ESTMATION MODELS FOR PRODUCTION RATES OF HIGHWAY CONSTRUCTION ACTIVITIES

By

ASREGEDEW KASSA WOLDESENBET

Bachelor of Science in Civil Engineering

Bahir Dar University

Bahir Dar, Ethiopia

2005

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
May, 2010

ESTMATION MODELS FOR PRODUCTION RATES OF

HIGHWAY CONSTRUCTION ACTIVITIES

Thesis Committee:

Dr. Hyunseok (David) Jeong

Thesis Adviser

Dr. Garold Oberlender

Dr. Rifat Bulut

Dr. A. Gordon Emslie

Dean of the Graduate College

ACKNOWLEDGEMENTS

I would like to express my deepest appreciation to my advisor, Dr. Hyunseok (David) Jeong for all of his invaluable support, dedication and guidance throughout the completion of this study. I would also like to thank my committee members, Dr. Garold Oberlender and Dr. Rifat Bulut for their support in this research.

I would also like to thank ODOT engineer Mr. Phil Loafman, Division 4 residencies and ODOT database management team especially Ms Ann Wilson for sharing their experience and support in extracting ODOT's construction data. I would like to extend my gratitude to my parents as I would not be standing where I am today without their unconditional love and support.

TABLE OF CONTENTS

Chapter Page

LIST OF TABLES

Table Page

CHAPTER VII

LIST OF FIGURES

Table Page

CHAPTER V

CHAPTER VI

CHAPTER VII

CHAPTER 1

INTRODUCTION

1.1 Introduction:

Production rates of highway construction activities are an important issue in the construction industry. Highway construction productivity is vital to both State Department of Transportations' (DOT) and participants in the construction industry. Research conducted on the process of estimating construction time of highway projects shows that production rates of highway construction activities greatly affect the determination of contract time of highway projects. Production rate prediction prior to actual commencement of operations is an important task that planners or managers in construction have made a top priority from the viewpoint of management (Capachi 1987 and Schaufelberger 1999).

Realistic production rates are the key in determining reasonable contract times (Herbsman and Ellis, 1995). The most reliable production rates of highway activities will approach to the reality in determining the most probable construction duration. A good estimate increases management's efficiency, reduce delays in completion of a project on time, minimize claims & disputes, reduces traffic inconvenience to the public, and lowers the overall project cost. Excessive contract time is costly, extends the construction crew's exposure to traffic, prolongs the inconvenience to the public (unnecessary increase of road user costs), and subjects motorists to less than desirable safety conditions for longer periods of time. In contrast, insufficient contract time results in higher bids, overrun of contract time, increased claims, substandard performance, and safety issues. Therefore an accurate forecast of production rates of construction highway activities is crucial to contract administration as the predicted duration and associated cost form a basis for budgeting, planning, monitoring, and even litigation purposes.

1.2 Problem Statement:

The Oklahoma Department of Transportation (ODOT) has a production rate chart which ODOT engineers and schedulers use in planning and scheduling of new highway projects as well as rehabilitation projects. This production rate chart was developed based on ODOT engineers' experience and judgments. But currently no one in ODOT can verify the accuracy of this chart and it has not been updated for more than 15 years. In addition, these production rates are not adjustable for different site conditions and project factors. Highway construction productivity has improved through the years with the development and application of new technologies in construction methods, equipment, materials and management (Jiang & Wu, 2007). Therefore there is a need to develop a system to update the ODOT's production rate chart for estimating reasonably accurate production rates of controlling highway activities.

1.3 Research Objectives:

The ultimate goal of this study is to help ODOT engineers efficiently and effectively plan, execute, and manage highway projects in the context of project contract time determination by developing models to estimate reasonably accurate production rates for controlling activities of highway projects. The objectives of this study include:

a. Identification of critical factors affecting highway construction production rates and assessing the relationship of these factors with controlling highway activities,
b. Development of production rate prediction models for selected controlling highway activities and
c. Development of a standalone software program which will be expandable in the future.

1.4 Research Methodology:

The study has selected seven tasks to accomplish the objectives of the research. These include: a) Literature Review, b) Meetings & Interviews, c) Historical Data Collection, d) Survey of Experienced Engineers, e) Analysis of Collected Data, f) Development of Productivity Estimation Models, and g) Development of a Standalone Program. The above work tasks are summarized into three basic stages as shown in Figure 1.1.

The first stage of the methodology focuses on identifying controlling highway activities, studying current approaches practiced by State DOTs and selecting ongoing and recently completed highway projects through literature reviews and meetings with ODOT engineers and contractors. The second stage involves collecting production rate data and identifying critical factors by employing Daily Work Reports (DWR) and questionnaire surveys. In addition, the factors obtained from the study are statistically analyzed to determine the significance on production rates of controlling highway activities. Based on the first two stages, production rate prediction models and a standalone software program are developed in the final stage.

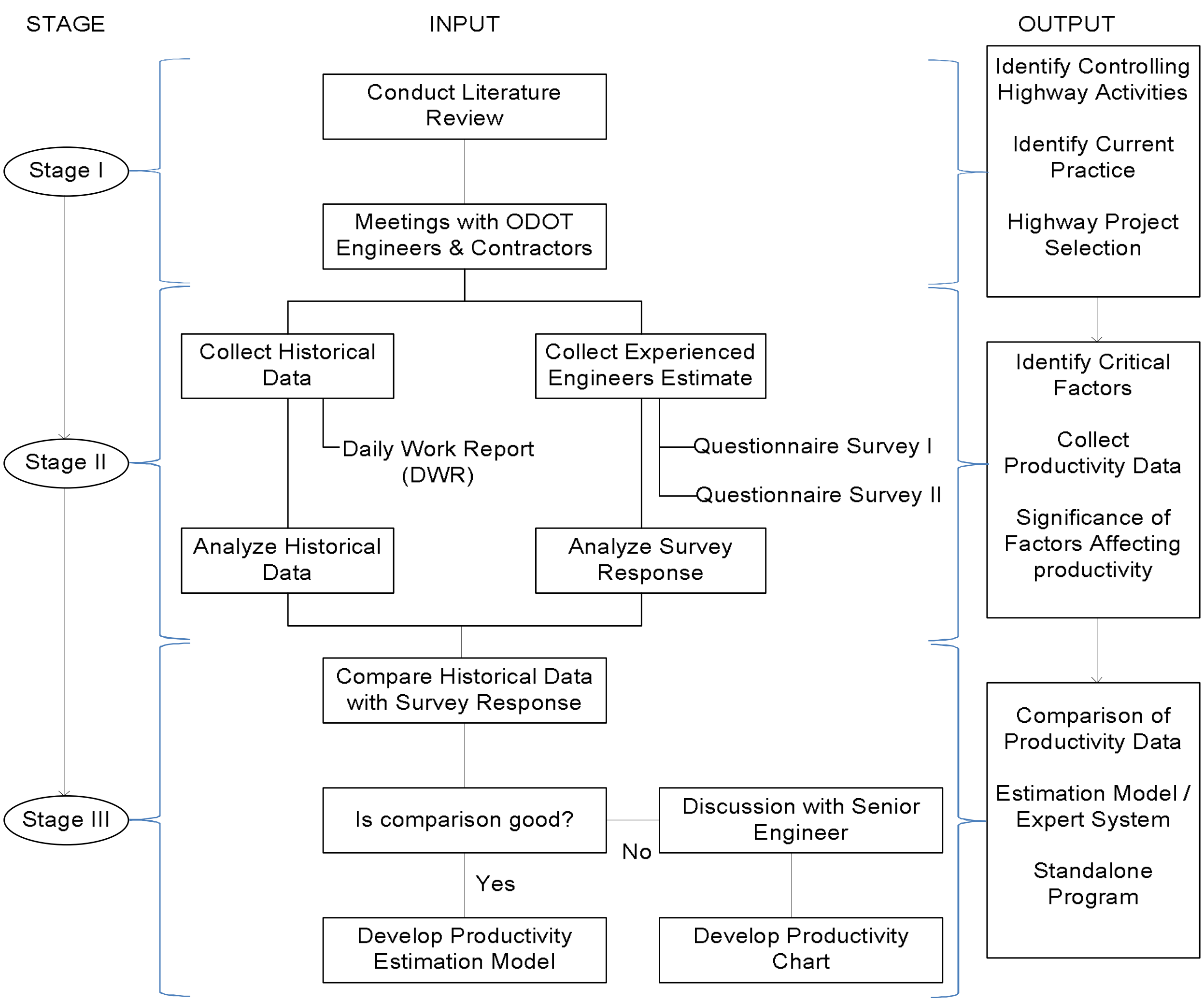


Figure 1.1 Methodology Flow Chart

1.4.1 Literature Review:

The literature review helps in assessing prior research works and relative studies conducted on highway construction production rates. It focuses on reviewing current approaches used by various researchers and DOTs in the determination of production rates of highway construction activities and factors affecting their productivity.

1.4.2 Meetings & Interviews:

A series of meetings & interviews with senior ODOT engineers, residencies, and contractors are conducted to collect appropriate data, select highway construction projects, and identify controlling highway activities and factors affecting production rates.

1.4.3 Historical Highway Project Data:

Once the controlling highway activities and factors are identified, collection of production rate data of these activities is made through selected highway projects from previously completed highway projects (historical records). Major factors affecting the production rates of specific controlling activities and their durations are gathered from Daily Work Reports (DWR).

1.4.4 Survey of Experienced Engineers:

Historical data collection may not be sufficient, or may lack some information, to identify factors affecting production rates and their degree of impact. Therefore, two set of questionnaire surveys with highly experienced engineers are conducted to capture their accumulated knowledge and experience on productivity of controlling highway activities. The first questionnaire survey is used to identify and rank critical factors affecting productivity. The second survey is used to extract production rate data and compare different perspectives of contractors and residencies.

1.4.5 Analysis of Collected Data:

Based on the collected data from historical records, data analysis is conducted using statistical methods. The statistical analysis assesses the relationship between factors affecting productivity and controlling highway activities. It identifies the statistical significance of factors and their degree of impact on production rates of controlling highway activities.

1.4.6 Development of Productivity Estimation Model:

The outputs of the previous tasks are used to develop prediction models to estimate approximate and reasonable production rates of controlling highway activities. Different controlling activities may have different factors and their degrees of impact are different. Thus a set of production rate estimation models is developed. Statistical prediction models are developed for controlling activities with a significant number of data. Prediction models based on subjective data from the survey are developed for other controlling activities.

1.4.7 Development of a Standalone Program

Based on the estimation models, a standalone software program is developed for estimating production rates of controlling highway activities. A Microsoft Excel Visual Basic is used to develop the program. A reasonable range of production rates for controlling activities can be estimated by using the developed program. Finally, an evaluation of the software is conducted for validating the program.

1.5 Thesis Organization:

Prior studies conducted on production rates of highway construction activities are summarized in Chapter II of Literature Review. Chapter III discusses the collection of production rate data from two sources: Daily Work Report (DWR) and Experienced Engineers survey. Chapter IV discusses the descriptive analysis based on the data collected from DWR. The experienced engineers survey results and analysis are summarized in chapter V. Chapter VI illustrates the development of production rate estimation models. Chapter VII demonstrates the standalone software program and its evaluation results. The final chapter summarizes the research and recommends future study in this area.

CHAPTER II

REVIEW OF LITERATURE

Prior studies conducted in the determination of production rates indicate that highway construction production rates are influenced by a wide variety of factors such as weather, location, soil condition, material delivery, crew size, etc. The variety and complexity of these factors would create difficulties in determining a reasonable production rate. Therefore there is a need to investigate what factors are critically affecting the production rates of activities by how much. This chapter discusses the current practice of State DOTs, prior research works and relative studies conducted in determining these factors and estimating production rates of highway construction activities.

2.1 Definition of Production Rate

Production rate is defined as the number of units of work accomplished or produced over a specific period of time (FHWA, 1991). The Federal Highway Administration (FHWA) Guide suggests dividing the total quantity of an item on previously completed projects by the number of days/hours the contractor used to complete the item as one method of establishing production rates (Equation 2.1).

Production rates can actually be established from site visits, review of project records (field diaries), detailed survey of engineers' experience and judgments, or use of cost estimating manuals such as RS Means Cost Guide or Richardson's Manual. Bellanca et al. (1981) recommends that a construction data file that covers the previous 3 to 5 years should be used in determining production rates and contract time.

$$\Pr oductionRate = \frac{Total\, estimated\, quantity\, of\,\, the\, activity}{ActivityDuration} \qquad (Eq.\ 2.1.)$$

2.2 FHWA Guide

FHWA Guide for Construction Contract Time Determination Procedures (1991) states that estimating realistic production rates is important when determining appropriate contract completion time. It further states that production rates may vary considerably depending on project size, geographic location, and rural or urban setting, even for the same item of work. Therefore, the FHWA has put the following guidelines in establishing production rates,

a. Production rate changes should be established in the State's written procedures based on project type (grading, structure, etc), size and location for controlling items of work.
b. An accurate database should be established by using normal historical rates of efficient contractors to estimate production rates for determining contract time. FHWA recommends that production rates should be based upon eight-hour crew days or per piece of equipment. Production rates developed by reviewing total quantities and total time are not recommended as they may result in misleading

rates which tend to be low since they may include startup, cleanup, interruptions, etc.

c. The most accurate data will be obtained from site visits or review of project records (i.e. field diaries and other construction documents) where the contractor's progress is clearly documented based on work effort, including work crew make up, during a particular time frame. Therefore a data file based on three to five years of historical data (time, weather, production rates, etc) should be maintained.
d. The production rates used should be based on the desired level of resource commitment (labor, equipment, etc) given the physical limitations of the project. These production rates should be regularly updated to assure that they accurately represent the statistical average rate of production in the area.
e. Finally, production rate taken from published rate guides may be used as guidance as the relationship of these production rates to actual highway construction projects may be difficult to correlate.

2.3 Prior Studies on Production Rate Estimation

Recent studies reveal that actual production rates of highway construction activities from the field are influenced by a wide variety of factors. Sonmez (1996) listed 23 factors under three categories: management related, project related and labor related. Thomas and his colleagues (1989) suggested 42 factors summarized under three categories: within-project, project-to-project and regional. Hebsman and Ellis (1995) recognized 17 factors that affect the overall construction duration of a transportation facility project.

These factors include weather and seasonal effects, location of a project, traffic impacts, relocation of construction utilities, type of project, letting time, special items, night and weekend work, dominant activities, environmental, material delivery time, conflicting construction operation, permits, waiting and delay time, budget and contract payment control and legal aspects. Though these factors may vary from project to project, these are some of the many factors encountered in our day to day construction activity. A summary of the critical factors identified from these prior studies along with the type of construction considered is shown in Table 2.1.

