Deck Overlay Time Estimate Formula 61

Figure 13. Bridge Deck Replacement Time Estimate Formula 62

CHAPTER 1

INTRODUCTION

Self-evaluation is one of the most important keys to the success of an individual or an organization. Individuals and organizations must periodically analyze their operational methods to determine areas of ineffective approaches that are prohibiting efficient use of resources and time. The extent of action taken as a result of such a self-evaluation determines the legacy that an individual or an organization will leave upon the pages of history. With the conclusion of the twentieth century approaching, the Tennessee Department of Transportation (TDOT) performed a series of self-evaluations or internal-evaluations to identify existing or potential areas of ineffectiveness and inefficiency. At the conclusion of this internal-evaluation the agency identified several areas of possible improvement in its management of construction operations. One area of concern was the agency's approach to the management of bridge deck rehabilitation projects. Several factors were identified as contributing to the agency's ineffectiveness or inefficiency in this area. Some of the factors discussed were TDOT's effectiveness in providing realistic time estimates to contractors before the bid process, and the agency's effectiveness in providing a consistent and fair method for evaluating contractor claims which may arise during or at the conclusions of projects. These factors prevent the agency from maximizing its level of efficiency in the management of bridge deck rehabilitation projects. The efficient management of bridge deck rehabilitation projects

becomes a major issue when one considers the magnitude of traffic delays such work causes on interstate expressways and on urban center streets.

Efficiency is not only important in minimizing the inconvenience to the general public and to commercial shipping, but also in maximizing transportation safety. Transportation safety is compromised by the deterioration of interstate and other high-traffic density highways, and inefficiency in managing bridge deck rehabilitation projects leads to extended public exposure to deteriorating roadways. Bridge decks that are not rehabilitated promptly continue to be exposed to many adverse conditions that promote deterioration in the form of scaling, cracking, spalling, and delamination.

Scaling is the flaking off of the concrete surface mortar and the loosening of the surface aggregates. In time scaling can reduce a deck to mere gravel. Cracking occurs when the tensile forces in the deck exceeded the deck's tensile strength. Generally, this condition causes transverse cracks over the steel reinforcing. If these transverse cracks are not combated the deterioration of the concrete may grow larger and result in the break out of large sections also known as spalling. Or the cracks may allow in moisture that corrodes the steel and as the steel expands the slab is split horizontally in laminates, which is called delamination. What causes this deterioration? Bridge deck deterioration is usually a combination of several factors consisting of bending, pounding, water saturation, deicing and salt, the freeze-thaw cycle, temperature changes, concrete shrinkage, inconsistent concrete mix, and shallow cover.

Bending is simply the result of traffic loads being transferred in two directions, one direction between bents and another between the stringers. The two-way bending

frequently results in cracks. The pounding of traffic can further aggravate these cracks. Pounding is a result of deck irregularities and rough transitions between adjoining pavement, approaches, and expansion joints. As the traffic passes over these conditions, they create a pounding and a vibration not experienced by normal roadways. The pounding and vibrations increase the cracks and as water collects on the decks due to heavy rains or poor drainage, the moisture carries salt and calcium chloride through the cracks in the bridge deck and corrodes the reinforcing steel. These chemicals are present as a result of deicing and salting of the bridge deck. Steel corrosion becomes extensive rapidly when there is an insufficient concrete cover providing the protection for the steel reinforcing. The steel corrosion causes transverse crack in the deck as the deck is exposed to the freeze-thaw cycle or to temperature changes that produce expansive pressure. The situation is made worse if there has been an inconsistency in the concrete mix. Areas of inconsistent concrete mix when subjected to transverse cracking can result in large areas of spalling or delamination.

Bridge deck deterioration is usually not evident until it is in an advanced stage. In addition to this, asphalt overlays make it impossible to see corroding rebar, delamination, and disintegrating concrete. Therefore, it is impossible to assess the extent of bridge deck deterioration from initial inspections. Yet, maintenance and rehabilitation decisions are being made. Thus, the initial material quantity estimates, such as concrete removal and replacement, must be established through engineering experience and quantities from pervious bridge rehabilitation projects. However, neither engineering experience nor previous case studies can accurately predict the actual conditions of the current project.

Even if a bridge deck has a concrete driving surface (no asphalt overlay), a complete bridge deck inspection cannot occur until the bridge inspectors' safety can be insured. Currently such safety cannot be insured until the contract has been awarded and traffic controls are in place. Yet TDOT must provide material quantity estimates to potential contractors before the bid process can begin and the contract awarded. This scheduling dilemma is a major factor affecting TDOT's ability to establish realistic time estimates for bridge deck rehabilitation projects; material quantities must be set despite their inaccuracies. The potential for discrepancies between estimated material quantities and actual material quantities is substantially large, creating a "catch twenty-two" situation for the agency since time estimates are usually influenced by material quantities. Such inaccuracies in material quantity estimates may affect project time duration, as well as project cost and public perception.

The problems associated with project cost which arise when there is a large discrepancy between estimated quantities and actual quantities have been resolved by TDOT by using unit price bids. Instead of paying the contractor a specific amount based on the initial material estimates, the agency pays the contractor an agreed price for each unit of material that is removed or placed. This practice eliminates the possibility of underpaying or overpaying the contractor as a result of material discrepancy. The underpayment or overpayment of contractors would occur if the contractors were paid according to the initial estimated material quantities. However, the issue of accurate time estimates remains a problem. Inaccuracies in material quantity estimates may result in time duration overruns or underruns. Underestimating the actual magnitude of materials

required and/or scope of the work required contributes to contractor claims for time extensions and may result in claims for additional funds to cover labor, equipment, and moblization costs. Overestimating the time required for construction completion results in low contractor production rates and inconveniences the public through unnecessary traffic delays. These factors take on critical importance when considering TDOT's allocation of funds, management of its yearly budget, and public relations. Also of critical importance is TDOT's relationship to the contractors who perform the actual bridge rehabilitation.

To maintain good working relations with the contractors, it becomes necessary for TDOT to establish a fair and consistent method for evaluating contractor claims that may arise. However, the method of analysis chosen or developed should utilize documented contractor production rates established through historical documentation or first-hand field observation and should recognize adverse conditions that may affect contractor production. Such a method will provide the agency with a consistent method to assess each contractor claim fairly since issues critical to the contractor would be considered and the method of evaluation would be based on recent observed or documented contractor production rates. It was for this reason TDOT commissioned a study of bridge rehabilitation by the University of Tennessee, Knoxville (UTK).

Problem Statement

The purpose of the bridge rehabilitation study was to three-fold:

1. To formulate a solution methodology that would determine the production rates associated with the work activities involved in bridge rehabilitation.
2. To conduct the necessary field and historical research to establish preliminary production rates for the work activities that controls a large portion of the project time.
3. To develop a formula utilizing these production rates that would aid in the provision of preliminary time estimates for project duration and the evaluation of contractor claims.

Research Objectives

To provide a method for the formulation of predictive time estimates for bridge rehabilitation projects, the following objectives were set.

1. The identification of various bridge deck rehabilitation project types.
2. The identification of tasks or activities that control the critical path of each bridge deck rehabilitation type.
3. The approximation of the percentage of total project time duration that these critical activities represent.
4. The provision of preliminary production rates for each of the individual critical activities.
5. The development of a representative production formula capable of producing time estimates and evaluating contractor claims.

These research objectives were achieved through the adaptation of several construction management techniques, first-hand field observations, and the development of an original method for the analysis of TDOT project records.

Preliminary Research Methodology

Determining production rates for construction operations is a difficult task, especially for rehabilitation operations. Unlike new construction, which consists of well-defined material quantities and material locations, a rehabilitation operation consists of unknown material quantities and material locations. Therefore, developing a research methodology for bridge rehabilitation became a process of theory development and theory revision. The preliminary research methodology assumptions were as follows:

1. Approximately eighty percent of the time necessary to complete a bridge rehabilitation project would be composed of approximately twenty percent of the tasks involved in the project.
2. The majority of bridge rehabilitation project tasks were repetitive or cyclic in nature.
3. The production rates for specific tasks could be established through random observations of production cycles. These observations would be "random" in that they would be taken during various times of day, during various seasons, during various stages of production (i.e. the beginning, the middle, and the end), and while being performed by various contractors across the state of Tennessee.
4. The random nature of the observations would capture the variations in production that can occur due to differing conditions in the field.

The original methodology was to obtain three first-hand job site observations per outlined task for each of the four TDOT regions, which would provide a total of twelve observations per outlined task. It was believed that twelve observations would provide enough data to establish production trends for each task and to conduct accepted production analysis techniques to determine common production delays encountered in the field. It was believed that a combination of production trends and delay trends would lead to the establishment of task duration times which would predict realistic project duration. Finally, it was hoped that these task duration times, delay duration times, and delay frequencies could be modeled in a simulation program and the models given to TDOT for use in establishing preliminary time estimates and evaluating contractor claims. Throughout the research this original methodology was edited and augmented.

Final Research Methodology

The final methodology used consisted of the following assumptions and conclusions:

1. Approximately seventy-five percent of a bridge rehabilitation's project time is composed of a combination of the following work activity categories:
    1. Traffic Control
    2. Concrete Removal
    3. Concrete Placement
    4. Form Work
    5. Steel Reinforcement Placement

2. The majority of bridge rehabilitation projects work activities do not possess discrete production cycles and are, therefore, not cyclic or repetitive.
3. Work activity production rates could be established through job site observations (repetitive work activities) or through analysis of historical project records (non-repetitive work activities).
4. Through observation experience and analysis of historical records, a production formula using the newly determined production rates could be formulated.
5. The new production formula could predict preliminary time duration for a project once expected material quantities were determined.
6. The new production formula could also be used to verify or dispute contractor claims by determining time requirements for final material quantities used on a project.

At the conclusion of this study UTK provided TDOT with a method of determining the estimated number of days required to complete the average bridge deck rehabilitation project based on historically documented and field observed productions rates. The only drawback to the proposed formula and its use is the fact that preliminary material quantities for bridge rehabilitation projects are rarely accurate. This inaccuracy in material quantity results in inaccurate time predictions, thus rendering the new formula a less than desirable solution for predicting time duration.

To combat the problem of inaccurate initial material estimates, several state-of-the-art techniques have been developed for the rapid inspection of bridge decks (These methods are discussed in Chapter 2). These new methods utilize impulse radar and infrared thermography. The advantage of these approaches lies in their rapid assessment

of bridge deck deterioration with minimum traffic disruption. Both ground-penetrating radar and infrared thermography use truck-mounted scanning devices that can scan a deck at approximately five miles per hour. These methods do not require complete lane closures to perform the scans, but use truck-mounted arrow boards to redirect traffic.

CHAPTER 2

LITERATURE REVIEW: NEW TECHNOLOGY IN BRIDGE DECK INSPECTION

Although great lengths were taken to find literature concerning the determination of production rates for rehabilitation work, no such literature was found to be relevant to the research. Therefore, the literature review was devoted to the development of techniques which would increase the effectiveness of the research by determining accurate material quantities and extent of bridge deck deterioration.

If an observer were to watch the performance of the conventional methods for bridge deck inspection, he or she could only surmise that there must be a better way. Currently, the most commonly used method for bridge deck inspection consists of a seemingly primitive use of a chain to take soundings. This is done by literally dragging a metal chain across the bridge deck and listening to the various sounds that are produced, because areas of deteriorated concrete make a very distinct sound in contrast to areas of non-deteriorated concrete. Of course, the true accuracy of such a method is questionable and its use requires a bare concrete deck. Other techniques include chloride content tests and corrosion potential measurements. However, critics of these methods state that they only "infer" deterioration without actually measuring it. These methods have also been proven to "infer" substantially different deterioration conditions than what actually existed. In addition to the accuracy question, all the above methods are cumbersome, slow, labor-intensive, and can only be performed after traffic controls are in place to

insure the bridge inspectors' safety. Thus, a thorough inspection of the bridge deck cannot be done until the contract has been awarded. The conventional methods seem to leave considerable room for improvement. Currently, several alternative methods have been developed for the assessment of bridge deck deterioration. The two most promising applications are ground-penetrating radar and infrared thermography. These two methods have been shown in studies to be able to detect parameters related to bridge deck deterioration. At the same time these two methods are nondestructive and quick, which results in the analysis of in-service bridge decks without major disruption of traffic. Of these two methods infrared thermography has been more fully developed as a commercial technique due to its relative straightforward application. However, research has shown that infrared thermography is sensitive to various surface conditions as well as weather conditions, which influence thermographic readings and could potentially contaminate the collected data. This method is also limited by thick asphalt overlays. Ground-penetrating radar is less sensitive to ambient conditions and equally effective on bare concrete or thick asphalt overlays. Its drawback is in the complex signal it produces, which is not straightforward in its interpretation.

Infrared Thermography

Infrared thermography detects emitted infrared radiation and in doing so detects the strength and location of thermal anomalies. Thermography detects varying bridge deck surface temperatures produced by the bridge deck's thermal convective interaction with the surrounding environment. Transverse cracks and delaminations produce air spaces beneath the concrete causing the pavement above the crack to become warmer on

a sunny day than the solid areas of the bridge deck. Infrared cameras are then used to detect this temperature variation and locate potential areas of deterioration. Initially, these infrared cameras were equipped with a single infrared band used to detect temperature variations. Recently, a dual-band infrared camera has been developed by Lawrence Livermore National Laboratory from technology used during the Gulf War to detect land mines. The new dual-band cameras are more precise at a higher rate of speed than the single band cameras and provide the possibility to inspect decks at even higher rates of speed. The prototype for this method has been turned over to the Federal Highway Administration and is currently being refined.

Infrared Thermography Case Studies

Two case studies were found which illustrated the effective use of infrared thermography in the detection of bridge deck deterioration. The two case studies consist of the eleven-mile, eight-lane Dan Ryan Expressway in Chicago and the seven-lane Walt Whitman Bridge and sixteen approach structures between New Jersey and Pennsylvania.

The Dan Ryan Expressway is one of the most heavily traveled expressways in the nation and the closure of even a single lane would result in monstrous traffic delays. These conditions precluded the use of conventional deck inspection methods. Therefore, infrared thermography was used to detect areas of concrete deterioration. The images taken by the infrared cameras were recorded on videotape and then converted to hard copy photography or strip charts. These strip charts were then used in conjunction with documented locations of lane stripes, curbs, and parapets, to map out actual location and size of delaminations. Since infrared cameras distinguish solid deck areas as dark areas

and deteriorated areas as light areas, a conventional video camera was also used to document spills or pavement discoloration that might contaminate the collected data. This information was then coupled with visual inspection of the bridge deck's underside to determine areas of partial depth repair and full depth repair. All this information was then converted to actual plan drawings documenting the exact location, size, and type of repair. The accuracy of the infrared cameras was checked daily by taking random chain soundings over thermographic identified areas of deterioration. These soundings helped to confirm the size and shape of deterioration areas. For further confirmation of the thermographic data, seventeen infrared-identified zones of deterioration were checked by core test and all seventeen areas were confirmed as areas of deterioration. Collection of all thermographic data was completed in fourteen hours on five separate days of collection. The cameras were truck-mounted and driven at a rate of five miles an hour, making one pass in each lane.

Similar results were obtained on the Walt Whitman Bridge and approaches where 966,000 square feet of deck were scanned over five days. It was noted on this project that temperature variations of 1.5 to 9 degrees Fahrenheit could be detected down to seven inches within a concrete slab.

Limitations of Infrared Thermography

Infrared thermography detects emitted infrared radiation, and since a bridge deck's internal thermal behavior of heat conduction and absorption must balance its radiant and convective interaction with its surroundings, thermographic readings are

sensitive to atmospheric conditions. The convection flow of heat in a bridge deck is a function of the temperature difference between the air and the deck and of the air velocity. Thus, factors affecting thermographic readings are deck emissivity, deck surface temperature, ambient air temperature, deck thermal conductivity, deck volumetric heat, thickness of the heated layer, intensity of incident solar radiation, and air velocity. For this reason the best time to perform an infrared thermography scan of a bridge deck is a dry day when there has been a period of significant overnight temperature swings. Research has shown that infrared thermography is limited in its capability when there is a large asphalt overlay, the delamination openings are small, and the cracks are deep.

Ground-Penetrating Radar

Ground-penetrating radar is a bridge deck deterioration assessment technique that is not as common as infrared thermography due to complexity of the data it produces. No case studies were found where ground-penetrating radar was used singularly. Most often it is used as a method for confirming thermographic readings. Ground-penetrating radar utilizes an electromagnetic analog of ultrasound composed of short pulses of electromagnetic energy. The short electromagnetic pulses are transmitted and are reflected back off various interfaces within the medium being analyzed. These reflected impulses, or echoes, are picked up and converted into a signal. Unfortunately, this signal is complex in nature, and an improved method of interpretation is needed to simplify the analysis procedure.

Unlike infrared thermography, ground-penetrating radar is not limited by overlay thickness or sensitive to ambient conditions. It is limited by moist conditions and influenced by chloride conditions associated with deteriorating bridge decks. This method is slower and requires more staffing than the infrared thermography. A combination of infrared thermography and ground-penetrating radar is usually the best method of deck scanning. On the Dan Ryan Expressway case study, thermography and ground-penetrating radar were used in conjunction with each other until it was decided that the additional information obtained from ground-penetrating radar was not significant enough to prove cost effective. Therefore, ground-penetrating radar was dropped as an analysis method and thermography used singularly.

Conclusion

The use of infrared thermography and ground-penetrating radar would greatly increase the accuracy of the initial material quantity estimates. This increased accuracy would positively affect the application of this research. As a result this research would prove to be a beneficial method for the establishment of initial project time estimates. However, the initial cost, operating cost, and maintenance costs of these inspection techniques are not completely known and may be more than states are willing to pay. Therefore, an alternate method for determining initial material quantities associated with bridge deck rehabilitation has been formulated by the researcher and presented in Chapter seven under the heading "Research Continuance".

CHAPTER 3

TDOT HISTORICAL PERFORMANCE SURVEY

The following survey was conducted by analyzing one hundred and eighty-seven project records in an effort to evaluate the status of TDOT estimation accuracy throughout the state of Tennessee. The areas of analysis consisted of accuracy variation in predicted project time and project cost verses actual project time duration and project cost. Accuracy was defined as the following variations between the estimate quantity associated with time or cost and the final quantity associated with time or cost:

CORRECT ESTIMATING:	$\pm$10% variation
OVER ESTIMATING:	+11% variation and above
UNDER ESTIMATING:	-11% variation and below

In addition to TDOT regional category separation, the researcher separated the data according to project size categories. Project size categories were established according to final project cost and were defined as follows:

SMALL PROJECT:	$500,000 and below
MEDIUM PRJECT:	$500,001 – 1,000,000
LARGE PROJECT:	$1,000,001 and above

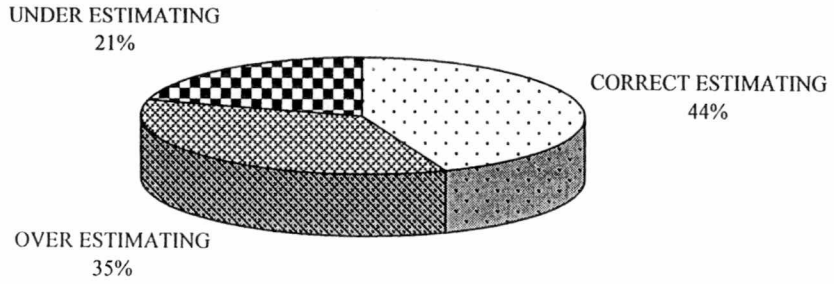
TDOT regions are geographically defined areas of the state of Tennessee, with TDOT regional offices located in one of the region's major urban centers.

REGION ONE:	Knoxville, covering East Tennessee
REGION TWO:	Chattanooga, covering East Middle Tennessee
REGION THREE:	Nashville, covering West Middle Tennessee
REGION FOUR:	Jackson, covering West Tennessee

The results of the estimating survey have been presented in Figures 1-5.

Figure 1 shows that TDOT has been correctly estimated time duration of projects within 10% of the actual project duration in 45% percent of the cases, and is correctly predicting the cost of a project in 60% of it projects. While this is a commendable performance it still leaves room for improvement in each area, and a closer look at the numbers reveals this fact. Consider the largest sample group from the survey, the small project category, the average project cost for this group is approximately $250,000. The average project duration of this group is 70 working days. Examining the small project category from Figure 2 and 3, the survey shows that TDOT is experiencing excessive time allowance in 43% percent of these projects and cost overruns in 30% percent of these projects. If the lowest percentage for an overrun in time and cost is considered, by definition 11%, the Agency is experiencing a minimum cost overrun of approximately $25,000 in 30% of its small projects. It is also experiencing excessive time allowances of

TIME ESTIMATION
(187 samples)



COST MANAGEMENT
(187 samplings)

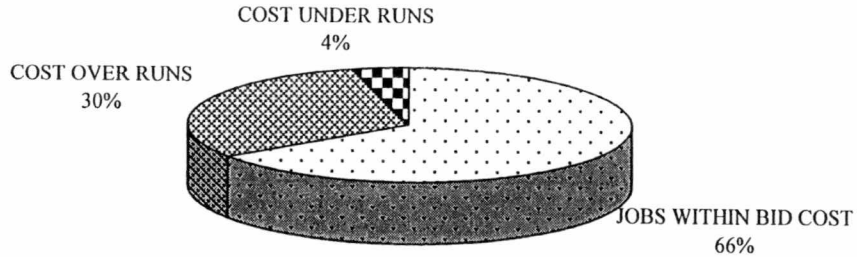
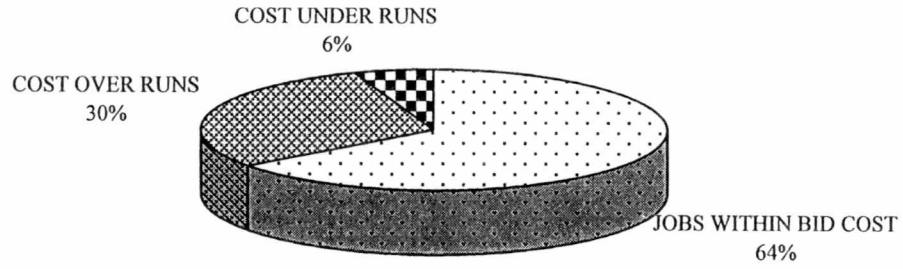
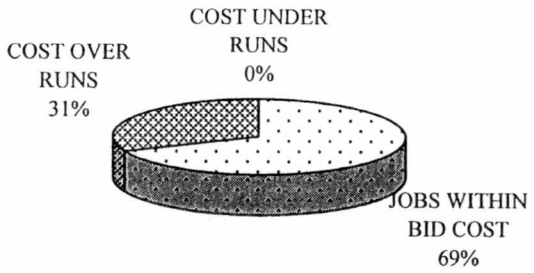


Figure 1 Overall Estimating Survey

SMALL PROJECTS
(142 samplings)



MEDIUM PROJECTS
(35 sampling)



LARGE PROJECTS
(10 samplings)

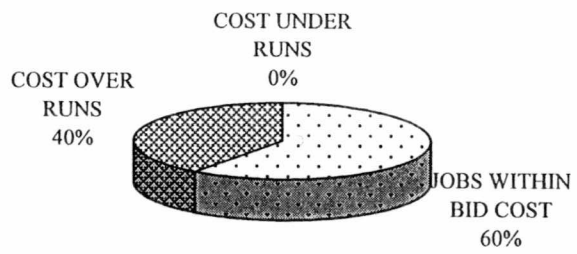
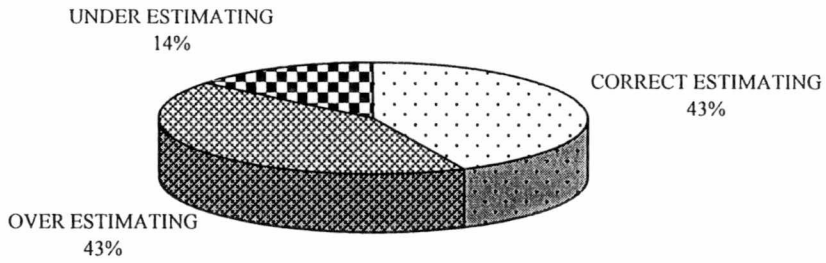
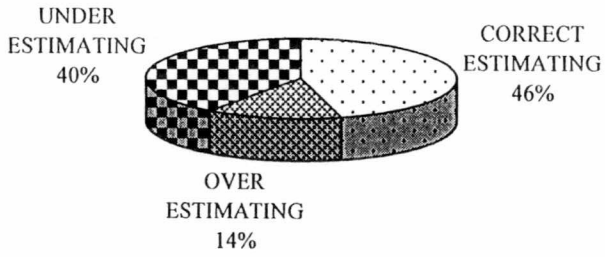


Figure 2 Project Size Cost Estimating Survey

SMALL PROJECTS
(142 samplings)



MEDIUM PROJECTS
(35 sampling)



LARGE PROJECTS
(10 samplings)

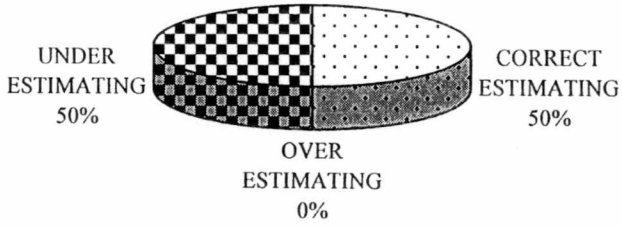
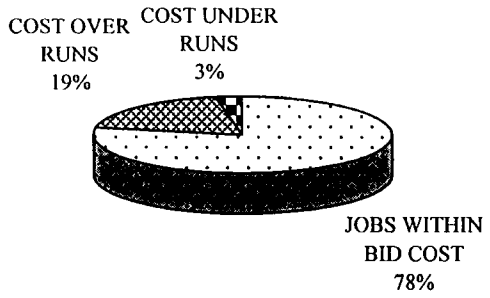
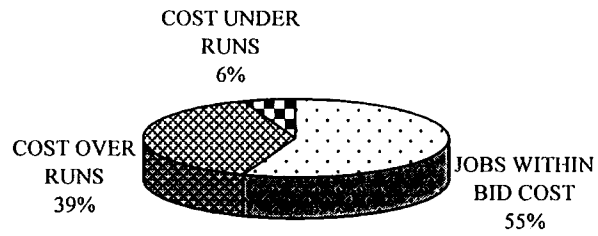


Figure 3 Project Size Time Estimating Survey

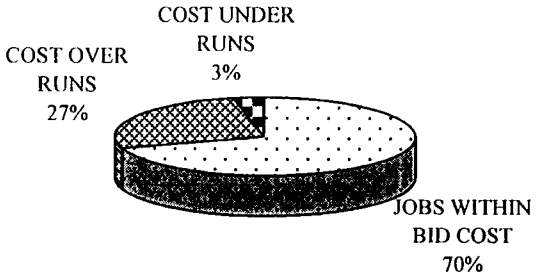
REGION ONE
(36 samplings)



REGION TWO
(36 samplings)



REGION THREE
(60 samplings)



REGION FOUR
(55 samplings)

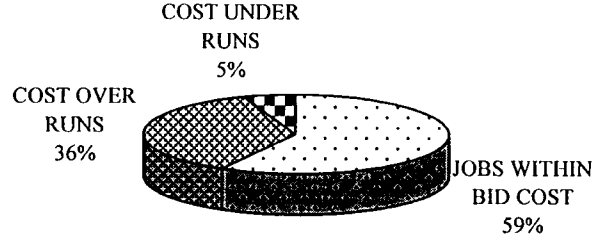
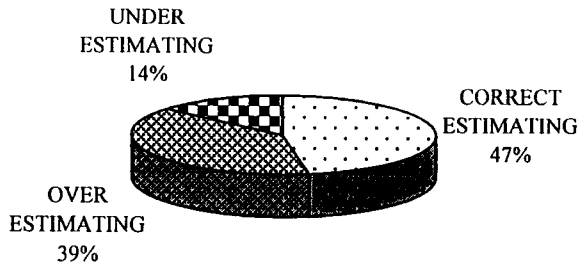
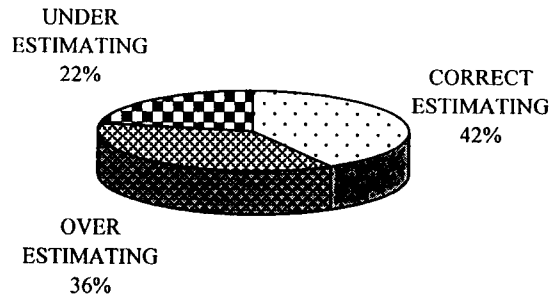


Figure 4 Regional Cost Estimating Survey

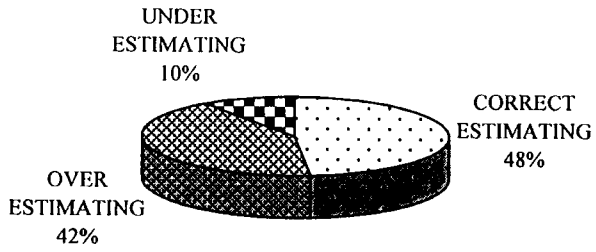
REGION ONE
(36 samplings)



REGION TWO
(36 samplings)



REGION THREE
(60 samplings)



REGION FOUR
(55 samplings)

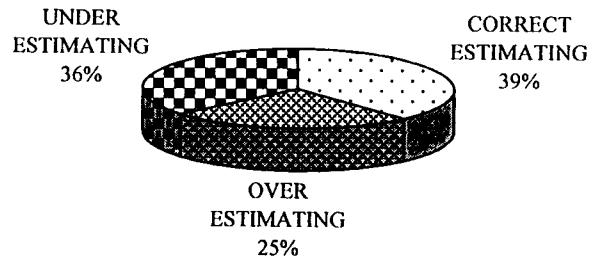


Figure 5 Regional Time Estimating Survey

at least eight working days (approximately two weeks) in 43% percent of its small projects. Thus, it would be a prudent managerial decision if the agency improved its performance in the area of time estimating and cost management.

CHAPTER 4

RESEARCH DEVELOPMENT

The following research methodology was developed through an extensive process of bid document analyses, on-site project observations, and historical TDOT project record analyses. The on-site observations were originally intended to establish cyclic production rates. Although this proved not to be practical, these observations became invaluable in providing an in-depth understanding of rehabilitation processes.

Types of Bridge Deck Rehabilitation

Project observations revealed four possible classifications of bridge deck rehabilitation:

1. Bridge Deck Retrofitting
2. Bridge Deck Patching
3. Bridge Deck Overlays
4. Bridge Deck Replacements

Bridge deck retrofitting includes replacement of the rollers and rockers that support bridge girders that transmit the bridge deck loads to the bridge piers. It also consists of repair to the concrete or steel support girders, upgrading the existing bridge

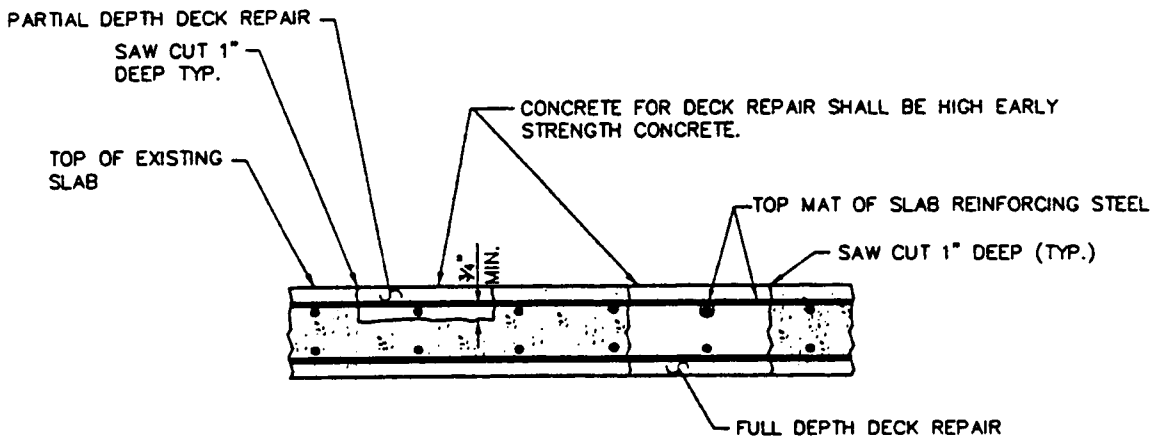
piers and connections to meet new seismic requirements, and the replacement of thermal expansion joints in the bridge deck. Although bridge deck retrofitting occasionally is contracted out independently, it is not usually done exclusively on its own. Usually it is included with other types of bridge deck repair contracts. When this occurs, the activities associated with bridge deck retrofitting are not critical activities that control the project completion time. Therefore, the work activities associated with bridge deck retrofitting have been excluded from receiving separate consideration in this research.

Bridge deck patching occurs when an existing bridge deck exhibits local areas of deteriorating concrete. The current method for determining the location of such areas is a process called "chaining". The process of chaining consists of dragging a metal chain across a bridge deck and listening to the various sounds that are produced. Areas of deteriorating concrete make a very distinct sound in contrast to areas of good concrete. The deteriorating areas must then be identified as being areas of partial bridge deck depth deterioration (partial depth) or full bridge deck depth deterioration (full depth). Full depth deterioration is determined by inspecting the underside of the bridge deck. If large cracks and/or calcium leaks are located beneath areas of deterioration, it is considered an area of full depth deck deterioration. The large cracks and/or calcium leaks usually mean that water and salt have penetrated the concrete and corrosion of the bridge deck reinforcing steel is occurring. These areas of weakness become highly susceptible to breakout due to freeze-thaw cycles or due to high traffic loading, and such potential areas of concrete breakout must be removed. Areas of partial depth concrete deterioration are

removed to one inch below the first mat of bridge deck reinforcing steel, and areas of full depth deterioration require the removal of the full deck depth of concrete (Figure 6.)

After the deteriorated concrete is removed, the bridge deck reinforcing steel is inspected for excessive corrosion. If excessive corrosion exists, then the reinforcing must be replaced in that area and, if not, it is cleaned with a steel brush. After the steel reinforcing is repaired or cleaned, then the areas of concrete deterioration are replaced with new concrete.

Bridge deck overlays occur when an insufficient concrete cover exists on a bridge deck. The cover becomes an insufficient protection against bridge deck reinforcing steel corrosion, which may result from increased traffic loads on the bridge deck. These increased loads may exceed the original design loads, resulting in extensive cracking and the rapid wearing down of the bridge deck. On several job site observations the researcher saw bridge deck concrete covers worn down by traffic to the point that the first mat of reinforcing steel was exposed. Bridge deck overlays may also be placed on older bridges due to the potential increase in the traffic loads on a bridge deck. The increased traffic loads result in the need for a thicker bridge deck to support the traffic load. Thus, a new mat or layer of steel reinforcing is placed on the deck, and a four to six inch layer of new concrete is poured over the entire deck surface. Many times bridge deck overlays also include both full and partial depth repairs to the existing deck. These areas are removed, and the reinforcing steel is cleaned or replaced. The new layer of steel reinforcing is placed over the deck surface, and finally the entire bridge deck surface receives a concrete overlay.



DETAIL SHOWING FULL AND PARTIAL DEPTH DECK REPAIR

Figure 6 Distinguishing the difference between full and partial depth deck repair.

Bridge deck replacement is the replacement of the entire existing bridge deck with a new deck. This usually occurs when a bridge deck has extensive full depth deck deterioration, and it becomes more economical to replace the bridge deck with a new one than to repair the old deck. The old deck is sawn into large sections and the sections removed by crane. A new deck is formed with deck panels of concrete or steel, new epoxy coated reinforcing steel is placed, and a new bridge deck is poured. It is not unusual to have a project with a bridge deck that has a portion of its deck patched and, then it receives an overlay, and finally other portions of its deck replaced.

The Identification of Bridge Deck Rehabilitation Work Activities

Although there are various bridge deck rehabilitation project types, there seems to be a common set of work activities shared by all project types. The identification of these general work activities critical to the time duration of a bridge deck rehabilitation project was fundamental. An extensive examination of TDOT bid documents was performed to determine the general work activities associated with bridge deck rehabilitation. Work items found on bid sheets were identified as being associated with specific work activities as illustrated in Table 1. These identified bridge deck rehabilitation activities were then cataloged under the general groupings and sub-groupings of traffic control, foundation repair, concrete removal, concrete placement, form work, steel placement, and miscellaneous (Table 2.)

Once the work activities associated with bridge deck rehabilitation are established it becomes necessary to outline the general procession of these activities. A

Table 1 An example of work activity identification via bidsheet analyses.

ITEM NUMBER	ITEM DESCRIPTION	PROJECT ACTIVITY
203.03	Borrow Excavation (Unclass)	Excavation
303.01	Mineral Aggregate, Type A Base, Grade D	Excavation
307.03.15	Bituminous Plant Mix Base (HM) Grade B-M	Paving
403.01	Bituminous Material (T C)	Paving
411.01.01	Mineral Aggregate (ACS) Grading D	Paving
411.01.02	Asphalt Cement (ACS) Grading D	Paving
415.01.02	Cold Planing Bituminous Pavement	Milling
604.03.09	Class D Concrete (Bridge Deck)	Concrete Placement
604.04.02	Applied Texture Finish (Existing Structure)	Miscellaneous
604.05.31	Bridge Deck Grooving	Miscellaneous
604.10.02	Concrete Repairs	Concrete Removal and Placement
604.10.13	Concrete Slab Removal	Miscellaneous
604.10.14	Remove Existing Wearing Surface	Milling
604.10.18	Reinforcing Steel (Repairs)	Steel Reinforcing Placement
615.02.05	Prestressed Concrete Box Beam (33 x 36)	Miscellaneous
620.03	Concrete Parapet	Concrete Removal and Placement
705.01.04	Guardrail at Bridge Ends	Guardrail Placement
705.02.02	Single Guardrail (Type 2)	Guardrail Placement
706.01	Guardrail Removal	Guardrail Removal
712.01	Traffic Control	Traffic Control
712.02.02	Interconnected Portable Barrier Rail	Barrier Placement
712.04.01	Flexible Drums (Channelizing)	Traffic Control
712.05.01	Warning Lights (Type A)	Light Placement
712.05.02	Warning Lights (Type B)	Light Placement
712.06.01	Vertical Panels	Traffic Control
712.06.10	New Signs (Construction)	Sign Placement
712.06.15	New Signs (Construction) (Bee Alert)	Sign Placement
712.06.16	Signs (Construction) (Red Speed Warning)	Sign Placement
712.08.03	Arrow Board (Type C)	Traffic Control
712.09.01	Removable Pavement Marking Line	Barrier Placement
716.02.01	Plastic Pavement Marking	Barrier Placement
716.05.01	Painted Pavement Marking	Paving

Table 2 Identified work categories and associated work activities.

CATEGORIES	ACTIVITIES
TRAFFIC CONTROL	Sign and Light Placement
	Barrier Placement
	Drum Placement (Channelization)
FOUNDATION REPAIR	Excavation
	Concrete Removal
	Concrete Placement
CONCRETE REMOVAL	Partial Depth (Bridge Deck)
	Full Depth (Bridge Deck)
	Overhang and Parapet Removal
CONCRETE PLACEMENT	Partial Depth (Bridge Deck)
	Full Depth (Bridge Deck)
	Overhang and Parapet Removal
FORM WORK	All Concrete Placement
STEEL PLACEMENT	Bridge Deck
	Parapet
	Foundation Repair
GENERAL MISCELLANEOUS	Paving
	Milling Pavement
	Grooving Deck
	Curing Time
	General Clean-Up
SPECIFIC MISCELLANEOUS	Guardrail Removal
	Guardrail Installation
	Painting

Gantt or bar chart schedule provides a simple graphical presentation of the project's progression. The Gantt chart has been adapted in Figure 7 to illustrate the general sequence of activities associated with bridge deck rehabilitation as found through the analyses of historical TDOT project records. The Gantt chart was constructed without using any exact activity time duration. Therefore, it should be noted that the time scale on the bar chart in Figure 7 is not representative of actual documented days of work. The Gantt chart in Figure 7 is meant to demonstrate sequential progression, and the time scale presented is used only as a coordinating system for the graph.

Establishing Critical Activities for Bridge Deck Rehabilitation

The Gantt chart illustrates graphically the sequence work activities and graphically illustrates how some work activities may overlap. However, it does not help to identify which activities are critical to the project. Critical activities are those work activities whose completion is required so another activity may begin. When there are simultaneous activities being performed, critical activities are the work activities that require the most human resources, equipment, or time to complete. Critical activities directly affect the time duration of a project and must be given special consideration. The above attributes were considered when determining the critical work activities associated with bridge deck rehabilitation projects. Critical activities were identified through a combination of job site observations, research advisory committee experience, TDOT

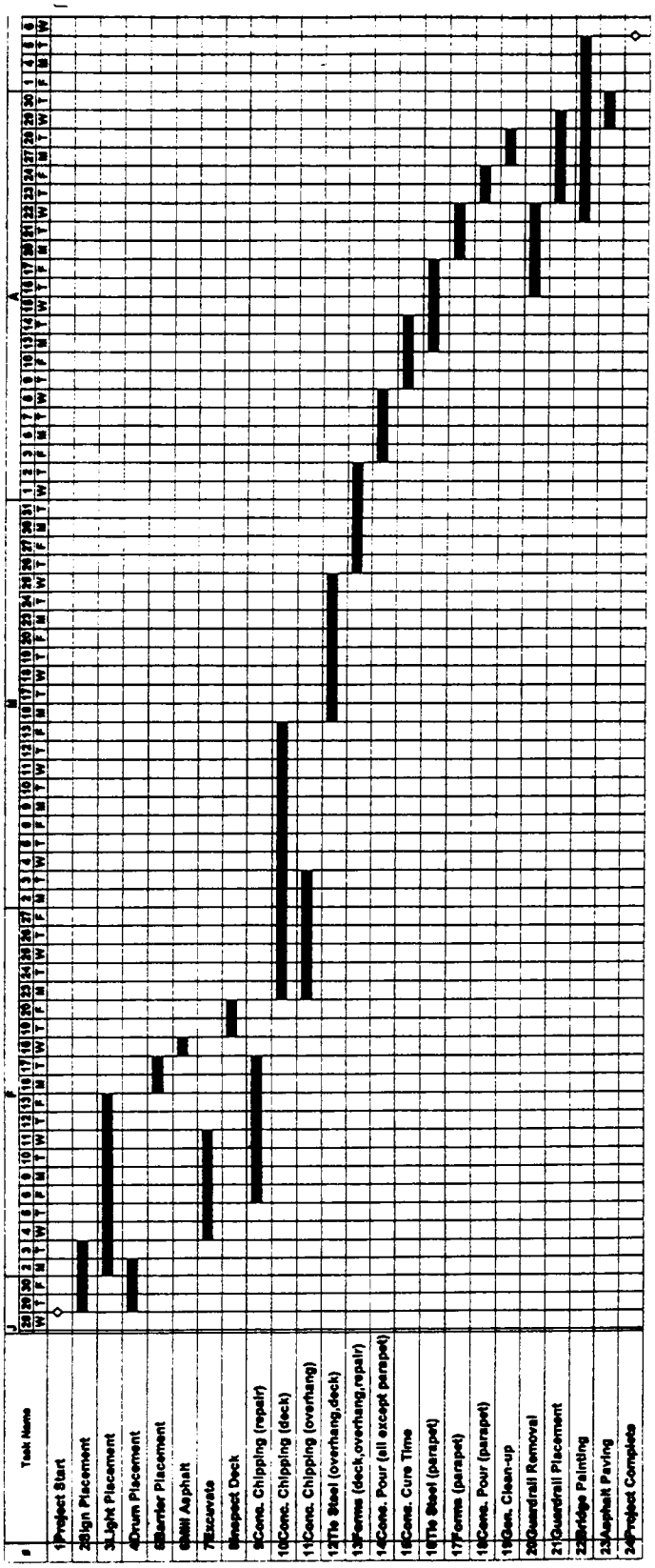


Figure 7 The general Gantt Chart for bridge deck rehabilitation projects.

bridge inspector interviews, and analysis of TDOT project records. These sources provided information concerning the degree of dependency or interdependency of each work activity associated with bridge deck rehabilitation. Those activities whose delay would affect the start time of succeeding activities or the overall time duration of a project were chosen as the critical activities. A listing of the overall critical work activity categories and the specific critical work activities associated with each category are shown in Table 3.

Establishing Production Rates

The establishment of the critical work activities presented in Table 3 determined the work activities that control the time duration of bridge deck rehabilitation projects. The focus of the research became the establishment of the production rates of these activities. It was assumed that the critical activities associated with bridge deck rehabilitation were cyclic in nature, and that their production rates could be determined through observation-based production analysis techniques. This assumption meant that production fluctuations could be determined through one-day site observations and that conventional observation-based production analysis techniques could be used to determine production trends. Once the production trends were determined, production rates could be determined by establishing the typical production range of each critical activity. However, after performing a significant number of on-site observations, it was determined that the majority of the critical activities associated with bridge deck rehabilitation could not be established by observation-based production analyses.

CATEGORIES	Bridge Deck Patching	Bridge Deck Overlay	Bridge Deck Replacement
	Sign Placement	Sign Placement	Sign Placement
TRAFFIC CONTROL	Barrier Placement	Barrier Placement	Barrier Placement
	Light Placement	Light Placement	Light Placement
	Partial Depth (Bridge Deck)	Partial Depth (Bridge Deck)	Bridge Deck (Total)
	Full Depth (Bridge Deck)	Full Depth (Bridge Deck)	Foundation Repair
CONCRETE REMOVAL	Foundation Repair	Foundation Repair	Miscellaneous Repair
	Miscellaneous Repair	Miscellaneous Repair	Overhang and Parapet Removal
	Overhang and Parapet Removal	Overhang and Parapet Removal	
	Partial Depth (Bridge Deck)	Bridge Deck Overlay	New Bridge Deck (Full Depth)
	Full Depth (Bridge Deck)	Foundation Repair	Foundation Repair
CONCRETE PLACEMENT	Foundation Repair	Miscellaneous Repair	Miscellaneous Repair
	Miscellaneous Repair	Overhang and Parapet Removal	Overhang and Parapet Removal
	Overhang and Parapet Removal		
FORM WORK	For All Concrete Placement	For All Concrete Placement	For All Concrete Placement
	Bridge Deck Full Depth Repair	New Bridge Deck Overlay Mat	All New Bridge Deck Reinforcing
STEEL PLACEMENT	Parapet	Parapet	Parapet
	Foundation Repair	Foundation Repair	Foundation Repair

Table 3 The critical work categories and associated work activities.

Although the critical activities associated with bridge deck rehabilitation contained repetitive tasks, these tasks could not be defined as repetitive over a short duration of time such as ten-minute segments. They were repetitive only over large segments of time such as a day. This meant their measurable production cycles could not be determined through one-day site observations because such an observation would constitute only one data point. The only critical activities that could be determined by observation-based production analysis techniques were barrier placement and concrete placement for large concrete pours. The remaining critical activities required a new approach for the determination of their production rates that determined production trends, and thus a production rate range, over a larger segment of time. It was determined that the time segment required to establish the production trends for these activities constituted the entire duration of the rehabilitation project. As a result of this determination, a new analysis method was developed that utilized TDOT project records documenting an entire project to establish project production rates. In the following sections the selected observation-based technique utilized in this research is discussed in detail as well as the development and implementation of the new historical record-based analysis technique.

Observation-based Production Analysis

An observation-based production analysis is an analysis that relies on the documentation of well-defined production cycles. Well-defined production cycles possess a clear beginning and end and occur many times over the course of a relatively short duration of time. Such production cycles can be observed many times over the

course of a day's production. Therefore, large quantities of data can be obtained during a one-day site observation and thus document production trends that can be used to determine typical production rates associated with a specific work activity. In this research the production rates of barrier placement and the placement of concrete on large concrete pours could be established through observation-based production analyses. The production cycle defined for barrier placement was defined as the time required to place one section of portable barrier rails. The production cycle defined for the placement of concrete on large concrete pours was defined as the time to empty and place one truckload of concrete.

Obtaining TDOT Job Site Locations

To conduct on-site observations of TDOT operations, some preliminary information had to be obtained. That information includes obtaining a current listing of all TDOT bridge deck rehabilitation projects in progress or in the process of beginning. This information is usually found via the monthly work progress reports submitted by each region and obtained through each regional office. The work progress form lists the current status of all the projects within that specific region, the project engineer, the location of the job, and the type of bridge rehabilitation being performed. The work progress report provides percentage of completion values that enables the researcher to determine which bridges were best suited for observation of specific tasks. Although not the only possible contact, the project engineer provides a contact person who can provide more updated status reports and work schedules. Another possible contact is the site

supervisor for the contractor. The work progress report also helps in the planning of job site observations by listing the location of the work being performed. Having obtained this preliminary information the researcher is now able to plan and prepare for on-site observations.

The Use of Method Production Delay Models (MPDM's)

The analysis of on-site observation production trends can be achieved through the use of conventional production analysis techniques. The analysis technique chosen for this research was the method productivity delay model (MPDM) developed by J. J. Adrian (Halpin1992). The application of this technique is straightforward and simple. The technique records the time duration of each production cycle associated with a specific construction process and notes the cause and frequency of any delays occurring during production. Simple calculations are then employed to determine the productivity of the operation and the effects of any observed delays. This production analysis technique is implemented in the three stages: data collection, data processing, model structuring, and production determination. The goal of the method productivity delay model is to measure, predict, and improve construction method productivity.

Preliminary Information

Before beginning data collection is begun, an overall description of the observed task is prepared. This description provides information such as observation date and weather conditions and existing site conditions. One also needs to establish production

units, define the production cycle, and to provide a general overview of the construction methods used. Such descriptive information helps to define the critical work activity resources to watch during the production process. The determination of the critical work activity resources prevents the observer from watching the wrong activity and thus obtaining unusable data, and it also alerts the observer to areas of potential delays before the observation begins. The entire method productivity delay model can be presented in a spreadsheet format that contains production cycle observations and production analysis.

Data Collection

The data collection form designed for this is shown in Figure 8. The specific elements of the data collection sheet are explained in the following paragraphs, and Appendix D contains examples of completed forms.

Contractor name: identifies the contractor or subcontractor performing the actual work and allows for productivity comparison between various contractors. A database of contractors and subcontractors can be constructed for use in evaluating or monitoring contractor production rates over a period of time.

Task observed: identifies the work activity for which the observation was conducted.

Construction method: identifies the specific method used by the contractor to perform the work activity observed. This is very important when comparing the efficiency rates of various methods used by different contractors performing the same task. It is important to be specific when identifying the method of

DATA COLLECTION REPORT

GENERAL INFORMATION

Contractor Name:	**Item Number:**
Task Observed:	**Date of Sampling:**
Construction Method Used:	**County:**
Crew Composition:	**Region:**
Time of Day:	**Contract Number:**
Weather During Observation:	**Production Units Observed:**
Site Conditions During Production:	**Production Units Per Hour:**

PRODUCTION CYCLE DELAY SAMPLING

[MPDM] TOTAL PRODUCTION FOR OBSERVATION DURATION

Cycle	Field Time	Cycle Duration	Delay (Yes or No)	Time Added	Delay Cause
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

Figure 8 The Data Collection Report Sheet

construction since variations in methods may prove to be a significant factor affecting the overall productivity.

Crew composition: identifies the crafts involved in the work activity.

Time of day, weather conditions, date of sampling, site conditions: identifies the conditions under which the observed work activity was performed. These data provide information on how site conditions, weather, and seasonal effects actually affects productivity.

Item number, region, county, contract number: identifies optional categories chosen by the researcher to label collected data. Such information becomes useful in grouping and comparing production trends.

Production units observed, production units per hour: identifies the actual units of production observed during the performance of the work activity.

The following portion of the data collection sheet records the actual cycle time and observed delays.

Cycle: identifies a discrete duration of time in which one production unit is recorded.

Field time: records the running clock of the observation

Cycle duration: identifies the time associated with one production cycle and is determined by calculating the difference between each field time entry.

Delays and their cause: documents any observed production delays and several delay types that may occur in one cycle duration. Appropriate time percentages

can be assigned to document this type of occurrence. For this research, only one delay was assigned to any one-cycle duration. If in the course of the observations, several delays occurred during one cycle, then the delay causing the longest time duration was credited for causing the total time of all delays occurring during that cycle. This eliminated the need to assigning a percentage of the cycle duration time to each occurring delay. Thus, defining the time added by the delay as the delay cycle duration time minus the average non-delay cycle time.

Time added: defines the minutes added to the production project by each occurring delay. This column utilizes the mean non-delay cycle time calculated on the production analysis sheet and subtracts it from the delay duration.

Figure 9 presents a convenient format for processing the collected data into a usable productivity analysis and delay model, and can easily be constructed on any spreadsheet to perform the needed calculations with only a few data entries. Examples of this form completed with data can be found in Appendix D.

Cycle Information

This portion of the production analysis documents the non-delay, delay, and total production cycle times, determines the total number of such cycles, and calculates the cycle variations such as the mean, standard deviation, and range of extremes.

METHOD PRODUCTIVITY DELAY MODEL [MPDM]

CYCLE INFORMATION

Units	Total Production Time (Minutes)	Number Of Cycles	Mean Cycle Time	STD DEV data = population	Actual Range Extremes	
A) non-delay production cycles						
B) delay production cycles						
C) total production cycles						

DELAY INFORMATION

DELAY TYPES	Material Delivery	Equipment	Site	Management
D) occurrences				
E) total time added (minutes)				
F) probability of occurrence*				
G) relative severity**				
H) expected % delay time per production cycle***				

* delay cycles / total number of cycles
** mean added cycle time / mean overall cycle time = (row E / row D) / row C
*** Row F times Row G times 100%

PRODUCTIVITY

PRODUCTION

PRODUCTIVITY TYPE:	units/hour
IDEAL PRODUCTIVITY	
OVERALL PRODUCTIVITY	
PRODUCTIVITY CHECK	
FINAL PRODUCTIVITY	

COST ANALYSIS PRODUCTION

UNITS / HOUR

Definition of Terms: Ideal productivity = 1 / mean nondelay cycle time (convert units)
Overall productivity = 1 / mean overall cycle time (convert units)
Check productivity = Ideal productivity * (1 - summation of row H / 100)

PRODUCTIVITY ANALYSIS

PRODUCTIVITY	PRODUCTIVITY UNIT	DAY (HOURS)	WORKING DAY PRODUCTION
units / hour	CONVERSION		UNITS

Figure 9 The Method Productivity Delay Method Worksheet.

Delay Information

This portion of the production analysis considers the effects of delay cycles on overall productivity.

Occurrences: specifies the number of observations of each type of delay.

Total Time added: documents the total time added by the occurrence of each delay type. This is calculated by subtracting the mean non-delay time from each occurring delay cycle. The summation of all minutes added by a specific delay type in entered under the delay heading on line E of the MPDM worksheet.

Probability of occurrence: determines the possible delay frequency of a specific delay type based on the total number of cycles observed.

Delay severity: establishes the possible severity of a delay category on production. The most severe delay possesses the highest average "total time added" to the project for a single occurrence of that delay category, which can be determined by dividing Line E by Line D.

Expected % delay time per production cycle: If during the productivity process any delays occur, by definition of a delay cycle, the time duration of that cycle will be greater than the any non-delay cycle time. Thus, when you consider the mean of all cycle times including delays, also called the mean overall cycle time, a percentage of the mean overall cycle time will be composed of the time added by the occurrences of delayed cycles. For example, if a production process has a mean non-delay cycle time of 8 minutes and mean overall cycle time of 10 minutes, then 2 minutes of the mean overall cycle time or 20% of the mean

overall cycle time, are attributed to delays. Line H of the method productivity delay model calculates the expected percentage of that 20%, or 2 minutes, added by each delay category. For instance, what percentage, or how much of the 2 minutes, added by delays was a result of management delays.

Productivity and Productivity Analysis

It is in this section of the MPDM that the productivity is established and analyzed.

Ideal productivity: This is the projected productivity that would occur if there were no delay cycles. It is calculated by using the reciprocal of the mean non-delay cycle time and converting units so that the productivity is in units per hour.

Overall productivity: This is the productivity that occur considering all production cycles including delay cycles. It is calculated by using the reciprocal of the mean overall cycle time and converting units so that the productivity is in units per hour.

Productivity calculation check: This calculation provides a check for the overall productivity and is calculated by multiplying the ideal productivity times one minus the expected percentages (converted to decimals) of all delay categories found on Line H of the MPDM worksheet.

Historical-record based production analysis

Historical-record based production analysis was developed by the researcher to compensate for the inability to establish the production of non-cyclic work activities.

Such tasks required longer periods of time beyond one-day observations to establish production trends. To obtain project information over longer periods of time the Constant Path Distribution Method (CPDM) was developed to aid in the analysis of historical records. This approach used TDOT project records to obtain information on the total number of days spent over the duration of a project on each non-cyclic work task. The final material quantities used on a project for specific work activities could then be divided by the total number of days spent on that task and a production rate could be established.

Obtaining TDOT Historical Documentation

Obtaining historical documentation from TDOT requires access to a backlog of State of Tennessee notices to contractors of state highway construction bids. These documents provide information concerning job description, location, and project numbers. The job description allows the researcher to narrow the selection of jobs, and the project numbers provide the means for proceeding to the next step in the process. Having selected the jobs for historical analysis, the researcher must proceed to each regional office records department to obtain the state record box number for the specific project numbers. Once the state record box numbers for each project number from each regional office have been obtained, the next step is to submit this box number to the state records office located in Nashville. The state records office will then have the records assembled for the researcher's analysis.

The Development of the Constant Path Distribution Method (CPDM)

The establishment of production rates for critical activities that were not cyclic in nature required an alternative analysis method to that of MPDM. Although such activities possess repetitive processes, these processes were not sequentially consistent. This attribute renders one-day observation and conventional production and delay analysis methods ineffective. To determine an average production rate for non-cyclic work activities, an overall documentation of rehabilitation work was required. Such information was found to be documented in the daily project dairy kept by TDOT field inspectors. These historical reports document the work preformed each day of the project, equipment present on site, work crew sizes, final material quantities used on the project. An example of a project's event table constructed from TDOT inspector's project diary is shown in Table 4, and an example of the final material quantity records for a project is shown in Table 5. The general method for establishing production rates for an activity through the use of historical records is a simple process of document scanning and bookkeeping. Document scanning is required to document the work that was performed on a project each day of the project's duration as recorded in the TDOT inspector's project diary. Bookkeeping is required to account for each day of the project devoted to or associated with each specific task. The final count of days devoted to a work activity becomes the total work activity time duration in days. To obtain the average production rate for a specific work activity in units per day, one must determine the main material quantity associated with that activity and find the total material quantity used on the project. This information can be found in the final material quantity

Table 4 A project's event table as obtained through historical record analyses.

DAY	EVENT	DAY	EVENT
1	sign construction	33	saw and remove overhang
2	set barriers rails for phase one	34	Weekend – remove concrete debris
3	sign construction, mill asphalt	35	Weekend – remove concrete debris
4	saw and remove overhang	36	saw and remove overhang
5	saw and remove overhang	37	remove overhang, set jacks
6	weekend - no work	38	form overhang
7	weekend - no work	39	form overhang
8	saw and remove overhang	40	tie overhang steel
9	saw and remove overhang	41	tie overhang steel
10	saw and remove overhang	42	place screed rail and test grades
11	saw and remove overhang	43	rain day - no work
12	set overhang jacks, form overhang	44	pour bridge deck concrete
13	weekend - shift barriers rails	45	no work - cure time
14	weekend - no work	46	no work - cure time
15	clean deck, form overhang	47	weekend - no work, rain day
16	tie steel, place screed rail	48	weekend - tie parapet steel
17	test screed, set grades for pour	49	set parapet forms
18	pour bridge deck concrete	50	set parapet forms
19	cure time	51	pour parapet concrete
20	weekend - cure time	52	rain day - no work
21	weekend - cure time	53	remove forms
22	tie steel - parapet, abutment	54	weekend - no work
23	set parapet slip forms	55	weekend - no work
24	parapet forms, chip concrete	56	remove guardrail, general clean-up
25	pour parapet concrete	57	remove guardrail, general clean-up
26	remove forms	58	replace guardrail, general clean-up
27	weekend - general clean-up	59	replace guardrail, general clean-up
28	weekend - no work	60	groove bridge deck
29	set barrier rails for phase two	61	asphalt overlay on bridge deck
30	set barrier rails, mill asphalt	62	remove traffic signs, clean-up
31	saw and remove overhang	63	remove traffic signs, clean-up
32	saw and remove overhang	64	remove barrier rails, paint traffic lines

Table 5 Material quantities specified for a typical project as found in historical records.

			ORIGINAL ESTIMATE QUANTITIES				FINAL ESTIMATE QUANTITIES			
ITEM NO.	ITEM DESCRIPTION	UNIT	QUANTITIES	UNIT PRICE	AMOUNT	REFERENCE	QUANTITIES	OVERRUN	(UNDERRUN)	AMOUNT
000.00.00	WORKING DAYS	DAYS	125.000				112.000		-13.000	
209.08.01	TEMPORARY FILTER BARRIER	L F	240.000	3.0000	720.00		200.000		-40.000	600.00
403.01	BITUMINOUS MATERIAL (T C)	TON	1.000	500.0000	500.00				-1.000	
411.01.01	MINERAL AGGREGATE (ACS) GRADING D	TON	93.000	80.0000	7440.00		131.500	38.500		10520.00
411.01.02	ASPHALT CEMENT (ACS) GRADING D	TON	6.000	250.0000	1500.00		7.360	1.360		1840.00
411.02.01	MINERAL AGGREGATE (ACS) GRADING E	TON	150.000	75.0000	11250.00		187.600	37.600		14070.00
411.02.02	ASPHALT CEMENT (ACS) GRADING E	TON	10.000	250.0000	2500.00		10.500	0.500		2625.00
415.01.02	COLD PLANING BITUMINOUS PAVEMENT	S Y	133.000	15.0000	1995.00		159.000	26.000		2385.00
602.10.06	STRUCTURAL STEEL	L B	240.000	14.0000	3360.00		240.000			3360.00
602.10.31	STEEL BR DRAINS (REPAIRS)	EACH	34.000	130.0000	4420.00		34.000			4420.00
603.02.01	REPAINT EXISTING STEEL ST(BRIDGE OVER DI	L S	1.000	32000.0000	32000.00		1.000			32000.00
603.05.21	CONTAINMENT & DISPOSAL OF(BRIDGE OVER	L S	1.000	9000.0000	9000.00		1.000			9000.00
604.03.09	CLASS D CONCRETE (BRIDGE DECK)	C Y	137.000	370.0000	50690.00		137.000			50690.00
604.10.13	CONCRETE SLAB REMOVAL	L S	1.000	28000.0000	28000.00		1.000			28000.00
604.10.14	REMOVE EXISTING WEARING SURFACE	L S	1.000	12000.0000	12000.00		1.000			12000.00
604.10.17	NON-PENETRATING CONCRETE SEAL	S Y	74.000	21.0000	1554.00		70.700		-3.300	1484.70
604.10.18	REINFORCING STEEL (REPAIRS)	L B	28264.000	0.6500	18371.60		28264.000			18371.60
604.10.30	BR DECK REPAIR (FULL DPTH OF SLB)	S Y	250.000	140.0000	35000.00		97.900		-152.100	13706.00
604.10.40	EXPANSION JOINT REPAIRS (TYPE D)	L F	51.000	265.0000	13515.00		51.000			13515.00
604.10.42	CONCRETE REPAIRS	C F	7.000	300.0000	2100.00		15.000	8.000		4500.00
604.10.50	BR DECK RPAR (PART. DPTH OF SLAB)	S Y	450.000	78.0000	35100.00		484.700	34.700		37806.60
604.10.53	CONCRETE REPAIRS	S Y	21.000	525.0000	11025.00		41.300	20.300		21682.50
604.10.54	CONCRETE REPAIR	S F	9.000	200.0000	1800.00		174.900	165.900		34980.00
604.10.90	MISCELLANEOUS BRIDGE ITEM	L S	1.000	4000.0000	4000.00		1.000			4000.00
617.01	BRIDGE DECK SEALANT	S Y	918.000	16.0000	14688.00		1412.900	494.900		22606.40
712.01	TRAFFIC CONTROL	L S	1.000	7000.0000	7000.00		1.000	0.000		7000.00
712.02.02	INTERCONNECTED PORTABLE BARRIER RAIL	L F	672.000	15.0000	10080.00		663.600		-8.400	9954.00
712.04.01	FLEXIBLE DRUMS (CHANNELIZING)	EACH	13.000	50.0000	650.00		29.000	16.000		1450.00
712.05.01	WARNING LIGHTS (TYPE A)	EACH	8.000	75.0000	600.00		8.000			600.00
712.05.03	WARNING LIGHTS (TYPE C)	EACH	9.000	75.0000	675.00		9.000			675.00
712.06	SIGNS (CONSTRUCTION)	S F	483.000	9.0000	4347.00		384.500		-98.500	3460.50
712.06.01	VERTICAL PANELS	S F	76.000	20.0000	1520.00		74.000		-2.000	1480.00
712.09.01	REMOVABLE PAVEMENT MARKING LINE	L F	480.000	2.6500	1272.00		480.000			1272.00

column found on the bidsheet that is also present in TDOT historical project records. The production rate determination is merely a matter of dividing the total material quantity documented for a work activity by the total numbers of days also documented for that work activity. This ratio is the average production rate for that work activity in material units per day. This is the average production rate achieved by the average crew size committed to that work activity over the duration of the project. This method of historical record analysis is simple and straightforward, except in cases where simultaneous occurrences of critical work activities are encountered on a single day. The question then arises as to which activity should the day be accounted to. A consistent method was required to distribute the days amongst the simultaneously occurring activities. To provide this consistent method, the researcher developed a system for prioritizing critical work activities. This priority system was developed into a new historical record analysis method called the Constant Path Distribution Method.

The Constant Path Distribution Method (CPDM) utilizes a priority system that assigns project days in which simultaneous critical work activities occur according to their rankings in that priority system. This distribution of days of simultaneous work activities according to priority results in the elimination of the occurrence of overlapping critical work activities. The result of such a distribution of days is a constant path of work activities. When one activity is completed, then another work activity begins with no overlapping. The elimination of overlapping work activities is achieved by distributing each workday documented in TDOT project records to one and only one work activity. When simultaneous work activities occur, the work activity with the

highest priority ranking receives credit for that day of work. The priority ranking of the critical activities for bridge deck rehabilitation as determined by the researcher is as follows:

1. Concrete Placement
2. Reinforcing Steel Placement
3. Concrete Removal
4. Barrier Placement
5. Form Work (placement and removal)
6. Traffic Control
7. Miscellaneous (all other unspecified activities)

(It should be noted that a researcher might choose to rotate the assignment of simultaneous workdays between priorities 1 and 2 as a way of better describing a project.)

Work activity priority was established by considering the typical amount of time a crew would spend to complete an activity, the amount of labor and equipment resources required for an activity, and its position on the critical path of work progress. Thus, a day of production is assigned to an activity in order of occurrence as long as no simultaneous work activity of higher priority ranking is encountered. If a work activity of higher priority is encountered along the critical path, then the day is assigned to the higher priority ranking activity. Days of production will not be assigned to the previous work activity until it is once again the highest ranking work activity being preformed. This method results in a lower production rate for higher ranking activities and a higher production rate for lower ranking activities. When the resulting production rates are used in a predictive production formula, more days are predicted for the higher-ranking

activities than the lower-ranking activities. The Constant Path Distribution Method provides a means of distributing the overall number of production days of a project as determined from historical records while at the same time considering simultaneous performance of work activities. CPDM is a way of simplifying a Gantt chart schedule (Figure 2) consisting of simultaneous work activities into one constant path of work activities. A CPDM graphical presentation of the final results of a historical record analysis can be seen in Figure 10. Results of historical record analyses using CPDM are found in Appendix A.