Table 2.1 Summary of Critical Factors Identified from Prior Studies

Factors	Jiang & Wu (2007)	Chang (2005)	O'Connor & Huh (2005)	Smith (1999)	Chao & Skibniewski (1994)	AbouRizk & Colleagues (2001)	Pan (2005)	Christian & Hachey (1992)	El-Rayes & Moselhi (2001)
a. Location	X	X			X	X			
b. Capacity of Contractors	X								
c. Weather	X			X	X	X	X	X	
d. Traffic Condition		X							X
e. Soil Type		X		X	X	X	X	X	
f. Quantity & Size of Work		X	X						
g. Operating Condition				X	X	X			
h. Material Delivery									X
i. Hauling Constraints									X
j. Construction Methods								X	X
Type of Construction	Pavement Bridge Earthwork	Pavement Earthwork	Bridge	Earthwork	Earthwork	Pipe Installation	Pavement Earthwork	Pavement Earthwork	Removal

For instance, Jiang & Wu (2007) has taken into account pavement, bridge components and earthwork construction activities for their study. And the study has identified location, capacity of contractors and weather as critical factors affecting these activities. Based on the studies conducted, a relative percentage comparison is made between critical factors by summing up the number of occurrences of each critical factor in Table 2.1 and dividing it to the total identified factors in the overall studies. A relative comparison of these factors identified from prior studies is shown in Figure 2.1.

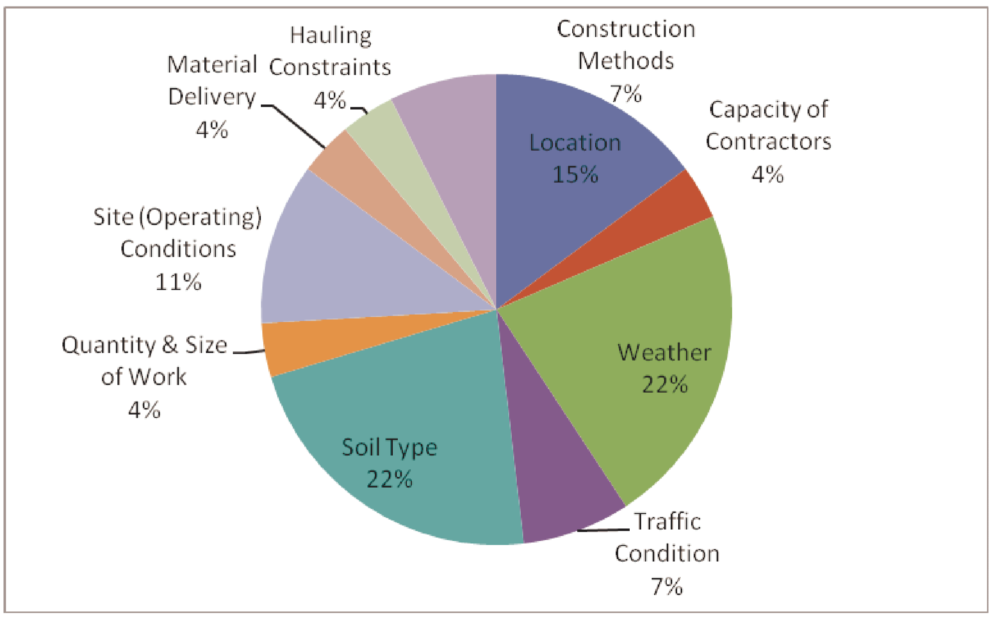


Figure 2.1 Factors Affecting Productivity of Highway Projects

The results show that location (15%), weather condition (22%) and soil types (22%) are the most significant factors affecting highway construction activities. It also indicates earthwork and pavement construction as controlling components of highway constructions. It is also noticed that 67% of these studies focused on earthwork construction while more than 40% considered pavement construction for their research works.

Numerous researchers have tried to correlate these factors with the construction activities and have implemented several scientific methods in determining production rates of these activities. Based on the analytical and prediction methods used, the studies were classified into four basic approaches. These include statistical approach, neural network, fuzzy theory and historical data. The next sub-sections summarize prior research under each category.

2.3.1 Statistical Approach

The statistical analysis is the most widely used approach in analyzing collected data in determining production rates of highway construction activities. Statistical methods include linear and non linear regression analysis, frequency plot, ANOVA, t-tests and multiple regressions modeling which are used to determine & quantify the relationship between production rate and drivers in developing a model for highway construction activities or pay items.

Jiang & Wu (2007) analyzed and updated Indiana Department of Transportation’s (INDOT) highway construction productivities which were not updated for more than ten years based on completed highway projects in Indiana. The study used INDOT’s Construction Daily Reports as their primary source of productivity which stored a data of 1818 highway construction projects between 1995 and 2002.

The study first determined a statistical distribution by selecting a possible model from a frequency distribution plot using the available data. Then the estimations of the key distribution model parameters were calculated and the goodness-of-fit was tested using chi-square to test whether the model was appropriate for the given data. Based on the study, three frequency distributions represented INDOT's highway production rates: exponential distribution, normal distribution and lognormal distribution, with the majority of the production rates falling in the normal distribution.

Jiang & Wu (2007) considered four categories of highway construction in their study; roadways, bridges, excavations & removals of construction activities. The mean production rates of these selected activities were computed based on production quantity per eight-hour of continuous operation of a regular calendar day. In addition production rates under ideal construction conditions (baseline production rates) were calculated based on Thomas and Zavrski (1999) description.

The new production rates showed an increase in highway construction productivity. Based on INDOT's analysis construction firms/contractors, construction project location and weather condition were identified as major factors affecting production rate. The study also showed the effects of these factors on highway construction production rates. Although this research greatly adds to the accuracy of estimating highway production rates, a productivity estimation model which encompasses all the aforementioned factors was not developed.

Chang (2005) developed a system called Highway Production Rate Information System (HyPRIS) for determining production rates of highway activities for Texas Department of Transportation (TxDOT). The study focused on two areas of highway construction production estimation: earthwork and pavement. The critical construction activities were first identified from a questionnaire survey. These include drilled shaft foundations, pre-cast concrete piling foundations, pre-cast concrete box culverts, cast-in-place concrete box culverts, cast-in-place concrete box culverts, pre-cast reinforced concrete pipes, headwalls and wing walls, inlets & manholes and mechanized stabilized earth wall.

Data were collected from selected ongoing Texas Highway projects. A total of sixty-three projects which were between 15 percent and 85 percent complete & had contract periods between 145 days to six years were selected across seven TxDOT districts. These data were recorded from weekly site visits of field operations which included foremen's diaries; data input systems and short term memories of foremen and project managers which are supported by data forms for tracking production rates and identified factors.

Then the collected data were analyzed using t-tests, ANOVA, linear and nonlinear regressions. From the analysis production rate models were developed for the selected nine work items. Further, the impacts of construction delays and disruption were quantified and a production rate adjustment model was developed. Finally a user friendly production rate information system, HyPRIS was developed.

The major factors that were identified from the study include location, traffic condition complexity, soil condition and quantity of work. The study further divided the factors into project, work item and work zone levels. Project level factors are factors that are generally considered to have an effect on productivity owing to the nature of the project while work zone level factors include factors that are related to the conditions of the work zone. Work item level factors refer to work item (activity) specific factors.

Tables 2.2, 2.3 and 2.4 show factors found from literature that have been used for the study at work zone level, project level and work item level respectively.

Table 2.2 Proposed Work Zone Level Factors (Chang, 2005)

Factors from Literature	Proposed Factors
Site conditions	Work Zone Accessibility
	Work Zone Construction Congestion
Weather/Soil and site conditions	Work Zone Site Drainage Effectiveness
Soil Conditions	Clay Content of Soil
	Land Slope
	Water Table Depth

Table 2.3 Proposed Project Level Factors (Chang, 2005)

Factors from Literature	Proposed Factors
Construction Type	Project Type
Location	Location
Traffic Conditions	Traffic Flow
	Traffic Count
Rain	Weather (Precipitation)
Other weather impact	Weather (Winter Length)
Learning Curves	% of Construction Completion
Project Size	Contract Amount
Project Complexity	Technical Complexity
Nature of Contract	Contractual Drivers
	Soil Types
	Clay Content of Site
	Land Slope of Site
	Soil/Site conditions
	Water Table Depth of Site
Technology	Scheduling Technique used
Management	Contract Administration System
	Contractor Management Skill
Workers' related productivity	Work Schedule (Days/week)
	Work Schedule (Hours/day)

Table 2.4 Proposed Work Item Level Factors (Chang, 2005)

Factors from Literature	Proposed Factors
Crew Size	Workmen Size
	Equipment Size
	Crew Size
Weather and other disruptions	Weather
	Equipment breakdown
	Utility Conflict
	Construction Accident
	Incomplete Crew Size
Size of operations/learning curves	Work Zone/Item Quantity
Types of construction	Orientation
	Materials/Types
Soil and other disruptions	Soil Type
Site Conditions	Location conditions

The study quantitatively analyzed the factors that would create uncertainty and non-linear relationship in predicting realistic production rates. Based on the statistical tools, the study resulted in a range of production rates for the nine critical activities with an option of multiple regression formula in estimating production rate.

A similar study was conducted by O'Connor and Huh (2005) on crew production rates for estimating contract time. The critical work items that were selected by the research team included bent footing, column (rectangular & round) and cap of highway bridges. A data collection tool was developed to acquire 93 data points from 25 ongoing highway projects across six districts in the State of Texas. The data collection tool consisted of data forms for tracking production rates. These forms were organized at three levels: project level; work zone level; and work item level. The work zone level forms included the work item sheet which was used for specifying scope of each work item. The work item sheet contained a list of work item specific factors which may affect production rate of each work item. A pilot data collection was then conducted to validate the effectiveness of measurement systems and possible improvements to the data collection methodology.

The study used influence diagrams in identifying possible factors affecting the selected critical work items. The factors were then refined through the application of statistical tools based on the collected data. Scatter plots were visually inspected for identifying the critical factors. Then analysis of variance (ANOVA) and simple regression analyses were employed to test the statistical significance of their relationships with the respective work item production rates. From the statistical analysis the critical factors found for each work item included the following;

a. Footing: footing size (m3/ea), excavation depth (m), number of footings per bent;
b. Column-rectangle: column size (m3/ea), column height (m), number of columns per bent;
c. Column-round: column height (m), column diameter (m), number of columns per bent; &
d. Cap: cap size (m3/ea), cap length (m), shape of cap (rectangle: inverted T).

Crew production rates for each critical work item were calculated and adjusted for delays and crew size. This study would approach to a more realistic production rates if a prediction model such as multiple regression model had been developed that quantifies the critical factors. O’Connor and Huh have conducted a second study in 2006 on three other work items; beam erection, bridge deck and bridge rail for determining crew production rates for contract time estimation. But due to the insufficient data points, both studies could not develop prediction models.

Smith (1999) performed a linear regression technique for estimating earthmoving productivity. The earthmoving operation was taken to be a unique activity of loading, hauling, dumping, returning, and queuing; each operation with varying combinations of plant types and quantity, material types, operating conditions, weather, time of year, etc. The study investigated on data collected from 140 separate earthmoving operations taken from four different highway construction projects in the U.K.

A stepwise multiple regression technique was used in analyzing these collected data. The analysis showed two results; actual productivity when fitted to the collected data resulted in adequate regression equation and bunch factor didn't fit to the data which led to a conclusion that the bunch factor is a function of many more explanatory variables such as type of plant, the age, servicing history and payload which is difficult to monitor and record. The bunch factor is an indication of how efficient the earthmoving operation is in terms of the variability of the plant working rates. Although the model was designed to work for one loader and was overestimating productivity for operations that are over- or under resourced, the study indicated that there is a strong relationship between operating conditions and production rates.

2.3.2 Neural-Network Approach

Chao & Skibniewski (1994) presented a Neutral-Network-Based Approach in estimating construction productivity. The study experimented on how neural networks can be used to model the complex relationships between the job conditions and the productivity of an activity. The researchers used an excavation-hauling operation for demonstrating their approach. They first listed out the factors that affect the cycle time to excavate and haul a quantity of soil. Then they broke down the problems for establishing a relationship between cycle time & physical job conditions and excavator efficiency & operation attributes. An experimental excavation was devised to train the neutral network using a desktop robot. The trained neutral network was tested and resulted in a sufficient accuracy level. The study also showed the potential for applying neural networks in predicting construction productivity, but real-job data was recommended to further validate the methodology.

AbouRizk, Knowles & Hermann (2001) conducted a study on estimating labor production rates for industrial construction activities such as welding and pipe installation. Their approach was based on artificial neural networks that would enable an estimator to predict a reliable labor production rate (labor/unit) for the construction activities. The study first identified the factors affecting labor production rates for the purpose of defining input to the neural networks. The study has identified thirty-three factors categorized under nine groups: project characteristics, site characteristics, labor characteristics, equipment characteristics, overall project difficulty, general activity characteristics, activity quantities, activity design, and activity difficulty. Of all these factors activity design and project characteristics were found to be the most significant ones.

Then the neural network was utilized on a two-stage process for predicting an efficiency multiplier that the estimator can use to adjust the average productivity. The productivity output was in the form of a histogram reflecting the likelihood of the production rate rather than a single production rate. The study indicated an improvement in the quality of predicting production rates compared to utilizing a simple back-propagation network.

The greatest advantage of using neural networks in predicting construction productivity is that it can perform complex mapping of environmental and management factors during productivity estimation (Chao & Skibniewski, 1994). But the size and quality of available data usually limit the effectiveness of the neural network approach. In addition the practical application of neural networks is limited for actual construction activities.

2.3.3 Fuzzy set approach

Pan (2005) assessed the impact of rain on highway construction activities. He presented a model that utilizes historical rainfall data and experts knowledge and employs the fuzzy set concept for assessing the impact of rain on project completion. The study showed how rainfall has a direct and an indirect impact on activity production. The direct impact is attributed to the day of raining while the indirect impact is attributed to the inability of construction personnel to work, the difficulty in operating machinery and inability to use construction material due to much absorbed water. Rainfall levels, soil drainage conditions, exposure levels of an activity, and work situations were accounted in presenting a model that analyzed the impact of rain. The model employed a rule-based knowledge, fuzzy set theory and Mamdani's fuzzy reasoning method.

Based on the proposed model a system called FRESS was developed that is capable of assessing the impact of rainfall on productivity loss and duration of highway construction activities. The study indicated that the system would simulate experts' judgment and allows contractors unfamiliar with the rainfall pattern in a certain location to better estimate activity duration and project completion. Smith and Hancher (1989) also presented a fuzzy set-based model implemented with Markov Chain process to predict rain states (dry or wet) for estimating the impact of rain on construction productivity.