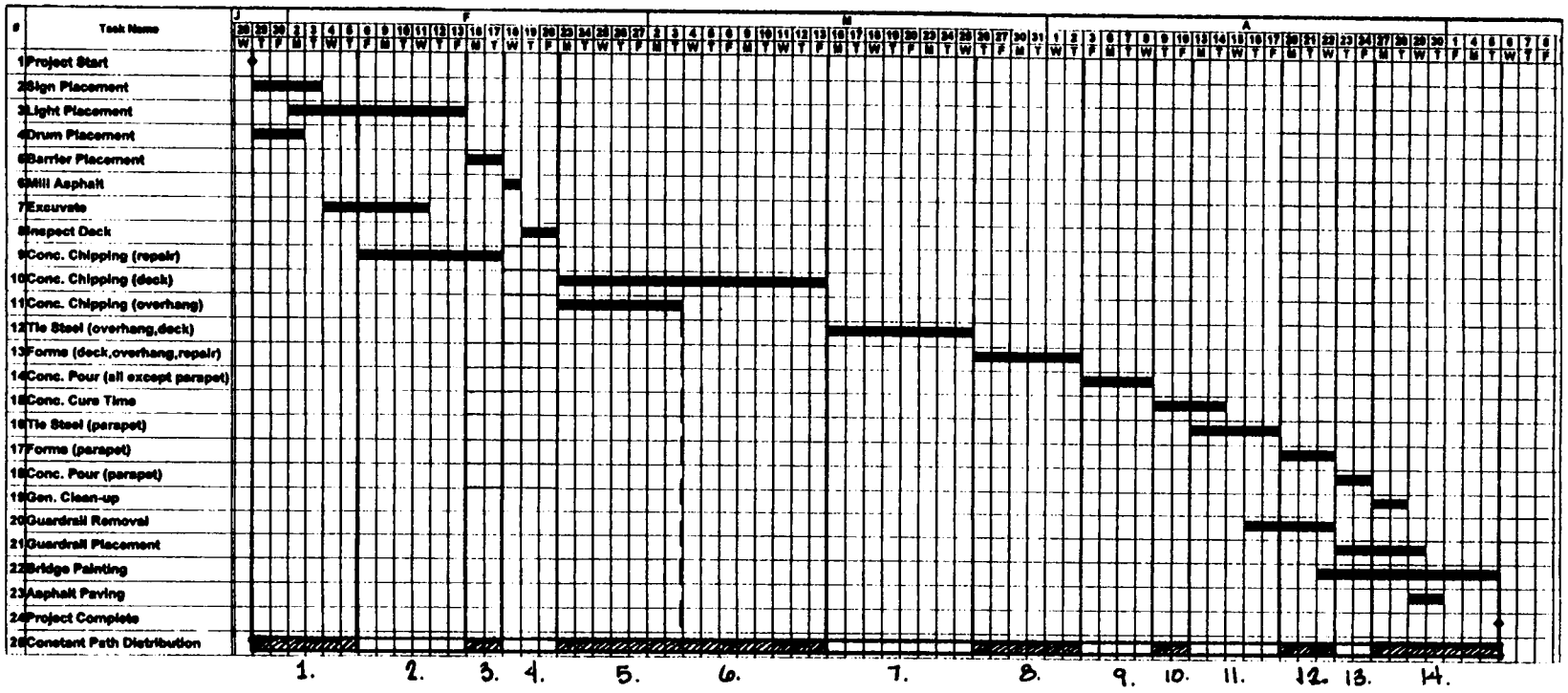


Figure 10 Constant Path Distribution Method (CPDM)

1. **Traffic Control (6 days)**
2. **Concrete Removal - foundation repair (6 days)**
3. **Barrier Placement (2 days)**
4. **Miscellaneous (3 days)**
5. **Concrete Removal - overhang/parapet (7 days)**
6. **Concrete Removal - deck (15 days)**
7. **Reinforcing Steel Placement - deck/overhang (8 days)**
8. **Form Placement (6 days)**
9. **Concrete Placement - all except parapet (4 days)**
10. **Miscellaneous (2 days)**
11. **Reinforcing Steel Placement - parapet (5 days)**
12. **Form Placement (3 days)**
13. **Concrete Placement - parapet (2 days)**
14. **Miscellaneous or Painting (7 days)**

CHAPTER 5

PREDICTIVE TIME ESTIMATE FORMULA

The methods for production data collection that was established in Chapter 4 led to the establishment of preliminary production rates as presented in Chapter 6. To utilize the preliminary production rates, a predictive formula was developed to estimate the typical time duration related to bridge deck rehabilitation. The time estimate formulas combine all critical work activities in a matter that modeled the characteristics of a each type of bridge deck rehabilitation projects. The unknowns in the equation are the material quantities associated with critical work activities. If the final material quantities were known, such as in the case of contractor claims, the formulas can be used to evaluate the time extension requests and the cost associated with such time extensions. If accurate material estimates could be obtained, then the formulas could be used to determine preliminary time estimates for the duration of bridge deck rehabilitation.

Basic Formula Concept

One of the initial assumptions of this research is that the performance of the established critical work activities (Table 3) would compose some relative large percentage of the total time required to complete a project. (Preliminary production analyses show that percentage to be approximately seventy-five percent as shown in

Appendix C under Task Factor.) Therefore, the total working days necessary to complete a rehabilitation project can be established through a ratio of the total days necessary to complete all the critical work tasks and the percentage of total project time that such tasks represent.

Equation 1

$$\frac{D_{CR}}{D_{PD}} = \frac{\%}{100}$$

Where

$$D_{CR} = \sum \frac{M_{CRi}}{P_{CRi}}$$

Equation 1.1 Rearranging the equation yields

$$D_{PD} = \frac{D_{CR}\,(100)}{\%}$$

If

$$\gamma = \frac{100}{\%}$$

Equation 1.2 Then

$$(D_{PD}) = \gamma D_{CR}$$

D_{PD} = Total Project Duration (days)

D_{CR} = Total Task Days (days associated with the completion of critical work tasks)

M_{CRI} = Material Quantity (associated with a single work task)

P_{CRI} = Production Rate (associated with a single work task)

γ = Task Factor (a conversion factor)

General Prediction Formula

Based on the above arguments and using the critical work activity categories shown in Table 3, the following general prediction formula was derived.

Equation 2

$$\text{Estimated Project Duration} = \gamma\left(T + M\left(\frac{B}{r_b}\right) + \frac{C}{r_c} + F\left(\frac{P}{r_p}\right) + \frac{S}{r_s}\right)$$

γ = Conversion Factor

T = Traffic Control Constant

C = Concrete Removal Quantity

P = Concrete Placement Quantity

r_c = Material Removal Rates

F = Form Work Factor

M = Barrier Shift Factor

B = Traffic Barrier Quantity

S = Steel Reinforcing Quantity

$r_{b,p,s}$ = Material Placement Rates

Formula Features

The predictive formula calculates an estimate of working days by having each material quantity divided by a production rate containing the same material quantity units.

$$\text{Work Days} = \gamma\left(T\,(\text{days}) + M\left(\frac{B\,(\text{l.f.})}{r_b\,(\text{l.f./day})}\right) + \frac{C\,(\text{s.y.})}{r_c\,(\text{s.y./day})} + F\left(\frac{P\,(\text{c.y.})}{r_p\,(\text{c.y./day})}\right) + \frac{S\,(\text{lbs.})}{r_s\,(\text{lbs./day})}\right)$$

Equation 3 application of a calendar day factor (C_{DF}) yields estimates in calendar days

$$\text{Estimated Project Duration} = \gamma\left(T + M\left(\frac{B}{r_b}\right) + \frac{C}{r_c} + F\left(\frac{P}{r_p}\right) + \frac{S}{r_s}\right)C_{DF}$$

Equation Constants

The general equation determines the estimated number of days associated with the completion of all critical work activities. The critical work activities, however, compose only a percentage (approximately 75%) of the total time required to complete a rehabilitation project. The Task Factor (γ), which is a conversion factor that converts the percentage of days estimated for the completion of critical work activities into the full number of days estimated for the project, including miscellaneous days.

The general equation returns the project duration time in working days. If estimated project duration is required in calendar days, then a calendar day factor (C_{DF}) is applied to the general formula. The Calendar Day Factor projects additional days to the duration of a project to account for major production delays, inclement weather delays, labor holidays, and weekends. The result is an estimate that predicts the number of calendar days necessary to complete a project.

The Traffic Control Constant (T) models the time spent on typical bridge deck rehabilitation projects to place traffic control, which consists of the time spent to build construction signs, place traffic lights, and to place traffic barrels. A constant was chosen to model this segment of bridge deck rehabilitation work since the days required to perform these tasks varies from project to project depending on project location, traffic levels, bridge length, and whether traffic lights are installed. Although barrier placement is a part of placing traffic control, it has been given separate consideration due to its cyclic nature and specifically defined quantity.

The Barrier Shift Factor (M) models the typical condition on a rehabilitation project that requires the traffic barriers to be shifted as work is complete in one lane of traffic and begins in the next lane. Traffic barriers may also be shifted to provide improved traffic channelization or to gain greater access to one specific area of the project.

The Form Work Factor (F) models the typical condition on a rehabilitation project that requires the forming for concrete placement. This factor is applied to the concrete placement quantity because, typically, the more concrete that is placed on a project the more days are required to provide the forms for that concrete. The form factor not only includes the days to construct the necessary form work for all concrete placement including repair, but also the time to wreck the forms and to construct any false work necessary for concrete beam repairs.

Formula Expansion

Once the general predictive formula for bridge deck rehabilitation, was formulated, the formula was expanded to model each of the separate bridge deck rehabilitation project types and their specific characteristics. These characteristics included the defining of what tasks constituted total concrete removal and total concrete placement, as well as how these tasks' related to the equation factors.

For bridge deck spot patching, the concrete removal consists of full and partial deck depth, concrete repair work on the underside of the bridge deck and the foundation, and overhang and parapet removal. The placement of the concrete falls into these same

categories. However, in the bridge deck spot patching equation, the Form Factor is not applied to the time estimated for the placement of the partial depth concrete quantity, since no form work is necessary. This characteristic can be seen in the separation of the estimated days for partial depth placement from the total estimated time for all concrete placement.

For bridge deck overlays, the concrete removal also consists of full and partial deck depth, concrete repair work on the underside of the bridge deck and the foundation, and the removal of the deck overhang and parapet wall. The placement of the concrete, however, consists of the overlay quantity and the concrete repair quantity since the overlay will fill the partial and the full depth repair areas. This characteristic can be seen in the bridge deck overlay equation in the defining of the total time estimated for all concrete placements.

For bridge deck replacement work, the concrete removal consists of removing the entire deck slab, the deck overhang and parapet wall, as well as any foundation repair. The placement of concrete reflects the same removal categories. These characteristics are seen in the defining of the time estimated for the total removal and replacement of all concrete quantities.

Although these formula features may seem minor, they model unique characteristics associated with the various types of bridge deck rehabilitation projects as seen in Figures 11-13. The attention to such uniqueness provides a more accurate time estimate formula.

Bridge Deck Spot Patching

$$\text{EstimatedProject Duration} = \gamma\left(T + M\left(\frac{B}{r_8}\right) + C_T + F\left(P_T - \frac{P_P}{r_5}\right) + \frac{P_P}{r_5} + \frac{S}{r_9}\right)$$

Where

$$C_T = \frac{C_F}{r_1} + \frac{C_P}{r_2} + \frac{C_R}{r_3} + \frac{C_O}{r_4} \qquad P_T = \frac{P_F + P_P}{r_5} + \frac{P_R}{r_6} + \frac{P_O}{r_7}$$

EQUATION TERMS

C_T = Total Concrete Removal **(Days)**

P_T = Total Concrete Placement **(Days)**

CONSTANTS AND FACTORS

γ = Task Factor

T = Traffic Control Constant **(Days)**

M = Barrier Shift Factor

F = Form Work Factor

MATERIAL QUANTITIES AND UNITS

C_F = Concrete Removal; Full Depth **(S.Y.)**
C_P = Concrete Removal; Partial Depth **(S.Y.)**
C_R = Concrete Removal; Repair **(S.Y.)**
C_O = Concrete Removal; Deck Overhang and Parapet Wall **(L.F.)**

P_F = Concrete Placement; Full Depth **(S.Y.)**
P_P = Concrete Placement; Partial Depth **(S.Y.)**
P_R = Concrete Placement; Repair **(S.Y.)**
P_O = Concrete Placement; Deck Overhang and Parapet Wall **(L.F.)**

B = Traffic Barrier Placement **(L.F.)**
S = Concrete Reinforcing Steel Placement **(Lbs.)**

PRODUCTION RATES

r_1 = Concrete Removal Rate; Full Depth **(S.Y./Day)**
r_2 = Concrete Removal Rate; Partial Depth **(S.Y./Day)**
r_3 = Concrete Removal Rate; Concrete Repair Work **(S.Y./Day)**
r_4 = Concrete Removal Rate; Deck Overhang and Parapet Wall **(L.F./Day)**
r_5 = Concrete Placement Rate; Full and Partial Depth **(S.Y./Day)**
r_6 = Concrete Placement Rate; Concrete Repair Work **(S.Y./Day)**
r_7 = Concrete Placement Rate; Parapet Wall **(L.F./Day)**
r_8 = Traffic Barrier Placement **(L.F./Day)**
r_9 = Concrete Steel Reinforcing Placement **(Lbs./Day)**

Figure 11 Bridge Deck Spot Patching Time Estimate Formula

Bridge Deck Overlay

$$\text{Estimated Project Duration} = \gamma\left(T + M\left(\frac{B}{r_8}\right) + C_T + FP_T + \frac{S}{r_9}\right)$$

$$C_T = \frac{C_F}{r_1} + \frac{C_P}{r_2} + \frac{C_R}{r_3} + \frac{C_O}{r_4} \qquad P_T = \frac{P_D}{r_5} + \frac{P_R}{r_6} + \frac{P_O}{r_7}$$

Where

EQUATION TERMS

C_T = Total Concrete Removal **(Days)**

P_T = Total Concrete Placement **(Days)**

CONSTANTS AND FACTORS

γ = Task Factor

M = Barrier Shift Factor

T = Traffic Control Constant **(Days)**

F = Form Work Factor

MATERIAL QUANTITIES AND UNITS

C_F = Concrete Removal; Full Depth **(S.Y.)**
C_P = Concrete Removal; Partial Depth **(S.Y.)**
C_R = Concrete Removal; Repair **(S.Y.)**
C_O = Concrete Removal; Deck Overhang and Parapet Wall **(L.F.)**

P_D = Concrete Placement; Deck Overlay **(C.Y.)**
P_R = Concrete Placement; Repair **(S.Y.)**
P_O = Concrete Placement; Deck Overhang and Parapet Wall **(L.F.)**

B = Traffic Barrier Placement **(L.F.)**
S = Concrete Reinforcing Steel Placement **(Lbs.)**

PRODUCTION RATES

r_1 = Concrete Removal Rate; Full Depth **(S.Y./Day)**
r_2 = Concrete Removal Rate; Partial Depth **(S.Y./Day)**
r_3 = Concrete Removal Rate; Concrete Repair Work **(S.Y./Day)**
r_4 = Concrete Removal Rate; Deck Overhang and Parapet Wall **(L.F./Day)**
r_5 = Concrete Placement Rate; Deck Overlay **(S.Y./Day)**
r_6 = Concrete Placement Rate; Concrete Repair Work **(S.Y./Day)**
r_7 = Concrete Placement Rate; Parapet Wall **(L.F./Day)**
r_8 = Traffic Barrier Placement **(L.F./Day)**
r_9 = Concrete Steel Reinforcing Placement **(Lbs./Day)**

Figure 12 Bridge Deck Overlay Time Estimate Formula

Bridge Deck Replacement

$$\text{EstimatedProject Duration} = \gamma\left(T + M\left(\frac{B}{r_8}\right) + C_T + FP_T + \frac{S}{r_9}\right)$$

Where

$$C_T = \frac{C_D}{r_1} + \frac{C_R}{r_3} + \frac{C_O}{r_4} \qquad P_T = \frac{P_D}{r_5} + \frac{P_R}{r_6} + \frac{P_O}{r_7}$$

EQUATION TERMS

C_T = Total Concrete Removal **(Days)** P_T = Total Concrete Placement **(Days)**

CONSTANTS AND FACTORS

γ = Task Factor
T = Traffic Control Constant **(Days)**
M = Barrier Shift Factor
F = Form Work Factor

MATERIAL QUANTITIES AND UNITS

C_D = Concrete Removal; Complete Deck **(S.Y.)**
C_R = Concrete Removal; Repair **(S.Y.)**
C_O = Concrete Removal; Deck Overhang and Parapet Wall **(L.F.)**

P_D = Concrete Placement; New Deck **(C.Y.)**
P_R = Concrete Placement; Repair **(S.Y.)**
P_O = Concrete Placement; Deck Overhang and Parapet Wall **(L.F.)**

B = Traffic Barrier Placement **(L.F.)**
S = Concrete Reinforcing Steel Placement **(Lbs.)**

PRODUCTION RATES

r_1 = Concrete Removal Rate; Complete Deck **(S.Y./Day)**
r_3 = Concrete Removal Rate; Concrete Repair Work **(S.Y./Day)**
r_4 = Concrete Removal Rate; Deck Overhang and Parapet Wall **(L.F./Day)**
r_5 = Concrete Placement Rate; Full and Partial Depth **(S.Y./Day)**
r_6 = Concrete Placement Rate; Concrete Repair Work **(S.Y./Day)**
r_7 = Concrete Placement Rate; Parapet Wall **(L.F./Day)**
r_8 = Traffic Barrier Placement **(L.F./Day)**
r_9 = Concrete Steel Reinforcing Placement **(Lbs./Day)**

Figure 13 Bridge Deck Replacement Time Estimate Formula

CHAPTER 6

PRODUCTION RATE ANALYSES

The core of this research was devoted to the establishment of the production rates for the critical work activities associated with bridge deck rehabilitation. The data analyses establishing the presented production rates can be found in Appendix C. Although considerable effort was devoted to the establishment of these production rates, they are not definitive and additional research would be beneficial. For instance, the production rate (r_1, r_2) for deck removal rate on bridge deck replacement projects was not established due to lack of data. However, the presented production rates serve as an excellent starting point for the use of the provided production formulas in the determination of preliminary project duration estimates or the evaluation of contractor claims.

Production Rate Features

The provided work activity production rate information is accompanied by statistical information such as the data sample group's mean and standard deviation, as well as the results of applying the Kolmogorov-Smirnov (K-S) test to the data set. The K-S test was used to determine whether the data collected for bridge deck rehabilitation work activities were normally or lognormally distributed. All work activity data groups

passed the K-S test for both normal and lognormal distribution as seen in Appendix C. This information was originally intended to be used to define a work activity's production rate. The production rate would be chosen by selecting a number of standard deviations from the calculated mean so as to capture a large percentage of the work activity's recorded production rates, which represented documented bridge deck rehabilitation contractor production capability. Taking the data's calculated mean plus or minus a number of standard deviations would then establish a production rate. This would insure that the selected production rate would represent the percentage of bridge deck rehabilitation contractors capable of meeting or exceeding that production rate. However, the effectiveness of approach was questioned when extreme variations in documented production rates were found. It was believed that factors outside the scope of this research were producing these extreme variations and that using a number of standard of deviations from the mean may not be a good reflection of common contractor production capability. Therefore, the mean of the data sets was chosen as the established production rates.

The mean for each data set was determined by dividing the total material quantity associated with a critical work activity by the total number of working days associated with the sample group. Therefore, a sample group with a total of two hundred square yards of concrete placed and a total of twenty workdays associated with that group would have a calculated mean of ten square yards per working day. This would be the preliminary production rate associated with that data sample group. It is hoped that future research will define the factors contributing to the extreme variations in work

activity production rates so as to lead to an accurate assessment of which production rates reflect typical conditions and which reflect abnormal conditions. This should lead to a means of editing the data so as to reduce the extremities. The case may be that additional date is required to fill in the current gaps in the data set. In hopes of aiding future research, the mean, standard deviation, and the results of the K-S tests have been included in the provided production rate information.

Concrete Repair Material Quantity Determination

The majority of critical work activities had only one bidsheet line item number listed for associated material quantities, and these can be taken directly from the bidsheet material quantity listings. This was not the case for concrete repair material quantities. Under the line item title of "concrete repair" there existed four different bidsheet line items numbers listed in the bidsheet material quantity listing and each one possessed a different unit of material quantity. The four line item numbers listed and the material unit are as follows:

1.) 604.10.42	C. F. (cubic foot)
2.) 604.10.02	C.Y. (cubic yard)
3.) 604.10.54	S.F. (square foot)
4.) 604.10.53	S.Y. (square yard)

Since in the production formula a total concrete quantity is calculated, the material unit selected for concrete repair needed to be compatible with the other concrete material quantities. Therefore, all material quantities associated with concrete repair needed to be

in square yards. To convert the cubic yards and cubic feet to square yards, researcher chose to convert the volume units into a comparable quantity unit of partial depth repair by using the partial depth dimension of 3.5 inches. This dimension was used as the depth dimension needed as the conversion factor from a volume quantity to an area quantity.

Production Rates

Tables 6, 7, 8 presents a listing of the determined production rates, constants, and factors to be used in the appropriate predictive time estimate formula presented in Figures 11-13. These rates, constants, and factors have been determined as described in the above sections and the calculated work presented in Appendix C. Certain work activities presented in Tables 6-8 contain more than one production rate, and is given to allow for better modeling of certain conditions. These conditions are defined with the production rates in Appendix C. Figures 11-13, Tables 6-8, and Appendix C work in conjunction to provide all the necessary information for formulating a predictive time estimate.

Sample Calculation

Contract 3733 used in the rate test presented in Table 9 will be used in the following sample calculations. Contract 3733 is an overlay project and will utilize the formula found in Figure 12. The appropriate production rate values are found in Table 7. Table 9 contains the material quantities to be entered into the estimated project duration formulas, which have been obtained from material quantity sheets such as the example found in Table 5.

Table 6 Bridge Deck Spot Patching Production Rates

BRIDGE DECK SPOT PATCHING PRODUCTION RATES					
Categories	**Symbol**		**Unit**		**Rate**
FACTORS					
Task Factor	γ		**none**		**1.32**
Barrier Shift Factor	**M**		**none**		**4**
Form Work Factor	**F**		**none**		**2.66**
CONSTANTS					
Traffic Control Constant	**T**		**days**		**6**
PRODUCTION RATES					
Concrete Removal Rates					
Full and Partial Depth	r_1, r_2		**s.y./day**	*	**3, 14, 67**
Concrete Repair	r_3		**s.y./day**	*	**7, 56**
Deck Overhang / Parapet Wall	r_4		**l.f./day**		**54**
Concrete Placement Rates					
Full and Partial Depth	r_5		**s.y./day**		**67**
Concrete Repair	r_6		**s.y./day**		**47**
Parapet Wall	r_7		**l.f./day**		**107**
OTHER					
Barrier Placement Rate	r_8		**l.f./day**		**820**
Steel Reinforcing Placment Rate	r_9		**lbs./day**		**1343**

* RATE VARIATION BASED ON QUANTITY REMOVED SEE APPENDIX C

Table 7 Bridge Deck Overlay Production Rates

BRIDGE DECK OVERLAY PRODUCTION RATES					
Categories	**Symbol**		**Units**		**Rate**
FACTORS					
Task Factor	γ		**none**		**1.32**
Barrier Shift Factor	**M**		**none**		**4**
Form Work Factor	**F**		**none**		**1.88**
CONSTANTS					
Traffic Control Constant	**T**		**days**		**8**
PRODUCTION RATES					
Concrete Removal Rates					
Full and Partial Depth	r_1, r_2		**s.y./day**	*	**3, 14, 67**
Concrete Repair	r_3		**s.y./day**	*	**7, 56**
Deck Overhang / Parapet Wall	r_4		**l.f./day**		**54**
Concrete Placement Rates					
Deck Overlay	r_5		**c.y./day**	**	**75, 350**
Concrete Repair	r_6		**s.y./day**		**47**
Parapet Wall	r_7		**l.f./day**		**107**
OTHER					
Barrier Placement Rate	r_8		**l.f./day**		**820**
Steel Reinforcing Placment Rate	r_9		**lbs./day**		**3145**

* RATE VARIATION BASED ON QUANTITY REMOVED SEE APPENDIX C

** RATE VARIATION BASED ON METHOD OF PLACEMENT SEE APPENDIX C

Table 8 Bridge Deck Replacement Production Rates

BRIDGE DECK REPLACEMENT PRODUCTION RATES					
Categories	**Symbol**		**Units**		**Rate**
FACTORS					
Task Factor	γ		**none**		**1.30**
Barrier Shift Factor	**M**		**none**		**4**
Form Work Factor	**F**		**none**		**2.69**
CONSTANTS					
Traffic Control Constant	**T**		**days**		**6**
PRODUCTION RATES					
Concrete Removal Rates					
Bridge Deck	r_1, r_2		**s.y./day**	***	**unknown**
Concrete Repair	r_3		**s.y./day**	*	**7, 56**
Deck Overhang / Parapet Wall	r_4		**l.f./day**		**54**
Concrete Placement Rates					
Bridge Deck	r_5		**s.y./day**	**	**75, 350**
Concrete Repair	r_6		**s.y./day**		**47**
Parapet Wall	r_7		**l.f./day**		**107**
OTHER					
Barrier Placement	r_8		**l.f./day**		**820**
Steel Reinforcing Placement	r_9		**lbs./day**		**3912**

* RATE VARIATION BASED ON QUANTITY REMOVED SEE APPENDIX C

** RATE VARIATION BASED ON METHOD OF PLACEMENT SEE APPENDIX C

** RATE NOT ESTABLISHED BY DUE TO LACK OF INFORMATION

Table 9 Production Rate Test

Information		Quantity Removal			Quantity Placement					
Contract	Type	Full & Partial	Repair	Overhang	Barrier	Deck Concrete		Repair	Parapet	Steel
		(S.Y.)	(S.Y.)	(L.F.)	(L.F.)	(C.Y.)	(S.Y.)	(S.Y.)	(L.F.)	(LB)
3830	repair	1452	0	0	1760		1452	0	0	0
3733	overlay	421	267	971	950	293		267	971	81658
3110	overlay	111	0	212	280	30		0	212	13577
2938	overlay	0	1915	348	350	161		1915	348	32901
3007	overlay	40	1815	570	740	215			570	55572
3268	repair	261	109	0	4900		370	109	0	0
3330	repair	116	13	484	930		129	13	184	20011
3420	overlay	142	3	744	949	250		3	744	49221
3386	overlay	2716	1861	0	4340	250		1861	0	48743
8439	overlay	278	7	42	850	40		7	1217	75711
2596	overlay	46	30	202	610	120		30	202	23152
8497	overlay	81	2	189	730	168		2	374	13037

Contract	Days Estimated	Days Actual	Variance	%	CDF Estimate	CD Actual	CDF Variance	%
3830	81	96	-15	-16%	162	248	-86	-35%
3733	159	111	48	43%	318	326	-8	-2%
3110	40	101	-61	-60%	80	319	-239	-75%
2938	191	98	93	95%	382	280	102	36%
3007	128	241	-113	-47%	256	498	-242	-49%
3268	104	122	-18	-15%	208	414	-206	-50%
3330	69	115	-46	-40%	138	363	-225	-62%
3420	89	145	-56	-39%	178	362	-184	-51%
3386	256	205	51	25%	512	479	33	7%
8439	106	127	-21	-17%	212	277	-65	-23%
2596	62	108	-46	-43%	124	349	-225	-64%
8497	43	121	-78	-64%	86	286	-200	-70%

In Table 7 the concrete removal for full and partial depth and the concrete placement rate of the deck concrete, possess to possible production rates. By consulting Appendix C6, the production rate for 421 square yards of concrete removal is 14 square yards per day. The production rate for placing 293 cubic yards of concrete is 350 cubic yards per day (Appendix C11) assuming use of the most common method of concrete placement, pumptruck and shoot. The estimated project duration can then be calculated as follows:

$$\text{Estimated Project Duration} = \gamma\left(T + M\left(\frac{B}{r_8}\right) + C_T + FP_T + \frac{S}{r_9}\right)$$

$$C_T = \frac{C_F}{r_1} + \frac{C_P}{r_2} + \frac{C_R}{r_3} + \frac{C_O}{r_4} \qquad P_T = \frac{P_F + P_P}{r_5} + \frac{P_R}{r_6} + \frac{P_O}{r_7}$$

$$P_T = \frac{293\,(\text{c.y.})}{350\,(\text{c.y./day})} + \frac{267\,(\text{s.y.})}{47\,(\text{s.y./day})} + \frac{971\,(\text{l.f.})}{107\,(\text{l.f./day})} = 15.59$$

$$C_T = \frac{421\,(\text{s.y.})}{14\,(\text{s.y./day})} + \frac{267\,(\text{s.y.})}{56\,(\text{s.y./day})} + \frac{971\,(\text{l.f.})}{54\,(\text{l.f./day})} = 52.82$$

$$1.32\left(8 + 4\left(\frac{950\,(\text{l.f.})}{820\,(\text{l.f./day})}\right) + 52.82 + 1.88(15.59) + \frac{81658\,(\text{lbs.})}{3145\,(\text{lbs./day})}\right) = 159$$

Production Rate Test

Table 9 presents a production rate test performed on data samples not used to determine any production rates. However, The data presented in the "Day Actual" column of Table 9, was not checked against historical documents to verify its values. This means this data may be incorrect due to incorrect documentation by TDOT

inspectors. The "Days Actual" column of Table 9 was taken from Appendix A, which was constructed from TDOT records. It was found that such documents contain incorrect working day documentation. According to TDOT inspector notation found in Appendix A, the estimated duration of contract 8717 was 75 working days and the actual number of working days charged by the inspector was 74. However, after going through each day of the project, as noted in Appendix B, the researcher noted 115 days of work. Discrepancies such as these are common and the result of inspectors and engineers not documenting working days correctly to avoid extra paper work caused by time overruns and to avoid conflicts with contractors. Incorrect documentation of more working days than actually occurs can also be found in TDOT documentation such as contract 3625, which (Appendix A) records that the project was estimated to take 160 working days and 145 days were charged. Yet after examining historical documentation, 83 days were spent on bridge rehabilitation and 55 days spent painting the bridge for a total of 138 days. Thus, the column used to compare the working days estimated by the predictive formulas, the "actual" working days column, is more than likely incorrect.

Another factor that could contribute to improper conclusions from the rate tests presented in Table 9 is the possible incorrect determination of material quantities used on a project. Although, every attempt was made by the researcher to be thorough, there may have been project quantity corrections listed in other portions of the historical records unbeknownst to the researcher, or flaws in the assumption of how to convert volume quantities of concrete repairs to area quantities. Any discrepancies in material quantities would throw the rate test off, but not prove that the preliminary rates are incorrect.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

The rate test presented in Table 9 contains possible error and, therefore, it is the opinion of the researcher that the presented rate test is not indicative of how well the rates match actual project results. The rate test was included as standard research procedure and for a quick check of this research if someone were to gain access to the contracts used in the rate test and determine the real length of the projects. This test does not prove that the production rates provided by this research are good or bad, but that the rate test is inadequate proof of validity. It is the strong belief of the researcher that the simple logic behind the development of formulas and production rates is correct, although the production rates may needed augmentation through continued monitoring.

Continued Monitoring of Production Rates

The collection of additional production data by TDOT is essential to the evaluation of this study and to the agency's effort to effectively manage bridge deck rehabilitation projects. The collection of important production information can be achieved by refining the current information collected by TDOT field inspectors and organizing it into a concise document. This form should specify work activities performed with special notation given to critical work activities, the quantity of material

placed, and the number of hours worked on each work activity. From such information daily production can be determined and monitored, which would increase accuracy in the modeling of production trends and provide the detailed information necessary to evaluate potential claims by contractors.

Preliminary Production Rates

The production rates provided by this research are best considered as preliminary production rates because these production rates have been provided to serve as a starting point for continued production rate updates. Although its was the full intention of this research to provide definitive production rates for all work activities, as the scope and complexity of the research grew it became evident that this could not be achieved within the allotted research budget and time schedule. It is believed that the production rates provided will prove to be valuable aids providing preliminary project time duration and in evaluating contractor claims. However, production rate refinement is always necessary to reflect changes in construction industry as well as new techniques and technology. A case in point is the growth in the use of concrete demolition utilizing water also known as hydrodemolition. The use of hydrodemolition greatly speeds up the concrete removal process, which is currently the most time consuming portion of bridge deck rehabilitation projects. The production rates provided by this research do not include the use of this new technology, therefore, continued production rate refinement is necessary to remain abreast of construction trends. Continuous monitoring of production

rates will increase the data sample size from which the production rates are established and inform TDOT official of any shifts or changes in current production trends.

Calendar Day verses Working Day Contracts

It has become apparent through the progression of this research that the more effective and efficient bridge deck rehabilitation contract is the calendar day contract. A calendar day contract is a contract that specifies that a project must be completed on or before a specific calendar date. In contrast, working day contracts are contracts that specify that a project must be completed within a given number of working days. It is the charging of working days, which is the weakness of such a contract method.

Working days are charged at the discretion of the TDOT inspectors and results in a great variation as to what constitutes a working day. TDOT has defined a working day, as a calendar day, exclusive of Saturdays, Sundays and State recognized holidays. It is also exclusive of days on which weather or other conditions beyond the control of the contractor that prevent construction operations to proceed for at least five hours of the day. Although defined, the interpretation of the working day definition varies from one inspector to another inspector. No definition interpretation is required with the use of calendar day contracts.

Another factor affecting the charging of working days is the influence of the contractor on inspectors. Many times it was evident to the researcher when review historical documents that conditions for the charging of working days existed and yet no day was charged. This was also seen in the field observations and when confronted,

inspectors stated that the slight inaccurate charging of workdays kept the relationship between themselves and the contractor affable. Such conflicts in the field can be eliminated by the use of calendar day contracts that do not rely on the charging of working days by the field inspectors.

The use of calendar day contracts is a much more effective and efficient method of conducting bridge deck rehabilitation. These contracts eliminate the conflict between field inspectors and contractors over what days should be considered working days. The use of calendar day contracts also provides the contractor with a concise completion date before work is begun. This date is effective despite holidays and weekends. Only extreme weather conditions and extreme material discrepancy results in contract extension.

Research Continuance

The solution to the inaccuracies of initial material quantity estimates, which render time duration estimates as mere guestimation, is the fundamental key to the success of the predictive methods outlined in this research. Therefore, it is the researcher's recommendation that immediate attention be given by TDOT to research methods that will help in the establishment of initial material quantity estimates. If the methods of thermography or ground-penetrating radar are beyond the resources of TDOT, then additional research should be funded to identify the factors affecting or related to the quantity of rehabilitation material quantities. Any advancement in the accuracy of predictive material quantities will result in a direct improvement in the use of predictive time estimate formulas in establishing preliminary project time duration.

BIBLIOGRAPHY

BIBLIOGRAPHY

Tennessee Department of Transportation Standard Specification for Road and Bridge Construction. March 15, 1995 Edition. Nashville, TN: Tennessee Department of Transportation, 1995.

"Infrared Scanning Speeds Bridge Deck Inspection" *Public Works*. Vol. 119, June 1988, pp. 77-79.

Banks, Ralph K. "Bridge Decks: Their Problems and Solutions" *Public Works*. Vol. 117, Dec. 1986, pp. 26-28.

Bentil, Kweku K. *Fundamentals of the Construction Process*. Kingston, MA: R. S. Means Company Inc., 1989.

Frein, Joseph P. *Handbook of Construction Management and Organization*. Second Edition. New York, NY: Van Nostrand Reinhold Company Inc., 1980.

Halpin, Daniel W. and Leland S. Riggs. *Planning and Analysis of Construction Operations*. New York, NY: John Wiley and Son Inc., 1992.

Kipp, Jerry S. "Thermographic Investigation of a Bridge Deck" *Public Works*. Vol. 114, Sept. 1983, pp. 70-73.

Kobelt, Paul S. "Drive-Through Bridge Deck Inspection" *Public Works*. Vol. 127, June 1996, pp. 25-27.

Maser, Kenneth R. and W. M. Kim Roddis. "Principles of Thermography and Radar for Bridge Deck Assessment". *Journal of Transportation Engineering*. Vol. 116, No. 5, Sept./ Oct. 1990, pp. 583-601.

Nunnally, S. W. *Construction Methods and Management*. Second Edition. Englewood Cliffs, NJ: Prentice-Hall Inc., 1987.

APPENDICES

APPENDIX A

HISTORICAL SURVEY DATA

Contract	Region	County	Calendar	Estimated	Actual	Run	Variance	CDF	Initial	Final	Difference	Percentage
7385	4	Shelby	447	125	164	39	31.20%	2.73	$915,820.50	$953,317.13	$37,496.63	4.09%
7417	3	Giles	98	50	41	-9	-18.00%	2.39	$95,496.63	$102,158.30	$6,661.67	6.98%
7488	2	Coffee	174	70	67	-3	-4.29%	2.60	$229,997.36	$240,906.08	$10,908.72	4.74%
7595	3	Lewis	66	40	32	-8	-20.00%	2.06	$493,408.25	$501,315.58	$7,907.33	1.60%
7626	1	Campbell	87	90	47	-43	-47.78%	1.85	$145,478.75	$143,813.50	($1,665.25)	-1.14%
7667	3	Maury	224	100	97	-3	-3.00%	2.31	$361,903.60	$365,183.64	$3,280.04	0.91%
7740	2	Hamilton	91	35	35	0	0.00%	2.60	$369,757.11	$391,203.83	$21,446.72	5.80%
7768	4	Obion	504	115	120	5	4.35%	4.20	$528,609.20	$534,932.89	$6,323.69	1.20%
7795	1	Washington	298	90	90	0	0.00%	3.31	$1,459,319.99	$1,449,719.28	($9,600.71)	-0.66%
7853	4	Lauderdale	722	150	151	1	0.67%	4.78	$456,654.64	$644,135.74	$187,481.10	41.06%
7868	3	Smith	116	50	43	-7	-14.00%	2.70	$82,087.48	$91,961.02	$9,873.54	12.03%
7933	3	Perry	171	90	84	-6	-6.67%	2.04	$297,609.64	$284,429.79	($13,179.85)	-4.43%
7981	1	Cocke	109	70	68	-2	-2.86%	1.60	$166,012.00	$169,381.47	$3,369.47	2.03%
8001	2	Hamilton	81	35	39	4	11.43%	2.08	$288,573.55	$302,338.60	$13,765.05	4.77%
8007	3	Humphreys	126	75	74	-1	-1.33%	1.70	$293,349.40	$303,859.90	$10,510.50	3.58%
8037	2	Warren	212	70	67	-3	-4.29%	3.16	$181,151.40	$163,679.68	($17,471.72)	-9.64%
8111	2	Hamilton	60	50	45	-5	-10.00%	1.33	$215,000.00	$214,700.00	($300.00)	-0.14%
8112	2	Hamilton	81	60	50	-10	-16.67%	1.62	$499,434.00	$413,341.28	($86,092.72)	-17.24%
8114	2	Hamilton	38	65	32	-33	-50.77%	1.19	$135,500.00	$133,349.99	($2,150.01)	-1.59%
8129	4	Shelby	240	60	60	0	0.00%	4.00	$207,684.20	$217,253.76	$9,569.56	4.61%
8168	2	Hamilton	517	110	110	0	0.00%	4.70	$1,223,332.50	$1,669,359.63	$446,027.13	36.46%
8218	3	Sumner	36	45	29	-16	-35.56%	1.24	$306,376.29	$302,243.39	($4,132.90)	-1.35%
8326	2	Fentress	275	125	164	39	31.20%	1.68	$389,736.95	$526,403.27	$136,666.32	35.07%
8327	2	Fentress	190	120	77	-43	-35.83%	2.47	$233,429.84	$259,319.89	$25,890.05	11.09%
8331	4	Hardeman	305	100	115	15	15.00%	2.65	$555,388.70	$634,506.15	$79,117.45	14.25%
8332	4	Hardeman	541	125	144	19	15.20%	3.76	$606,242.87	$651,219.84	$44,976.97	7.42%
8338	4	Madison	245	70	96	26	37.14%	2.55	$84,236.30	$94,833.99	$10,597.69	12.58%
8384	4	Carroll	160	125	71	-54	-43.20%	2.25	$378,644.40	$432,829.41	$54,185.01	14.31%
8400	4	Dyer	224	60	48	-12	-20.00%	4.67	$128,723.00	$128,998.31	$275.31	0.21%
8401	2	Fentress	132	70	69	-1	-1.43%	1.91	$138,020.00	$130,267.64	($7,752.36)	-5.62%
8421	2	Polk	118	65	73	8	12.31%	1.62	$221,550.04	$203,292.37	($18,257.67)	-8.24%
8428	4	Shelby	62	60	16	-44	-73.33%	3.88	$97,388.84	$111,435.46	$14,046.62	14.42%
8432	3	Smith	146	80	78	-2	-2.50%	1.87	$181,287.34	$226,975.19	$45,687.85	25.20%
8434	3	Sumner	109	90	56	-34	-37.78%	1.95	$122,256.50	$138,618.94	$16,362.44	13.38%

Contract	Region	County	Calendar	Estimated	Actual	Run	Variance	CDF	Initial	Final	Difference	Percentage
8439	4	Weakley	277	125	127	2	1.60%	2.18	$448,685.49	$466,150.00	$17,464.51	3.89%
8441	3	Williamson	220	115	97	-18	-15.65%	2.27	$226,642.74	$255,050.30	$28,407.56	12.53%
8442	3	Williamson	212	90	90	0	0.00%	2.36	$113,736.36	$107,169.36	($6,567.00)	-5.77%
8465	1	Blount	216	120	128	8	6.67%	1.69	$636,636.75	$658,110.66	$21,473.91	3.37%
8497	4	Haywood	286	100	121	21	21.00%	2.36	$294,450.10	$340,243.07	$45,792.97	15.55%
8499	3	Hickman	111	45	42	-3	-6.67%	2.64	$171,056.00	$109,524.24	($61,531.76)	-35.97%
8502	1	Jefferson	119	80	77	-3	-3.75%	1.55	$198,405.00	$198,687.39	$282.39	0.14%
8504	4	Lake	92	40	26	-14	-35.00%	3.54	$112,794.00	$131,800.85	$19,006.85	16.85%
8515	1	Morgan	48	60	29	-31	-51.67%	1.66	$109,751.35	$371,262.85	$261,511.50	238.28%
8519	3	Robertson	127	110	72	-38	-34.55%	1.76	$198,562.00	$225,015.89	$26,453.89	13.32%
8530	3	Sumner	184	110	103	-7	-6.36%	1.79	$156,480.00	$164,106.08	$7,626.08	4.87%
8541	3	Bedford	188	75	75	0	0.00%	2.51	$281,039.05	$256,673.25	($24,365.80)	-8.67%
8542	3	Bedford	315	90	90	0	0.00%	3.50	$294,297.50	$312,755.11	$18,457.61	6.27%
8546	4	Chester	351	80	102	22	27.50%	3.44	$286,800.50	$216,769.91	($70,030.59)	-24.42%
8562	4	Hardin	327	170	160	-10	-5.88%	2.04	$628,972.00	$630,288.73	$1,316.73	0.21%
8563	4	Hardin	192	90	95	5	5.56%	2.02	$196,279.10	$241,858.46	$45,579.36	23.22%
8572	1	Knox	329	90	101	11	12.22%	3.26	$265,992.50	$339,490.37	$73,497.87	27.63%
8576	1	Loudon	154	100	94	-6	-6.00%	1.64	$243,664.00	$245,473.14	$1,809.14	0.74%
8590	3	Smith	250	60	78	18	30.00%	3.21	$176,406.27	$179,475.57	$3,069.30	1.74%
8598	1	Union	132	70	66	-4	-5.71%	2.00	$319,298.00	$315,812.00	($3,486.00)	-1.09%
8613	4	Fayette	303	75	69	-6	-8.00%	4.39	$110,324.50	$123,978.90	$13,654.40	12.38%
8628	3	Maury	183	75	86	11	14.67%	2.13	$267,286.30	$250,104.98	($17,181.32)	-6.43%
8638	3	Wilson	62	30	30	0	0.00%	2.07	$39,355.00	$38,093.51	($1,261.49)	-3.21%
8654	1	Carter	214	90	55	-35	-38.89%	3.89	$235,498.40	$224,141.67	($11,356.73)	-4.82%
8667	1	Carter	387	175	169	-6	-3.43%	2.29	$679,092.20	$667,150.93	($11,941.27)	-1.76%
8682	3	Hickman	247	110	98	-12	-10.91%	2.52	$364,060.76	$356,664.89	($7,395.87)	-2.03%
8693	4	Madison	123	100	60	-40	-40.00%	2.05	$115,082.00	$119,175.16	$4,093.16	3.56%
8694	4	Madison	73	75	52	-23	-30.67%	1.40	$72,280.00	$72,995.67	$715.67	0.99%
8717	1	Washington	167	75	74	-1	-1.33%	2.26	$351,018.75	$382,298.39	$31,279.64	8.91%
8723	1	Anderson	177	70	28	-42	-60.00%	6.32	$226,833.48	$228,874.76	$2,041.28	0.90%
8745	2	Hamilton	218	70	66	-4	-5.71%	3.30	$278,768.00	$282,829.74	$4,061.74	1.46%
8746	1	Hancock	74	30	30	0	0.00%	2.47	$315,224.97	$304,853.84	($10,371.13)	-3.29%
8757	3	Lincoln	219	35	34	-1	-2.86%	6.44	$531,288.26	$557,627.73	$26,339.47	4.96%
8772	1	Roane	172	80	76	-4	-5.00%	2.26	$214,209.00	$217,571.88	$3,362.88	1.57%

Contract	Region	County	Calendar	Estimated	Actual	Run	Variance	CDF	Initial	Final	Difference	Percentage
8782	4	Shelby	40	70	19	-51	-72.86%	2.11	$75,126.14	$79,965.60	$4,839.46	6.44%
8793	3	Williamson	198	75	73	-2	-2.67%	2.71	$225,676.00	$226,020.26	$344.26	0.15%
8795	3	Williamson	97	90	54	-36	-40.00%	1.80	$392,752.16	$417,700.85	$24,948.69	6.35%
8820	1	Cocke	126	60	45	-15	-25.00%	2.80	$170,311.00	$175,367.90	$5,056.90	2.97%
8837	1	Roane	199	90	93	3	3.33%	2.14	$647,996.60	$693,237.58	$45,240.98	6.98%
8840	4	Shelby	299	110	122	12	10.91%	2.45	$655,421.52	$645,564.55	($9,856.97)	-1.50%
8841	4	Shelby	155	70	34	-36	-51.43%	4.56	$169,584.56	$155,017.01	($14,567.55)	-8.59%
8842	3	Stewart	142	90	82	-8	-8.89%	1.73	$144,136.68	$158,224.15	$14,087.47	9.77%
2020	4	Dyer	507	150	193	43	28.67%	2.63	$1,148,277.80	$1,313,795.49	$165,517.69	14.41%
2046	2	McMinn	157	90	89	-1	-1.11%	1.76	$228,563.77	$231,797.17	$3,233.40	1.41%
2060	3	Moore	211	75	75	0	0.00%	2.81	$166,097.38	$163,203.76	($2,893.62)	-1.74%
2071	4	Shelby	63	45	22	-23	-51.11%	2.86	$96,450.00	$97,770.60	$1,320.60	1.37%
2074	3	Smith	202	105	99	-6	-5.71%	2.04	$402,672.82	$407,141.06	$4,468.24	1.11%
2099	2	Cumberland	420	150	180	30	20.00%	2.33	$104,688.50	$162,883.45	$58,194.95	55.59%
2181	4	Hardeman	391	100	118	18	18.00%	3.31	$1,001,546.70	$1,186,375.70	$184,829.00	18.45%
2214	1	Anderson	74	75	50	-25	-33.33%	1.48	$199,534.50	$213,332.17	$13,797.67	6.91%
2250	1	Greene	119	90	66	-24	-26.67%	1.80	$186,479.43	$193,280.75	$6,801.32	3.65%
2277	4	Shelby	77	45	37	-8	-17.78%	2.08	$87,269.80	$89,339.29	$2,069.49	2.37%
2381	4	Hardeman	422	120	178	58	48.33%	2.37	$956,608.07	$956,608.07	$0.00	0.00%
2384	4	Henderson	265	90	73	-17	-18.89%	3.63	$181,771.00	$182,158.55	$387.55	0.21%
2387	4	McNairy	820	100	143	43	43.00%	5.73	$604,890.20	$621,885.80	$16,995.60	2.81%
2398	3	Smith	356	110	113	3	2.73%	3.15	$623,864.46	$818,564.43	$194,699.97	31.21%
2400	3	Trousdale	160	70	59	-11	-15.71%	2.71	$129,944.05	$140,807.35	$10,863.30	8.36%
2404	3	Wilson	295	90	89	-1	-1.11%	3.31	$192,759.20	$194,694.38	$1,935.18	1.00%
2548	4	Madison	150	60	60	0	0.00%	2.50	$102,921.00	$121,783.11	$18,862.11	18.33%
2566	4	Weakley	445	80	89	9	11.25%	5.00	$168,859.62	$191,524.60	$22,664.98	13.42%
2575	3	Cheatham	394	100	142	42	42.00%	2.77	$344,109.25	$388,083.40	$43,974.15	12.78%
2582	3	Davidson	290	110	150	40	36.36%	1.93	$454,755.63	$457,492.42	$2,736.79	0.60%
2596	4	Henry	349	110	108	-2	-1.82%	3.23	$269,043.64	$270,600.85	$1,557.21	0.58%
2610	3	Perry	348	120	105	-15	-12.50%	3.31	$513,526.94	$643,182.82	$129,655.88	25.25%
2619	1	Sullivan	139	90	77	-13	-14.44%	1.81	$169,545.90	$192,121.69	$22,575.79	13.32%
2652	3	Hickman	174	110	97	-13	-11.82%	1.79	$248,997.97	$240,453.26	($8,544.71)	-3.43%
2654	3	Humphreys	319	120	120	0	0.00%	2.66	$569,588.63	$599,639.62	$30,050.99	5.28%
2660	2	Marion	525	120	157	37	30.83%	3.34	$559,534.85	$611,568.53	$52,033.68	9.30%

Contract	Region	County	Calendar	Estimated	Actual	Run	Variance	CDF	Initial	Final	Difference	Percentage
2657	1	Knox	224	75	72	-3	-4.00%	3.11	$222,830.00	$296,812.85	$73,982.85	33.20%
2666	1	Roane	237	120	100	-20	-16.67%	2.37	$685,054.00	$689,583.30	$4,529.30	0.66%
2696	4	Dyer	334	110	104	-6	-5.45%	3.21	$279,403.90	$329,505.55	$50,101.65	17.93%
2716	1	Knox	77	142	71	-71	-50.00%	1.08	$194,677.00	$218,115.84	$23,438.84	12.04%
2767	1	Cocke	300	80	142	62	77.50%	2.11	$337,137.22	$591,278.77	$254,141.55	75.38%
2774	3	Davidson	207	95	70	-25	-26.32%	2.96	$236,224.99	$255,192.76	$18,967.77	8.03%
2782	3	Giles	93	60	45	-15	-25.00%	2.07	$106,125.00	$123,184.85	$17,059.85	16.08%
2787	4	Henderson	426	90	90	0	0.00%	4.73	$278,460.32	$321,902.61	$43,442.29	15.60%
2796	3	Lewis	313	100	99	-1	-1.00%	3.16	$273,466.75	$300,761.29	$27,294.54	9.98%
2839	1	Cocke	329	100	130	30	30.00%	2.53	$827,853.15	$833,525.82	$5,672.67	0.69%
2847	3	Hickman	260	60	60	0	0.00%	4.33	$457,194.39	$492,669.98	$35,475.59	7.76%
2853	1	Morgan	210	60	55	-5	-8.33%	3.82	$141,931.00	$144,814.62	$2,883.62	2.03%
2881	4	Shelby	157	95	52	-43	-45.26%	3.02	$353,533.66	$365,896.76	$12,363.10	3.50%
2922	4	Carroll	279	90	86	-4	-4.44%	3.24	$386,192.21	$422,638.28	$36,446.07	9.44%
2938	4	Hardin	280	90	98	8	8.89%	2.86	$215,472.40	$242,081.64	$26,609.24	12.35%
2969	3	Wilson	435	125	151	26	20.80%	2.88	$1,017,622.24	$1,045,183.11	$27,560.87	2.71%
3007	2	Cumberland	498	140	241	101	72.14%	2.07	$411,093.40	$739,214.83	$328,121.43	79.82%
3017	3	Giles	317	110	101	-9	-8.18%	3.14	$322,681.32	$321,130.70	($1,550.62)	-0.48%
3026	4	Hardin	373	75	97	22	29.33%	3.85	$134,768.65	$141,139.31	$6,370.66	4.73%
3055	3	Sumner	381	110	109	-1	-0.91%	3.50	$373,158.30	$341,906.24	($31,252.06)	-8.38%
3077	2	Cumberland	103	130	72	-58	-44.62%	1.43	$250,522.40	$241,423.40	($9,099.00)	-3.63%
3081	2	Dekalb	287	120	113	-7	-5.83%	2.54	$178,876.00	$207,306.72	$28,430.72	15.89%
3110	4	McNairy	319	80	101	21	26.25%	3.16	$155,987.23	$156,489.84	$502.61	0.32%
3119	2	Putnam	409	130	171	41	31.54%	2.39	$227,324.00	$210,175.21	($17,148.79)	-7.54%
3123	3	Stewart	236	45	38	-7	-15.56%	6.21	$143,280.00	$126,862.61	($16,417.39)	-11.46%
3146	4	Carroll	420	90	87	-3	-3.33%	4.83	$534,319.50	$578,887.86	$44,568.36	8.34%
3167	3	Hickman	115	80	71	-9	-11.25%	1.62	$752,501.10	$763,289.93	$10,788.83	1.43%
3173	4	Madison	414	60	70	10	16.67%	5.91	$547,032.75	$561,236.40	$14,203.65	2.60%
3209	2	Bradley	90	35	30	-5	-14.29%	3.00	$400,895.59	$412,891.38	$11,995.79	2.99%
3223	2	Dekalb	272	120	113	-7	-5.83%	2.41	$185,769.12	$188,727.73	$2,958.61	1.59%
3238	4	Haywood	423	125	149	24	19.20%	2.84	$557,305.45	$571,002.30	$13,696.85	2.46%
3240	4	Haywood	267	75	74	-1	-1.33%	3.61	$128,365.25	$146,410.16	$18,044.91	14.06%
3268	4	Shelby	414	125	122	-3	-2.40%	3.39	$1,215,820.50	$1,142,403.51	($73,416.99)	-6.04%
3278	3	Wayne	385	125	123	-2	-1.60%	3.13	$1,100,660.10	$1,164,868.05	$64,207.95	5.83%

Contract	Region	County	Calendar	Estimated	Actual	Run	Variance	CDF	Initial	Final	Difference	Percentage
3302	3	Giles	57	50	24	-26	-52.00%	2.38	$77,701.00	$88,992.49	$11,291.49	14.53%
3306	1	Hamblen	536	100	179	79	79.00%	2.99	$532,997.30	$575,474.89	$42,477.59	7.97%
3315	3	Hickman	231	90	90	0	0.00%	2.57	$281,493.11	$284,911.28	$3,418.17	1.21%
3118	1	Jefferson	208	90	89	-1	-1.11%	2.34	$434,587.98	$411,787.97	($22,800.01)	-5.25%
3322	1	Knox	418	120	109	-11	-9.17%	3.83	$708,662.10	$740,890.38	$32,228.28	4.55%
3330	4	Madison	363	75	115	40	53.33%	3.16	$527,150.80	$488,327.00	($38,823.80)	-7.36%
3335	3	Marshall	243	110	104	-6	-5.45%	2.34	$453,059.46	$454,844.19	$1,784.73	0.39%
3338	3	Moore	229	90	63	-27	-30.00%	3.63	$223,431.10	$253,476.41	$30,045.31	13.45%
3352	2	Sequatchie	321	140	158	18	12.86%	2.03	$482,188.35	$499,153.65	$16,965.30	3.52%
3362	3	Trousdale	235	90	73	-17	-18.89%	3.22	$169,168.80	$186,392.79	$17,223.99	10.18%
3367	4	Weakley	279	90	74	-16	-17.78%	3.77	$278,781.56	$298,662.24	$19,880.68	7.13%
3386	3	Davidson	479	150	205	55	36.67%	2.34	$1,030,492.25	$1,493,138.14	$462,645.89	44.90%
3392	1	Greene	392	150	168	18	12.00%	2.33	$1,219,704.50	$1,208,567.38	($11,137.12)	-0.91%
3393	1	Greene	317	110	110	0	0.00%	2.88	$565,968.50	$547,370.61	($18,597.89)	-3.29%
3403	2	McMinn	478	200	185	-15	-7.50%	2.58	$1,078,906.77	$1,054,026.64	($24,880.13)	-2.31%
3407	3	Perry	202	100	98	-2	-2.00%	2.06	$203,949.60	$231,247.34	$27,297.74	13.38%
3409	2	Putnam	301	50	52	2	4.00%	5.79	$168,622.54	$245,902.98	$77,280.44	45.83%
3420	4	Weakley	362	120	145	25	20.83%	2.50	$458,482.85	$487,915.29	$29,432.44	6.42%
3421	3	Wilson	248	110	109	-1	-0.91%	2.28	$380,704.15	$401,034.26	$20,330.11	5.34%
3434	2	Fentress	312	145	80	-65	-44.83%	3.90	$292,220.02	$315,607.90	$23,387.88	8.00%
3518	2	White	332	150	140	-10	-6.67%	2.37	$442,754.15	$373,124.23	($69,629.92)	-15.73%
3557	3	Davidson	76	50	50	0	0.00%	1.52	$354,476.50	$352,988.92	($1,487.58)	-0.42%
3568	2	Jackson	173	100	105	5	5.00%	1.65	$225,142.08	$243,897.43	$18,755.35	8.33%
3576	4	McNairy	229	40	83	43	107.50%	2.76	$137,799.04	$110,551.14	($27,247.90)	-19.77%
3588	3	Rutherford	81	75	53	-22	-29.33%	1.53	$162,194.00	$164,953.87	$2,759.87	1.70%
3592	4	Shelby	129	100	255	155	155.00%	0.51	$892,038.60	$810,805.43	($81,233.17)	-9.11%
3613	2	Dekalb	158	120	97	-23	-19.17%	1.63	$193,675.10	$214,544.27	$20,869.17	10.78%
3623	2	Hamilton	64	85	55	-30	-35.29%	1.16	$245,181.00	$293,115.64	$47,934.64	19.55%
3624	2	Hamilton	318	110	90	-20	-18.18%	3.53	$293,864.00	$336,170.95	$42,306.95	14.40%
3625	2	Hamilton	232	160	145	-15	-9.38%	1.60	$680,546.70	$794,473.23	$113,926.53	16.74%
3665	1	Blount	371	110	85	-25	-22.73%	4.36	$417,090.78	$419,388.90	$2,298.12	0.55%
3676	3	Dickson	269	75	66	-9	-12.00%	4.08	$183,889.10	$211,114.03	$27,224.93	14.81%
3680	4	Fayette	302	110	109	-1	-0.91%	2.77	$486,615.20	$562,128.90	$75,513.70	15.52%
3708	1	Roane	104	100	61	-39	-39.00%	1.70	$322,948.50	$344,686.39	$21,737.89	6.73%

Contract	Region	County	Calendar	Estimated	Actual	Run	Variance	CDF	Initial	Final	Difference	Percentage
3730	3	Bedford	253	75	66	-9	-12.00%	3.83	$141,775.08	$143,089.47	$1,314.39	0.93%
3733	4	Benton	326	115	111	-4	-3.48%	2.94	$639,041.52	$688,960.00	$49,918.48	7.81%
3760	4	Dyer	142	75	71	-4	-5.33%	2.00	$270,356.92	$305,702.27	$35,345.35	13.07%
3767	1	Greene	254	100	69	-31	-31.00%	3.68	$285,958.75	$249,755.77	($36,202.98)	-12.66%
3778	1	Hawkins	281	110	114	4	3.64%	2.46	$526,408.00	$624,582.78	$98,174.78	18.65%
3799	2	Overton	297	110	98	-12	-10.91%	3.03	$232,380.30	$272,942.07	$40,561.77	17.45%
3830	2	Coffee	248	120	96	-24	-20.00%	2.58	$412,892.50	$528,991.75	$116,099.25	28.12%
3850	4	Henderson	303	75	82	7	9.33%	3.70	$390,287.00	$440,448.62	$50,161.62	12.85%
3865	4	Madison	258	75	87	12	16.00%	2.97	$376,983.55	$412,033.67	$35,050.12	9.30%
3911	1	Greene	271	90	80	-10	-11.11%	3.39	$339,242.50	$333,672.13	($5,570.37)	-1.64%
3924	2	Meigs	235	110	97	-13	-11.82%	2.42	$290,188.50	$282,767.74	($7,420.76)	-2.56%
3931	4	Shelby	143	35	30	-5	-14.29%	4.77	$248,013.40	$240,613.46	($7,399.94)	-2.98%
3932	4	Shelby	321	125	129	4	3.20%	2.49	$475,383.25	$424,870.61	($50,512.64)	-10.63%
3960	2	Hamilton	171	70	61	-9	-12.86%	2.80	$180,194.80	$230,960.71	$50,765.91	28.17%
3968	3	Rutherford	146	90	47	-43	-47.78%	3.11	$120,600.70	$109,939.74	($10,660.96)	-8.84%
3969	3	Rutherford	223	90	69	-21	-23.33%	3.23	$175,643.00	$178,799.41	$3,156.41	1.80%
4016	3	Davidson	140	125	82	-43	-34.40%	1.71	$282,962.09	$267,349.70	($15,612.39)	-5.52%
4054	3	Williamson	159	90	87	-3	-3.33%	1.83	$217,886.40	$256,236.66	$38,350.26	17.60%

APPENDIX B

HISTORICAL RECORD ANALYSIS

TABLE OF CONTENTS - APPENDIX B

Bridge Deck Spot Patching Historical Record Analysis 90

Bridge Deck Overlay Historical Record Analysis 96

Bridge Deck Replacement Historical Record Analysis 100

Contract Number	3799	
Rehabilitation Type	Patching	
Miscellaneous	**16**	
Forms	**20**	
Traffic Control	**4**	
Barriers	**3**	
Conc. Placement Total	**7**	
	Deck Patching	3
	Parapet	4
	Conc. Repair	0
Conc. Removal Total	**38**	
	Overhang	20
	Deck Patches	18
	Conc. Repair	0
Rebar Placement	**10**	
Total Days (w/o painting)	98	
Painting	0	

Contract Number	8421	
Rehabilitation Type	Patching	
Miscellaneous	**26**	
Forms	**9**	
Traffic Control	**2**	
Barriers	**2**	
Conc. Placement Total	**6**	
	Deck Patching	x
	Parapet	x
	Conc. Repair	x
Conc. Removal Total	**18**	
	Overhang	x
	Deck Patches	x
	Conc. Repair	x
Rebar Placement	**0**	
Total Days (w/o painting)	63	
Painting	20	

Contract Number	3625	
Rehabilitation Type	Patching	
Miscellaneous	**30**	
Forms	**15**	
Traffic Control	**7**	
Barriers	**4**	
Conc. Placement Total	**8**	
	Deck Patching	7
	Parapet	1
	Conc. Repair	0
Conc. Removal Total	**16**	
	Overhang	x
	Deck Patches	x
	Conc. Repair	x
Rebar Placement	**3**	
Total Days (w/o painting)	83	
Painting	55	

Contract Number	3960	
Rehabilitation Type	Patching	
Miscellaneous	**13**	
Forms	**4**	
Traffic Control	**7**	
Barriers	**3**	
Conc. Placement Total	**6**	
	Deck Patching	2
	Parapet	4
	Conc. Repair	0
Conc. Removal Total	**11**	
	Overhang	2
	Deck Patches	9
	Conc. Repair	0
Rebar Placement	**5**	
Total Days (w/o painting)	49	
Painting	0	

Contract Number	**3613**	
Rehabilitation Type	Patching	
Miscellaneous	**21**	
Forms	**20**	
Traffic Control	**6**	
Barriers	**2**	
Conc. Placement Total	**4**	
	Deck Patching	x
	Parapet	x
	Conc. Repair	x
Conc. Removal Total	**28**	
	Overhang	x
	Deck Patches	x
	Conc. Repair	x
Rebar Placement	**0**	
Total Days (w/o painting)	81	
Painting	5	

Contract Number	**3624**	
Rehabilitation Type	Patching	
Miscellaneous	**11**	
Forms	**6**	
Traffic Control	**2**	
Barriers	**4**	
Conc. Placement Total	**2**	
	Deck Patching	x
	Parapet	x
	Conc. Repair	x
Conc. Removal Total	**14**	
	Overhang	x
	Deck Patches	x
	Conc. Repair	x
Rebar Placement	**0**	
Total Days (w/o painting)	39	
Painting	37	

Contract Number	**3568**	
Rehabilitation Type	Patching	
Miscellaneous	**28**	
Forms	**16**	
Traffic Control	**4**	
Barriers	**3**	
Conc. Placement Total	**4**	
	Deck Patching	x
	Parapet	x
	Conc. Repair	x
Conc. Removal Total	**40**	
	Overhang	x
	Deck Patches	x
	Conc. Repair	x
Rebar Placement	**2**	
Total Days (w/o painting)	97	
Painting	4	

Contract Number	**8326**	
Rehabilitation Type	Patching	
Miscellaneous	**28**	
Forms	**32**	
Traffic Control	**12**	
Barriers	**8**	
Conc. Placement Total	**26**	
	Deck Patching	10
	Parapet	16
	Conc. Repair	0
Conc. Removal Total	**59**	
	Overhang	x
	Deck Patches	x
	Conc. Repair	x
Rebar Placement	**18**	
Total Days (w/o painting)	183	
Painting	0	

Contract Number	4231	
Rehabilitation Type	Patching	
Miscellaneous	33	
Forms	12	
Traffic Control	13	
Barriers	13	
Conc. Placement Total	18	
	Deck Patching	x
	Parapet	x
	Conc. Repair	x
Conc. Removal Total	57	
	Overhang	x
	Deck Patches	x
	Conc. Repair	x
Rebar Placement	0	
Total Days (w/o painting)	146	
Painting	0	

Contract Number	3081	
Rehabilitation Type	Patching	
Miscellaneous	28	
Forms	31	
Traffic Control	11	
Barriers	7	
Conc. Placement Total	10	
	Deck Patching	6
	Parapet	4
	Conc. Repair	0
Conc. Removal Total	37	
	Overhang	x
	Deck Patches	x
	Conc. Repair	x
Rebar Placement	8	
Total Days (w/o painting)	132	
Painting	0	

Contract Number	4183	
Rehabilitation Type	Patching	
Miscellaneous	25	
Forms	0	
Traffic Control	11	
Barriers	4	
Conc. Placement Total	4	
	Deck Patching	x
	Parapet	x
	Conc. Repair	x
Conc. Removal Total	16	
	Overhang	x
	Deck Patches	x
	Conc. Repair	x
Rebar Placement	0	
Total Days (w/o painting)	60	
Painting	0	

Contract Number	2250	
Rehabilitation Type	Patching	
Miscellaneous	15	
Forms	4	
Traffic Control	9	
Barriers	2	
Conc. Placement Total	7	
	Deck Patching	x
	Parapet	x
	Conc. Repair	x
Conc. Removal Total	28	
	Overhang	x
	Deck Patches	x
	Conc. Repair	x
Rebar Placement	4	
Total Days (w/o painting)	69	
Painting	0	

Contract Number	8465	
Rehabilitation Type	Patching	
Miscellaneous	**20**	
Forms	**17**	
Traffic Control	**1**	
Barriers	**3**	
Conc. Placement Total	**33**	
	Deck Patching	8
	Parapet	8
	Conc. Repair	17
Conc. Removal Total	**35**	
	Overhang	6
	Deck Patches	18
	Conc. Repair	11
Rebar Placement	**25**	
Total Days (w/o painting)	134	
Painting	0	

Contract Number	8772	
Rehabilitation Type	Patching	
Miscellaneous	**15**	
Forms	**17**	
Traffic Control	**10**	
Barriers	**5**	
Conc. Placement Total	**14**	
	Deck Patching	0
	Parapet	7
	Conc. Repair	7
Conc. Removal Total	**26**	
	Overhang	3
	Deck Patches	10
	Conc. Repair	13
Rebar Placement	**11**	
Total Days (w/o painting)	98	
Painting	0	

Contract Number	8717	
Rehabilitation Type	Patching	
Miscellaneous	**31**	
Forms	**14**	
Traffic Control	**2**	
Barriers	**2**	
Conc. Placement Total	**15**	
	Deck Patching	5
	Parapet	6
	Conc. Repair	4
Conc. Removal Total	**39**	
	Overhang	3
	Deck Patches	30
	Conc. Repair	7
Rebar Placement	**12**	
Total Days (w/o painting)	115	
Painting	0	

Contract Number	4555	
Rehabilitation Type	Patching	
Miscellaneous	**13**	
Forms	**1**	
Traffic Control	**5**	
Barriers	**4**	
Conc. Placement Total	**12**	
	Deck Patching	9
	Parapet	0
	Conc. Repair	3
Conc. Removal Total	**60**	
	Overhang	0
	Deck Patches	30
	Conc. Repair	30
Rebar Placement	**1**	
Total Days (w/o painting)	96	
Painting	0	

Contract Number	4277	
Rehabilitation Type	Patching	
Miscellaneous	**32**	
Forms	**16**	
Traffic Control	**4**	
Barriers	**3**	
Conc. Placement Total	**17**	
	Deck Patching	9
	Parapet	0
	Conc. Repair	8
Conc. Removal Total	**31**	
	Overhang	0
	Deck Patches	27
	Conc. Repair	4
Rebar Placement	**10**	
Total Days (w/o painting)	113	
Painting	9	

Contract Number	3557	
Rehabilitation Type	Patching	
Miscellaneous	**11**	
Forms	**4**	
Traffic Control	**8**	
Barriers	**6**	
Conc. Placement Total	**9**	
	Deck Patching	2
	Parapet	0
	Conc. Repair	7
Conc. Removal Total	**14**	
	Overhang	0
	Deck Patches	5
	Conc. Repair	9
Rebar Placement	**4**	
Total Days (w/o painting)	56	
Painting	0	

Contract Number	4054	
Rehabilitation Type	Patching	
Miscellaneous	**21**	
Forms	**8**	
Traffic Control	**5**	
Barriers	**4**	
Conc. Placement Total	**17**	
	Deck Patching	3
	Parapet	11
	Conc. Repair	3
Conc. Removal Total	**26**	
	Overhang	1
	Deck Patches	8
	Conc. Repair	17
Rebar Placement	**10**	
Total Days (w/o painting)	91	
Painting	0	

Contract Number	2881	
Rehabilitation Type	Patching	
Miscellaneous	**14**	
Forms	**8**	
Traffic Control	**4**	
Barriers	**2**	
Conc. Placement Total	**10**	
	Deck Patching	9
	Parapet	1
	Conc. Repair	0
Conc. Removal Total	**22**	
	Overhang	4
	Deck Patches	14
	Conc. Repair	4
Rebar Placement	**8**	
Total Days (w/o painting)	68	
Painting	0	