2.3.4 Historical Records

The construction industry participants have used and are still using historical records as their primary source in predicting highway construction production rates. These records include historical data of three to fifteen years of completed and ongoing highway projects. A well organized record of these completed projects provides information in estimating reliable production rates. This information starts from project level data to factors encountered during construction of the project such as: project location; job-site conditions; rainfall data; weather conditions such as air temperature, humidity, contractors' productivity and other productivity related information. These data can be found from records kept by contractors, project managers, or clients' construction daily reports which are stored mostly as a database in State DOTs.

A survey conducted by Christian & Hachey (1992) on participants of the construction industry reveals that previous job records are one of the reliable sources of information in estimating production rates of highway activities. Figure 2.2 shows the result of the survey regarding methods used to predict production rates.

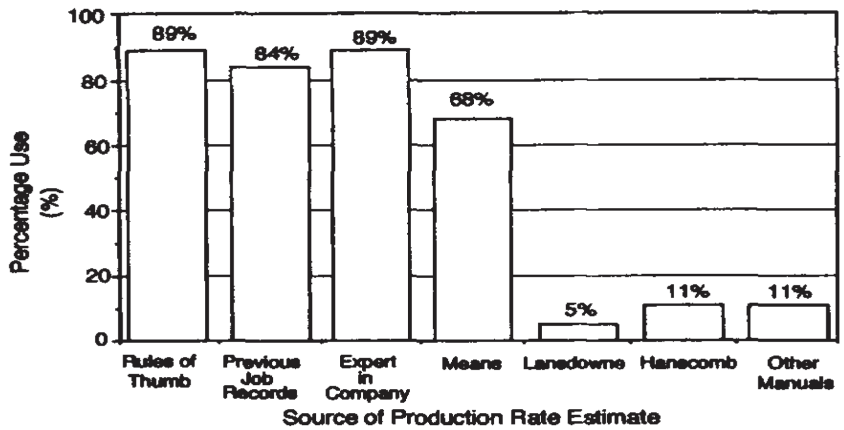


Figure 2.2: Sources of Information when Estimating Production Rates (Christian & Hachey 1992)

A similar survey conducted that same year by Hancher et al (1992) on thirty six State DOTs showed that 44% relied on personal experience, 30% on standard production rates and 22% relied on previous job records. The results of the surveys imply how the unique work requirements and the influence of different factors on construction projects make prediction of highway construction production rates challenging.

The main limitation in using experienced engineers estimate is that contractors might not reveal their records for the purpose of bidding while historical records might miss important information regarding factors affecting construction activity in recording data.

2.3.5 Other Studies

Christian and Hachey (1992) developed an expert system to assist in the acquisition and evaluation of knowledge and data for the estimation of production rates. The study selected factors that can be fairly easily identified and modified and can lead to significant improvements in production rates. The effect of idle and waiting times which create delays in construction activities has been shown by the variation in production rates used by contractors' estimators with actual on-site production rates. Based on a series of interviews with site personnel, supervisors, experts, field data collection and questionnaire surveys a prototype expert system was developed using the Personal Consultant Plus shell program. It was developed to handle and store the knowledge and data from all of the sources of intelligence, and create a decision support system that would enable a user in estimating probable production rates through question and answer routine.

El-Rayes and Moselhi (2001) developed a decision support system called WEATHER that quantifies the impact of rainfall on productivity and duration of highway construction operations. The system incorporates a knowledgebase acquired from experts which identifies daily productivity losses in highway construction operations due to rainfall and a database which contained hourly records of rain, temperature, humidity, wind speed and sunshine over a number of historical years. The system showed a positive result when compared with common practices utilized by contractors and Ministry of Transportation.

The types of construction operations that were considered in the study included earthmoving operation, construction of base courses, construction of drainage layers and paving. The study showed how rainfall resulted in delays to highway construction due to saturated and unworkable soil conditions. It also indicated that productivity losses for highway construction operations may vary significantly due to the specific nature of construction and sensitivity of the rainfall. The amounts of rainfall, the timing of rainfall, soil type & condition, efficiency of drainage system, weather condition after rainfall were identified to have a great impact on productivity losses. The study concluded that rainfall-related productivity losses are affected by three factors: type of construction, intensity of rainfall and drying condition of the soil.

Lee and Ibbs (2007) conducted case studies on productivity aspects of urban freeway rehabilitation utilizing an accelerated construction approach. Their study was to monitor and compare the production rates of five major rehabilitation operations (concrete slab demolition, roadway excavation, base placement, AC paving and concrete paving) which was implemented at three experimental projects in California. Based on the study, a higher production rates was observed on full-width rehabilitation rather than partial-width rehabilitation; continuous lane reconstruction was more productive compared with random slab replacements; full roadbed closures were more productive and less inconvenient to the public compared with partial lane closures.

The study suggested evaluating project-specific conditions and constraints (such as traffic volume, pavement condition, resource and budget availabilities, etc) that might restrict use of a preferred rehabilitation scheme, by taking production rate variances into account when establishing schedule baselines of construction staging plans and incentive/disincentive contracts for urban freeway rehabilitation projects. Further the analysis showed that contractors' production rates varied considerably depending upon the construction logistics, material delivery and hauling methods, lane closure tactics, and/or pavement designs being implemented. Among these factors the study concluded that material delivery and hauling constraints have a larger impact on production rates.

A similar study conducted by Hinze and Carlisle (1990) evaluated factors related to the productivity of night-time rehabilitation and maintenance activities on major urban highways. The study indicated that night-time productivity is affected by traffic volume, type of work, material delivery, lighting supervision, communication, and worker morale.

Overall, these studies revealed that different construction activities are affected by a wide variety of factors. These factors include weather and seasonal effects, location of a project, traffic impacts, relocation of construction utilities, type of project, letting time, special items, night and weekend work, dominant activities, environmental, material delivery time, conflicting construction operation, permits, waiting and delay time, budget and contract payment control and legal aspects.

Table 2.5 Scientific Tools used in Studying Production Rate of Highway Activities

Approach/ Methodology	Year			
	Late 1970's	1980's	1990's	> 2000
Statistical Methods	*	*	*	*
Neural Networks			*	*
Fuzzy Set Approach				*
Others (Simulation, Expert System....…)		*	*	*

The previous studies also show how various researchers tried to correlate these factors with highway construction activities and had implemented several scientific tools in determining production rates of these activities. Of all the scientific tools or approaches used in determining production rates, statistical methods are the most widely used and consistent approach compared to the others in determining production rates of highway construction activities. In addition, statistical methods are more practical and applicable in the construction industries. Although simulation and other scientific approaches have been used since the 80’s, their application has been limited to cyclic construction activities and work tasks. Table 2.5 briefly summarizes these scientific tools or approaches used in determining production rates during the past five decades.

Chapter 3

DATA COLLECTION

This study implements statistical methods of historical recorded data of previously completed projects as its primary sources with the addition of experienced engineers estimate in predicting production rates of controlling highway activities and updating ODOT's production rate chart. This Chapter discusses the data collection process. Data is collected using three methods: a) Meetings & Interviews, b) Historical Highway Project Data, and c) Survey of Experienced Engineers. Figure 3.1 illustrates the data collection process.

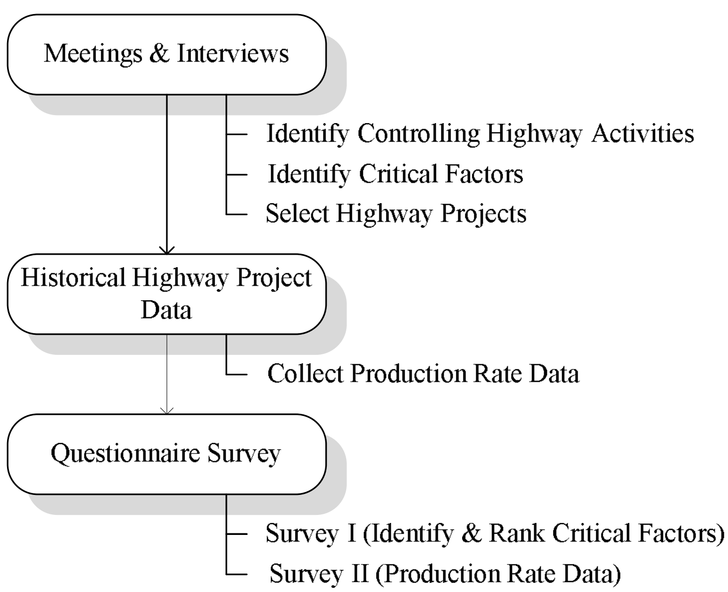


Figure 3.1 Data Collection Methodology

3.1 Meetings & Interviews

A series of meetings & interviews was conducted with highly experienced ODOT engineers, residencies and selected contractors working across Oklahoma. The primary aim of these meetings and interviews is to capture their accumulated knowledge and experience on controlling highway activities and their drivers. It also helped in identifying controlling highway activities and factors affecting their production rates, selecting highway construction projects, and finding appropriate data collection methods.

3.1.1 Pay Item Selection

ODOT has a list of pay-items retained in its website under the Office Engineer Division section of contracts and proposals (http://www.okladot.state.ok.us/). ODOT has compiled a production rate chart of 82 pay-items Based on rigorous meetings and interviews, three main components were determined to be critical highway projects; a) earthwork, b) bridge, and c) pavement. Controlling highway activities in these three components were selected as they are likely to fall in the critical path of a project schedule and have a huge impact on project planning and scheduling. They would mostly govern the overall contract time of highway construction projects. Of these controlling components, 8 controlling highway activities were selected from ODOT's pay-item list for this study. Table 3.1 lists these pay-items.

Table 3.1 Major Controlling Highway Activities

ITEM NO.	PAY-ITEM DESCRIPTION	UNIT
202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY
202(C) 0184	UNCLASSIFIED BORROW, RDY	CY
303 0192	AGGREGATE BASE, RDY	CY
414(A1) 5755	10" P.C. DOWEL JOINTED CONCRETE PAVEMENT , RDY	SY
326(E) 4240	(SP) CEMENTETIOUS STABILIZED SUBGRADE, RDY	SY
511(B) 6010	EPOXY COATED REINFORCING STEEL	LB
411(S3) 5945	(SP)ASPHALT CONCRETE TYPE S3	TON
619(B) 4727	REMOVAL OF CONCRETE PAVEMENT	SY

3.1.2 Project Selection

ODOT classifies highway projects into three different categories as Tier I, II & III based on the scope and complexity of a project. This study selected Tier II projects for historical project data collection. The scope of Tier II projects lies in between the complexity of Tier I and the simplicity of Tier III. The work involves traffic control, construction phases, congestion etc, in interstates, state highways and other major roads. Tier II projects are further classified into eight divisions; Reconstruct Existing Alignment/Rural Interchange, Widen/Reconstruct Existing Alignment, Reconstruct City Street, Construct Bridges and Approaches, Construct Bridge Box Approaches, Intersection Modification, Bridge Rehabilitation/Repair, and Roadway Repair/Overlay.

3.2 Historical Project Data Collection

The FHWA Guide for Construction Contract Time Determination Procedures states that in establishing production rates to be used for determining contract time, an accurate database should be established by using normal historical rates of efficient contractors. It further states that the most accurate data can be obtained from site visits or review of project records (i.e. field diaries and other construction documents) where the contractor's progress is clearly documented based on work effort, including work crew makeup, during a particular time frame. Therefore historical records of previously completed projects are used as a primary source in the determination of production rates.

Information on highway construction projects is stored electronically in ODOT contract administration software called SITEMANAGER. The software contains a database of 1,374 previously completed and ongoing construction projects since 2002. The database also includes daily work reports of highway construction projects along with information such as project descriptions, construction pay items, project magnitudes, weather condition, temperature, and reported quantity. The daily work reports (DWR) were selected to be utilized in our historical data collection process.

The DWRs were reviewed line by line to determine the quantity of work and durations for the selected controlling highway activities. Average temperatures were also recorded for the specified time period. Annual average daily traffic (AADT) and other inventory data for the respective projects were obtained from ODOT's planning and research division. In addition, soil data was collected from ODOT's Material Division. It is important to note that a) information regarding factors affecting construction activities might be missed while recording the data and b) the data collection is an extensive time consuming process. Figure 3.2 summarizes the overall data collection process. A sample data collection excel sheet is attached in Appendix A.

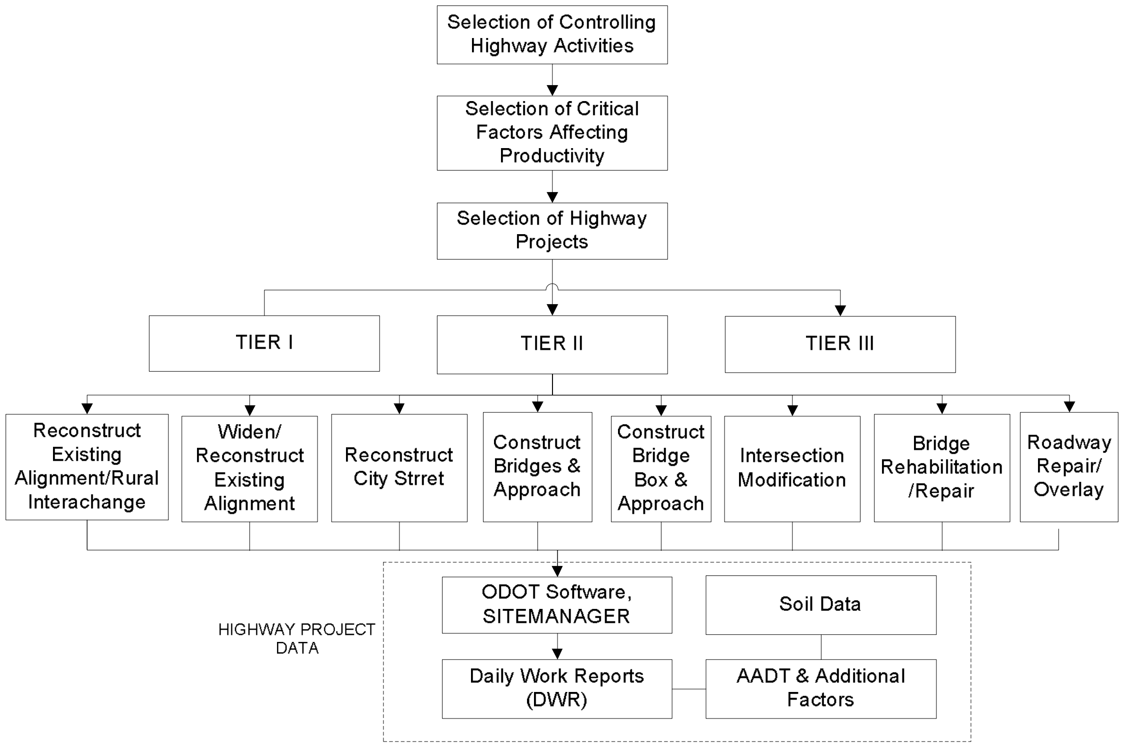


Figure 3.2 Data Collection Process

3.3 Survey of Experienced Engineers

Actual production rates in the field depend on many factors such as weather, topography, project size, soil conditions, etc. For most of the time, the actual impact of these factors on the production rates is very difficult to be accurately forecasted. A survey conducted by Hancher et al (1992) on thirty six State DOTs showed that 44% relied on personal experience, 30% on standard production rates and 22% relied on previous job records. The results of the survey imply how the unique work requirements and the influence of different factors on construction projects make prediction of highway construction production rates challenging.