Contract Number	3576	
Rehabilitation Type	Patching	
Miscellaneous	38	
Forms	8	
Traffic Control	7	
Barriers	4	
Conc. Placement Total	9	
	Deck Patching	3
	Parapet	4
	Conc. Repair	2
Conc. Removal Total	26	
	Overhang	2
	Deck Patches	21
	Conc. Repair	3
Rebar Placement	14	
Total Days (w/o painting)	106	
Painting	0	

Contract Number	3026	
Rehabilitation Type	Patching	
Miscellaneous	23	
Forms	0	
Traffic Control	4	
Barriers	2	
Conc. Placement Total	5	
	Deck Patching	x
	Parapet	x
	Conc. Repair	x
Conc. Removal Total	25	
	Overhang	x
	Deck Patches	x
	Conc. Repair	x
Rebar Placement	0	
Total Days (w/o painting)	59	
Painting	36	

Contract Number	3830	
Rehabilitation Type	Overlay	
Miscellaneous	35	
Forms	14	
Traffic Control	11	
Barriers	5	
Conc. Placement Total	9	
	Deck Overlay	x
	Parapet	x
	Conc. Repair	x
Conc. Removal Total	41	
	Overhang	x
	Deck Repair	x
	Conc. Repair	x
Rebar Placement	7	
Total Days (w/o painting)	122	
Painting	0	

Contract Number	3119	
Rehabilitation Type	Overlay	
Miscellaneous	38	
Forms	29	
Traffic Control	14	
Barriers	3	
Conc. Placement Total	12	
	Deck Overlay	2
	Parapet	10
	Conc. Repair	0
Conc. Removal Total	53	
	Overhang	x
	Deck Repair	x
	Conc. Repair	x
Rebar Placement	18	
Total Days (w/o painting)	167	
Painting	0	

Contract Number	4458	
Rehabilitation Type	Overlay	
Miscellaneous	19	
Forms	10	
Traffic Control	2	
Barriers	4	
Conc. Placement Total	4	
	Deck Overlay	2
	Parapet	2
	Conc. Repair	x
Conc. Removal Total	10	
	Overhang	10
	Deck Repair	x
	Conc. Repair	x
Rebar Placement	5	
Total Days (w/o painting)	54	
Painting	0	

Contract Number	2619	
Rehabilitation Type	Overlay	
Miscellaneous	28	
Forms	7	
Traffic Control	3	
Barriers	5	
Conc. Placement Total	5	
	Deck Overlay	3
	Parapet	0
	Conc. Repair	2
Conc. Removal Total	16	
	Overhang	x
	Deck Repair	x
	Conc. Repair	x
Rebar Placement	11	
Total Days (w/o painting)	75	
Painting	0	

Contract Number	3322	
Rehabilitation Type	Overlay	
Miscellaneous	**37**	
Forms	**43**	
Traffic Control	**7**	
Barriers	**3**	
Conc. Placement Total	**24**	
	Deck Overlay	2
	Parapet	16
	Conc. Repair	6
Conc. Removal Total	**22**	
	Overhang	21
	Deck Repair	0
	Conc. Repair	1
Rebar Placement	**22**	
Total Days (w/o painting)	158	
Painting	40	

Contract Number	4461	
Rehabilitation Type	Overlay	
Miscellaneous	**25**	
Forms	**26**	
Traffic Control	**8**	
Barriers	**5**	
Conc. Placement Total	**19**	
	Deck Overlay	x
	Parapet	x
	Conc. Repair	x
Conc. Removal Total	**70**	
	Overhang	12
	Deck Repair	44
	Conc. Repair	14
Rebar Placement	**7**	
Total Days (w/o painting)	160	
Painting	0	

Contract Number	3421	
Rehabilitation Type	Overlay	
Miscellaneous	**16**	
Forms	**28**	
Traffic Control	**3**	
Barriers	**2**	
Conc. Placement Total	**16**	
	Deck Overlay	2
	Parapet	5
	Conc. Repair	9
Conc. Removal Total	**47**	
	Overhang	9
	Deck Repair	21
	Conc. Repair	17
Rebar Placement	**29**	
Total Days (w/o painting)	141	
Painting	6	

Contract Number	3017	
Rehabilitation Type	Overlay	
Miscellaneous	**12**	
Forms	**16**	
Traffic Control	**5**	
Barriers	**3**	
Conc. Placement Total	**18**	
	Deck Overlay	2
	Parapet	8
	Conc. Repair	8
Conc. Removal Total	**18**	
	Overhang	14
	Deck Repair	3
	Conc. Repair	1
Rebar Placement	**10**	
Total Days (w/o painting)	82	
Painting	0	

Contract Number	3407	
Rehabilitation Type	Overlay	
Miscellaneous	**26**	
Forms	**21**	
Traffic Control	**4**	
Barriers	**3**	
Conc. Placement Total	**14**	
	Deck Overlay	4
	Parapet	6
	Conc. Repair	4
Conc. Removal Total	**22**	
	Overhang	9
	Deck Repair	4
	Conc. Repair	9
Rebar Placement	**10**	
Total Days (w/o painting)	100	
Painting	0	

Contract Number	3338	
Rehabilitation Type	Overlay	
Miscellaneous	**17**	
Forms	**34**	
Traffic Control	**9**	
Barriers	**3**	
Conc. Placement Total	**9**	
	Deck Overlay	2
	Parapet	4
	Conc. Repair	3
Conc. Removal Total	**22**	
	Overhang	13
	Deck Repair	8
	Conc. Repair	1
Rebar Placement	**9**	
Total Days (w/o painting)	103	
Painting	0	

Contract Number	3362	
Rehabilitation Type	Overlay	
Miscellaneous	**29**	
Forms	**27**	
Traffic Control	**8**	
Barriers	**3**	
Conc. Placement Total	**7**	
	Deck Overlay	4
	Parapet	2
	Conc. Repair	1
Conc. Removal Total	**12**	
	Overhang	5
	Deck Repair	4
	Conc. Repair	3
Rebar Placement	**13**	
Total Days (w/o painting)	99	
Painting	0	

Contract Number	4016	
Rehabilitation Type	Overlay	
Miscellaneous	**18**	
Forms	**17**	
Traffic Control	**10**	
Barriers	**2**	
Conc. Placement Total	**6**	
	Deck Overlay	2
	Parapet	4
	Conc. Repair	0
Conc. Removal Total	**23**	
	Overhang	15
	Deck Repair	7
	Conc. Repair	1
Rebar Placement	**12**	
Total Days (w/o painting)	88	
Painting	0	

Contract Number	**4157**	
Rehabilitation Type	Overlay	
Miscellaneous	**18**	
Forms	**2**	
Traffic Control	**6**	
Barriers	**4**	
Conc. Placement Total	**2**	
	Deck Overlay	2
	Parapet	0
	Conc. Repair	0
Conc. Removal Total	**8**	
	Overhang	0
	Deck Repair	5
	Conc. Repair	3
Rebar Placement	**4**	
Total Days (w/o painting)	44	
Painting	0	

Contract Number	**3335**	
Rehabilitation Type	Overlay	
Miscellaneous	**48**	
Forms	**67**	
Traffic Control	**25**	
Barriers	**10**	
Conc. Placement Total	**21**	
	Deck Overlay	6
	Parapet	7
	Conc. Repair	8
Conc. Removal Total	**97**	
	Overhang	12
	Deck Repair	40
	Conc. Repair	45
Rebar Placement	**17**	
Total Days (w/o painting)	285	
Painting	0	

Contract Number	**3865**	
Rehabilitation Type	Overlay	
Miscellaneous	**30**	
Forms	**39**	
Traffic Control	**5**	
Barriers	**6**	
Conc. Placement Total	**17**	
	Deck Overlay	7
	Parapet	6
	Conc. Repair	4
Conc. Removal Total	**35**	
	Overhang	18
	Deck Repair	17
	Conc. Repair	0
Rebar Placement	**13**	
Total Days (w/o painting)	145	
Painting	0	

Contract Number	3223
Rehabilitation Type	Replacement
Miscellaneous	**30**
Forms	**28**
Traffic Control	**4**
Barriers	**2**
Conc. Placement Total	**8**
New Deck	6
Parapet	2
Conc. Repair	0
Conc. Removal Total	**35**
Overhang	x
Bridge Deck	x
Conc. Repair	x
Rebar Placement	**15**
Total Days (w/o painting)	122
Painting	0

Contract Number	3518
Rehabilitation Type	Replacement
Miscellaneous	**26**
Forms	**30**
Traffic Control	**5**
Barriers	**5**
Conc. Placement Total	**21**
New Deck	16
Parapet	5
Conc. Repair	0
Conc. Removal Total	**52**
Overhang	x
Bridge Deck	x
Conc. Repair	x
Rebar Placement	**16**
Total Days (w/o painting)	155
Painting	0

Contract Number	3924
Rehabilitation Type	Replacement
Miscellaneous	**31**
Forms	**44**
Traffic Control	**8**
Barriers	**5**
Conc. Placement Total	**10**
New Deck	4
Parapet	6
Conc. Repair	0
Conc. Removal Total	**19**
Overhang	11
Bridge Deck	8
Conc. Repair	0
Rebar Placement	**13**
Total Days (w/o painting)	130
Painting	0

Contract Number	4122
Rehabilitation Type	Replacement
Miscellaneous	**48**
Forms	**56**
Traffic Control	**6**
Barriers	**3**
Conc. Placement Total	**37**
New Deck	x
Parapet	x
Conc. Repair	x
Conc. Removal Total	**50**
Overhang	x
Bridge Deck	x
Conc. Repair	x
Rebar Placement	**14**
Total Days (w/o painting)	214
Painting	15

Contract Number	3434
Rehabilitation Type	Replacement
Miscellaneous	**18**
Forms	**19**
Traffic Control	**5**
Barriers	**4**
Conc. Placement Total	**12**
New Deck	7
Parapet	5
Conc. Repair	0
Conc. Removal Total	**15**
Overhang	x
Bridge Deck	x
Conc. Repair	x
Rebar Placement	**11**
Total Days (w/o painting)	84
Painting	8

Contract Number	3352
Rehabilitation Type	Replacement
Miscellaneous	**38**
Forms	**50**
Traffic Control	**10**
Barriers	**6**
Conc. Placement Total	**10**
New Deck	5
Parapet	5
Conc. Repair	0
Conc. Removal Total	**45**
Overhang	x
Bridge Deck	x
Conc. Repair	x
Rebar Placement	**24**
Total Days (w/o painting)	183
Painting	5

Contract Number	4550
Rehabilitation Type	Replacement
Miscellaneous	**12**
Forms	**20**
Traffic Control	**1**
Barriers	**1**
Conc. Placement Total	**7**
New Deck	x
Parapet	x
Conc. Repair	x
Conc. Removal Total	**27**
Overhang	x
Bridge Deck	x
Conc. Repair	x
Rebar Placement	**9**
Total Days (w/o painting)	77
Painting	0

Contract Number	4165
Rehabilitation Type	Replacement
Miscellaneous	**50**
Forms	**36**
Traffic Control	**7**
Barriers	**8**
Conc. Placement Total	**14**
New Deck	7
Parapet	5
Conc. Repair	2
Conc. Removal Total	**44**
Overhang	10
Bridge Deck	30
Conc. Repair	4
Rebar Placement	**18**
Total Days (w/o painting)	177
Painting	0

Contract Number	3733	
Rehabilitation Type	Replacement	
Miscellaneous	**31**	
Forms	**43**	
Traffic Control	**7**	
Barriers	**9**	
Conc. Placement Total	**21**	
	New Deck	9
	Parapet	12
	Conc. Repair	0
Conc. Removal Total	**44**	
	Overhang	19
	Bridge Deck	0
	Conc. Repair	25
Rebar Placement	**30**	
Total Days (w/o painting)	185	
Painting	0	

Contract Number	3420	
Rehabilitation Type	Replacement	
Miscellaneous	**75**	
Forms	**37**	
Traffic Control	**6**	
Barriers	**6**	
Conc. Placement Total	**19**	
	New Deck	6
	Parapet	10
	Conc. Repair	3
Conc. Removal Total	**45**	
	Overhang	x
	Bridge Deck	x
	Conc. Repair	x
Rebar Placement	**23**	
Total Days (w/o painting)	211	
Painting	0	

APPENDIX C

PRODUCTION RATE ANALYSES

TABLE OF CONTENTS - APPENDIX C

C1.1	Bridge Deck Spot Patching Task Factor	105
C1.2	Bridge Deck Overlay Task Factor	106
C1.3	Bridge Deck Replacement Task Factor	107
C2	Barrier Shift Factor	108
C3.1	Bridge Deck Spot Patching Form Factor	109
C3.2	Bridge Deck Overlay Form Factor	110
C3.3	Bridge Deck Replacement Form Factor	111
C4.1	Bridge Deck Spot Patching Traffic Control Factor	112
C4.2	Bridge Deck Overlay Traffic Control Factor	113
C4.3	Bridge Replacement Traffic Control Factor	114
C5	Concrete Removal Rate for Full and Partial Depth	115
C6	Concrete Removal Rate for Concrete Repair	116
C7	Chipping Rate Data Test	117
C8	Overhang Removal Rate	118
C9	Concrete Pour Rate for Full and Partial Depth	119
C10	Concrete Pour Rate for Overlays and Replacements	120
C11	Concrete Pour Rate for Concrete Repair	121
C12.1	Concrete Pour Rate for Parapet Walls	122
C12.2	Concrete Pour Rate for Parapet Walls	123
C13	Placement Rate for Interconnected Portable Barriers	124
C14.1	Bridge Deck Spot Patching Steel Reinforcing Placement Rate	125
C14.2	Bridge Deck Overlay Steel Reinforcing Placement Rate	126
C14.3	Bridge Deck Replacement Steel Reinforcing Placement Rate	127
C15.1	Calendar Day Factor	128
C15.2	Calendar Day Factor	129

TASK FACTOR (γ)

GENERAL INFORMATION		K - S TEST			LOGNORMAL DIST.		NORMAL DIST.	
Contract	Task %	Rank	Ascending Order	Cumulative Frequency	Cumulative Probability	Deviation	Cumulative Probability	Deviation
3335	84	1	59	0.02128	0.00784	0.01344	0.01450	0.00677
4054	77	2	59	0.04255	0.00784	0.03471	0.01450	0.02805
3362	71	3	61	0.06383	0.01847	0.04536	0.02731	0.03652
4016	80	4	63	0.08511	0.03861	0.04650	0.04841	0.03670
4157	59	5	64	0.10638	0.05356	0.05282	0.06304	0.04334
3338	83	6	64	0.12766	0.05356	0.07410	0.06304	0.06462
3557	80	7	64	0.14894	0.05356	0.09537	0.06304	0.08590
3407	74	8	65	0.17021	0.07244	0.09777	0.08090	0.08931
4277	72	9	71	0.19149	0.27958	0.08810	0.26938	0.07789
3421	89	10	71	0.21277	0.27958	0.06682	0.26938	0.05662
3017	85	11	71	0.23404	0.27958	0.04554	0.26938	0.03534
4461	83	12	72	0.25532	0.32792	0.07260	0.31421	0.05889
4555	86	13	72	0.27660	0.32792	0.05132	0.31421	0.03761
8717	73	14	72	0.29787	0.32792	0.03005	0.31421	0.01634
4165	72	15	73	0.31915	0.37860	0.05945	0.36196	0.04281
8772	85	16	73	0.34043	0.37860	0.03817	0.36196	0.02153
3322	77	17	73	0.36170	0.37860	0.01690	0.36196	0.00025
8465	85	18	74	0.38298	0.43073	0.04775	0.41196	0.02898
2619	63	19	74	0.40426	0.43073	0.02647	0.41196	0.00770
2250	78	20	75	0.42553	0.48337	0.05784	0.46343	0.03790
4550	84	21	76	0.44681	0.53561	0.08880	0.51553	0.06872
4183	73	22	77	0.46809	0.58658	0.11849	0.56736	0.09928
4458	65	23	77	0.48936	0.58658	0.09722	0.56736	0.07800
3119	77	24	77	0.51064	0.58658	0.07594	0.56736	0.05672
3081	79	25	77	0.53191	0.58658	0.05466	0.56736	0.03545
3352	79	26	77	0.55319	0.58658	0.03339	0.56736	0.01417
8326	82	27	78	0.57447	0.63550	0.06103	0.61806	0.04359
4231	77	28	78	0.59574	0.63550	0.03975	0.61806	0.02231
3434	77	29	78	0.61702	0.63550	0.01847	0.61806	0.00104
3568	71	30	79	0.63830	0.68172	0.04342	0.66681	0.02851
4122	78	31	79	0.65957	0.68172	0.02214	0.66681	0.00723
3924	76	32	79	0.68085	0.68172	0.00087	0.66681	0.01404
3624	72	33	80	0.70213	0.72474	0.02262	0.71289	0.01076
3223	75	34	80	0.72340	0.72474	0.00134	0.71289	0.01052
3518	83	35	82	0.74468	0.79992	0.05524	0.79483	0.05015
3830	71	36	83	0.76596	0.83180	0.06584	0.82996	0.06400
3613	74	37	83	0.78723	0.83180	0.04457	0.82996	0.04273
3960	73	38	83	0.80851	0.83180	0.02329	0.82996	0.02145
3799	84	39	83	0.82979	0.83180	0.00201	0.82996	0.00017
8421	59	40	84	0.85106	0.85989	0.00883	0.86098	0.00992
3625	64	41	84	0.87234	0.85989	0.01245	0.86098	0.01136
3576	64	42	84	0.89362	0.85989	0.03373	0.86098	0.03264
3026	61	43	85	0.91489	0.88433	0.03056	0.88790	0.02699
2881	78	44	85	0.93617	0.88433	0.05184	0.88790	0.04827
3420	64	45	85	0.95745	0.88433	0.07311	0.88790	0.06954
3865	79	46	86	0.97872	0.90535	0.07337	0.91088	0.06785
3733	83	47	89	1.00000	0.95073	0.04927	0.95893	0.04107
Sum	3558							
Mean	75.70	**MAXIMUM DEVIATION**			**Lognormal**	0.11849	**Normal**	0.09928
Stan Dev	7.65							
Sample #	47	**D 95% for number of sample**			**0.19838**			
Zi	0.101							
Lambda	4.322	**THE TASK PERCENTAGE :**			76	**TASK FACTOR :**		1.32

APPENDIX C1.1 Bridge Deck Spot Patching Task Factor

TASK FACTOR (g)

GENERAL INFORMATION		K - S TEST			LOGNORMAL DIST.		NORMAL DIST.	
Contract	Task %	Rank	Ascending Order	Cumulative Frequency	Cumulative Probability	Deviation	Cumulative Probability	Deviation
2619	63	1	59	0.06667	0.01612	0.05055	0.02602	0.04064
3421	89	2	63	0.13333	0.05800	0.07533	0.06869	0.06464
3407	74	3	65	0.20000	0.09674	0.10326	0.10436	0.09564
3362	71	4	71	0.26667	0.29685	0.03018	0.28387	0.01720
4016	80	5	71	0.33333	0.29685	0.03649	0.28387	0.04947
3335	83	6	74	0.40000	0.43091	0.03091	0.40961	0.00961
4461	84	7	77	0.46667	0.56793	0.10126	0.54549	0.07883
3865	79	8	77	0.53333	0.56793	0.03460	0.54549	0.01216
3830	71	9	79	0.60000	0.65314	0.05314	0.63414	0.03414
3119	77	10	80	0.66667	0.69254	0.02587	0.67621	0.00954
4458	65	11	83	0.73333	0.79469	0.06136	0.78813	0.05480
3322	77	12	83	0.80000	0.79469	0.00531	0.78813	0.01187
3017	85	13	84	0.86667	0.82299	0.04368	0.81970	0.04696
3338	83	14	85	0.93333	0.84840	0.08493	0.84815	0.08519
4157	59	15	89	1.00000	0.92350	0.07650	0.93131	0.06869
Sum	1140							
Mean	76.00	**MAXIMUM DEVIATION**			**Lognormal**	0.10326	**Normal**	0.09564
Stan Dev	8.75							
Sample #	15	**D 95% for number of sample**			**0.35115**			
Zi	0.115							
Lambda	4.324	**THE TASK PERCENTAGE :**			**76**	**TASK FACTOR :**		**1.32**

TASK FACTOR (g)

GENERAL INFORMATION		K - S TEST			LOGNORMAL DIST.		NORMAL DIST.	
Contract	Task %	Rank	Ascending Order	Cumulative Frequency	Cumulative Probability	Deviation	Cumulative Probability	Deviation
3223	75	1	64	0.10000	0.00870	0.09130	0.01381	0.08619
3924	76	2	72	0.20000	0.19207	0.00793	0.19003	0.00997
4122	78	3	75	0.30000	0.36405	0.06405	0.35163	0.05163
3352	79	4	76	0.40000	0.42933	0.02933	0.41476	0.01476
4550	84	5	78	0.50000	0.56138	0.06138	0.54615	0.04615
4165	72	6	79	0.60000	0.62459	0.02459	0.61086	0.01086
3420	64	7	79	0.70000	0.62459	0.07541	0.61086	0.08914
3733	83	8	83	0.80000	0.82892	0.02892	0.82743	0.02743
3518	83	9	83	0.90000	0.82892	0.07108	0.82743	0.07257
3434	79	10	84	1.00000	0.86504	0.13496	0.86643	0.13357
Sum	773							
Mean	77.30	**MAXIMUM DEVIATION**			**Lognormal**	0.13496	**Normal**	0.13357
Stan Dev	6.04							
Sample #	10	**D 95% for number of sample**			**0.43007**			
Zi	0.078							
Lambda	4.345	**THE TASK PERCENTAGE :**			**77**	**TASK FACTOR :**		**1.30**

BARRIER SHIFT FACTOR (M)

					LOGNORMAL DIST.		NORMAL DIST.	
Contract	Days	Rank	Ascending Order	Cumulative Frequency	Cumulative Probability	Deviation	Cumulative Probability	Deviation
8772	5	1	1	0.02128	0.01021	0.01107	0.08502	0.06374
4183	4	2	2	0.04255	0.14110	0.09855	0.17091	0.12835
4122	3	3	2	0.06383	0.14110	0.07727	0.17091	0.10708
3624	4	4	2	0.08511	0.14110	0.05599	0.17091	0.08580
3613	2	5	2	0.10638	0.14110	0.03472	0.17091	0.06452
3223	2	6	2	0.12766	0.14110	0.01344	0.17091	0.04325
3924	5	7	2	0.14894	0.14110	0.00784	0.17091	0.02197
8326	8	8	2	0.17021	0.14110	0.02911	0.17091	0.00069
3518	5	9	2	0.19149	0.14110	0.05039	0.17091	0.02058
3568	3	10	2	0.21277	0.14110	0.07167	0.17091	0.04186
3434	4	11	3	0.23404	0.36385	0.12981	0.29837	0.06433
3119	3	12	3	0.25532	0.36385	0.10854	0.29837	0.04305
3352	6	13	3	0.27660	0.36385	0.08726	0.29837	0.02177
3081	7	14	3	0.29787	0.36385	0.06598	0.29837	0.00050
3625	4	15	3	0.31915	0.36385	0.04471	0.29837	0.02078
3830	5	16	3	0.34043	0.36385	0.02343	0.29837	0.04206
2250	2	17	3	0.36170	0.36385	0.00215	0.29837	0.06333
2619	5	18	3	0.38298	0.36385	0.01912	0.29837	0.08461
8465	3	19	3	0.40426	0.36385	0.04040	0.29837	0.10589
4461	5	20	3	0.42553	0.36385	0.06168	0.29837	0.12716
4555	4	21	3	0.44681	0.36385	0.08295	0.29837	0.14844
4277	3	22	3	0.46809	0.36385	0.10423	0.29837	0.16972
3733	9	23	4	0.48936	0.56663	0.07727	0.45715	0.03221
8717	2	24	4	0.51064	0.56663	0.05599	0.45715	0.05349
3322	3	25	4	0.53191	0.56663	0.03471	0.45715	0.07476
4458	4	26	4	0.55319	0.56663	0.01344	0.45715	0.09604
3799	3	27	4	0.57447	0.56663	0.00784	0.45715	0.11732
3960	3	28	4	0.59574	0.56663	0.02912	0.45715	0.13859
8421	2	29	4	0.61702	0.56663	0.05039	0.45715	0.15987
4231	13	30	4	0.63830	0.56663	0.07167	0.45715	0.18115
4165	8	31	4	0.65957	0.56663	0.09295	0.45715	0.20242
4016	2	32	5	0.68085	0.71499	0.03414	0.62319	0.05766
3335	10	33	5	0.70213	0.71499	0.01286	0.62319	0.07894
3557	6	34	5	0.72340	0.71499	0.00842	0.62319	0.10021
3338	3	35	5	0.74468	0.71499	0.02969	0.62319	0.12149
3421	2	36	5	0.76596	0.71499	0.05097	0.62319	0.14277
3576	4	37	5	0.78723	0.71499	0.07224	0.62319	0.16404
3017	3	38	6	0.80851	0.81461	0.00610	0.76894	0.03957
3407	3	39	6	0.82979	0.81461	0.01517	0.76894	0.06085
3362	3	40	6	0.85106	0.81461	0.03645	0.76894	0.08212
3420	6	41	6	0.87234	0.81461	0.05773	0.76894	0.10340
4550	1	42	7	0.89362	0.87930	0.01432	0.87633	0.01729
3865	6	43	8	0.91489	0.92088	0.00598	0.94275	0.02786
2881	2	44	8	0.93617	0.92088	0.01529	0.94275	0.00658
3026	2	45	9	0.95745	0.94762	0.00982	0.97724	0.01979
4157	4	46	10	0.97872	0.96495	0.01378	0.99227	0.01354
4054	4	47	13	1.00000	0.98875	0.01125	0.99989	0.00011

Sum	200						
Mean	4.26	**MAXIMUM DEVIATION**		**Lognormal**	0.12981	**Normal**	0.16972
Stan Dev	2.37						
Sample #	47	**D 95% for number of sample**		**0.19838**			
Zi	0.558						
Lambda	1.293			**BARRIER SHIFT FACTOR**			4

FORM FACTOR (F)

INFORMATION		K-S TEST			LOGNORMAL DIST.		NORMAL DIST.	
Contract	Ratio to Conc. Placement	Rank	Ascending Order	Cumulative Frequency	Cumulative Probability	Deviation	Cumulative Probability	Deviation
3799	3.86	1	1.44	0.05	0.16	0.11	0.17	0.13
8421	2.50	2	1.47	0.10	0.17	0.07	0.18	0.08
3960	1.67	3	1.52	0.14	0.18	0.04	0.19	0.05
3613	6.00	4	1.57	0.19	0.20	0.01	0.20	0.01
3624	4.00	5	1.67	0.24	0.24	0.00	0.22	0.01
8326	2.23	6	1.67	0.29	0.24	0.05	0.22	0.06
4231	1.67	7	1.80	0.33	0.29	0.04	0.25	0.08
3081	4.44	8	1.93	0.38	0.34	0.04	0.29	0.09
2250	1.57	9	1.94	0.43	0.34	0.08	0.29	0.14
8772	2.21	10	2.00	0.48	0.37	0.11	0.31	0.17
8717	1.93	11	2.21	0.52	0.45	0.08	0.37	0.16
4277	1.94	12	2.23	0.57	0.45	0.12	0.37	0.20
3557	1.44	13	2.37	0.62	0.50	0.12	0.41	0.21
4054	1.47	14	2.50	0.67	0.55	0.12	0.45	0.21
2881	1.80	15	2.88	0.71	0.66	0.06	0.57	0.15
3625	2.88	16	3.29	0.76	0.75	0.01	0.69	0.07
3568	5.00	17	3.86	0.81	0.84	0.03	0.82	0.01
8465	1.52	18	4.00	0.86	0.86	0.00	0.85	0.01
4461	2.37	19	4.44	0.90	0.90	0.00	0.92	0.01
3576	2.00	20	5.00	0.95	0.94	0.01	0.96	0.01
3865	3.29	21	6.00	1.00	0.97	0.03	1.00	0.00
Sum	55.79							
Mean	2.66	**MAXIMUM DEVIATION**			**Lognormal**	0.11926	**Normal**	0.21480
Stan Dev	1.30							
Sample #	21	**D 95% for number of sample**			**0.29678**			
Zi	0.488							
Lambda	0.858					**FORM FACTOR**		**2.66**

FORM FACTOR (F)

INFORMATION		K-S TEST			LOGNORMAL DIST.		NORMAL DIST.	
Contract	Ratio to Conc. Placement	Rank	Ascending Order	Cumulative Frequency	Cumulative Probability	Deviation	Cumulative Probability	Deviation
2619	0.60	1	0.28	0.07	0.00	0.07	0.07	0.00
3421	1.75	2	0.60	0.13	0.04	0.09	0.12	0.02
3407	1.50	3	0.70	0.20	0.07	0.13	0.14	0.06
3362	3.86	4	1.00	0.27	0.21	0.06	0.21	0.06
4016	2.83	5	1.37	0.33	0.39	0.06	0.32	0.02
3335	0.70	6	1.50	0.40	0.46	0.06	0.36	0.04
4461	1.37	7	1.56	0.47	0.48	0.02	0.38	0.08
3865	2.29	8	1.75	0.53	0.56	0.03	0.45	0.08
3830	1.56	9	1.79	0.60	0.58	0.02	0.47	0.13
3119	2.42	10	2.29	0.67	0.74	0.07	0.65	0.02
4458	2.50	11	2.42	0.73	0.77	0.03	0.69	0.04
3322	1.79	12	2.50	0.80	0.78	0.02	0.72	0.08
3017	0.28	13	2.83	0.87	0.84	0.03	0.81	0.06
3338	3.78	14	3.78	0.93	0.93	0.00	0.96	0.03
4157	1.00	15	3.86	1.00	0.94	0.06	0.97	0.03
Sum	28.23							
Mean	1.88	**MAXIMUM DEVIATION**			**Lognormal**	0.06870	**Normal**	0.13411
Stan Dev	1.07							
Sample #	15	**D 95% for number of sample**			**0.35115**			
Zi	0.571							
Lambda	0.469					**FORM FACTOR**		**1.88**

FORM FACTOR (F)

INFORMATION		K-S TEST			LOGNORMAL DIST.		NORMAL DIST.	
Contract	Ratio to Conc. Placement	Rank	Ascending Order	Cumulative Frequency	Cumulative Probability	Deviation	Cumulative Probability	Deviation
3223	3.50	1	1.43	0.10	0.13	0.03	0.16	0.06
3924	4.40	2	1.51	0.20	0.16	0.04	0.17	0.03
4122	1.51	3	1.58	0.30	0.18	0.12	0.19	0.11
3352	5.00	4	1.95	0.40	0.33	0.07	0.28	0.12
4550	2.86	5	2.05	0.50	0.37	0.13	0.31	0.19
4165	2.57	6	2.57	0.60	0.56	0.04	0.46	0.14
3420	1.95	7	2.86	0.70	0.64	0.06	0.56	0.14
3733	2.05	8	3.50	0.80	0.79	0.01	0.74	0.06
3518	1.43	9	4.40	0.90	0.90	0.00	0.91	0.01
3434	1.58	10	5.00	1.00	0.94	0.06	0.97	0.03
Sum	26.85							
Mean	2.69	**MAXIMUM DEVIATION**			**Lognormal**	0.13493	**Normal**	0.19386
Stan Dev	1.25							
Sample #	10	**D 95% for number of sample**			**0.43007**			
Zi	0.467							
Lambda	0.879					**FORM FACTOR**		**2.69**

TRAFFIC CONTROL FACTOR (T)

					LOGNORMAL DIST.		NORMAL DIST.	
Contract	Days	Rank	Ascending Order	Cumulative Frequency	Cumulative Probability	Deviation	Cumulative Probability	Deviation
8772	10	1	1	0.04545	0.00139	0.04406	0.06714	0.02168
4183	11	2	2	0.09091	0.03957	0.05134	0.11248	0.02157
3960	7	3	2	0.13636	0.03957	0.09679	0.11248	0.02389
3624	2	4	2	0.18182	0.03957	0.14224	0.11248	0.06934
3613	6	5	4	0.22727	0.30124	0.07397	0.25932	0.03204
8326	12	6	4	0.27273	0.30124	0.02851	0.25932	0.01341
3568	4	7	4	0.31818	0.30124	0.01694	0.25932	0.05887
3081	11	8	4	0.36364	0.30124	0.06240	0.25932	0.10432
3625	7	9	4	0.40909	0.30124	0.10785	0.25932	0.14978
2250	9	10	5	0.45455	0.45093	0.00362	0.35888	0.09567
8465	1	11	5	0.50000	0.45093	0.04907	0.35888	0.14112
4555	5	12	6	0.54545	0.57984	0.03438	0.46913	0.07632
4277	4	13	7	0.59091	0.68300	0.09209	0.58182	0.00909
8717	2	14	7	0.63636	0.68300	0.04663	0.58182	0.05455
3799	4	15	7	0.68182	0.68300	0.00118	0.58182	0.10000
8421	2	16	8	0.72727	0.76238	0.03511	0.68813	0.03915
4231	13	17	9	0.77273	0.82220	0.04948	0.78070	0.00797
3557	8	18	10	0.81818	0.86682	0.04864	0.85510	0.03692
3576	7	19	11	0.86364	0.89995	0.03632	0.91029	0.04665
2881	4	20	11	0.90909	0.89995	0.00914	0.91029	0.00120
3026	4	21	12	0.95455	0.92454	0.03000	0.94808	0.00646
4054	5	22	13	1.00000	0.94282	0.05718	0.97197	0.02803
Sum	138							
Mean	6.27	**MAXIMUM DEVIATION**			**Lognormal**	0.14224	**Normal**	0.14978
Stan Dev	3.52							
Sample #	22	**D 95% for number of sample**			**0.28995**			
Zi	0.561							
Lambda	1.679				**TRAFFIC CONTROL CONSTANT**			**6**

TRAFFIC CONTROL (T)

					LOGNORMAL DIST.		NORMAL DIST.	
Contract	Days	Rank	Ascending Order	Cumulative Frequency	Cumulative Probability	Deviation	Cumulative Probability	Deviation
2619	3	1	2	0.06667	0.05860	0.00806	0.14866	0.08199
3421	3	2	3	0.13333	0.15789	0.02456	0.19256	0.05922
3407	4	3	3	0.20000	0.15789	0.04211	0.19256	0.00744
3362	8	4	4	0.26667	0.27312	0.00646	0.24359	0.02308
4016	10	5	5	0.33333	0.38464	0.05131	0.30115	0.03219
3335	25	6	5	0.40000	0.38464	0.01536	0.30115	0.09885
4461	8	7	6	0.46667	0.48406	0.01740	0.36414	0.10252
3865	5	8	7	0.53333	0.56917	0.03583	0.43105	0.10228
3830	11	9	8	0.60000	0.64051	0.04051	0.50000	0.10000
3119	14	10	8	0.66667	0.64051	0.02616	0.50000	0.16667
4458	2	11	9	0.73333	0.69968	0.03365	0.56895	0.16438
3322	7	12	10	0.80000	0.74854	0.05146	0.63586	0.16414
3017	5	13	11	0.86667	0.78882	0.07784	0.69885	0.16781
3338	9	14	14	0.93333	0.87233	0.06101	0.85134	0.08199
4157	6	15	25	1.00000	0.97400	0.02600	0.99843	0.00157
Sum	120							
Mean	8.00	**MAXIMUM DEVIATION**			**Lognormal**	0.07784	**Normal**	0.16781
Stan Dev	5.76							
Sample #	15	**D 95% for number of sample**			**0.35115**			
Zi	0.720							
Lambda	1.821				**TRAFFIC CONTROL CONSTANT**			**8**