In addition, historical data collection may not be sufficient or miss important information regarding factors affecting construction activities and their degree of impact while recording data. Therefore questionnaire surveys of highly experienced engineers were conducted to capture their accumulated knowledge and experience on controlling activities. Two sets of questionnaire surveys were conducted in this study.

3.3.1 Survey I

The first questionnaire survey was used to identify and rank critical factors affecting productivity. Based on literature review and meetings with ODOT engineers, a set of critical factors was selected for each controlling highway activity. Then a group of research team which includes two senior resident engineers and two representative contractors were organized to identify and rank these critical factors. The first questionnaire survey is attached in Appendix B.

3.3.2 Survey II

Based on the discussions with the research team and results from survey I, a second questionnaire survey was prepared. This second survey was used to extract experienced engineers' valuable estimate of production rates for the selected controlling highway activities. The main limitation in using experienced engineers' estimate is that contractors might not reveal their records for the purpose of bidding. Therefore the survey involved two parties; contractors and residencies, to compare highway productivity from two different stakeholders. The second questionnaire survey is attached in Appendix C.

Chapter 4

DESCRIPTIVE ANALYSIS

This Chapter discusses tools and procedures employed to analyze the collected data in explaining the effects of factors on the production rates of highway construction activities. Based on the data collected from historical records, this study will employ statistical methods in analyzing critical factors affecting productivity.

4.1 Definition of Statistics

Statistics is the science of making effective use of numerical data relating to groups of individuals or experiments (Aron, 2002). It deals with not only the collection, analysis and interpretation of such data, but also the planning of the collection of data, in terms of the design of surveys and experiments. Statistics refers to the analysis and interpretation of data with a view toward evaluation of the reliability of the conclusions based on the data (Zar, 1996).

There are two main branches of statistical methods: descriptive statistics and inferential statistics. Descriptive statistics is used to summarize and describe the population data based on a sample data either numerically or graphically while inferential statistics is used to draw conclusions and inferences from the study. This chapter discusses the descriptive statistics.

Variables are classified into continuous or discrete variable (also called quantitative variable) and nominal variable (also called quantitative variable). Continuous variables are variables that take numeric forms in which the numbers stand for what is being measured. Nominal variables are variables that do not take any numeric form or the values are names or categories (Aron, 2002). In this study temperature, annual average daily traffic (AADT) and production rates are referred as continuous variables as they take quantitative forms, while type of soil, seasonal changes, type of roadway, type of route and number of lanes are referred as categorical. For instance, type of roadway is considered nominal as it takes the form of either concrete, asphalt or a combination of concrete and asphalt.

4.2 Data Analysis Procedure

Once data collection is completed from DWR, box plot and scatter plot are employed to visually describe the relationship between variables after classifying each factor into the respective categories. Mean, median and standard deviation are used as numerical descriptors, while frequency and percentage are used to graphically interpret categorical data. Statistical t test (pooled t test) and regression are also used to test the significance of factors on productivity.

A comparison is then made between factors obtained from the Daily Work report (DWR) with the results from the engineers' survey. If the comparison is good enough and there are sufficient data points, a regression analysis (inferential statistics) is employed to develop production rate prediction models for the selected controlling highway activities.

Otherwise discussions are made with senior engineers and prediction models based on subjective data from the survey are developed. The data analysis is performed using MINITAB 15 and SPSS statistical software packages. A simple data analysis procedure is illustrated in Figure 4.1.

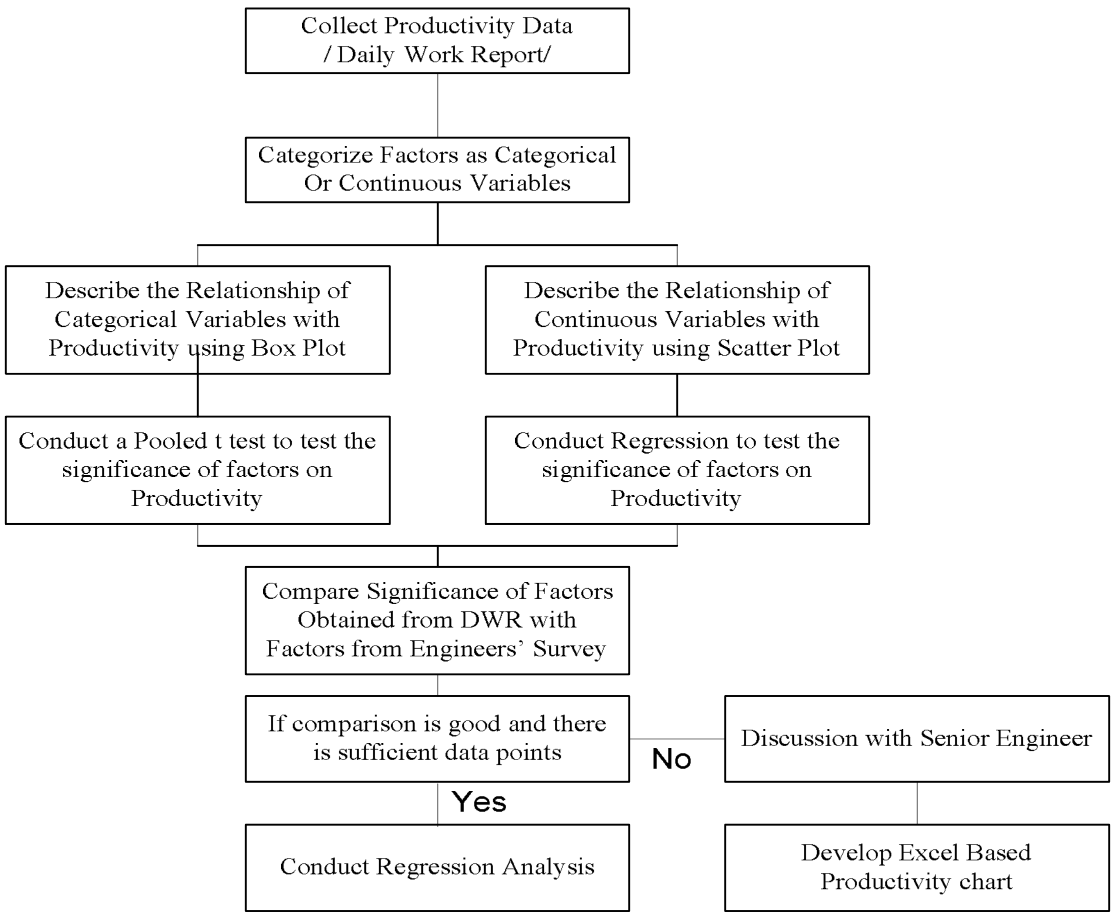


Figure 4.1 Data Analysis Procedure

4.3 Descriptive Statistics

One of the statistical tools used to assess and compare sample distributions is a box plot. A box plot sometimes called a box-and-whiskers plot is employed to display the distribution of scale variable and pinpoint outliers (Freund, 2003). A box plot shows the five statistics: minimum, first quartile, median, third quartile, and maximum values for a scale variable in a graphical format. Figure 4.2 illustrates the components of a box plot.

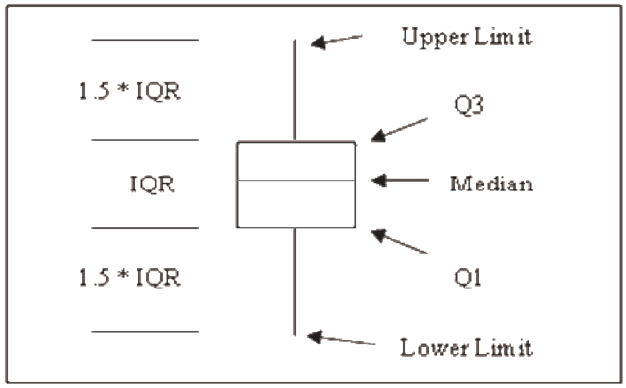


Figure 4.2 Box Plot Diagram (Freund, 2003)

The top of the box is the third quartile (Q3), which indicates that 75% of the data values are less than or equal to this value while the bottom of the box is the first quartile (Q1) in which 25% of the data values are less than or equal to this value. The inter-quartile range (IQR) is the difference between the 75th and 25th percentiles and corresponds to the length of the box. The center line represents the median, in which half the observations are less than or equal to it and half the observations are greater than or equal to it. The upper whisker extends to the highest data value within the upper limit (Q3 + 1.5*(Q3 - Q1)). Similarly, the lower whisker extends to the lowest value within the lower limit (Q1- 1.5*(Q3 - Q1)). Values beyond the whiskers or lower and upper limit are considered outliers (Freund, 2003).

Another statistical method used in describing patterns and relationships of variables is scatter plot. Scatter plot is used to illustrate the relationship between two variables by plotting one against the other. Scatter plot is usually used for interval variables. Once these relationships between factors affecting productivity and controlling highway activity have been visually described, the next step is to test the significance of factors on productivity.

4.4 Factors Affecting Production Rates of Highway Activities

Based on the literature review and meetings with highly experienced engineers the following factors have been identified as critical; a) weather (temperature and seasonal effects), b) location & traffic condition, c) contractor (construction firms), d) quantity of work, e) type of soil, and f) haul distance,. Additional factors that are incorporated in the study include a) type of highway route, b) number of lanes, and c) type of roadway. Figure 4.3 summarizes the breakdown of these factors investigated in this study.

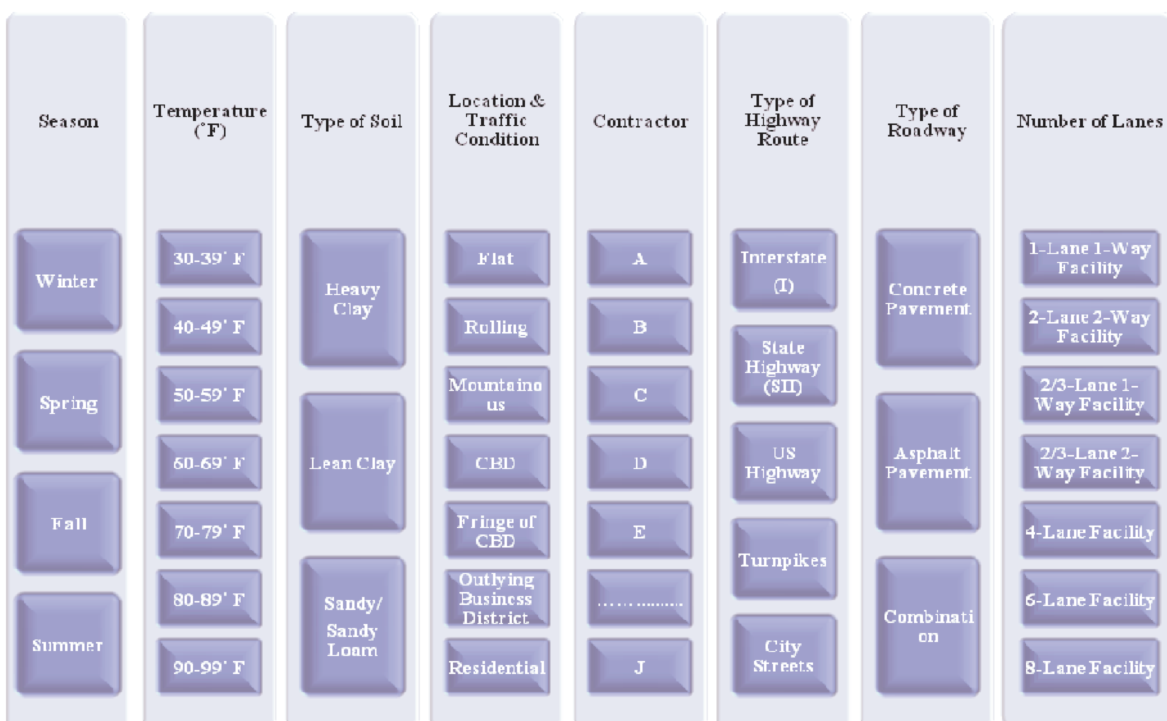


Figure 4.3 Break-down of Factors

Weather:

One of the critical factors affecting productivity of highway construction is the weather condition. Weather condition includes precipitation (rainfall), moisture, temperature, seasonal changes and humidity. Extreme weather conditions result in delay of work operations, lower productivity and difficulty in operating equipment and machineries. In this study, the effect of weather condition is interpreted in terms of temperature and seasonal changes.

Location & Traffic Condition:

The location of highway projects is another critical factor. Material delivery and supply, traffic condition, accessibility to the site and time periods of construction contribute to the effects of location on highway construction production rates. The ODOT has an inventory data for roadway and traffic characteristic on its website, Graphical Resource Internet Portal Lite (GRIPLITE), http://192.149.244.31/griplite/index.htm. The location of a project is classified into rural and urban based on Annual Average Daily Traffic (AADT) and Terrain or Area type in this study. The ODOT's classification of terrain type is shown in Table 4.1.

1. Flat Terrain – represents any combination of gradients, length of grade, horizontal or vertical alignment that permits trucks to maintain speeds that equal or approach the truck speed limit.
2. Rolling Terrain – includes any combination of gradients, length of grade horizontal or vertical alignment that causes trucks to reduce their speed substantially below the truck

speed limit on some sections of the highway, but which does not involve sustained crawl speed by trucks for any substantial distance.

3. Mountainous Terrain – represents any combination of gradients or lengths of grade, horizontal or vertical alignment that will cause trucks to operate at crawl speed for considerable distances, at frequent intervals.

Table 4.1 Terrain or Area Type

No	Terrain Type	Classification
a.	Flat	Rural Area
b.	Rolling	
c.	Mountainous	
d.	Central Business District (CBD)	Urban Area
e.	Fringe of Central Business District	
f.	Outlying Business District	
g.	Residential	

4. CBD – includes downtown area of city characterized by large number of pedestrians, loading zones and high parking demand.
5. Fringe CBD – represents areas adjacent to CBD with light industry, warehouses, auto service and low activity.
6. Outlying Business district – includes business districts located outside the CBD.
7. Residential Area – includes areas predominately used for dwelling.

Contractor:

The capacity of contractors in terms of resources (skilled labor, heavy machineries & equipment), utilization of advanced technology, construction methodology and management plays a major role in productivity variation among construction firms. Based on meetings with the ODOT engineers, 10 highly efficient and repetitive contractors working with the ODOT were selected from the Association of Oklahoma General Contractors. This is done to obtain representative and proficient productivity data. These selected contractors are large scale contractors and have long years of experience in the construction of highways. They are highly specialized in earthwork, bridge and pavement construction. In addition, they have senior project engineers and estimators with more than 30 years of highway construction experience.

Quantity of Work:

The amount or quantity of work to be accomplished in a construction project has huge impact on productivity. Based on the quantity of work, the availability of materials, allocation of resources, construction management and selection of construction methodology determines the range of highway productivity. The effect of quantity of work can be explained by the economies of scale. The economies of scale tend to occur in the highway construction industry as to distribute the costs across a large number of units of production (Wikipedia). Figure 4.4 explains the effect of quantity of production against cost. As shown in the figure, as quantity of production increases from Q to Q2, the average cost of each unit decreases from C to C1.

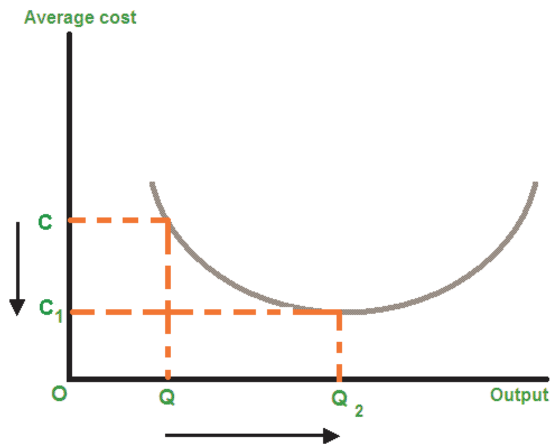


Figure 4.4 Economies of Scale (Wikipedia)

Type of Soil:

The type of soil encountered in a construction job site greatly affects the productivity of highway construction especially earthwork constructions. A job site may encounter different types of soil ranging from heavy clay or rock which requires heavy equipment & machineries to sandy soil or clay soils which are easier to operate and handle.

The American Standard for Testing Materials (ASTM) uses Unified Soil Classification System based on laboratory determination of particle size characteristics, liquid limit, and plasticity index. This classification system identifies three major soil divisions: coarse grained soils, fine grained soils, and highly organic soils. These three divisions are further subdivided into a total of 15 basic soil groups. The soil classification chart is attached in Appendix D.

The Soil Conservation Services (SCS) State Geographical database (STATGO) reveals that most of Oklahoma's soil is clay, cobbly--loam and very fine sandy loam. Based on ASTM and discussions with the ODOT engineers, the study has classified Oklahoma's soil into three major categories; loam/sandy loam, lean clay and heavy clay.

Haul Distance:

The distance to move materials to and from the job site is another critical factor affecting highway construction production rates. Haul distance has higher impact on earthmoving activities and pavement construction. Distances less than 1,000ft are considered to be within a project and are taken as short haul distances or else are considered as long haul distances. Considering an earthmoving activity, shorter haul distances will result in a reduced cycle time which in turn increases production rate.

Type of Highway Route:

ODOT classifies highway routes into four different types; Interstate (I), State Highway (S), US Highway (U), and Turnpikes (Non-Interstate). The study has included City Street (CS) as an additional classification to compare its productivity with the productivity of highway routes.

Type of Roadway:

The types of pavements mostly constructed in the State include concrete pavement, asphaltic pavement and Concrete-Asphalt (Combination) pavement in case of rehabilitation projects.

Number of Lanes:

The number of lanes greatly affects productivity in highway rehabilitation projects where the need of lane closure is important depending upon the traffic condition. In this study three types of lanes are considered; 2-Lane, 4-Lane and 8-Lane facility. GRIPLITE's classification of number of lanes is shown in Table 4.2

Table 4.2 The ODOT Lane Classification System

a -	ONE LANE ONE-WAY FACILITY(RAMP AND FRONTAGE ROAD ONLY)
b -	TWO LANE ONE-WAY FACILITY(RAMP AND FRONTAGE ROAD ONLY)
c -	TWO OR THREE LANE TWO-WAY FACILITY
d -	TWO OR THREE LANES ONE-WAY (CITY ONE-WAY PAIRS ONLY)
e -	FOUR LANE FACILITY
f -	SIX LANE FACILITY
g -	EIGHT LANE FACILITY

4.5 Data Categories

A total of 93 previously completed and ongoing highway projects are selected from the ODOT contract administration software SITEMANAGER. The number of data points collected for each controlling highway activity range from 15 to 90. The aforementioned factors are broken down into classes and range of intervals to visualize the effects on production rates. Based on the collected data, nearly 40% of the highway construction projects are Interstate highways; on average 42% of them are asphaltic pavements. More than 70% involve construction of 4 lane highways. The collected data shows that equal proportion of projects are constructed in rural and urban areas. Almost 41% the construction projects encountered lean clay soil. A descriptive data of the total number of data points collected for each category of factors is summarized in Table 4.3.

Table 4.3 Total Number of Data Points Obtained from DWR

FACTORS	UNCLASS. EXCAVATION	UNCLASS. BORROW	AC TYPE S3/S4	AGG BASE	SUBGRADE MODIFIC.	BRIDGE D REBAR	DOWEL J PAV'T	REMOVAL OF PAV'T
TOTAL DATA	90	55	69	46	31	39	15	42
ROUTE	% (n)	% (n)	% (n)	% (n)	% (n)	% (n)	% (n)	% (n)
US	40 (36)	33 (18)	32 (22)	26 (12)	16 (5)	36 (14)	13 (2)	33 (14)
I	40 (36)	20 (11)	28 (19)	30 (14)	45 (14)	36 (14)	60 (9)	57 (24)
SH	12 (11)	35 (19)	28 (19)	35 (16)	6 (2)	28 (11)	7 (1)	5 (2)
CS	8 (7)	7 (4)	9 (6)	4 (2)	26 (8)	0 ()	20 (3)	5 (2)
HIGHWAY								
ASPH	39 (35)	62 (34)	58 (40)	70 (32)	35 (11)	33 (13)	20 (3)	19 (8)
CONC	34 (31)	9 (5)	19 (13)	22 (10)	35 (11)	46 (18)	40 (6)	52 (22)
COMB	27 (24)	29 (16)	23 (16)	9 (4)	29 (9)	21 (8)	40 (6)	29 (12)
LANES								
2	13 (12)	33 (18)	16 (11)	30 (14)	3 (1)	10 (4)	0 ()	10 (4)
4	69 (62)	67 (37)	68 (47)	61 (28)	68 (21)	64 (25)	87 (13)	86 (36)
8	1 (1)	0 ()	3 (2)	0 ()	6 (2)	8 (3)		
LOCATION								
URBAN	37 (33)	16 (9)	30 (21)	39 (18)	48 (15)	31 (12)	47 (7)	57 (24)
RURAL	47 (42)	65 (36)	58 (40)	52 (24)	29 (9)	51 (20)	40 (6)	38 (16)
SEASON								
WINTER	30 (27)	24 (13)	28 (19)	17 (8)	26 (8)	15 (6)	20 (3)	43 (18)
SPRING	34 (31)	24 (13)	38 (26)	17 (8)	29 (9)	46 (18)	13 (2)	10 (4)
FALL	19 (17)	20 (11)	14 (10)	39 (18)	26 (8)	13 (5)	40 (6)	19 (8)
SUMMER	17 (15)	33 (18)	20 (14)	26 (12)	19 (6)	26 (10)	27 (4)	29 (12)
TEMP								
30-39	8 (7)	4 (2)	0 (14)	0 ()	0 ()	0 ()	13 (2)	10 (4)
40-49	16 (14)	11 (6)	20 (18)	17 (8)	23 (7)	10 (4)	13 (2)	24 (10)
50-59	28 (25)	20 (11)	26 (14)	9 (4)	23 (7)	31 (12)	13 (2)	24 (10)
60-69	20 (18)	18 (10)	20 (14)	22 (10)	19 (6)	28 (11)	13 (2)	0 ()
70-79	20 (18)	24 (13)	12 (8)	39 (18)	13 (4)	10 (4)	27 (4)	14 (6)
80-89	6 (5)	24 (13)	20 (14)	13 (6)	16 (5)	21 (8)	13 (2)	24 (10)
90-99	3 (3)	0 ()	1 (1)	0 ()	6 (2)	0 ()	7 (1)	5 (2)
SOIL								
SANDY	9 (8)	22 (12)			13 (4)			
LEAN CLAY	33 (30)	45 (25)			45 (14)			
HEAVY CLAY	17 (15)	24 (13)			6 (2)			
CONTRACTOR								
CONTR 1	3 (3)	7 (4)	4 (3)	0 ()	6 (2)	26 (10)	0 ()	5 (2)
CONTR 2	4 (4)	5 (3)	1 (1)	4 (2)	0 ()	13 (5)	13 (2)	5 (2)
CONTR 3	11 (10)	2 (1)	23 (16)	17 (8)	10 (3)	13 (5)	13 (2)	0 ()
CONTR 4	29 (26)	13 (7)	20 (14)	9 (4)	35 (11)	31 (12)	40 (6)	38 (16)
CONTR 5	17 (15)	4 (2)	14 (10)	22 (10)	16 (5)	5 (2)	20 (3)	19 (8)
CONTR 6	7 (6)	7 (4)	3 (2)	13 (6)	0 ()	0 ()	0 ()	5 (2)
CONTR 7	9 (8)	36 (20)	9 (6)	22 (10)	3 (1)	10 (4)	7 (1)	10 (4)
CONTR 8	9 (8)	2 (1)	1 (1)	4 (2)	0 ()	10 (4)	0 ()	5 (2)
CONTR 9	8 (7)	5 (3)	3 (2)	0 ()	13 (4)	0 ()	7 (1)	0 ()
CONTR 10	3 (3)	18 (10)	20 (14)	9 (4)	16 (5)	3 (1)	0 ()	14 6)

4.6 Effect of Factors on Production Rates of Highway Activities

Once factors affecting production rates of highway activities have been categorized, the concept of percentage complete matrix, box plot and scatter plot are employed in analyzing the effects of these factors to determine their significance on productivity. This study uses the ODOT's average production rate chart as a baseline production rate and calculates the 'percent unit' based on the mean production rate obtained from the DWR for each controlling highway activity (Equation 4.1)

$$PercentUnit = \frac{DWR\ Mean\ \mathrm{Pr}oduction\ Rate}{ODOT\ \ Average\ \mathrm{Pr}oduction\ Rate} \quad *100$$

A standard rate of highway construction operation is considered as 8 hrs per day for this study. DWR's mean production rates, ODOT's average production rates and percent unit of production for the selected controlling highway activities is calculated in Table 4.4. Although there is a decrease in the percent unit of production of unclassified excavation & borrow, there is an average increase of more than 150 percent unit of production for the selected controlling highway activities. The reason for the decrease in the percent unit of production for unclassified excavation and borrow is due to the fact that the most of the construction operations involved side works (ditch works) and were conducted during extreme weather conditions and difficult site or operating conditions. On the other hand, the increase in the percent unit of production of the other controlling activities may be attributed to the increase and advancement in construction technology and equipment, increased skilled labor, construction methodologies and better management.

Table 4.4 Percent unit of Production Rate

CONTROLLING ACTIVITY	UNIT	DWR Mean Production Rate	ODOT Average Production Rate	Percent Unit
UNCLASSIFIED EXCAVATION, RDY	CY	3330	3500	95%
UNCLASSIFIED BORROW, RDY	CY	1535	2150	71%
AGGREGATE BASE, RDY	CY	475.5	310	153%
(SP)ASPHALT CONCRETE TYPE S3	TON	1377.3	900	153%
LIME/CEMENTETIOUS STABILIZED SUBGRADE, RDY	SY	4638	2400	193%
DOWEL JOINTED CONCRETE PAVEMENT, RDY	SY	2936	1640	179%
BRIDGE DECK REBAR	LB	17910	8050	222%
REMOVAL OF CONCRETE PAVEMENT	SY	2222	1475	151%

4.6.1 Effect of Weather on Productivity

The effect of weather condition on productivity is visually explained by scatter plot and box plot. The scatter plot of production rate of unclassified excavation and aggregate base against temperature is shown in Figures 4.5 and 4.6.

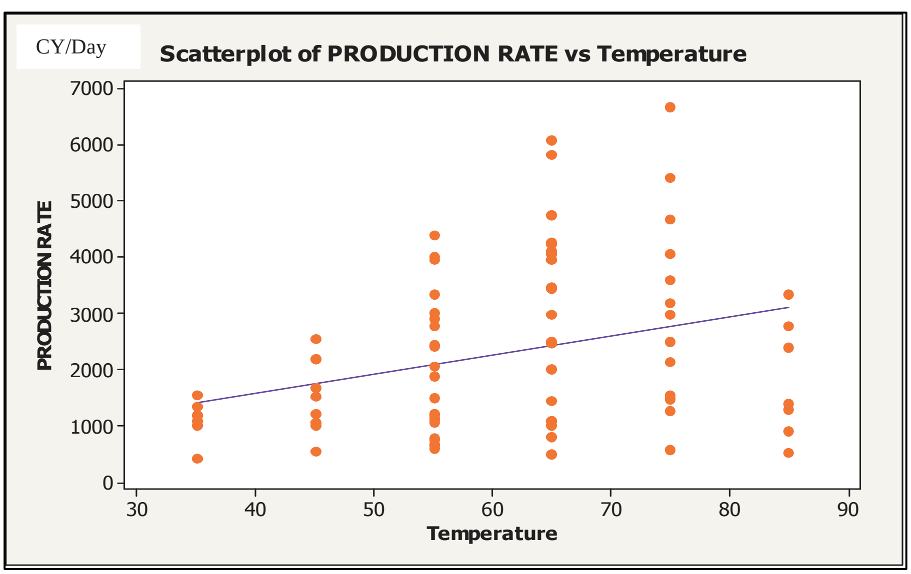


Figure 4.5 Scatter Plot of Production Rate against Temperature (Unclassified Excavation)

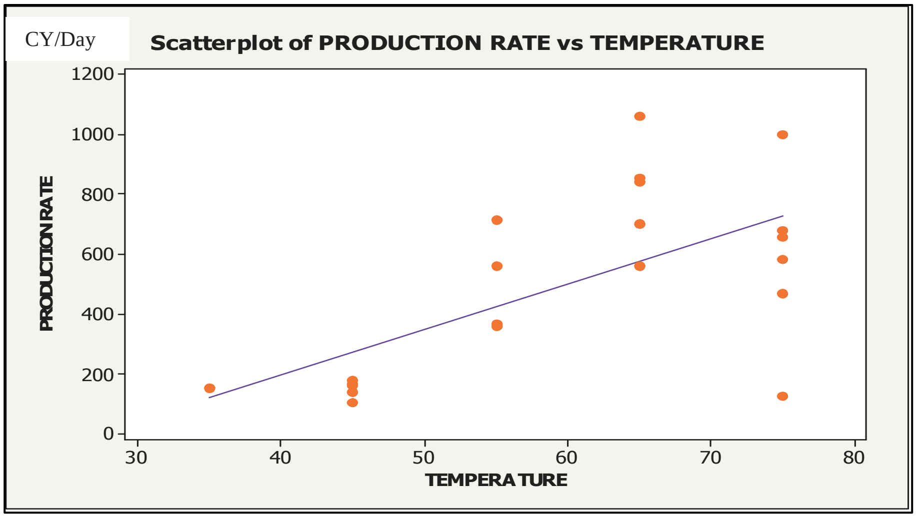


Figure 4.6 Scatter Plot of Production Rate against Temperature (Aggregate base)

As shown in Figures 4.5 and 4.6, production rates are likely to increase with the increase in temperature. Based on the plots, a higher production rate is observed at air temperature between 65F and 85F. Similarly, Figure 4.7 and 4.8 shows the two types of trends experienced in the percent unit of production rate with variation in temperature. The first trend shows an increase in the percent unit of production rate with an increase in temperature up to 75F and tends to drop beyond that. For instance, for unclassified excavation the percentage unit increases from 80% at 35F to 124% at 75F and tends to go down to 44% at 85F. This trend of productivity is experienced in unclassified excavation, asphaltic concrete, stabilized sub-grade and dowel jointed pavement. This decrease in productivity at temperature 85F is attributed to missing or lower number of data points.