TRAFFIC CONTROL (T)

					LOGNORMAL DIST.		NORMAL DIST.	
Contract	Days	Rank	Ascending Order	Cumulative Frequency	Cumulative Probability	Deviation	Cumulative Probability	Deviation
3223	4	1	1	0.10000	0.00002	0.09998	0.02163	0.07837
3924	8	2	4	0.20000	0.22954	0.02954	0.21661	0.01661
4122	6	3	5	0.30000	0.42178	0.12178	0.35524	0.05524
3352	10	4	5	0.40000	0.42178	0.02178	0.35524	0.04476
4550	1	5	6	0.50000	0.59730	0.09730	0.51645	0.01645
4165	7	6	6	0.60000	0.59730	0.00270	0.51645	0.08355
3420	6	7	7	0.70000	0.73286	0.03286	0.67498	0.02502
3518	5	8	7	0.80000	0.73286	0.06714	0.67498	0.12502
3434	5	9	8	0.90000	0.82804	0.07196	0.80681	0.09319
3733	7	10	10	1.00000	0.93182	0.06818	0.95459	0.04541
Sum	59							
Mean	5.90	**MAXIMUM DEVIATION**			**Lognormal**	0.12178	**Normal**	0.12502
Stan Dev	2.42							
Sample #	10	**D 95% for number of sample**			**0.43007**			
Zi	0.411							
Lambda	1.691				**TRAFFIC CONTROL CONSTANT**			**6**

CONCRETE REMOVAL (r1,r2)
(full & partial depth)

SMALL QUANTITY REMOVAL (below 50 square yards)

Contract	Deck (S.Y.)			Deck Days	Deck Average
	Partial	Full	Total		
8772	24	1	25	10	2.50
4016	13	14	27	7	3.86
			52	17	

AVERAGE 3
square yards per day

MEDIUM QUANTITY REMOVAL (50 - 1000 square yards)

Contract	Deck (S.Y.)			Deck Days	Deck Average
	Partial	Full	Total		
4461	485	98	583	44	13.25
8465	331	41	372	18	20.67
3407	171	75	246	4	61.50
3362	76.5	25	101.5	4	25.38
4054	56	0	56	8	7.00
4157	67	0	67	5	13.40
3576	86	0	86	21	4.10
4555	517	0	517	30	17.23
2881	145	0	145	14	10.36
3026	172	0	172	24	7.17
3421	282	19	301	21	14.33
3557	65	8	73	5	14.60
3335	458	42	500	45	11.11
3017	102	7	109	3	36.33
3338	257	60	317	8	39.63
		Total	3645.5	254	

AVERAGE 14
square yards per day

LARGE QUANTITY REMOVAL (above 1000 square yards)

Contract	Deck (S.Y.)			Deck Days	Deck Average
	Partial	Full	Total		
4277	1632	188	1820	27	67.41

AVERAGE 67
square yards per day

CONCRETE REMOVAL RATE (r_3)

(concrete repair)

AVERAGE QUANTITY REMOVAL (below 175 square yards)

Contract	Repair (S.Y)					Repair Days	Repair Average
	(S.Y.)	(S.F.)	(C.F.)	(C.Y.)	Total		
4461	41.3	175	15	0	66	4	16.50
3407	0	535	0	0	59	9	6.56
3362	0	0	24	0	8	3	2.67
3421	0	167	140	0	65	17	3.82
3557	0	0	60	0	20	9	2.22
4555	0	0	0	6	54	13	4.15
8772	0	0	248	0	83	13	6.38
3335	0	0	92	0	31	12	2.58
3576	0	0	342	0	114	3	38.00
3338	0	80	0	0	9	1	9.00
4054	39	359	242	0	160	17	9.41
4157	0	82	0	0	9	3	3.00
				Total	678	104	
				AVERAGE	7		
					square yards per day		

ABOVE AVERAGE QUANTITY REMOVAL (above 175 square yards)

Contract	Repair (S.Y)					Repair Days	Repair Average
	(S.Y.)	(S.F.)	(C.F.)	(C.Y.)	Total		
2881	0	103	0	19	183	4	45.75
4277	0	2613	0	0	290	4	72.50
8465	0	1314.5	200	42	591	11	53.73
				Total	1064	19	
				AVERAGE	**56**		
					square yards per day		

CONCRETE CHIPPING RATE TEST

K-S TEST FOR DECK CHIPPING					LOGNORMAL DIST.		NORMAL DIST.	
Contract	Average	Rank	Order	Cumulative Frequency	Cumulative Probablility	Deviation	Cumulative Probablility	Deviation
2881	10.36	1	2.50	0.06	0.03	0.02	0.18	0.13
3026	7.17	2	3.86	0.11	0.08	0.03	0.20	0.09
4461	13.25	3	4.10	0.17	0.09	0.07	0.21	0.04
8465	20.67	4	7.00	0.22	0.23	0.01	0.25	0.03
3407	61.50	5	7.17	0.28	0.24	0.04	0.26	0.02
3362	25.38	6	10.36	0.33	0.38	0.05	0.32	0.02
3421	14.33	7	13.25	0.39	0.49	0.10	0.38	0.01
3557	14.60	8	13.40	0.44	0.49	0.05	0.38	0.06
4277	67.41	9	14.29	0.50	0.52	0.02	0.40	0.10
4555	17.23	10	14.33	0.56	0.52	0.03	0.40	0.16
8772	2.50	11	14.60	0.61	0.53	0.08	0.41	0.21
4016	3.86	12	17.23	0.67	0.60	0.07	0.46	0.20
3335	14.29	13	20.67	0.72	0.67	0.05	0.54	0.18
3576	4.10	14	25.38	0.78	0.75	0.03	0.64	0.14
3017	36.33	15	36.33	0.83	0.86	0.02	0.83	0.00
3338	39.63	16	39.63	0.89	0.88	0.01	0.88	0.01
4054	7.00	17	61.50	0.94	0.95	0.01	0.99	0.05
4157	13.40	18	67.41	1.00	0.96	0.04	1.00	0.00
Sum	372.99							
Mean	20.72	**MAXIMUM DEVIATION**			**Lognormal**	0.09766	**Normal**	0.20572
Stan Dev	18.91							
Sample #	18	**D 95% for number of sample**				**0.32056**		
Zi	0.913							
Lambda	2.615							

K-S TEST FOR CONCRETE REPAIR					LOGNORMAL DIST.		NORMAL DIST.	
Contract	Average	Rank	Order	Cumulative Frequency	Cumulative Probablility	Deviation	Cumulative Probablility	Deviation
2881	45.75	1	2.22	0.07	0.14	0.07	0.23	0.17
4461	16.50	2	2.58	0.13	0.17	0.03	0.24	0.11
8465	21.11	3	2.67	0.20	0.17	0.03	0.24	0.04
3407	6.56	4	3.00	0.27	0.20	0.07	0.25	0.02
3362	2.67	5	3.82	0.33	0.26	0.07	0.26	0.07
3421	3.82	6	4.15	0.40	0.28	0.12	0.26	0.14
3557	2.22	7	6.38	0.47	0.41	0.05	0.30	0.17
4277	72.50	8	6.56	0.53	0.42	0.11	0.30	0.23
4555	4.15	9	9.00	0.60	0.53	0.07	0.35	0.25
8772	6.38	10	16.50	0.67	0.72	0.05	0.49	0.18
3335	2.58	11	21.11	0.73	0.78	0.05	0.58	0.15
3576	38.00	12	21.12	0.80	0.78	0.02	0.58	0.22
3338	9.00	13	38.00	0.87	0.90	0.03	0.85	0.02
4054	21.12	14	45.75	0.93	0.92	0.01	0.92	0.01
4157	3.00	15	72.50	1.00	0.96	0.04	1.00	0.00
Sum	255.36							
Mean	17.02	**MAXIMUM DEVIATION**			**Lognormal**	0.11799	**Normal**	0.25287
Stan Dev	20.41							
Sample #	15	**D 95% for number of sample**				**0.35115**		
Zi	1.199							
Lambda	2.116							

OVERHANG REMOVAL (r_4)

GENERAL INFORMATION				K-S TEST			LOGNORMAL DIST.		NORMAL DIST.	
Contract	L. Feet	Days	Average	Rank	Order	Cumulative Frequency	Cumulative Probablility	Deviation	Cumulative Probablility	Deviation
3799	464	20	23.20	1	16.83	0.06	0.09	0.03	0.18	0.13
4458	329	7	47.00	2	21.92	0.11	0.14	0.03	0.20	0.09
3960	250	2	125.00	3	23.20	0.17	0.16	0.01	0.21	0.04
3733	971	19	51.11	4	27.78	0.22	0.21	0.01	0.23	0.00
8465	1000	6	166.67	5	28.67	0.28	0.22	0.05	0.23	0.05
3924	621	11	56.45	6	32.22	0.33	0.27	0.07	0.24	0.09
4016	430	15	28.67	7	34.20	0.39	0.29	0.10	0.25	0.14
3335	505	30	16.83	8	45.81	0.44	0.41	0.03	0.31	0.14
3322	962	21	45.81	9	47.00	0.50	0.42	0.08	0.31	0.19
8772	553	3	184.33	10	51.11	0.56	0.46	0.10	0.33	0.22
8717	668	3	222.67	11	52.00	0.61	0.47	0.14	0.34	0.27
3362	171	5	34.20	12	56.45	0.67	0.50	0.16	0.36	0.31
3338	285	13	21.92	13	118.50	0.72	0.80	0.08	0.69	0.03
4165	2344	10	234.40	14	125.00	0.78	0.82	0.04	0.72	0.06
3421	468	9	52.00	15	166.67	0.83	0.89	0.06	0.87	0.04
3407	290	9	32.22	16	184.33	0.89	0.91	0.02	0.92	0.03
3576	237	2	118.50	17	222.67	0.94	0.94	0.00	0.97	0.03
3865	500	18	27.78	18	234.40	1.00	0.95	0.05	0.98	0.02

Sum	1488.76						
Mean	82.71	**MAXIMUM DEVIATION**		**Lognormal**	0.16297	**Normal**	0.30701
Stan Dev	73.05						
Sample #	18	**D 95% for number of sample**	**0.32056**				
Zi	0.883						
Lambda	4.025						

TOTAL LENGTH (Ft)	DAYS
11048	203
AVERAGE	54

CONCRETE POUR RATES (r_5)

(full and partial depth)

INFORMATION					
	Deck (S.Y.)			Deck	Deck
Contract	Partial	Full	Total	Days	Average
3026	172	0	172	5	34.40
4461	485	98	583	19	30.68
8465	331	41	372	8	46.50
3407	171	75	246	4	61.50
3557	65	8	73	2	36.50
4277	1632	188	1820	9	202.22
4555	517	0	517	9	57.44
3576	86	0	86	3	28.67
4054	56	0	56	3	18.67
8717	342	173	515	5	103.00
3865	172	229	401	5	80.20
		Total	4841	72	
		AVERAGE	**67**	**square yard per day**	

CONCRETE POUR TEST

K-S TEST FOR DECK SPOT POURS					LOGNORMAL DIST.		NORMAL DIST.	
Contract	Average	Rank	Order	Cumulative Frequency	Cumulative Probability	Deviation	Cumulative Probability	Deviation
3026	34.40	1	18.67	0.09	0.14	0.05	0.00	0.09
4461	30.68	2	28.67	0.18	0.29	0.11	0.02	0.17
8465	46.50	3	30.68	0.27	0.32	0.04	0.03	0.25
3407	61.50	4	34.40	0.36	0.37	0.00	0.05	0.31
3557	36.50	5	36.50	0.45	0.40	0.06	0.08	0.38
4277	202.22	6	46.50	0.55	0.51	0.03	0.30	0.24
4555	57.44	7	57.44	0.64	0.61	0.02	0.68	0.05
3576	28.67	8	61.50	0.73	0.64	0.08	0.80	0.07
4054	18.67	9	80.20	0.82	0.76	0.06	0.99	0.18
8717	103.00	10	103.00	0.91	0.84	0.07	1.00	0.09
3865	80.20	11	202.22	1.00	0.97	0.03	1.00	0.00
Sum	699.78							
Mean	63.62	**MAXIMUM DEVIATION**			**Lognormal**	0.10590	**Normal**	0.37829
Stan Dev	52.24							
Sample #	11	**D 95% for number of sample**				**0.41006**		
Zi	0.821							
Lambda	3.816							

CONCRETE POUR (large quantities) (r_5)

(Overlays and Replacements)

Contract	Time (Hr.) observed	C.Y. observed	Units observed	Units / Hr.	Unit (C.Y.) capacity	% Filled	Production (C.Y.) projected day	Method of Construction
4122	2.57	60	Trucks	2.3	10	100	186.4	shoot/pumptruck
1	8.35	500	Trucks	6	10	100	480	shoot/pumptruck
2	8.55	320	Trucks	3.7	10	100	296	combo
3	5.28	250	Trucks	4.7	10	100	376	shoot/pumptruck

Total	Time (Hr.) observed	C.Y. observed	Average C.Y./Hr.	Production (C.Y.) Daily	Production (C.Y.) projected day	Average of the Two Rates
	24.75	1130	45.66	365.25	334.60	350.00

Crane and Bucket

Contract	Time (Hr.) observed	C.Y. observed	Units observed	Units / Hr.	Unit (C.Y.) capacity	% Filled	Production (C.Y.) projected day	Method of Construction
4553	7.49	30	Bucket	6.8	0.75	78.5	32	crane and bucket
2	1.95	74	Bucket	21	2	90.25	303.64	crane and bucket
					Average	84		

Total	Time (Hr.) observed	C.Y. observed	Average C.Y./Hr.	Production (C.Y.) projected day	Production (C.Y.) projected day	Average of the Two Rates
	9.44	104	11.02	88.14	62.71	75.00

CONCRETE POUR RATES (r_6)
(concrete repair)

Repair (S.Y)					Repair	Repair
(S.Y.)	(S.F.)	(C.F.)	(C.Y.)	Total	Days	Average
0	0	0	0	0		
41.3	175	15	0	66	1	66.00
0	1314.5	200	42	591	17	34.76
0	535	0	0	59	4	14.75
0	0	60	0	20		
0	2613	0	0	290	8	36.25
0	0	0	6	54	1	54.00
0	0	342	0	114	2	57.00
39	359	242	0	160	3	53.33
0	0	307	0	102	4	25.50
0	0	0	38	342	4	85.50
				1798	44	
			AVERAGE	**41**		
				square yard per day		

K-S TEST FOR CONCRETE REPAIR POURS					LOGNORMAL DIST.		NORMAL DIST.	
Contract	Average	Rank	Order	Cumulative Frequency	Cumulative Probability	Deviation	Cumulative Probability	Deviation
4461	66.00	1	14.75	0.11	0.01	0.10	0.07	0.04
8465	34.76	2	25.50	0.22	0.13	0.09	0.16	0.07
3407	14.75	3	34.76	0.33	0.33	0.01	0.28	0.05
4277	36.25	4	36.25	0.44	0.36	0.08	0.30	0.14
4555	54.00	5	53.33	0.56	0.69	0.13	0.61	0.05
3576	57.00	6	54.00	0.67	0.70	0.03	0.62	0.05
4054	53.33	7	57.00	0.78	0.74	0.04	0.67	0.11
8717	25.50	8	66.00	0.89	0.83	0.06	0.80	0.09
3865	85.50	9	85.50	1.00	0.93	0.07	0.96	0.04
Sum	427.09							
Mean	47.45	**MAXIMUM DEVIATION**			**Lognormal**	0.13018	**Normal**	0.14090
Stan Dev	21.79							
Sample #	9	**D 95% for number of sample**				**0.45333**		
Zi	0.459							
Lambda	3.754				**CONCRETE REPAIR POUR RATE**			**47**

CONCRETE PLACEMENT (Parapet Walls) (R_7)

Historical				Rank	Order	Cumulative Frequency	Cumulative Probability	Deviation	Cumulative Probability	Deviation
Contract	Length	Days	Average							
3799	464	4	116.00	1	21.00	0.04	0.06	0.02	0.16	0.13
4458	329	2	164.50	2	24.00	0.08	0.08	0.00	0.17	0.10
3960	250	4	62.50	3	42.75	0.12	0.24	0.13	0.23	0.12
3733	971	12	80.92	4	48.33	0.15	0.29	0.14	0.25	0.10
8465	1000	8	125.00	5	59.25	0.19	0.38	0.19	0.29	0.10
3081	277	4	69.25	6	62.50	0.23	0.41	0.17	0.31	0.08
3924	621	6	103.50	7	69.25	0.27	0.45	0.18	0.33	0.07
8326	1611	16	100.69	8	70.13	0.31	0.46	0.15	0.34	0.03
3223	306	2	153.00	9	71.25	0.35	0.47	0.12	0.34	0.00
4016	430	4	107.50	10	72.14	0.38	0.47	0.09	0.35	0.04
3335	505	7	72.14	11	79.00	0.42	0.52	0.09	0.38	0.05
3518	500	5	100.00	12	80.92	0.46	0.53	0.07	0.38	0.08
3865	500	6	83.33	13	83.33	0.50	0.54	0.04	0.39	0.11
3434	120	5	24.00	14	93.00	0.54	0.60	0.06	0.44	0.10
3119	210	10	21.00	15	93.60	0.58	0.60	0.02	0.44	0.14
3017	561	8	70.13	16	100.00	0.62	0.63	0.01	0.47	0.15
3338	285	4	71.25	17	100.69	0.65	0.63	0.02	0.47	0.18
4165	2344	5	468.80	18	103.50	0.69	0.65	0.05	0.49	0.21
3352	1262	5	252.40	19	107.50	0.73	0.66	0.07	0.50	0.23
8772	553	7	79.00	20	111.33	0.77	0.68	0.09	0.52	0.25
8717	668	6	111.33	21	116.00	0.81	0.70	0.11	0.54	0.27
3362	171	4	42.75	22	125.00	0.85	0.73	0.12	0.58	0.26
3421	468	5	93.60	23	153.00	0.88	0.80	0.08	0.70	0.18
3407	290	6	48.33	24	164.50	0.92	0.83	0.10	0.75	0.18
3576	237	4	59.25	25	252.40	0.96	0.93	0.03	0.95	0.01
3420	744	8	93.00	26	468.80	1.00	0.99	0.01	1.00	0.00

Sum	2773.17						
Mean	106.66	**MAXIMUM DEVIATION**		**Lognormal**	0.18774	**Normal**	0.26523
Stan Dev	87.58						
Sample #	26	**D 95% for number of sample**	**0.26672**				
Zi	0.821						
Lambda	4.333			**PARAPET WALL PLACEMENT**			**107**

RECORDED PARAPET WALL POUR

STATE INSPECTOR'S RECORDED PARAPET POURS

Pour	Rank	Ascending Order	Cumulative Frequency	Cumulative Probability	Deviation	Cumulative Probability	Deviation
35	1	35	0.02	0.02	0.01	0.05	0.03
43	2	43	0.05	0.08	0.03	0.11	0.06
43.3	3	43.3	0.07	0.08	0.01	0.11	0.04
50	4	50	0.10	0.18	0.08	0.18	0.08
50	5	50	0.12	0.18	0.06	0.18	0.06
50	6	50	0.14	0.18	0.03	0.18	0.04
50	7	50	0.17	0.18	0.01	0.18	0.01
52	8	52	0.19	0.21	0.02	0.21	0.01
54.6	9	54.6	0.21	0.26	0.05	0.24	0.03
54.6	10	54.6	0.24	0.26	0.02	0.24	0.00
54.6	11	54.6	0.26	0.26	0.00	0.24	0.02
54.6	12	54.6	0.29	0.26	0.02	0.24	0.04
55	13	55	0.31	0.27	0.04	0.25	0.06
55	14	55	0.33	0.27	0.06	0.25	0.09
55	15	55	0.36	0.27	0.09	0.25	0.11
55	16	55	0.38	0.27	0.11	0.25	0.13
55	17	55	0.40	0.27	0.13	0.25	0.16
60	18	60	0.43	0.37	0.06	0.33	0.10
60	19	60	0.45	0.37	0.08	0.33	0.12
60	20	60	0.48	0.37	0.10	0.33	0.15
60	21	60	0.50	0.37	0.13	0.33	0.17
60	22	60	0.52	0.37	0.15	0.33	0.20
60	23	60	0.55	0.37	0.17	0.33	0.22
65.3	24	65.3	0.57	0.48	0.09	0.42	0.15
70	25	70	0.60	0.57	0.02	0.51	0.08
70	26	70	0.62	0.57	0.05	0.51	0.11
80	27	80	0.64	0.73	0.09	0.69	0.05
80	28	80	0.67	0.73	0.07	0.69	0.03
80	29	80	0.69	0.73	0.04	0.69	0.00
80	30	80	0.71	0.73	0.02	0.69	0.02
85	31	85	0.74	0.79	0.06	0.77	0.03
85.5	32	85.5	0.76	0.80	0.04	0.78	0.02
85.5	33	85.5	0.79	0.80	0.01	0.78	0.01
85.5	34	85.5	0.81	0.80	0.01	0.78	0.03
85.5	35	85.5	0.83	0.80	0.03	0.78	0.06
87.5	36	87.5	0.86	0.82	0.04	0.80	0.05
90	37	90	0.88	0.84	0.04	0.84	0.05
101	38	101	0.90	0.92	0.01	0.93	0.03
114	39	114	0.93	0.96	0.03	0.98	0.05
114	40	114	0.95	0.96	0.01	0.98	0.03
114	41	114	0.98	0.96	0.01	0.98	0.01
114	42	114	1.00	0.96	0.04	0.98	0.02

Sum	2913.50						
Mean	69.37	**MAXIMUM DEV.**		**Lognormal**	0.17492	**Normal**	0.21905
Stan Dev	21.11						
Sample #	42	**D 95% for number of sample**				**0.20985**	
Zi	0.304						
Lambda	4.193						

BARRIER PLACEMENT RATE (R_8)

Contract	L.M. / Day observed	L.F. / Day observed	Units / Hr observed	Projected Units / Day	Production (L.M.) projected	Production (L.F.) projected
4665	291.312	956	7.7	61.6	234.70	771
4491	212.415	697	15.7	125.6	478.54	1571
4231	376.764	1237	17	136	518.16	1701
4253	582.624	1912	12.8	102.4	390.14	1281
4419	97.536	321	3.19	25.52	97.23	320
4419	88.392	291	3.61	28.88	110.03	362
4419	30.48	101	1.43	11.44	43.59	144
4419	30.48	101	5.35	42.8	163.07	536
4359	509.796	1673	9.03	72.24	275.23	904
4553	491.589	1613	6.9	55.2	210.31	691
4419	30.48	101	5.35	42.8	163.07	536
Average	249.00	818.00	8.00	64.00	244.00	802.00

	L. M.	L.F.
OBSERVED	249.00	818
PROJECTED	244.00	802
AVERAGE	247.00	810.00

Production Per Day

L.M.	L.F.
248.829	820

These numbers are used due to compatibility with common portable barrier sizes.

STEEL REINFORCING (deck patching)
PLACEMENT RATES (r9)

GENERAL INFORMATION				K-S TEST						
Contract	Days	Total Steel (LB)	# / Day	Rank	Order	Cumulative Frequency	Cumulative Probability	Deviation	Cumulative Probability	Deviation
3799	10	23421	2342.10	1	186.29	0.09	0.11	0.02	0.22	0.13
8326	18	13903	772.39	2	197.25	0.18	0.12	0.06	0.22	0.04
3081	8	1578	197.25	3	262.75	0.27	0.18	0.10	0.23	0.04
2250	4	2400	600.00	4	478.27	0.36	0.35	0.01	0.28	0.08
8465	25	21382	855.28	5	600.00	0.45	0.43	0.02	0.31	0.15
8772	11	5261	478.27	6	772.39	0.55	0.52	0.02	0.35	0.20
8717	12	10705	892.08	7	855.28	0.64	0.56	0.08	0.37	0.27
3576	14	2608	186.29	8	892.08	0.73	0.57	0.16	0.38	0.35
2881	8	2102	262.75	9	2342.10	0.82	0.85	0.04	0.75	0.07
3865	13	53953	4150.23	10	4037.71	0.91	0.94	0.03	0.97	0.06
4461	7	28264	4037.71	11	4150.23	1.00	0.94	0.06	0.97	0.03
Sum	14774.36									
Mean	1343.12	**MAXIMUM DEVIATION**					**Lognormal**	0.15501	**Normal**	0.34668
Stan Dev	1484.07									
Sample #	11	**D 95% for number of sample**			**0.41006**					
Zi	1.105									
Lambda	6.592					**STEEL REINFORCING PLACEMENT RATE**				**1343**

STEEL REINFORCING (deck overlay)
PLACEMENT RATES (r9)

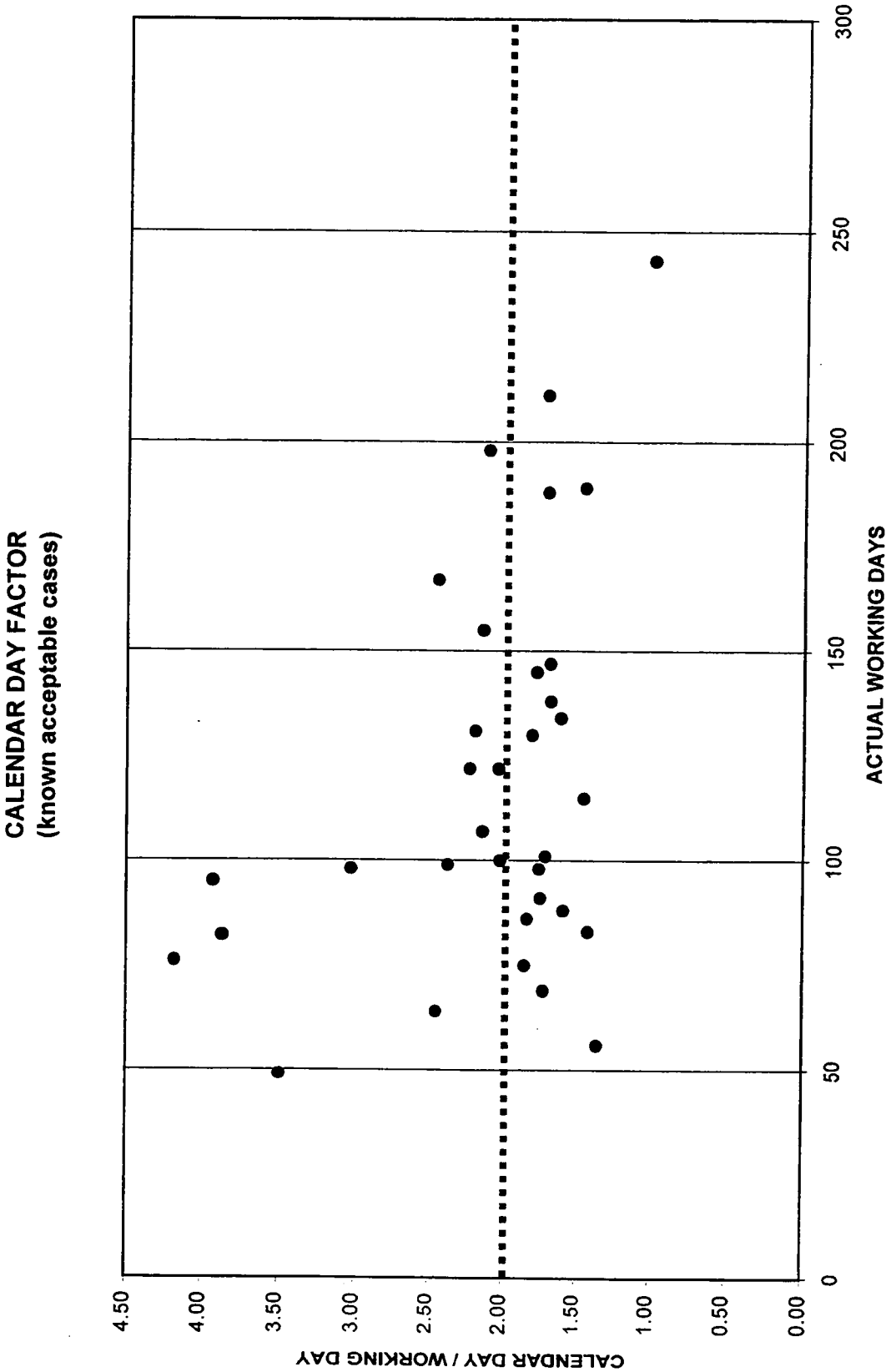
GENERAL INFORMATION				K-S TEST						
Contract	Days	Total Steel (LB)	# / Day	Rank	Order	Cumulative Frequency	Cumulative Probability	Deviation	Cumulative Probability	Deviation
3865	13	53953	4150.23	1	1240.46	0.07	0.08	0.01	0.13	0.06
4157	4	29307	7326.75	2	1277.67	0.14	0.09	0.06	0.14	0.00
3421	29	38106	1314.00	3	1314.00	0.21	0.09	0.12	0.14	0.07
2619	11	22979	2089.00	4	1724.60	0.29	0.21	0.08	0.21	0.08
3017	10	43620	4362.00	5	2089.00	0.36	0.32	0.04	0.27	0.09
3338	9	23830	2647.78	6	2565.67	0.43	0.46	0.03	0.37	0.06
3119	18	22998	1277.67	7	2647.78	0.50	0.48	0.02	0.39	0.11
3335	17	49579	2916.41	8	2916.41	0.57	0.55	0.02	0.45	0.12
3362	13	16126	1240.46	9	3309.50	0.64	0.64	0.00	0.54	0.10
3407	10	17246	1724.60	10	4037.71	0.71	0.77	0.05	0.70	0.02
3322	22	72809	3309.50	11	4150.23	0.79	0.78	0.00	0.72	0.07
4016	12	30788	2565.67	12	4362.00	0.86	0.81	0.05	0.76	0.10
4461	7	28264	4037.71	13	5060.80	0.93	0.87	0.06	0.87	0.06
4458	5	25304	5060.80	14	7326.75	1.00	0.97	0.03	0.99	0.01
Sum	44022.58									
Mean	**3144.47**	**MAXIMUM DEVIATION**					**Lognormal**	0.12015	**Normal**	0.12400
Stan Dev	1725.54									
Sample #	14	**D 95% for number of sample**				**0.36348**				
Zi	0.549									
Lambda	7.903					**STEEL REINFORCING PLACEMENT RATE**				**3145**

STEEL REINFORCING (deck replacement)
PLACEMENT RATES (r9)

GENERAL INFORMATION				K-S TEST						
Contract	Days	Total Steel (LB)	# / Day	Rank	Order	Cumulative Frequency	Cumulative Probablility	Deviation	Cumulative Probablility	Deviation
3924	13	30520	2347.69	1	1022.94	0.17	0.28	0.11	0.26	0.09
3223	15	25794	1719.60	2	1473.55	0.33	0.39	0.06	0.29	0.04
3352	24	97008	4042.00	3	1719.60	0.50	0.45	0.05	0.31	0.19
3434	11	16209	1473.55	4	2347.69	0.67	0.55	0.11	0.36	0.30
3518	16	16367	1022.94	5	4042.00	0.83	0.73	0.11	0.51	0.32
4165	18	231611	12867.28	6	12867.28	1.00	0.95	0.05	0.98	0.02
Sum	23473.05									
Mean	**3912.18**	**MAXIMUM DEVIATION**					**Lognormal**	0.11347	**Normal**	0.32185
Stan Dev	4511.33									
Sample #	6	**D 95% for number of sample**				**0.55522**				
Zi	1.153									
Lambda	7.607					**STEEL REINFORCING PLACEMENT RATE**				**3912**

CALENDAR DAY FACTOR (C_{DF})

INFORMATION		K-S TEST			LOGNORMAL DIST.		NORMAL DIST.	
Contract	Ratio to Actual Working Days	Rank	Ascending Order	Cumulative Frequency	Cumulative Probability	Deviation	Cumulative Probability	Deviation
3420	1.72	1	1.00	0.03	0.02	0.01	0.06	0.03
2881	2.45	2	1.36	0.06	0.10	0.04	0.13	0.07
3576	2.14	3	1.42	0.09	0.12	0.03	0.14	0.05
3026	3.93	4	1.45	0.12	0.14	0.02	0.15	0.03
3865	1.78	5	1.46	0.15	0.14	0.01	0.15	0.01
3362	2.37	6	1.59	0.18	0.20	0.02	0.20	0.02
3335	1.00	7	1.61	0.21	0.21	0.00	0.20	0.00
3407	2.02	8	1.68	0.24	0.25	0.01	0.23	0.01
3017	3.87	9	1.69	0.26	0.25	0.02	0.23	0.03
4016	1.59	10	1.71	0.29	0.26	0.03	0.24	0.06
4054	1.75	11	1.71	0.32	0.26	0.06	0.24	0.08
3557	1.36	12	1.72	0.35	0.26	0.09	0.24	0.11
3322	2.11	13	1.72	0.38	0.27	0.11	0.25	0.14
8717	1.45	14	1.75	0.41	0.28	0.13	0.25	0.16
8465	1.61	15	1.76	0.44	0.29	0.16	0.26	0.18
3613	1.84	16	1.78	0.47	0.30	0.17	0.27	0.20
3625	1.68	17	1.81	0.50	0.32	0.18	0.28	0.22
8421	1.42	18	1.84	0.53	0.33	0.20	0.29	0.24
3223	2.23	19	1.85	0.56	0.34	0.22	0.30	0.26
3518	2.14	20	2.02	0.59	0.43	0.15	0.37	0.21
8326	1.46	21	2.03	0.62	0.44	0.18	0.38	0.24
3924	1.81	22	2.11	0.65	0.48	0.16	0.42	0.23
3119	2.45	23	2.14	0.68	0.50	0.18	0.43	0.25
3421	1.69	24	2.14	0.71	0.50	0.21	0.43	0.27
3568	1.71	25	2.19	0.74	0.53	0.21	0.46	0.28
3830	2.03	26	2.23	0.76	0.55	0.22	0.48	0.29
3352	1.71	27	2.37	0.79	0.61	0.18	0.55	0.25
3081	2.19	28	2.45	0.82	0.65	0.18	0.58	0.24
2250	1.72	29	2.45	0.85	0.65	0.20	0.59	0.27
8772	1.76	30	3.03	0.88	0.84	0.04	0.83	0.06
2619	1.85	31	3.49	0.91	0.92	0.01	0.93	0.02
3799	3.03	32	3.87	0.94	0.95	0.01	0.98	0.03
3624	4.18	33	3.93	0.97	0.96	0.01	0.98	0.01
3960	3.49	34	4.18	1.00	0.97	0.03	0.99	0.01
Sum	29.63							
Mean	2.28	**MAXIMUM DEVIATION**			**Lognormal**	0.21930	**Normal**	0.28922
Stan Dev	0.80							
Sample #	34	**D 95% for number of sample**			**0.23324**			
Zi	0.352							
Lambda	0.762							