The second trend shows an increase in the percent unit of production rate with an increase in temperature up to 85F and tends to decrease beyond that. This trend of productivity is experienced in aggregate base, bridge deck rebar, and removal of pavement. Although there is not a distinct trend seen for unclassified borrow, a favorable temperature for controlling highway construction activities may be taken between 65F and 85F.

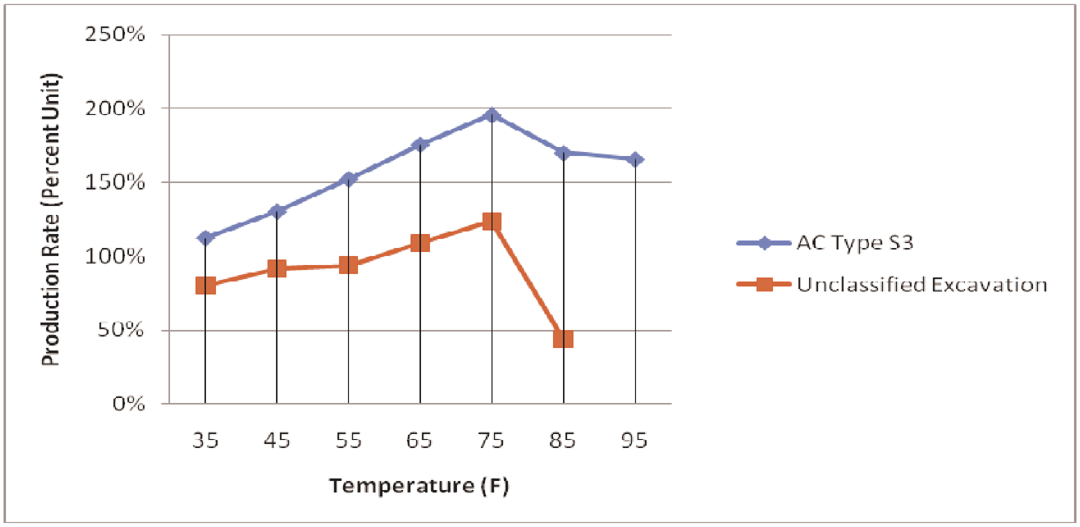


Figure 4.7 Effect of Temperature on Productivity (Trend 1)

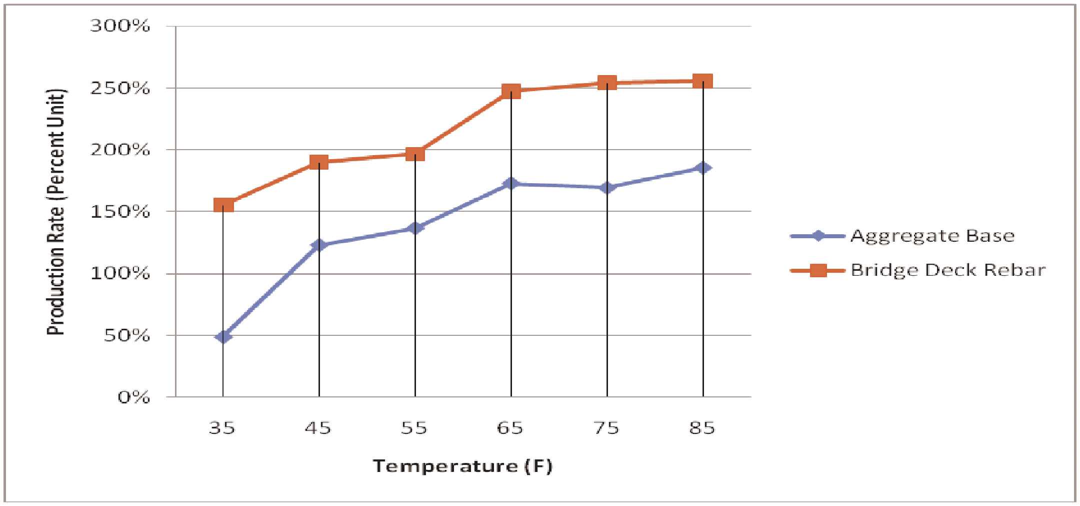


Figure 4.8 Effect of Temperature on Productivity (Trend 2)

A box plot of production rate for unclassified borrow against seasonal changes is shown in Figure 4.9. Higher productivity is achieved during the summer and fall seasons compared to spring and winter. The lowest mean production rate is experienced during the winter season. The box plot reveals that the maximum production rates may even go down up to 900CY/Day during winter season. Based on the box plot of median productivity, there is an increase in productivity in the order of winter, spring, fall and summer except for unclassified excavation. For unclassified excavation, higher production rate occurred during the fall season. The box plot and scatter plot of temperature and seasonal changes for the other controlling activities is attached in Appendix F.

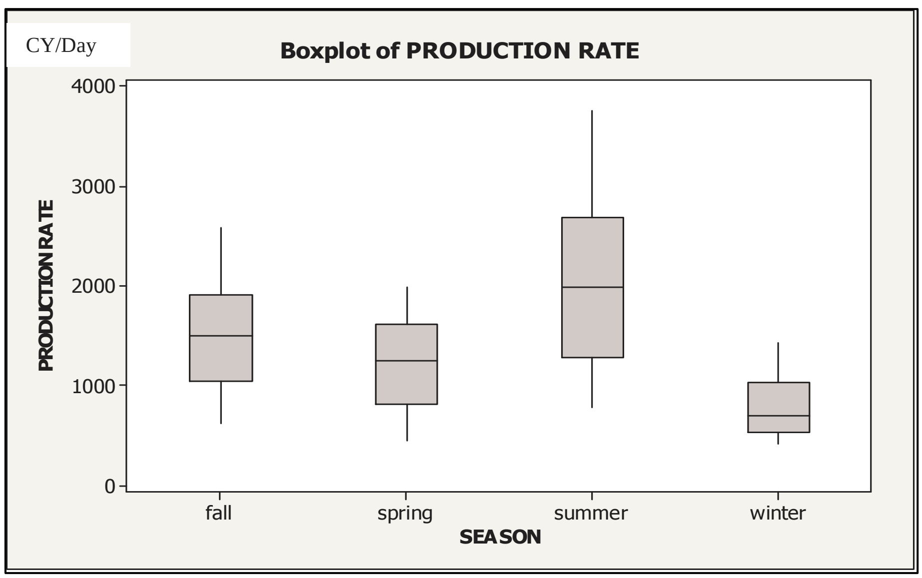


Figure 4.9 Box Plot of Production Rate against Season (Unclassified Borrow)

Similarly, a percent unit of production rate revealed two trends of productivity except for unclassified borrow. The inconsistency in production rates for borrow may be attributed for the same reason mentioned above. The first trend shows an increase in the percent unit of production rate in the order of winter, spring, fall and summer (Figure

4.10). In the second trend, productivity has increased during spring rather than fall (Figure 4.11). The first trend of productivity is experienced in unclassified excavation, asphaltic concrete, stabilized sub-grade and dowel jointed pavement and the second is experienced in aggregate base, bridge deck rebar, and removal of pavement. This may be attributed to the fluctuation in temperature, moisture content, precipitation and humidity experienced during the fall and spring seasons. The effect of temperature and seasonal changes on other controlling activities is attached in Appendix E.

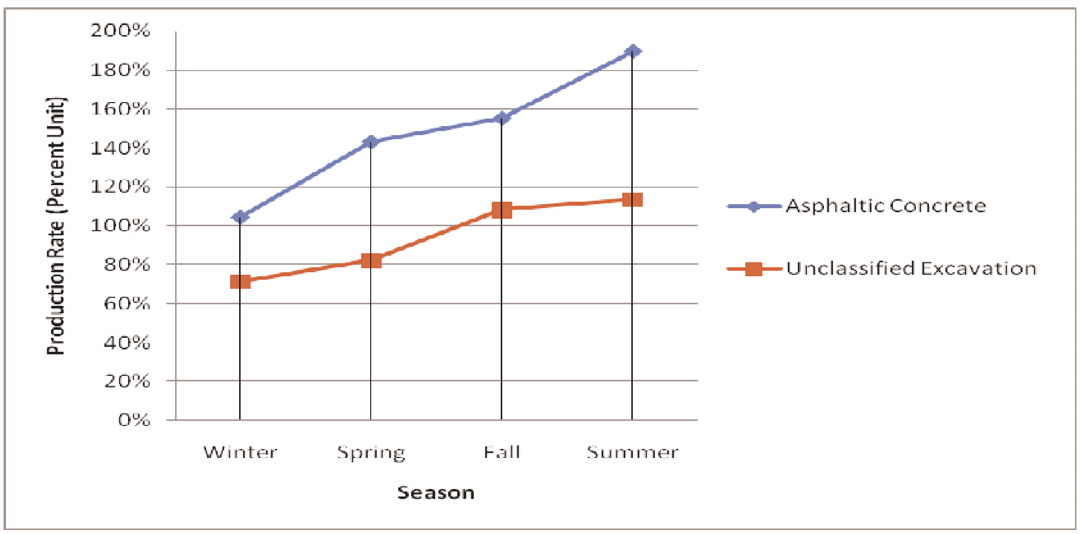


Figure 4.10 Effect of Seasonal Change on Productivity (Trend 1)

Lower productivity of controlling highway activities may be attributed to the extreme weather conditions (temperature and seasonal changes) which lead in delay of work operations, lower labor productivity and difficulty in operating equipment & machineries. Extreme temperatures tend to produce unfavorable conditions for workers and construction operations. Low temperature may increase workers' idle time as the workers tend to stop their work to warm themselves or take shelter to avoid heat during high temperature (Borcherding 1991).

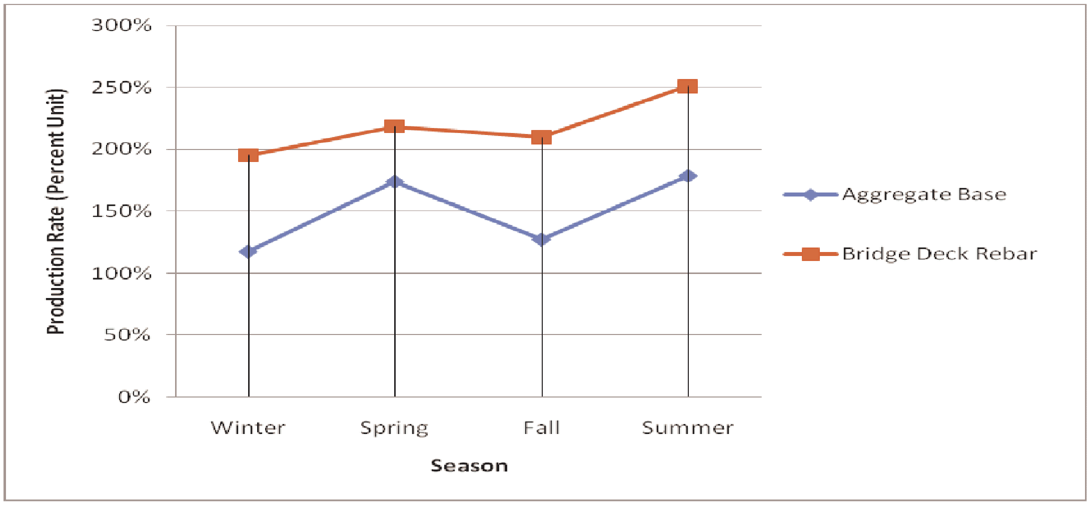


Figure 4.11 Effect of Seasonal Change on Productivity (Trend 2)

4.6.2 Effect of Soil Type on Productivity

The effect of soil on productivity of laying an aggregate base is explained in Figure 4.12. Although the productivity range is wide, the median reveals that higher productivity is achieved for projects which encountered loam/sandy soil. ODOT's production rate chart shows a minimum, average and maximum production rate chart of 160, 310 & 775Cy/day respectively, are all lower by more than one third when compared to DWR's heavy clay, lean clay and sandy soils maximum production rate (Figure 4.12).

The lower production rate in heavy clay is attributed to its poor drainage and compaction which makes it difficult for equipment and machineries to handle construction operations. The overlap of productivity may be explained as dry clay soils are more stable than sandy soils which make excavation works easier.