APPENDIX C15.2 Calendar Day Factor Chart

APPENDIX D

FIELD OBSERVATIONS

TABLE OF CONTENTS - APPENDIX D

D1.1	Barrier Placement (4253) Data Collection	132
D1.2	Barrier Placement (4235) Production Analysis	135
D2.1	Barrier Placement (4491) Data Collection	136
D2.2	Barrier Placement (4491) Production Analysis	138
D3.1	Barrier Placement (4453) Data Collection	139
D3.2	Barrier Placement (4453) Production Analysis	142
D4.1	Barrier Placement (4231) Data Collection	143
D4.2	Barrier Placement (4231) Production Analysis	146
D5.1	Barrier Placement (4359) Data Collection	147
D5.2	Barrier Placement (4359) Production Analysis	150
D6.1	Barrier Placement (4419) Data Collection	151
D6.2	Barrier Placement (4419) Production Analysis	155
D7.1	Barrier Placement (4665) Data Collection	160
D7.2	Barrier Placement (4665) Production Analysis	162
D8.1	Large Concrete Pour (1) Data Collection	163
D8.2	Large Concrete Pour (1) Production Analysis	165
D9.1	Large Concrete Pour (2) Data Collection	166
D9.2	Large Concrete Pour (2) Production Analysis	169
D10.1	Large Concrete Pour (3) Data Collection	171
D10.2	Large Concrete Pour (3) Production Analysis	172
D11.1	Large Concrete Pour (4122) Data Collection	173
D11.2	Large Concrete Pour (4122) Production Analysis	174
D12.1	Large Concrete Pour (4553) Data Collection	175
D12.2	Large Concrete Pour (4553) Production Analysis	177

DATA COLLECTION REPORT

GENERAL INFORMATION

Contractor: Bell Construction	**Item Number:** 712-02.02
Task: Placement of barriers	**Date of Sampling:** March 19, 1997
Method: Cherry picker with barrier clamp	**County:** Shelby
Crew: Crane operator, foreman, six laborers	**Region:** Four
	Contract Number: 4253
Weather: weather was an insignificant factor	**Time of Day:** spring day (low 50's)
Site: there wer no specific site characteristic contributing to any delays	**Units Observed:** 6.069 meter sections
	Production Unit: Meters / Hour

PRODUCTION CYCLE DELAY SAMPLING

[MPDM] TOTAL PRODUCTION FOR ALL SECTIONS

Cycle	Field Time	Cycle Duration	Delay	Time Added	Cause
1	2.20	2.20			
2	5.17	2.97			
3	7.90	2.73			
4	11.92	4.02			
5	16.07	4.15			
6	18.72	2.65			
7	21.35	2.63			
8	25.33	3.98			
9	35.55	**10.22**	Yes	7.02	equipment
10	39.70	4.15			
11	43.73	4.03			
12	46.57	2.84			
13	48.90	2.33			
14	57.93	9.03			
15	60.98	3.05			
16	69.70	8.72			
17	72.57	2.87			
18	118.08	**45.51**	Yes	42.31	equipment
19	121.08	3.00			
20	123.40	2.32			
21	127.00	3.60			
22	130.47	3.47			
23	134.35	3.88			

PRODUCTION CYCLE DELAY SAMPLING

[MPDM] TOTAL PRODUCTION FOR ALL SECTIONS

Cycle	Field Time	Cycle Duration	Delay	Time Added	Cause
24	137.67	3.32			
25	142.02	4.35			
26	144.55	2.53			
27	147.67	3.12			
28	150.90	3.23			
29	155.35	4.45			
30	156.52	1.17			
31	161.20	4.68			
32	163.43	2.23			
33	167.00	3.57			
34	168.57	1.57			
35	175.27	6.70			
36	176.80	1.53			
37	180.03	3.23			
38	181.43	1.40			
39	185.37	3.94			
40	186.30	0.93			
41	191.88	5.58			
42	288.35	**96.47**	Yes	93.27	delivery
43	291.33	2.98			
44	293.33	2.00			
45	296.00	2.67			
46	299.98	3.98			
47	303.07	3.09			
48	306.70	3.63			
49	309.10	2.40			
50	311.02	1.92			
51	313.93	2.91			
52	316.75	2.82			
53	320.47	3.72			
54	323.78	3.31			
55	326.37	2.59			
56	328.52	2.15			
57	331.72	3.20			
58	335.77	4.05			
59	338.88	3.11			
60	342.00	3.12			
61	345.77	3.77			
62	349.30	3.53			
63	352.45	3.15			

APPENDIX D1.1 Barrier Placement 4253 Data Collection

PRODUCTION CYCLE DELAY SAMPLING

[MPDM] TOTAL PRODUCTION FOR ALL SECTIONS

Cycle	Field Time	Cycle Duration	Delay	Time Added	Cause
64	356.37	3.92			
65	359.95	3.58			
66	363.97	4.02			
67	365.85	1.88			
68	367.95	2.10			
69	371.25	3.30			
70	375.62	4.37			
71	379.12	3.50			
72	382.67	3.55			
73	384.50	1.83			
74	387.53	3.03			
75	391.90	4.37			
76	394.53	2.63			
77	401.83	7.30			
78	409.36	7.53			
79	412.64	3.28			
80	415.87	3.23			
81	418.24	2.37			
82	420.14	1.90			
83	421.72	1.58			
84	424.07	2.35			
85	426.2	2.17			
86	429.26	3.02			
87	430.67	1.41			
88	432.77	2.10			
89	434.57	1.80			
90	436.57	2.00			
91	438.44	1.87			
92	440.91	2.47			
93	444.12	3.21			
94	446.34	2.22			
95	448.01	1.67			
96	450.09	2.08			

METHOD PRODUCTIVITY DELAY MODEL [MPDM]

CYCLE INFORMATION

Units	Total Production Time (Minutes)	Number Of Cycles	Mean Cycle Time	STD DEV data = population	Actual Range Extremes	
A) non-delay production cycles	297.89	93	3.20			
B) delay production cycles	152.2	3	50.73			
C) total production cycles	450.09	96	4.69			

DELAY INFORMATION

DELAY TYPES	Material Delivery	Equipment	Site	Management
D) occurrences	1	2	0	0
E) total time added (minutes)	93.27	49.33	0	0
F) probability of occurrence*	0.010	0.0208	0.0000	0.000
G) relative severity**	19.894	5.261	0.000	0.000
H) expected % delay time per production cycle***	20.72	10.96	0.00	0.00

* delay cycles / total number of cycles
** mean added cycle time / mean overall cycle time = (row E / row D) / row C
*** Row F times Row G times 100%

PRODUCTIVITY

PRODUCTIVITY TYPE:	PRODUCTION units/hour
IDEAL PRODUCTIVITY	18.732
OVERALL PRODUCTIVITY	12.797
PRODUCTIVITY CHECK	12.797
FINAL PRODUCTIVITY	**12.8**

COST ANALYSIS PRODUCTION

12.8

UNITS / HOUR

Definition of Terms:
Idea productivity = 1 / mean nondelay cycle time (convert units)
Overall productivity = 1 / mean overall cycle time (convert units)
Check productivity = Ideal productivity * (1 - summation of row H / 100)

PRODUCTIVITY ANALYSIS

PRODUCTIVITY	SECTION	METERS PER HOUR	DAY (HOURS)	WORKING DAY PRODUCTION
12.8	6.096	78.029	8	624.230
units / hour				METERS

DATA COLLECTION REPORT

GENERAL INFORMATION

Contractor: Dement Construction	**Item Number:** 712-02.02
Task: Placement of barriers	**Date of Sampling:** June 5, 1997
Method: Truck crane with rod and strap (chain)	**County:** Shelby
Crew: Crane operator, foreman, four laborers	**Region:** Four
	Contract Number: 4491
Weather: weather was an insignificant factor	**Time of Day:** spring day (low 70's)
Site: Difficult site due to space limitations that may contributing to delays	**Units Observed:** 6.069 meter sections
	Production Unit: Meters / Hour

PRODUCTION CYCLE DELAY SAMPLING

[MPDM] TOTAL PRODUCTION FOR ALL SECTIONS

Cycle	Field Time	Cycle Duration	Delay	Time Added	Cause
1	3.12	3.12			
2	6.50	3.38			
3	11.50	5.00			
4	19.00	7.50			
5	23.75	4.75			
6	29.75	6.00			
7	32.43	2.68			
8	36.90	4.47			
9	39.00	2.10			
10	43.33	4.33			
11	47.32	3.98			
12	52.02	4.70			
13	54.07	2.05			
14	59.17	5.10			
15	61.67	2.50			
16	66.50	4.83			
17	69.08	2.58			
18	73.67	4.58			
19	75.57	1.90			
20	79.83	4.27			
21	82.28	2.45			
22	87.00	4.72			
23	89.38	2.38			

APPENDIX D2.1 Barrier Placement 4491 Data Collection

PRODUCTION CYCLE DELAY SAMPLING

[MPDM] TOTAL PRODUCTION FOR ALL SECTIONS

Cycle	Field Time	Cycle Duration	Delay	Time Added	Cause
24	93.67	4.28			
25	95.62	1.95			
26	99.65	4.03			
27	101.38	1.73			
28	106.70	5.32			
29	110.37	3.67			
30	115.58	5.22			
31	118.67	3.08			
32	124.78	6.12			
33	127.27	2.48			
34	132.55	5.28			
35	133.90	1.35			

METHOD PRODUCTIVITY DELAY MODEL [MPDM]

CYCLE INFORMATION

Units	Total Production Time (Minutes)	Number Of Cycles	Mean Cycle Time	STD DEV data = population	Actual Range Extremes	
A) non-delay production cycles	133.90	35	3.83			
B) delay production cycles	0.00	0	0.00			
C) total production cycles	133.90	35	3.83			

DELAY INFORMATION

DELAY TYPES	Material Delivery	Equipment	Site	Management
D) occurrences	0	0	0	0
E) total time added (minutes)	0	0	0	0
F) probability of occurrence*	0.000	0.0000	0.0000	0.000
G) relative severity**	0.000	0.000	0.000	0.000
H) expected % delay time per production cycle***	0.00	0.00	0.00	0.00

* delay cycles / total number of cycles
** mean added cycle time / mean overall cycle time = (row E / row D) / row C
*** Row F times Row G times 100%

PRODUCTIVITY

PRODUCTIVITY TYPE:	PRODUCTION units/hour
IDEAL PRODUCTIVITY	15.683
OVERALL PRODUCTIVITY	15.683
PRODUCTIVITY CHECK	15.683
FINAL PRODUCTIVITY	**15.7**

COST ANALYSIS PRODUCTION

15.7

UNITS / HOUR

Definition of Terms: Idea productivity = 1 / mean nondelay cycle time (convert units)
Overall productivity = 1 / mean overall cycle time (convert units)
Check productivity = Ideal productivity * (1 - summation of row H / 100)

PRODUCTIVITY ANALYSIS

PRODUCTIVITY	SECTION	METERS PER HOUR	DAY (HOURS)	WORKING DAY PRODUCTION
15.7	6.096	95.707	8	765.658
units / hour				METERS

DATA COLLECTION REPORT

GENERAL INFORMATION

Contractor: Mid State Construction	**Item Number:** 712-02.02
Task: Placement of barriers	**Date of Sampling:** March 4, 1997
Method: Truck crane with barrier clamp	**County:** Knox
Crew: Crane operator, foreman, six laborers	**Region: One**
	Contract Number: 4553
Weather: weather was an insignificant factor	**Time of Day:** spring day (low 60's)
Site: there wer no specific site characteristic contributing to any delays	**Units Observed:** 6.069 meter sections
	Production Unit: Meters / Hour

PRODUCTION CYCLE DELAY SAMPLING

[MPDM] TOTAL PRODUCTION FOR ALL SECTIONS

Cycle	Field Time	Cycle Duration	Delay	Time Added	Cause
1	6.83	6.83			
2	17.90	**11.07**	Yes	5.96	equipment
3	27.97	**10.07**	Yes	4.96	equipment
4	33.67	5.70			
5	42.63	8.96			
6	45.77	3.14			
7	51.20	5.43			
8	60.65	9.45			
9	65.15	4.50			
10	77.85	**12.70**	Yes	7.59	equipment
11	82.68	4.83			
12	87.65	4.97			
13	96.68	9.03			
14	100.52	3.84			
15	111.58	**11.06**	Yes	5.95	equipment
16	115.17	3.59			
17	124.43	9.26			
18	128.37	3.94			
19	137.67	9.30			
20	142.17	4.50			
21	165.63	**23.46**	Yes	18.35	equipment
22	168.45	2.82			
23	175.75	7.30			

APPENDIX D3.1 Barrier Placement 4553 Data Collection

PRODUCTION CYCLE DELAY SAMPLING (Cont.)

[MPDM] TOTAL PRODUCTION FOR ALL SECTIONS

Cycle	Field Time	Cycle Duration	Delay	Time Added	Cause
24	179.62	3.87			
25	186.78	7.16			
26	189.47	2.69			
27	196.00	6.53			
28	199.77	3.77			
29	206.28	6.51			
30	209.83	3.55			
31	224.88	**15.05**	Yes	9.94	equipment
32	229.73	4.85			
33	247.00	**17.27**	Yes	12.16	equipment
34	251.45	4.45			
35	262.82	**11.37**	Yes	6.26	equipment
36	267.82	5.00			
37	276.67	8.85			
38	281.73	5.06			
39	296.38	**14.65**	Yes	9.54	equipment
40	299.88	3.50			
41	312.50	**12.62**	Yes	7.51	equipment
42	315.43	2.93			
43	475.10	**159.67**	Yes	154.56	equipment
44	480.23	5.13			
45	491.27	**11.04**	Yes	5.93	equipment
46	494.48	3.21			
47	503.15	8.67			
48	506.17	3.02			
49	513.63	7.46			
50	515.92	2.29			
51	523.27	7.35			
52	525.68	2.41			
53	537.22	**11.54**	Yes	6.43	equipment
54	541.85	4.63			
55	553.50	**11.65**	Yes	6.54	equipment
56	556.33	2.83			
57	560.08	3.75			
58	563.20	3.12			
59	577.07	**13.87**	Yes	8.76	equipment
60	580.05	2.98			
61	588.12	8.07			
62	590.38	2.26			

PRODUCTION CYCLE DELAY SAMPLING (Cont.)

[MPDM] TOTAL PRODUCTION FOR ALL SECTIONS

Cycle	Field Time	Cycle Duration	Delay	Time Added	Cause
63	593.38	3.00			
64	600.53	7.15			
65	607.25	6.72			
66	616.27	9.02			
67	624.00	7.73			
68	626.00	2.00			
69	629.28	3.28			
70	637.43	8.15			
71	641.00	3.57			
72	645.57	4.57			
73	654.97	9.40			
74	657.08	2.11			
75	660.25	3.17			
76	680.25	**20.00**	Yes	14.89	manangement
77	684.00	3.75			
78	687.23	3.23			
79	700.00	**12.77**	Yes	7.66	manangement
80	701.50	1.50			
81	707.12	5.62			

METHOD PRODUCTIVITY DELAY MODEL [MPDM]

CYCLE INFORMATION

Units	Total Production Time (Minutes)	Number Of Cycles	Mean Cycle Time	STD DEV data = population	Actual Range Extremes	
A) non-delay production cycles	327.26	64	5.11			
B) delay production cycles	379.86	17	22.34			
C) total production cycles	707.12	81	8.73			

DELAY INFORMATION

DELAY TYPES	Material Delivery	Equipment	Site	Management
D) occurrences	0	15	0	2
E) total time added (minutes)	0	270.44	0	22.55
F) probability of occurrence*	0.000	0.1852	0.0000	0.025
G) relative severity**	0.000	2.065	0.000	1.292
H) expected % delay time per production cycle***	0.00	38.25	0.00	3.19

* delay cycles / total number of cycles
** mean added cycle time / mean overall cycle time = (row E / row D) / row C
*** Row F times Row G times 100%

PRODUCTIVITY

PRODUCTIVITY TYPE:	PRODUCTION units/hour
IDEAL PRODUCTIVITY	11.734
OVERALL PRODUCTIVITY	6.873
PRODUCTIVITY CHECK	6.872
FINAL PRODUCTIVITY	**6.9**

COST ANALYSIS PRODUCTION

6.9

UNITS / HOUR

Definition of Terms: Idea productivity = 1 / mean nondelay cycle time (convert units)
Overall productivity = 1 / mean overall cycle time (convert units)
Check productivity = Ideal productivity * (1 - summation of row H / 100)

PRODUCTIVITY ANALYSIS

PRODUCTIVITY	SECTION	METERS PER HOUR	DAY (HOURS)	WORKING DAY PRODUCTION
6.9	6.096	42.062	8	336.499
units / hour				METERS

DATA COLLECTION REPORT

GENERAL INFORMATION

Contractor: Southern Constructors, Inc.	**Item Number:** 712-02.02
Task: Placement of barriers	**Date of Sampling:** July 16, 1996
Method: Truck crane with barrier clamp	**County:** Jefferson
Crew: Crane operator, foreman, four skilled laborers	**Region:** One
	Contract Number: 4231
Weather: weather was an insignificant factor	**Time of Day:** Fall afternoon (low 70's)
Site: there were two bridges on this contract, delays due to relocation	**Units Observed:** 3.048, 6.069 m
	Production Unit: Meters / Hour

PRODUCTION CYCLE DELAY SAMPLING

[MPDM] TOTAL PRODUCTION FOR ALL SECTIONS

Cycle	Field Time	Cycle Duration	Delay	Time Added	Cause
1	56.07	**56.07**	Yes	53.68	equipment
2	57.20	1.13			
3	58.12	0.92			
4	59.57	1.45			
5	62.22	2.65			
6	63.77	1.55			
7	64.50	0.73			
8	65.68	1.18			
9	88.83	**23.15**	Yes	20.76	site
10	90.72	1.89			
11	92.57	1.85			
12	96.58	4.01			
13	98.33	1.75			
14	106.88	8.55			
15	109.08	2.20			
16	110.73	1.65			
17	113.27	2.54			
18	120.38	7.11			
19	123.38	3.00			
20	125.50	2.12			
21	127.68	2.18			
22	129.28	1.60			
23	135.53	6.25			
24	155.12	**19.59**	Yes	17.20	site

PRODUCTION CYCLE DELAY SAMPLING

[MPDM] TOTAL PRODUCTION FOR ALL SECTIONS

Cycle	Field Time	Cycle Duration	Delay	Time Added	Cause
25	156.75	1.63			
26	157.90	1.15			
27	159.38	1.48			
28	163.73	4.35			
29	165.32	1.59			
30	170.22	4.90			
31	171.73	1.51			
32	174.80	3.07			
33	175.82	1.02			
34	176.88	1.06			
35	177.83	0.95			
36	182.18	4.35			
37	183.67	1.49			
38	184.70	1.03			
39	185.92	1.22			
40	191.50	5.58			
41	193.05	1.55			
42	194.20	1.15			
43	197.33	3.13			
44	198.83	1.50			
45	202.40	3.57			
46	203.65	1.25			
47	206.65	3.00			
48	208.13	1.48			
49	211.33	3.20			
50	213.17	1.84			
51	215.83	2.66			
52	217.13	1.30			
53	219.47	2.34			
54	220.50	1.03			
55	223.03	2.53			
56	224.37	1.34			
57	227.02	2.65			
58	228.38	1.36			
59	231.28	2.90			
60	232.30	1.02			
61	235.22	2.92			
62	236.88	1.66			
63	239.80	2.92			

PRODUCTION CYCLE DELAY SAMPLING

[MPDM] TOTAL PRODUCTION FOR ALL SECTIONS

Cycle	Field Time	Cycle Duration	Delay	Time Added	Cause
64	242.75	2.95			
65	245.17	2.42			
66	246.53	1.36			
67	253.17	6.64			
68	254.47	1.30			
69	257.00	2.53			
70	257.97	0.97			
71	260.73	2.76			
72	262.10	1.37			
73	265.50	3.40			
74	266.80	1.30			
75	269.22	2.42			
76	271.50	2.28			
77	274.42	2.92			
78	275.62	1.20			
79	278.50	2.88			
80	282.50	4.00			

METHOD PRODUCTIVITY DELAY MODEL [MPDM]

CYCLE INFORMATION

Units	Total Production Time (Minutes)	Number Of Cycles	Mean Cycle Time	STD DEV data = population	Actual Range Extremes	
A) non-delay production cycles	183.69	77	2.39			
B) delay production cycles	98.81	3	32.94			
C) total production cycles	282.50	80	3.53			

DELAY INFORMATION

DELAY TYPES	Material Delivery	Equipment	Site	Management
D) occurrences	0	1	2	0
E) total time added (minutes)	0	53.68	37.96	0
F) probability of occurrence*	0.000	0.0125	0.0250	0.000
G) relative severity**	0.000	15.201	5.375	0.000
H) expected % delay time per production cycle***	0.00	19.00	13.44	0.00

* delay cycles / total number of cycles
** mean added cycle time / mean overall cycle time = (row E / row D) / row C
*** Row F times Row G times 100%

PRODUCTIVITY

PRODUCTIVITY TYPE:	PRODUCTION units/hour
IDEAL PRODUCTIVITY	25.151
OVERALL PRODUCTIVITY	16.991
PRODUCTIVITY CHECK	16.992
FINAL PRODUCTIVITY	**17.00**

COST ANALYSIS PRODUCTION

17.00

UNITS / HOUR

Definition of Terms: Idea productivity = 1 / mean nondelay cycle time (convert units)
Overall productivity = 1 / mean overall cycle time (convert units)
Check productivity = Ideal productivity * (1 - summation of row H / 100)

PRODUCTIVITY ANALYSIS

OBSERVED PRODUCTION								
TOTAL	3.048 m	6.096 m	UNITS /	PERCENT	NUMBER	SECTION	METERS	WORKING DAY
80	36	44	17	45	7.65	3.048	23.32	**80.32**
PERCENT	45	55	HOUR	55	9.35	6.096	57.00	**meters / hour**

PRODUCTIVITY	SECTION	NUMBER	METERS PER HOUR	DAY (Hrs.)	WORKING DAY PRODUCTION
17.00	3.048	17	51.82	8	414.528
units / hour	6.096	17	103.63	8	829.056
					METERS

DATA COLLECTION REPORT

GENERAL INFORMATION

Contractor: The Long Land Corporation	**Item Number:** 712-02.02
Task: Placement of barriers	**Date of Sampling:** September 16, 1996
Method: Track Hoe with barrier clamp	**County:** Hamilton
Crew: Track Hoe operator, foreman, four laborers	**Region:** Two
	Contract Number: 4359
Weather: weather was an insignificant factor	**Time of Day:** Fall afternoon (low 30's)
Site: this job was a part of a large road project on I-65 and was not connected to bridge work	**Units Observed:** 6.069 meter sections
	Production Unit: Meters / Hour

PRODUCTION CYCLE DELAY SAMPLING

[MPDM] TOTAL PRODUCTION FOR ALL SECTIONS

Cycle	Field Time	Cycle Duration	Delay	Time Added	Cause
1	330.45	**330.45**	Yes	327.91	management
2	336.33	5.88			
3	339.92	3.59			
4	343.25	3.33			
5	345.43	2.18			
6	348.72	3.29			
7	351.18	2.46			
8	354.17	2.99			
9	357.15	2.98			
10	359.18	2.03			
11	362.17	2.99			
12	368.75	6.58			
13	371.35	2.60			
14	374.58	3.23			
15	376.12	1.54			
16	377.75	1.63			
17	379.73	1.98			
18	381.25	1.52			
19	382.92	1.67			
20	384.75	1.83			
21	386.58	1.83			
22	388.20	1.62			
23	389.92	1.72			

PRODUCTION CYCLE DELAY SAMPLING

[MPDM] TOTAL PRODUCTION FOR ALL SECTIONS

Cycle	Field Time	Cycle Duration	Delay	Time Added	Cause
24	391.78	1.86			
25	394.33	2.55			
26	396.18	1.85			
27	416.00	**19.82**	Yes	17.28	equipment
28	420.37	4.37			
29	427.55	7.18			
30	431.27	3.72			
31	435.00	3.73			
32	437.87	2.87			
33	444.08	6.21			
34	446.90	2.82			
35	448.95	2.05			
36	451.08	2.13			
37	455.42	4.34			
38	457.53	2.11			
39	459.12	1.59			
40	460.87	1.75			
41	463.50	2.63			
42	464.83	1.33			
43	466.33	1.50			
44	469.87	3.54			
45	472.50	2.63			
46	474.15	1.65			
47	477.83	3.68			
48	480.45	2.62			
49	482.15	1.70			
50	484.58	2.43			
51	486.00	1.42			
52	487.92	1.92			
53	490.33	2.41			
54	492.53	2.20			
55	493.92	1.39			
56	495.63	1.71			
57	498.73	3.10			
58	500.42	1.69			
59	502.05	1.63			
60	504.17	2.12			
61	505.72	1.55			

APPENDIX D5.1 Barrier Placement 4359 Data Collection

PRODUCTION CYCLE DELAY SAMPLING

[MPDM] TOTAL PRODUCTION FOR ALL SECTIONS

Cycle	Field Time	Cycle Duration	Delay	Time Added	Cause
62	508.33	2.61			
63	510.88	2.55			
64	513.17	2.29			
65	515.08	1.91			
66	519.50	4.42			
67	521.12	1.62			
68	523.00	1.88			
69	525.50	2.50			
70	527.45	1.95			
71	529.12	1.67			
72	531.47	2.35			
73	533.50	2.03			
74	535.42	1.92			
75	537.45	2.03			
76	541.50	4.05			
77	543.83	2.33			
78	545.58	1.75			
79	546.92	1.34			
80	549.08	2.16			
81	551.50	2.42			
82	553.58	2.08			
83	555.83	2.25			
84	558.17	2.34			

METHOD PRODUCTIVITY DELAY MODEL [MPDM]

CYCLE INFORMATION

Units	Total Production Time (Minutes)	Number Of Cycles	Mean Cycle Time	STD DEV data = population	Actual Range Extremes	
A) non-delay production cycles	207.9	82	2.54			
B) delay production cycles	350.27	2	175.14			
C) total production cycles	558.17	84	6.64			

DELAY INFORMATION

DELAY TYPES	Material Delivery	Equipment	Site	Management
D) occurrences	0	1	0	1
E) total time added (minutes)	0	17.28	0	327.91
F) probability of occurrence*	0.0000	0.0119	0.0000	0.0119
G) relative severity**	0.0000	2.6005	0.0000	49.3478
H) expected % delay time per production cycle***	0.00	3.10	0.00	58.75

* delay cycles / total number of cycles

** mean added cycle time / mean overall cycle time = (row E / row D) / row C

*** Row F times Row G times 100%

PRODUCTIVITY ANALYSIS

PRODUCTION

PRODUCTIVITY TYPE:	units/hour
IDEAL PRODUCTIVITY	23.665
OVERALL PRODUCTIVITY	9.030
PRODUCTIVITY CHECK	9.030
FINAL PRODUCTIVITY	**9.03**

COST ANALYSIS PRODUCTION

9.03

UNITS / HOUR

Definition of Terms: Idea productivity = 1 / mean nondelay cycle time (convert units)

Overall productivity = 1 / mean overall cycle time (convert units)

Check productivity = Ideal productivity * (1 - summation of row H / 100)

PRODUCTIVITY ANALYSIS

PRODUCTIVITY	SECTION	METERS PER HOUR	DAY (HOURS)	WORKING DAY PRODUCTION
9.03	6.096	55.047	8	440.38
units / hour				**METERS**

APPENDIX D5.2 Barrier Placement 4359 Production Analysis

DATA COLLECTION REPORT

GENERAL INFORMATION

Contractor: Cecil Jamison	**Item Number:** 712-02.02
Task: Placement of barriers	**Date of Sampling:** January 26, 1996
Method: Back Hoe with chain and rods	**County:** Anderson
Crew: Back Hoe operator (cost in barrier rental) foreman, four laborers	**Region:** One
	Contract Number: 4419
Weather: Very cold	**Time of Day:** winter day (low teens)
Site: This job had delays due to traffic being stopped and released during barrier placement	**Units Observed: 3.048** meter sections
	Production Unit: Meters / Hour

PRODUCTION CYCLE DELAY SAMPLING

[MPDM] TOTAL PRODUCTION FOR ALL SECTIONS

DAY ONE OF THE OPERATION

Cycle	Field Time	Cycle Duration	Delay	Time Added	Cause
1	110.88	**110.88**	Yes	105.77	delivery
2	144.67	**33.79**	Yes	28.68	management
3	151.15	6.48			
4	155.67	4.52			
5	159.78	4.11			
6	164.00	4.22			
7	171.00	7.00			
8	176.75	5.75			
9	181.60	4.85			
10	186.53	4.93			
11	190.00	3.47			
12	363.17	**173.17**	Yes	168.06	delivery
13	369.20	6.03			
14	374.83	5.63			
15	381.47	6.64			
16	387.42	5.95			
17	392.00	4.58			
18	397.87	5.87			
19	401.12	3.25			
20	405.22	4.10			
21	545.67	**140.45**	Yes	135.34	delivery

APPENDIX D6.1 Barrier Placement 4419 Data Collection

PRODUCTION CYCLE DELAY SAMPLING

[MPDM] TOTAL PRODUCTION FOR ALL SECTIONS

Cycle	Field Time	Cycle Duration	Delay	Time Added	Cause
22	553.07	7.40			
23	558.34	5.27			
24	563.84	5.50			
25	568.57	4.73			
26	572.52	3.95			
27	579.27	6.75			
28	583.27	4.00			
29	587.67	4.40			
30	595.27	7.60			
31	599.49	4.22			
32	601.25	1.76			

PRODUCTION CYCLE DELAY SAMPLING

[MPDM] TOTAL PRODUCTION FOR ALL SECTIONS

DAY TWO OF THE OPERATION

Cycle	Field Time	Cycle Duration	Delay	Time Added	Cause
33	54.00	**54.00**	Yes	48.71	delivery
34	60.00	6.00			
35	65.33	5.33			
36	70.08	4.75			
37	78.02	7.94			
38	82.90	4.88			
39	87.83	4.93			
40	92.92	5.09			
41	202.97	**110.05**	Yes	104.76	delivery
42	208.78	5.81			
43	214.55	5.77			
44	218.77	4.22			
45	225.10	6.33			
46	232.17	7.07			
47	237.47	5.30			
48	242.67	5.20			
49	250.72	8.05			
50	257.00	6.28			
51	431.72	**174.72**	Yes	169.43	delivery
52	434.80	3.08			
53	440.55	5.75			
54	443.82	3.27			
55	454.60	**10.78**	Yes	5.49	management
56	459.24	4.64			
57	464.62	5.38			
58	468.65	4.03			
59	475.34	6.69			
60	480.92	5.58			
61	481.89	0.97			

PRODUCTION CYCLE DELAY SAMPLING

[MPDM] TOTAL PRODUCTION FOR ALL SECTIONS

DAY THREE OF THE OPERATION

Cycle	Field Time	Cycle Duration	Delay	Time Added	Cause
62	373.22	373.22	Yes	367.91	delivery
63	377.82	4.60			
64	383.05	5.23			
65	389.40	6.35			
66	392.45	3.05			
67	398.25	5.80			
68	403.42	5.17			
69	411.75	8.33			
70	418.38	6.63			
71	420.97	2.59			

PRODUCTION CYCLE DELAY SAMPLING

[MPDM] TOTAL PRODUCTION FOR ALL SECTIONS

DAY FOUR OF THE OPERATION

Cycle	Field Time	Cycle Duration	Delay	Time Added	Cause
72	73.10	73.10	Yes	68.75	delivery
73	76.45	3.35			
74	81.77	5.32			
75	86.88	5.11			
76	91.78	4.90			
77	94.58	2.80			
78	98.85	4.27			
79	104.78	5.93			
80	110.50	5.72			
81	112.25	1.75			

METHOD PRODUCTIVITY DELAY MODEL [MPDM]

CYCLE INFORMATION FOR DAY ONE (Cycle 1 - 32)

Units	Total Production Time (Minutes)	Number Of Cycles	Mean Cycle Time	STD DEV data = population	Actual Range Extremes	
A) non-delay production cycles	142.96	28	5.11			
B) delay production cycles	458.29	4	114.57			
C) total production cycles	601.25	32	18.79			

DELAY INFORMATION FOR DAY ONE (Cycle 1 - 32)

DELAY TYPES	Material Delivery	Equipment	Site	Management
D) occurrences	3	0	0	1
E) total time added (minutes)	409.17	0	0	28.68
F) probability of occurrence*	0.0938	0.0000	0.0000	0.0313
G) relative severity**	7.259	0.000	0.000	1.526
H) expected % delay time per production cycle***	68.05	0.00	0.00	4.77

* delay cycles / total number of cycles
** mean added cycle time / mean overall cycle time = (row E / row D) / row C
*** Row F times Row G times 100%

PRODUCTION FOR DAY ONE (Cycles 1 - 32)

PRODUCTIVITY TYPE:	PRODUCTION units/hour	COST ANALYSIS PRODUCTION
IDEAL PRODUCTIVITY	11.752	
OVERALL PRODUCTION	3.193	3.19
PRODUCTIVITY CHECK	3.194	
FINAL PRODUCTIVITY	**3.19**	UNITS / HOUR

Definition of Terms: Idea productivity = 1 / mean nondelay cycle time (convert units)
Overall productivity = 1 / mean overall cycle time (convert units)
Check productivity = Ideal productivity * (1 - summation of row H / 100)

PRODUCTIVITY ANALYSIS FOR DAY ONE (Cycles 1 - 32)

PRODUCTIVITY	SECTION	METERS PER HOUR	DAY (HOURS)	WORKING DAY PRODUCTION
3.19	3.048	9.72	8	77.785
units / hour				**METERS**

APPENDIX D6.2 Barrier Placement 4419 Production Analysis

METHOD PRODUCTIVITY DELAY MODEL [MPDM]

CYCLE INFORMATION FOR DAY TWO (Cycles 33 - 61)

Units	Total Production Time (Minutes)	Number Of Cycles	Mean Cycle Time	STD DEV data = population	Actual Range Extremes	
A) non-delay production cycles	132.34	25	5.29			
B) delay production cycles	349.55	4	87.39			
C) total production cycles	481.89	29	16.62			

DELAY INFORMATION FOR DAY TWO (Cycles 33 - 61)

DELAY TYPES	Material Delivery	Equipment	Site	Management
D) occurrences	3	0	0	1
E) total time added (minutes)	322.9	0	0	5.49
F) probability of occurrence*	0.1034	0.0000	0.0000	0.0345
G) relative severity**	6.477	0.000	0.000	0.330
H) expected % delay time per production cycle***	67.01	0.00	0.00	1.14

* delay cycles / total number of cycles
** mean added cycle time / mean overall cycle time = (row E / row D) / row C
*** Row F times Row G times 100%

PRODUCTIVITY FOR DAY TWO (Cycles 33 - 61)

PRODUCTIVITY TYPE:	PRODUCTION units/hour
IDEAL PRODUCTIVITY	11.334
OVERALL PRODUCTIVITY	3.611
PRODUCTIVITY CHECK	3.610
FINAL PRODUCTIVITY	**3.61**

COST ANALYSIS PRODUCTION

3.61

UNITS / HOUR

Definition of Terms: Idea productivity = 1 / mean nondelay cycle time (convert units)
Overall productivity = 1 / mean overall cycle time (convert units)
Check productivity = Ideal productivity * (1 - summation of row H / 100)

PRODUCTIVITY ANALYSIS FOR DAY TWO (Cycles 33 - 61)

PRODUCTIVITY	SECTION	METERS PER HOUR	DAY (HOURS)	WORKING DAY PRODUCTION
3.61	3.048	11.00	8	88.026
units / hour				**METERS**

METHOD PRODUCTIVITY DELAY MODEL [MPDM]

CYCLE INFORMATION FOR DAY THREE (Cycles 62 - 71)

Units	Total Production Time (Minutes)	Number Of Cycles	Mean Cycle Time	STD DEV data = population	Actual Range Extremes	
A) non-delay production cycles	47.75	9	5.31			
B) delay production cycles	373.22	1	373.22			
C) total production cycles	420.97	10	42.10			

DELAY INFORMATION FOR DAY THREE (Cycles 62 - 71)

DELAY TYPES	Material Delivery	Equipment	Site	Management
D) occurrences	1	0	0	0
E) total time added (minutes)	367.91	0	0	0
F) probability of occurrence*	0.1000	0.0000	0.0000	0.0000
G) relative severity**	8.740	0.000	0.000	0.000
H) expected % delay time per production cycle***	87.40	0.00	0.00	0.00

* delay cycles / total number of cycles
** mean added cycle time / mean overall cycle time = (row E / row D) / row C
*** Row F times Row G times 100%

PRODUCTIVITY FOR DAY THREE (Cycles 62-71)

PRODUCTIVITY TYPE:	PRODUCTION units/hour
IDEAL PRODUCTIVITY	11.309
OVERALL PRODUCTIVITY	1.425
PRODUCTIVITY CHECK	1.425
FINAL PRODUCTIVITY	**1.43**

COST ANALYSIS PRODUCTION

1.43

UNITS / HOUR

Definition of Terms: Idea productivity = 1 / mean nondelay cycle time (convert units)
Overall productivity = 1 / mean overall cycle time (convert units)
Check productivity = Ideal productivity * (1 - summation of row H / 100)

PRODUCTIVITY ANALYSIS FOR DAY THREE (Cycles 62 - 71)

PRODUCTIVITY	SECTION	METERS PER HOUR	DAY (HOURS)	WORKING DAY PRODUCTION
1.43	3.048	4.36	8	34.869
units / hour				**METERS**

METHOD PRODUCTIVITY DELAY MODEL [MPDM]

CYCLE INFORMATION FOR DAY FOUR (Cycles 72 - 81)

Units	Total Production Time (Minutes)	Number Of Cycles	Mean Cycle Time	STD DEV data = population	Actual Range Extremes	
A) non-delay production cycles	39.15	9	4.35			
B) delay production cycles	73.10	1	73.10			
C) total production cycles	112.25	10	11.23			

DELAY INFORMATION FOR DAY FOUR (Cycles 72 - 81)

DELAY TYPES	Material Delay	Equipment	Site	Management
D) occurrences	1	0	0	0
E) total time added (minutes)	68.75	0	0	0
F) probability of occurrence*	0.1000	0.0000	0.0000	0.0000
G) relative severity**	6.125	0.000	0.000	0.000
H) expected % delay time per production cycle***	61.25	0.00	0.00	0.00

* delay cycles / total number of cycles

** mean added cycle time / mean overall cycle time = (row E / row D) / row C

*** Row F times Row G times 100%

PRODUCTIVITY FOR DAY FOUR (Cycles 72 - 81)

PRODUCTIVITY TYPE:	PRODUCTION units/hour
IDEAL PRODUCTIVITY	13.793
OVERALL PRODUCTIVITY	5.345
PRODUCTIVITY CHECK	5.345
FINAL PRODUCTIVITY	**5.35**

COST ANALYSIS PRODUCTION

5.35

UNITS / HOUR

Definition of Terms: Idea productivity = 1 / mean nondelay cycle time (convert units)

Overall productivity = 1 / mean overall cycle time (convert units)

Check productivity = Ideal productivity * (1 - summation of row H / 100)

PRODUCTIVITY ANALYSIS FOR DAY FOUR (Cycles 72 - 81)

PRODUCTIVITY	SECTION	METERS PER HOUR	DAY (HOURS)	WORKING DAY PRODUCTION
5.35	3.048	16.31	8	130.454
units / hour				**METERS**

METHOD PRODUCTIVITY DELAY MODEL [MPDM]

CYCLE INFORMATION FOR ALL FOUR DAYS (Cycles 1 - 81)

Units	Total Production Time (Minutes)	Number Of Cycles	Mean Cycle Time	STD DEV data = population	Actual Range Extremes	
A) non-delay production cycles	362.2	71	5.10			
B) delay production cycles	1254.16	10	125.42			
C) total production cycles	1616.36	81	19.96			

DELAY INFORMATION FOR ALL FOUR DAYS (Cycles 1 - 81)

DELAY TYPES	Material Delivery	Equipment	Site	Management
D) occurrences	8	0	0	1
E) total time added (minutes)	1168.19	0	0	34.17
F) probability of occurrence*	0.0988	0.0000	0.0000	0.0123
G) relative severity**	7.318	0.000	0.000	1.712
H) expected % delay time per production cycle***	72.27	0.00	0.00	2.11

* delay cycles / total number of cycles
** mean added cycle time / mean overall cycle time = (row E / row D) / row C
*** Row F times Row G times 100%

PRODUCTIVITY FORALL FOUR DAYS (Cycles 1 - 81)

PRODUCTIVITY TYPE:	PRODUCTION units/hour
IDEAL PRODUCTIVITY	11.761
OVERALL PRODUCTIVITY	3.007
PRODUCTIVITY CHECK	3.012
FINAL PRODUCTIVITY	**3.01**

COST ANALYSIS PRODUCTION

3.01

UNITS / HOUR

Definition of Terms: Idea productivity = 1 / mean nondelay cycle time (convert units)
Overall productivity = 1 / mean overall cycle time (convert units)
Check productivity = Ideal productivity * (1 - summation of row H / 100)

PRODUCTIVITY ANALYSIS FOR ALL FOUR DAYS (Cycles 1 - 81)

PRODUCTIVITY	SECTION	METERS PER HOUR	DAY (HOURS)	WORKING DAY PRODUCTION
3.01	3.048	9.17	8	73.396
units / hour				**METERS**

DATA COLLECTION REPORT

GENERAL INFORMATION

Contractor:Chris Hill Construction Company	**Item Number:** 712-02.02
Task: Placement of barriers	**Date of Sampling:** May 30, 1997
Method: Truck Crane with barrier clamp	**County:** Shelby
Crew: Crane operator, foreman, three laborers	**Region:** Four
	Contract Number: 4665
Weather: weather was an insignificant factor	**Time of Day:** spring day (low 70's)
Site: there were no specific site characteristic contributing to any delays	**Units Observed:** 6.069 meter sections
	Production Unit: Meters / Hour

PRODUCTION CYCLE DELAY SAMPLING

[MPDM] TOTAL PRODUCTION FOR ALL SECTIONS

Cycle	Field Time	Cycle Duration	Delay	Time Added	Cause
1	11.77	**11.77**	Yes	8.32	equipment
2	13.47	1.70			
3	15.32	1.85			
4	24.30	8.98			
5	30.43	6.13			
6	32.77	2.33			
7	35.43	2.67			
8	37.27	1.83			
9	41.42	4.15			
10	46.35	4.93			
11	49.08	2.73			
12	51.72	2.63			
13	124.77	**73.05**	Yes	69.60	delivery
14	126.50	1.73			
15	128.70	2.20			
16	134.02	5.32			
17	141.05	7.03			
18	142.83	1.78			
19	147.30	4.47			
20	149.57	2.27			
21	153.57	4.00			
22	158.63	5.07			
23	161.00	2.37			
24	222.85	**61.85**	Yes	58.40	delivery

PRODUCTION CYCLE DELAY SAMPLING

[MPDM] TOTAL PRODUCTION FOR ALL SECTIONS

Cycle	Field Time	Cycle Duration	Delay	Time Added	Cause
25	236.13	**13.28**	Yes	9.83	equipment
26	237.68	1.55			
27	239.72	2.03			
28	244.00	4.28			
29	246.00	2.00			
30	249.33	3.33			
31	253.85	4.52			
32	255.57	1.72			
33	258.45	2.88			
34	263.55	5.10			
35	265.18	1.63			
36	271.57	6.38			
37	338.33	**66.77**	Yes	63.32	delivery
38	342.50	4.17			
39	345.90	3.40			
40	348.00	2.10			
41	353.70	5.70			
42	355.68	1.98			
43	361.00	5.32			
44	362.90	1.90			
45	365.12	2.22			
46	370.37	5.25			
47	372.78	2.42			
48	375.00	2.22			

METHOD PRODUCTIVITY DELAY MODEL [MPDM]

CYCLE INFORMATION

Units	Total Production Time (Minutes)	Number Of Cycles	Mean Cycle Time	STD DEV data = population	Actual Range Extremes	
A) non-delay production cycles	148.28	43	3.45			
B) delay production cycles	226.72	5	45.34			
C) total production cycles	375.00	48	7.81			

DELAY INFORMATION

DELAY TYPES	Material Delivery	Equipment	Site	Management
D) occurrences	3	2	0	0
E) total time added (minutes)	191.32	18.15	0	0
F) probability of occurrence*	0.063	0.0417	0.0000	0.000
G) relative severity**	8.163	1.162	0.000	0.000
H) expected % delay time per production cycle***	51.02	4.84	0.00	0.00

* delay cycles / total number of cycles
** mean added cycle time / mean overall cycle time = (row E / row D) / row C
*** Row F times Row G times 100%

PRODUCTIVITY

PRODUCTIVITY TYPE:	PRODUCTION units/hour
IDEAL PRODUCTIVITY	17.400
OVERALL PRODUCTIVITY	7.680
PRODUCTIVITY CHECK	7.680
FINAL PRODUCTIVITY	7.7

COST ANALYSIS PRODUCTION

7.7

UNITS / HOUR

Definition of Terms: Idea productivity = 1 / mean nondelay cycle time (convert units)
Overall productivity = 1 / mean overall cycle time (convert units)
Check productivity = Ideal productivity * (1 - summation of row H / 100)

PRODUCTIVITY ANALYSIS

PRODUCTIVITY	SECTION	METERS PER HOUR	DAY (HOURS)	WORKING DAY PRODUCTION
7.7	6.096	46.939	8	375.514
units / hour				METERS

DATA COLLECTION REPORT

GENERAL INFORMATION

Contractor: Jones Brothers	**Item Number:** 604-03.09
Task: Placement of Concrete on Deck	**Date of Sampling:** April 24, 1997
Method: Pumptruck and Screed	**County:** Shelby
Crew: Pumptruck operator, screed operator, four foremen, three supervisors, thirty laborers	**Region:** Four
	Contract Number: 3809
Weather: weather was an insignificant factor	**Time of Day:** spring day (low 60's)
Site: New construction with no site condition problems, two truck hopper on pumptruck	**Units Observed:** cubic yards of concrete
	Production Unit: Cubic Yards / Hour

PRODUCTION CYCLE DELAY SAMPLING

[MPDM] TOTAL PRODUCTION FOR ALL SECTIONS

Cycle	Field Time	Cycle Duration	Delay	Time Added	Cause
1	8.00	8.00			
2	14.50	6.50			
3	19.73	5.23			
4	25.80	6.07			
5	31.00	5.20			
6	36.92	5.92			
7	62.00	**25.08**	Yes	16.82	delivery
8	74.70	12.70			
9	77.67	2.97			
10	88.73	11.06			
11	93.53	4.80			
12	101.40	7.87			
13	110.00	8.60			
14	114.67	4.67			
15	121.50	6.83			
16	128.78	7.28			
17	135.20	6.42			
18	140.00	4.80			
19	150.48	10.48			
20	158.20	7.72			
21	172.00	13.80			
22	184.00	12.00			
23	193.82	9.82			
24	202.95	9.13			

PRODUCTION CYCLE DELAY SAMPLING

[MPDM] TOTAL PRODUCTION FOR ALL SECTIONS

Cycle	Field Time	Cycle Duration	Delay	Time Added	Cause
25	216.30	13.35			
26	224.03	7.73			
27	291.75	**67.72**	Yes	59.46	site
28	303.08	11.33			
29	310.72	7.64			
30	317.00	6.28			
31	327.00	10.00			
32	333.00	6.00			
33	347.28	14.28			
34	359.00	11.72			
35	371.70	12.70			
36	381.00	9.30			
37	388.22	7.22			
38	394.57	6.35			
39	406.73	12.16			
40	420.70	13.97			
41	427.78	7.08			
42	447.63	**19.85**	Yes	11.59	delivery
43	455.35	7.72			
44	464.93	9.58			
45	469.07	4.14			
46	476.00	6.93			
47	482.00	6.00			
48	489.03	7.03			
49	495.42	6.39			
50	501.10	5.68			

METHOD PRODUCTIVITY DELAY MODEL [MPDM]

CYCLE INFORMATION

Units	Total Production Time (Minutes)	Number Of Cycles	Mean Cycle Time	STD DEV data = population	Actual Range Extremes	
A) non-delay production cycles	388.45	47	8.26			
B) delay production cycles	112.65	3	37.55			
C) total production cycles	501.10	50	10.02			

DELAY INFORMATION

DELAY TYPES	Delivery	Equipment	Site	Management
D) occurrences	2	0	1	0
E) total time added (minutes)	28.41	52.64	59.46	30.97
F) probability of occurrence*	0.0400	0.0000	0.0200	0.000
G) relative severity**	1.417	0.000	5.933	0.000
H) expected % delay time per production cycle***	5.67	0.00	11.87	0.00

* delay cycles / total number of cycles
** mean added cycle time / mean overall cycle time = (row E / row D) / row C
*** Row F times Row G times 100%

PRODUCTIVITY

PRODUCTIVITY TYPE:	PRODUCTION units/hour
IDEAL PRODUCTIVITY	7.260
OVERALL PRODUCTIVITY	5.987
PRODUCTIVITY CHECK	5.987
FINAL PRODUCTIVITY	**6.0**

COST ANALYSIS PRODUCTION

6.0

UNITS / HOUR

Definition of Terms: Idea productivity = 1 / mean nondelay cycle time (convert units)
Overall productivity = 1 / mean overall cycle time (convert units)
Check productivity = Ideal productivity * (1 - summation of row H / 100)

PRODUCTIVITY ANALYSIS

PRODUCTIVITY	Truck Capacity	Cubic	DAY	WORKING DAY PRODUCTION
6.0	10	60	8	480
units / hour	Cubic Yards	Yards	Hours	Cubic Yards

DATA COLLECTION REPORT

GENERAL INFORMATION

Contractor: Ray Bell Construction	**Item Number:** 604-03.09
Task: Placement of Concrete on Deck	**Date of Sampling:** May 23, 1997
Method: Truck crane with 2 yd Bucket	**County:** McMinn
Crew: Crane operator, pumptruck operator, two foremen, thirteen laborers	**Region:** Two
	Contract Number: 2
Weather: weather was an insignificant factor	**Time of Day:** summer morning (mid 50's)
Site: Rural, pour exceeded reach of pumptruck boom requiring partial use of crane and bucket	**Units Observed:** cubic yards of concrete
	Production Unit: Cubic Yards / Hour

PRODUCTION CYCLE DELAY SAMPLING

[MPDM] TOTAL PRODUCTION FOR ALL SECTIONS

Cycle	Field Time	Cycle Duration	Delay	Time Added	Cause
1	12.00	12.00			
2	22.00	10.00			
3	33.00	11.00			
4	45.00	12.00			
5	51.00	6.00			
6	77.00	**26.00**	Yes	13.75	delivery
7	115.00	**38.00**	Yes	25.75	delivery
8	128.00	13.00			
9	137.00	9.00			
10	150.00	13.00			
11	161.00	11.00			
12	177.00	16.00			
13	193.00	16.00			
14	225.00	**32.00**	Yes	19.75	crane & bucket
15	260.00	**35.00**	Yes	22.75	crane & bucket
16	280.00	20.00			crane & bucket
17	292.00	12.00			crane & bucket
18	307.00	15.00			crane & bucket
19	319.00	12.00			crane & bucket
20	339.00	**20.00**	Yes	7.75	site
21	364.00	**25.00**	Yes	12.75	delivery
22	374.00	10.00			
23	391.00	17.00			
24	400.00	9.00			
25	409.00	9.00			

PRODUCTION CYCLE DELAY SAMPLING

[MPDM] TOTAL PRODUCTION FOR ALL SECTIONS

Cycle	Field Time	Cycle Duration	Delay	Time Added	Cause
26	431.00	**22.00**	Yes	9.75	delivery
27	452.00	**21.00**	Yes	8.75	delivery
28	469.00	17.00			
29	476.00	7.00			
30	492.00	16.00			
31	508.00	16.00			
32	513.00	5.00			

PRODUCTION CYCLE DELAY SAMPLING

crane & bucket portion of placement (Trucks14-19)

[MPDM] TOTAL PRODUCTION FOR ALL SECTIONS

Cycle	Field Time	Cycle Duration	Delay	Time Added	Cause
1	2.00	2.00			
2	4.00	2.00			
3	7.00	3.00			
4	9.00	2.00			
5	11.00	2.00			
6	12.00	1.00			
7	33.00	**21.00**	Yes	19.05	site
8	36.00	3.00			
9	38.00	2.00			
10	40.00	2.00			
11	42.00	2.00			
12	44.00	2.00			
13	46.00	2.00			
14	48.00	2.00			
15	55.00	**7.00**	Yes	5.05	site
16	58.00	3.00			
17	60.00	2.00			
18	62.00	2.00			
19	64.00	2.00			
20	66.00	2.00			
21	68.00	2.00			
22	80.00	**12.00**	Yes	10.05	site
23	82.00	2.00			
24	84.00	2.00			
25	86.00	2.00			
26	88.00	2.00			
27	90.00	2.00			
28	95.00	**5.00**	Yes	3.05	site
29	97.00	2.00			
30	99.00	2.00			
31	101.00	2.00			
32	103.00	2.00			
33	104.00	1.00			
34	106.00	2.00			
35	110.00	4.00			
36	111.00	1.00			
37	112.00	1.00			
38	113.00	1.00			
39	114.00	1.00			
40	115.00	1.00			
41	117.00	2.00			

APPENDIX D9.1 Large Concrete Pour 2 Data Collection

METHOD PRODUCTIVITY DELAY MODEL [MPDM]

CYCLE INFORMATION

Units	Total Production Time (Minutes)	Number Of Cycles	Mean Cycle Time	STD DEV data = population	Actual Range Extremes	
A) non-delay production cycles	294.00	24	12.25			
B) delay production cycles	219.00	8	27.38			
C) total production cycles	513.00	32	16.03			

DELAY INFORMATION

DELAY TYPES	Delivery	Equipment	Site	Management
D) occurrences	5	2	1	0
E) total time added (minutes)	70.75	42.5	7.75	0
F) probability of occurrence*	0.1563	0.0625	0.0313	0.000
G) relative severity**	0.883	1.326	0.483	0.000
H) expected % delay time per production cycle***	13.79	8.28	1.51	0.00

* delay cycles / total number of cycles
** mean added cycle time / mean overall cycle time = (row E / row D) / row C
*** Row F times Row G times 100%

PRODUCTIVITY

PRODUCTIVITY TYPE:	PRODUCTION units/hour
IDEAL PRODUCTIVITY	4.898
OVERALL PRODUCTIVITY	3.743
PRODUCTIVITY CHECK	3.743
FINAL PRODUCTIVITY	**3.7**

COST ANALYSIS PRODUCTION

3.7

UNITS / HOUR

Definition of Terms: Idea productivity = 1 / mean nondelay cycle time (convert units)
Overall productivity = 1 / mean overall cycle time (convert units)
Check productivity = Ideal productivity * (1 - summation of row H / 100)

PRODUCTIVITY ANALYSIS

PRODUCTIVITY	Truck Capacity	Total	DAY	WORKING DAY PRODUCTION
3.7	10	37.00	8	296.00
units / hour	**Cubic Yards**	**Cubic Yards**	**Hours**	**Cubic Yards**

METHOD PRODUCTIVITY DELAY MODEL [MPDM]

CYCLE INFORMATION

Units	Total Production Time (Minutes)	Number Of Cycles	Mean Cycle Time	STD DEV data = population	Actual Range Extremes	
A) non-delay production cycles	72.00	37	1.95			
B) delay production cycles	45.00	4	11.25			
C) total production cycles	117.00	41	2.85			

DELAY INFORMATION

DELAY TYPES	Delivery	Equipment	Site	Management
D) occurrences	0	0	4	0
E) total time added (minutes)	0.00	0	37.20	0
F) probability of occurrence*	0.0000	0.0000	0.0976	0.000
G) relative severity**	0.000	0.000	3.259	0.000
H) expected % delay time per production cycle***	0.00	0.00	31.79	0.00

* delay cycles / total number of cycles
** mean added cycle time / mean overall cycle time = (row E / row D) / row C
*** Row F times Row G times 100%

PRODUCTIVITY

PRODUCTIVITY TYPE:	PRODUCTION units/hour
IDEAL PRODUCTIVITY	30.833
OVERALL PRODUCTIVITY	21.026
PRODUCTIVITY CHECK	21.030
FINAL PRODUCTIVITY	**21.0**

COST ANALYSIS PRODUCTION

21.0

UNITS / HOUR

Definition of Terms: Idea productivity = 1 / mean nondelay cycle time (convert units)
Overall productivity = 1 / mean overall cycle time (convert units)
Check productivity = Ideal productivity * (1 - summation of row H / 100)

PRODUCTIVITY ANALYSIS

Percentage Filled Calculation	Cubic Yds. Placed	Bucket Size Cubic Yards	Number of Lifts Bucket Full Capacity	Actual Lifts	Percentage Filled
	74.00	2.00	37	41	90.24%

PRODUCTIVITY	BUCKET	% Filled	ADJUSTED	DAY	WORKING DAY PRODUCTION
21.0	2.00	78.5	33.02	8	264.14
units / hour	SIZE	Average	PRODUCTIVITY	Hours	Cubic Yards

DATA COLLECTION REPORT

GENERAL INFORMATION

Contractor: Chris Hill	**Item Number:** 604-03.09
Task: Placement of Concrete on Deck	**Date of Sampling:** May 29, 1997
Method: Truck crane with 2 yd Bucket	**County:** Shelby
Crew: Screed operator, pumptruck operator, two foremen, twenty laborers, one mechanic	**Region:** Four
	Contract Number: 3
Weather: weather was an insignificant factor	**Time of Day:** summer morning (mid 50's)
Site: Interstate, long back-up for concrete truck drivers	**Units Observed:** cubic yards of concrete
	Production Unit: Cubic Yards / Hour

PRODUCTION CYCLE DELAY SAMPLING

[MPDM] TOTAL PRODUCTION FOR ALL SECTIONS

Cycle	Field Time	Cycle Duration	Delay	Time Added	Cause
1	18.00	18.00			
2	34.00	16.00			
3	45.00	11.00			
4	61.00	16.00			
5	73.00	12.00			
6	85.00	12.00			
7	95.00	10.00			
8	105.00	10.00			
9	113.00	8.00			
10	124.00	11.00			
11	135.00	11.00			
12	143.00	8.00			
13	155.00	12.00			
14	165.00	10.00			
15	173.00	8.00			
16	181.00	8.00			
17	190.00	9.00			
18	198.00	8.00			
19	240.00	**42.00**	Yes	30.54	delivery
20	251.00	11.00			
21	267.00	16.00			
22	282.00	15.00			
23	291.00	9.00			
24	303.00	12.00			
25	317.00	14.00			

APPENDIX D10.1 Large Concrete Pour 3 Data Collection

METHOD PRODUCTIVITY DELAY MODEL [MPDM]

CYCLE INFORMATION

Units	Total Production Time (Minutes)	Number Of Cycles	Mean Cycle Time	STD DEV data = population	Actual Range Extremes	
A) non-delay production cycles	275.00	24	11.46			
B) delay production cycles	42.00	1	42.00			
C) total production cycles	317.00	25	12.68			

DELAY INFORMATION

DELAY TYPES	Delivery	Equipment	Site	Management
D) occurrences	1	0	0	0
E) total time added (minutes)	30.54	0	0	0
F) probability of occurrence*	0.0400	0.0000	0.0000	0.000
G) relative severity**	2.409	0.000	0.000	0.000
H) expected % delay time per production cycle***	9.63	0.00	0.00	0.00

* delay cycles / total number of cycles
** mean added cycle time / mean overall cycle time = (row E / row D) / row C
*** Row F times Row G times 100%

PRODUCTIVITY

PRODUCTIVITY TYPE:	PRODUCTION units/hour
IDEAL PRODUCTIVITY	5.236
OVERALL PRODUCTIVITY	4.732
PRODUCTIVITY CHECK	4.732
FINAL PRODUCTIVITY	**4.7**

COST ANALYSIS PRODUCTION

4.7

UNITS / HOUR

Definition of Terms: Idea productivity = 1 / mean nondelay cycle time (convert units)
Overall productivity = 1 / mean overall cycle time (convert units)
Check productivity = Ideal productivity * (1 - summation of row H / 100)

PRODUCTIVITY ANALYSIS

PRODUCTIVITY	Truck Capacity	Cubic	DAY	WORKING DAY PRODUCTION
4.7	10	47	8	376
units / hour	Cubic Yards	Yards	Hours	Cubic Yards

DATA COLLECTION REPORT

GENERAL INFORMATION

Contractor: General Constructors, Inc.	**Item Number:** 604-03.09
Task: Placement of Concrete on Deck	**Date of Sampling:** July 3, 1996
Method: Pump truck and Screed	**County:** Jefferson
Crew: Screed operator, foreman, eight laborers	**Region:** One
	Contract Number: 4122
Weather: weather was an insignificant factor	**Time of Day:** spring day (low 60's)
Site: Delays due to reposition for sequential pours for proper loading of girders	**Units Observed:** concrete trucks (10 cub. yds.)
	Production Unit: Cubic Yards / Hour

PRODUCTION CYCLE DELAY SAMPLING

[MPDM] TOTAL PRODUCTION FOR ALL SECTIONS

CONTINUOUS CONCRETE POUR

Cycle	Field Time	Cycle Duration	Delay	Time Added	Cause
1	14.52	14.52			
2	30.82	16.30			
3	91.57	60.75	Yes	44.72	equipment
4	121.00	29.43	Yes	13.40	delivery
5	141.03	20.03			
6	154.30	13.27			

APPENDIX D11.1 Large Concrete Pour 4122 Data Collection

METHOD PRODUCTIVITY DELAY MODEL [MPDM]

CYCLE INFORMATION

Units	Total Production Time (Minutes)	Number Of Cycles	Mean Cycle Time	STD DEV data = population	Actual Range Extremes	
A) non-delay production cycles	64.12	4	16.03			
B) delay production cycles	90.18	2	45.09			
C) total production cycles	154.3	6	25.72			

DELAY INFORMATION

DELAY TYPES	Delivery	Equipment	Site	Management
D) occurrences	1	1	0	0
E) total time added (minutes)	13.40	44.72	0	0
F) probability of occurrence*	0.1667	0.1667	0.0000	0.000
G) relative severity**	0.521	1.739	0.000	0.000
H) expected % delay time per production cycle***	8.68	28.98	0.00	0.00

* delay cycles / total number of cycles
** mean added cycle time / mean overall cycle time = (row E / row D) / row C
*** Row F times Row G times 100%

PRODUCTIVITY

PRODUCTIVITY TYPE:	PRODUCTION units/hour
IDEAL PRODUCTIVITY	3.743
OVERALL PRODUCTIVITY	2.333
PRODUCTIVITY CHECK	2.333
FINAL PRODUCTIVITY	**2.33**

COST ANALYSIS PRODUCTION

2.33

UNITS / HOUR

Definition of Terms: Idea productivity = 1 / mean nondelay cycle time (convert units)
Overall productivity = 1 / mean overall cycle time (convert units)
Check productivity = Ideal productivity * (1 - summation of row H / 100)

PRODUCTIVITY ANALYSIS

PRODUCTIVITY	Truck Capacity	Cubic	DAY	WORKING DAY PRODUCTION
2.33	10	23.30	8	186.400
units / hour	Cubic Yards	Yards	HOURS	**Cubic Yards**

DATA COLLECTION REPORT

GENERAL INFORMATION

Contractor: Mid State Construction	**Item Number:** 604-03.09
Task: Placement of Concrete on Deck	**Date of Sampling:** April 7, 1997
Method: Truck crane with 3/4 yd Bucket	**County:** Knox
Crew: Crane operator, foreman, eight laborers	**Region: One**
	Contract Number: 4553
Weather: weather was an insignificant factor	**Time of Day:** spring day (low 60's)
Site: Urban site characteristic contributed to delays due to truck crane maneuvering	**Units Observed:** cubic yards of concrete
	Production Unit: Cubic Yards / Hour

PRODUCTION CYCLE DELAY SAMPLING

[MPDM] TOTAL PRODUCTION FOR ALL SECTIONS

Cycle	Field Time	Cycle Duration	Delay	Time Added	Cause
1	25.05	**25.05**	Yes	20.84	delivery
2	28.67	3.62			
3	38.10	9.43			
4	41.77	3.67			
5	45.68	3.91			
6	53.23	7.55			
7	66.22	**12.99**	Yes	8.78	equipment
8	100.62	**34.40**	Yes	30.19	equipment
9	107.45	6.83			
10	113.05	5.60			
11	117.85	4.80			
12	120.42	2.57			
13	123.10	2.68			
14	191.68	**68.58**	Yes	64.37	delivery
15	197.92	6.24			
16	200.00	2.08			
17	208.50	8.50			
18	211.60	3.10			
19	214.67	3.07			
20	217.27	2.60			
21	220.27	3.00			
22	224.83	4.56			
23	227.38	2.55			
24	243.40	**16.02**	Yes	11.81	management

PRODUCTION CYCLE DELAY SAMPLING

[MPDM] TOTAL PRODUCTION FOR ALL SECTIONS

Cycle	Field Time	Cycle Duration	Delay	Time Added	Cause
25	247.63	4.23			
26	248.28	0.65			
27	253.88	5.60			
28	257.08	3.20			
29	261.60	4.52			
30	264.62	3.02			
31	268.05	3.43			
32	279.17	**11.12**	Yes	6.91	management
33	281.83	2.66			
34	284.27	2.44			
35	287.00	2.73			
36	325.00	**38.00**	Yes	33.79	delivery
37	329.25	4.25			
38	333.05	3.80			
39	336.00	2.95			
40	339.00	3.00			
41	356.88	**17.88**	Yes	13.67	equipment
42	359.75	2.87			
43	370.00	**10.25**	Yes	6.04	management
44	375.00	5.00			
45	380.00	5.00			
46	390.42	**10.42**	Yes	6.21	management
47	397.00	6.58			
48	433.42	**36.42**	Yes	32.21	delivery
49	439.24	5.82			
50	446.78	7.54			
51	449.42	2.64			

METHOD PRODUCTIVITY DELAY MODEL [MPDM]

CYCLE INFORMATION

Units	Total Production Time (Minutes)	Number Of Cycles	Mean Cycle Time	STD DEV data = population	Actual Range Extremes	
A) non-delay production cycles	168.29	40	4.21			
B) delay production cycles	281.13	11	25.56			
C) total production cycles	449.42	51	8.81			

DELAY INFORMATION

DELAY TYPES	Delivery	Equipment	Site	Management
D) occurrences	4	3	0	4
E) total time added (minutes)	151.21	52.64	0	30.97
F) probability of occurrence*	0.0784	0.0588	0.0000	0.078
G) relative severity**	4.290	1.991	0.000	0.879
H) expected % delay time per production cycle***	33.65	11.71	0.00	6.89

* delay cycles / total number of cycles
** mean added cycle time / mean overall cycle time = (row E / row D) / row C
*** Row F times Row G times 100%

PRODUCTIVITY

PRODUCTIVITY TYPE:	PRODUCTION units/hour	COST ANALYSIS PRODUCTION
IDEAL PRODUCTIVITY	14.261	
OVERALL PRODUCTIVITY	6.809	6.8
PRODUCTIVITY CHECK	6.810	
FINAL PRODUCTIVITY	**6.8**	UNITS / HOUR

Definition of Terms: Idea productivity = 1 / mean nondelay cycle time (convert units)
Overall productivity = 1 / mean overall cycle time (convert units)
Check productivity = Ideal productivity * (1 - summation of row H / 100)

PRODUCTIVITY ANALYSIS

Percentage Filled Calculation	Cubic Yds. Placed	Bucket Size Cubic Yards	Number of Lifts Bucket Full Capacity	Actual Lifts	Percentage Filled
	30	0.75	40	51	78.43

PRODUCTIVITY	BUCKET	% FILLED	ADJUSTED	DAY	WORKING DAY PRODUCTION
6.8	0.75	78.5	4.01	8	32.08
units / hour	SIZE	Average	PRODUCTIVITY	HOURS	Cubic Yards

VITA

Dwight Anthony Allen was born in Kingston, Tennessee on December 27, 1970. He and his family moved to neighboring Rockwood, Tennessee where he attended schools in the Roane County Public School System. He attended Rockwood High where he graduated Valedictorian of his class in June 1989. He entered the School of Architecture at the University of Tennessee in the fall of 1989 where he received his Bachelor of Architecture in May 1994. It was during his architecture education that he was inspired by the example of Dr. Stan Rabun, who possessed degrees in Architecture and Engineering. He entered the College of Engineering in the fall of 1994 where he obtained his Masters of Science in May 1998. While pursuing his Master's he was a Teaching Assistant to Dr. Stan Rabun at the School of Architecture for three semesters, and spent two years as a Research Assistant in the College of Engineering conducting research on behalf of the Tennessee Department of Transportation.

He is presently pursuing a diverse career path featuring structural design, construction management, and architecture.