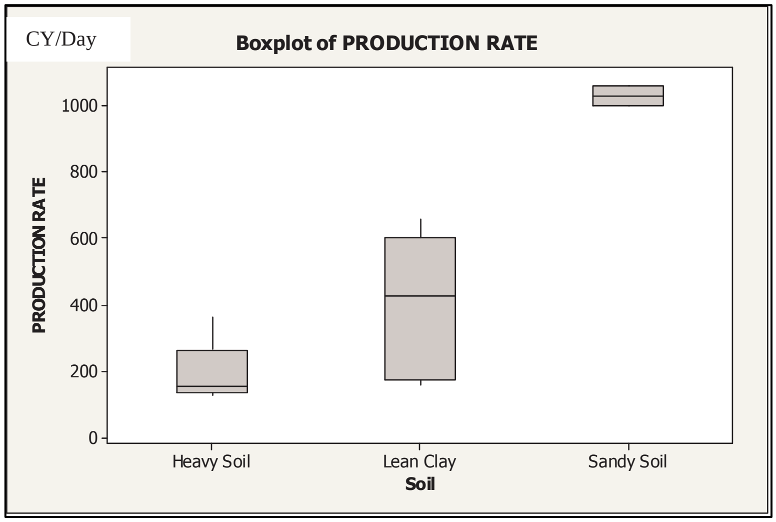


Figure 4.12 Box Plot of Production Rate against Soil Type (Aggregate Base)

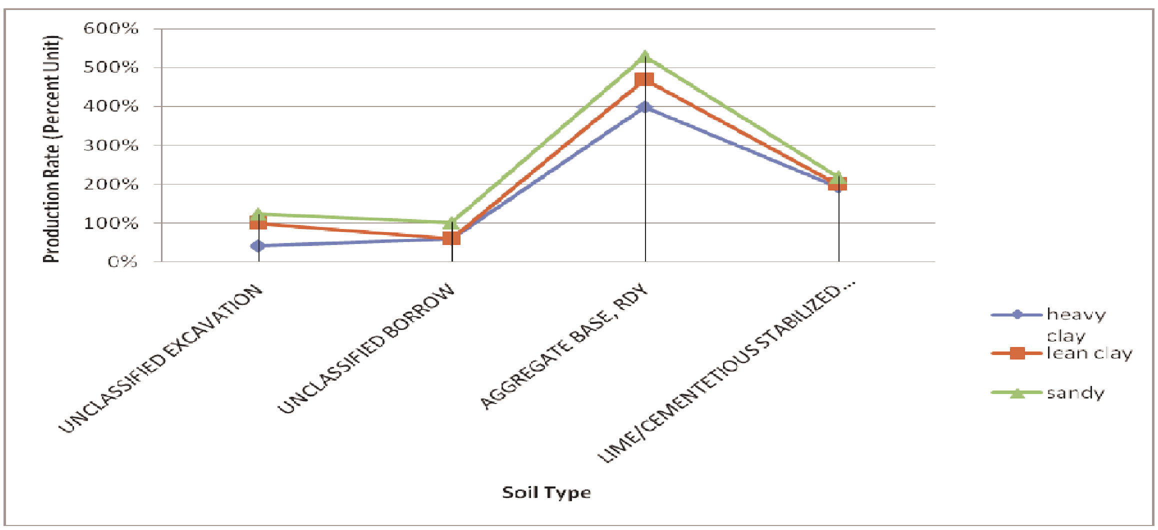


Figure 4.13 Effect of Soil Type on Productivity

Only four controlling activities, unclassified excavation, unclassified borrow, aggregate base and sub-grade modification were selected, as they are directly or indirectly involved with earthwork operations. A percent unit of production rate with variation in soil type is shown in Figures 4.13. Aggregate base, unclassified excavation and unclassified borrow are more sensitive to soil type compared to sub-grade modification. Despite their degree of sensitivity, the percent unit of production decreases as going from sandy soil to heavy clay for all controlling activities.

4.6.3 Effect of location & Traffic Condition on Productivity

The location of projects is classified into rural and urban areas based on Annual Average Daily Traffic (AADT) and Terrain or Area type. Figure 4.14 illustrates the production rates of unclassified borrow in rural and urban areas using box plot. The diagram reveals that higher production rates are achieved in rural areas compared to urban areas. It is studied that the location of a project affects material delivery and supply, traffic condition, accessibility to the site and time periods of construction which results in lower productivity. In addition, Figure 4.15 illustrates the reduction in the production rate of laying asphalt with an increase in the average daily traffic (ADT).

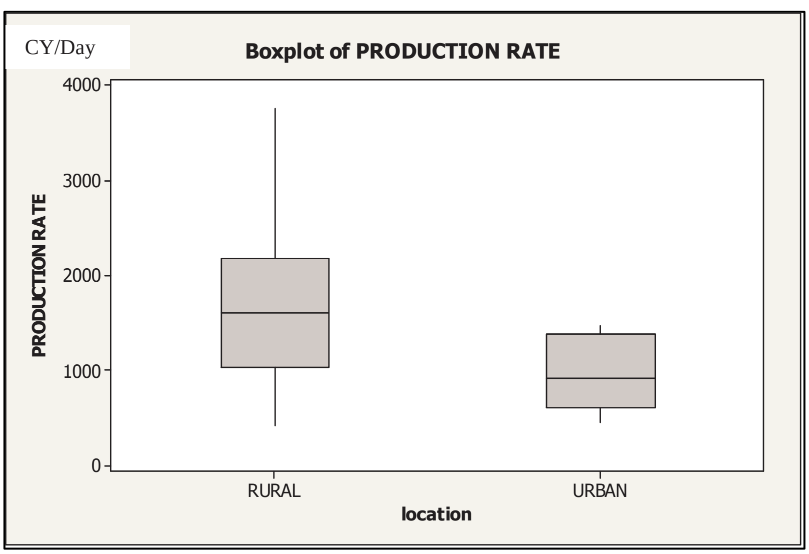


Figure 4.14 Box Plot of Production Rate against Location (Unclassified Borrow)

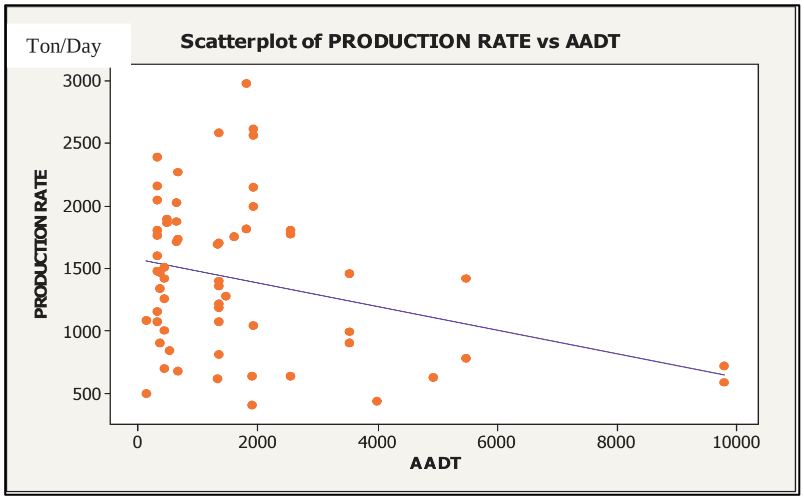


Figure 4.15 Scatter Plot with Regression for Laying Asphaltic Concrete (AADT)

Figures 4.16 further illustrates the differences in the percent unit of production for urban and rural areas. The same trend of percent unit production is experienced in all controlling activities. It is revealed that dowel jointed pavement is the most sensitive activity to location of a project. Unclassified borrow, aggregate base, bridge deck rebar, asphaltic concrete and removal of pavement are relatively sensitive while, unclassified excavation and subgrade modification are the least sensitive to project site location.

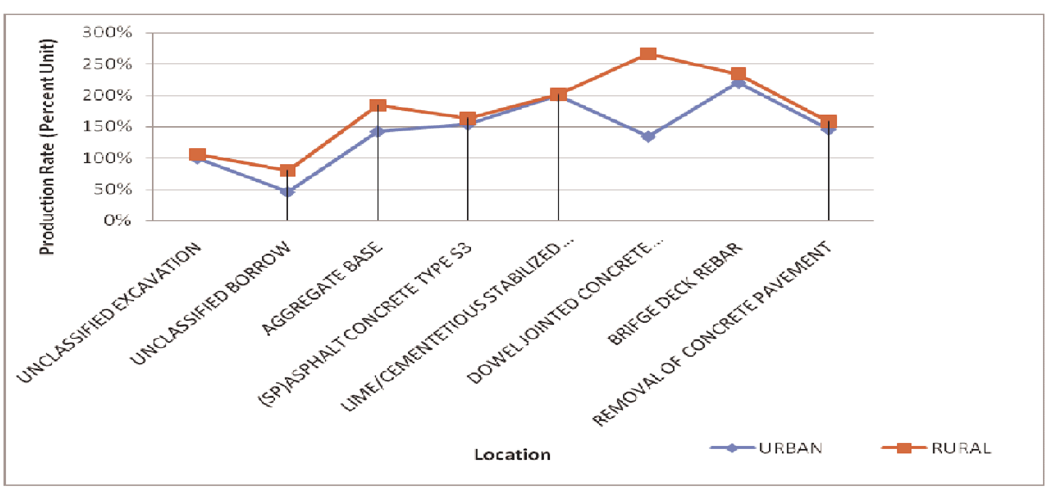


Figure 4.16 Effect of Location on Productivity

4.6.4 Effect of Contractors on Productivity

A comparison of the mean production rates are made among the selected contractors. A pooled t test is employed to test the significance of the difference in production rates of these contractors. A pooled t test for independent means is used for hypothesis testing with two samples of scores (Aron, 2002). There are two assumptions that should be taken into consideration when conducting a t test,

a. Each of the population distribution is assumed to follow a normal curve.

b. The two populations are assumed to have the same variance.

Due to the high variability in the factors affecting productivity, a significance level, α = 0.05 (95% Confidence Interval) is chosen to determine whether the mean production rates are affected by the capacity of contractors. The significance of difference in contractors productivity can be conducted by first setting the hypothesis whether the mean of two populations are equal or not,

$$H_o : \mu_1 - \mu_2 = \delta_0$$
$$H_1 : \mu_1 - \mu_2 \neq \delta_0 \quad \text{..........}(Eqn4.2)$$

We use the test statistic,

$$t = \frac{(\overline{y_1} - \overline{y_2}) - \delta}{\sqrt{(S_p{}^2 / n_1) + (S_p{}^2 / n_2)}} \quad \text{..........}(Eqn4.3)$$

Where $\overline{y_1}$ and $\overline{y_2}$ are the two sample means with sample size of n_1 and n_2 independently drawn from the two population randomly. S_p represents the pooled variance which is an estimate of a common variance obtained from the two independent samples.

S_p can be calculated as

$$S_p^{\ 2} = \frac{SS_1 + SS_2}{n_1 + n_2 - 2} \quad \text{...}(Eqn4.4)$$

Where, SS_1 and SS_2 are the sums of squares from the two samples.

Based on the pooled t-test, it is concluded that production rates greatly vary from one contractor to another. A comparison of production rates of two highway activities, unclassified excavation and unclassified borrow is made among contractors as shown in Figures 4.17 and 4.18 respectively.

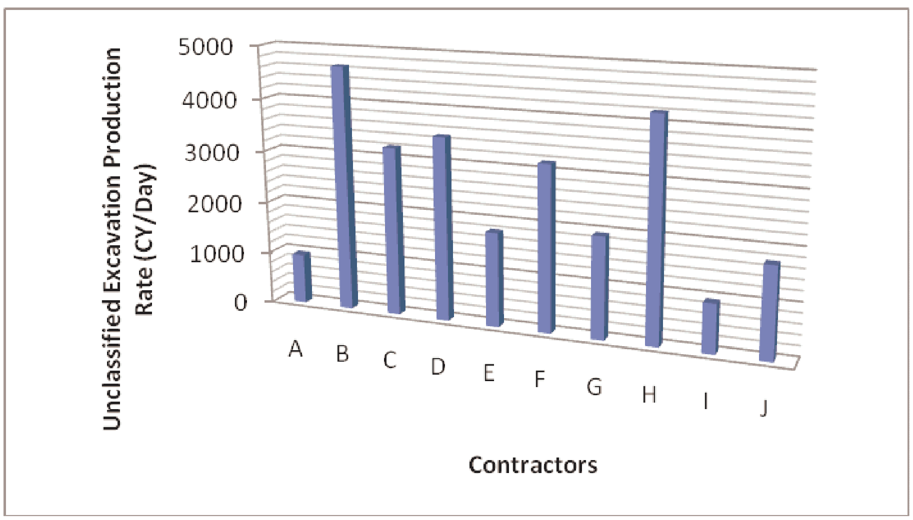


Figure 4.17 Comparison of Production Rate Among Contractors (Unclassified Excavation)

For instance, in Figure 4.17, contractor B has the highest productivity for unclassified excavation among the ten contractors, but is not the case for unclassified borrow as shown in Figure 4.18. This explains the productivity variation or inconsistency even among the same contractor. A contractor may be specialized (resource, equipment & machinery) in a particular type of work item. Therefore the size of contractors is one of the significant factors affecting highway construction production rates. These same variations are experienced in all controlling activities. The effect of contractors on other controlling activities is shown in Appendix G.

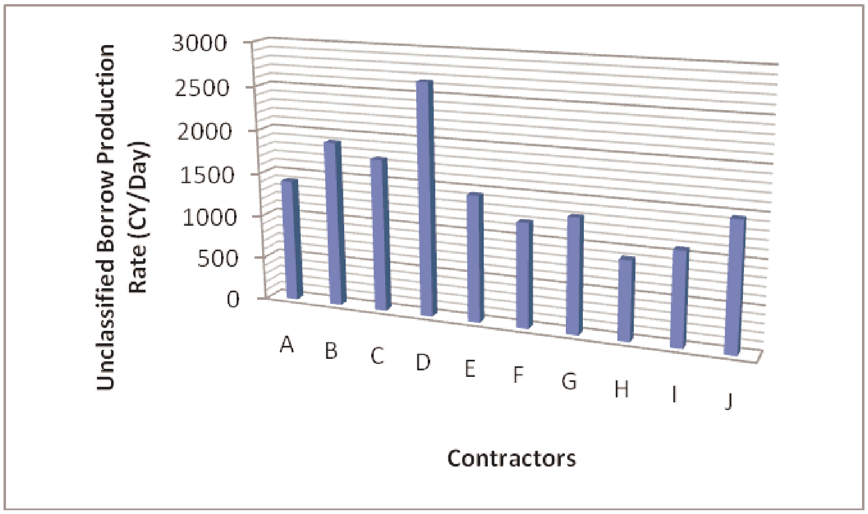


Figure 4.18 Comparison of Production Rate Among Contractors (Unclassified Borrow)

4.6.5 Effect of Number of Lanes on Productivity

Figure 4.19 illustrates the relationship between the number of lanes and production rates for laying asphaltic concrete. Higher production rate is achieved in 8-lane highways compared to 2-lane highways. Figure 4.20 further explains a summary of the percent unit of production rates of unclassified excavation and sub-grade modification against the number of lanes. An increase in the percent unit of production rate of highway activities occurred with the increase in the number of lanes to all controlling activities except aggregate base. This may be attributed to the construction of new highway projects or full lane closure of highways during rehabilitation projects. Lane closure or construction of a full lane highway project increases productivity as a result of lesser traffic which increases accessibility, better material delivery and supply and higher safety. The effect of contractors on other controlling activities is shown in Appendix G.

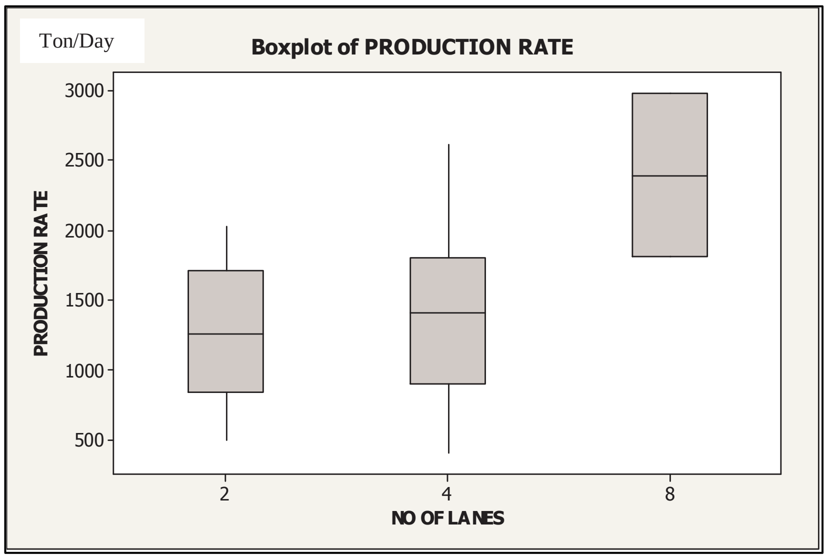


Figure 4.19Box Plot of Production Rate against No of Lanes (Asphaltic Concrete)

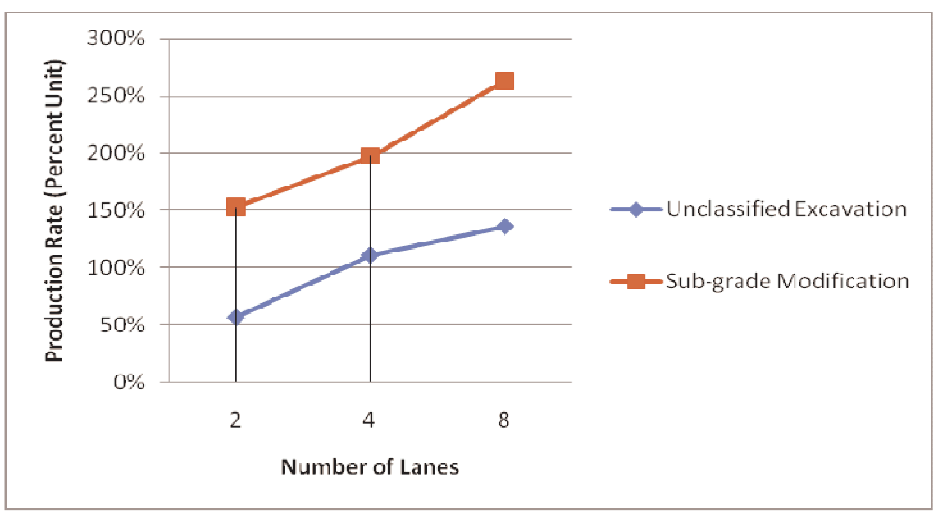


Figure 4.20 Effect of Number of Lanes on Productivity

4.6.6 Effect of Highway Type on Productivity

The effect of highway type on production rates is explained in Figure 4.21. Although there is a high overlap between the types of highways, a higher production rate is achieved in constructing concrete type highways compared to asphaltic highways. The reason for this high overlap is that, in rehabilitation projects, asphaltic pavements can be placed much quicker and turned over to traffic as it does need curing time like concrete pavements or unlike new highway projects.

The percent unit of production rates is shown in Figure 4.22. The trend shows that aggregate base, asphaltic concrete and dowel jointed pavement are the most sensitive activities to type of highways. Unclassified excavation, stabilized sub-grade and removal of pavement are also sensitive as compared to bridge deck rebar. A clear pattern for unclassified borrow could not be distinguished from the analysis.

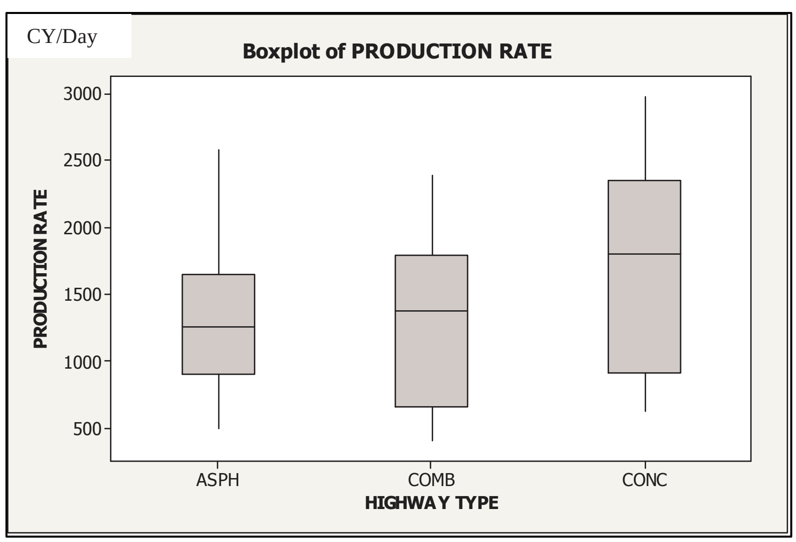


Figure 4.21 Box Plot of Production Rate against Highway Type (Aggregate Base)

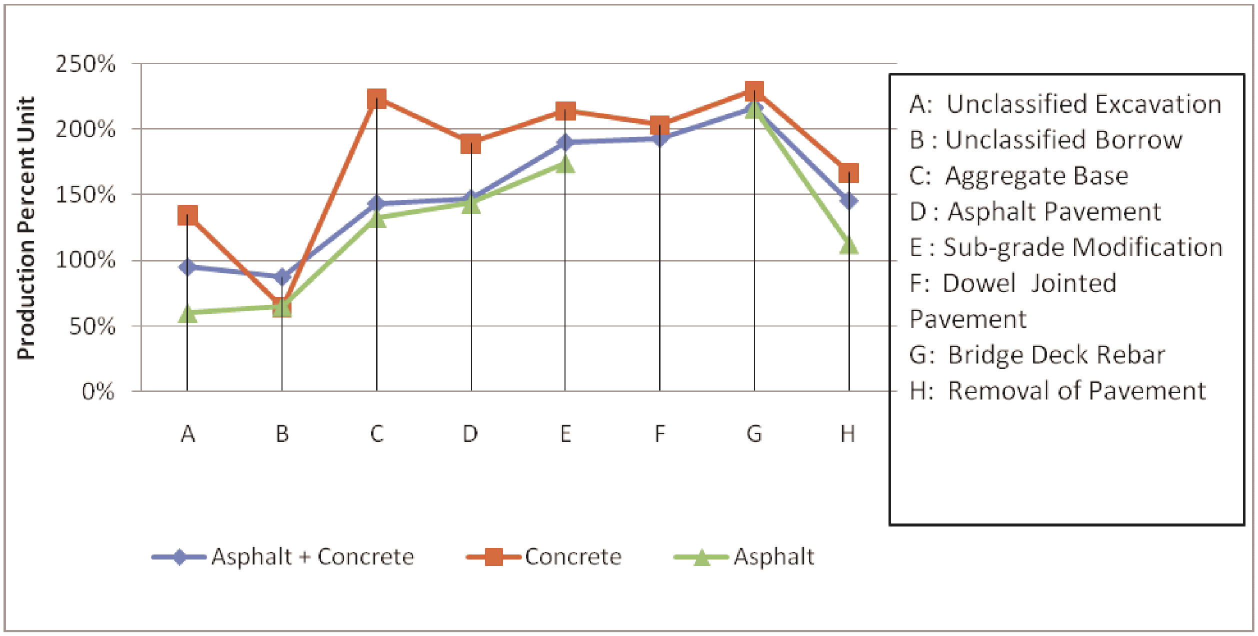


Figure 4.22 Effect of Type of Highway on Production Rate

4.6.7 Effect of Route Type on Productivity

A box plot of removal of concrete pavement against route type is shown in Figure 4.23. Although there are not much data points, city street has the lowest productivity compared to US and SH, while Interstate highways have the highest production rates. This is due to the high average daily traffic and congestion encountered in city streets compared to interstate highways.

Two trends occurred in the percent unit of production against changes in the route type. The first trend shows an increase in the percent unit of production rate in the order of City Street, State Highway, US Highway and Interstate Highways. Figure 4.24 shows the effect of route type for asphaltic concrete and unclassified borrow. This order is experienced in all controlling activities except unclassified excavation and aggregate base, where US Highway's percent unit of production is higher than Interstate (Figures

4.25). The effect of route type for the remaining controlling activities is shown in Appendix E.

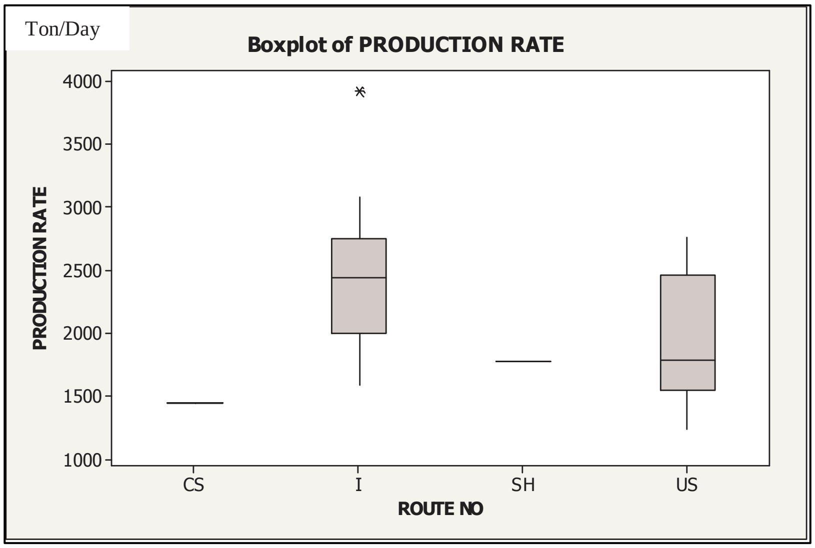


Figure 4.23 Box Plot of Production Rate against Lanes (Removal of Pavement)

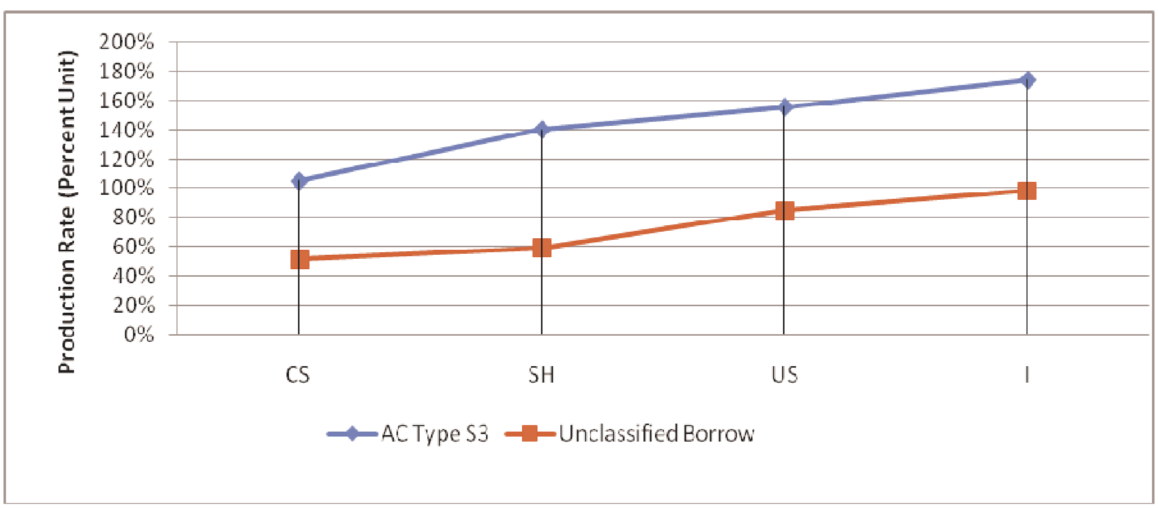


Figure 4.24 Effect of Type of Route Type on Production Rate (Trend 1)

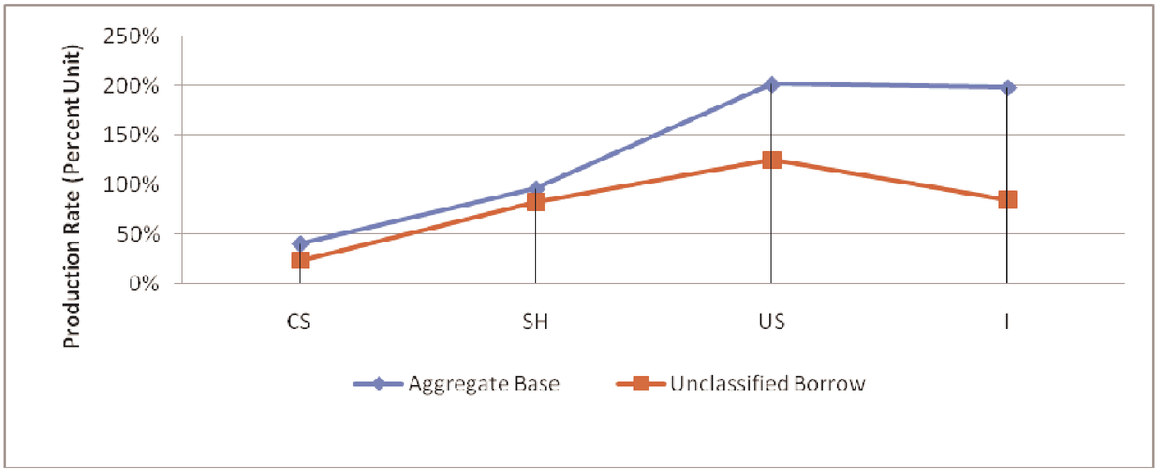


Figure 4.25 Effect of Route Type on Production Rate (Trend 2)

Based on the statistical analysis, Table 4.5 summarizes the effect of factors observed on highway production rates. Outliers can have a disproportionate influence on statistical results which can result in misleading interpretations. Therefore, outliers were removed from this study in order to avoid misleading statistical inferences. The complete analysis of the effect of factors on production rates of controlling highway activities is shown in Appendices E, F and G.

Table 4.5 Summary of Effect of Factors on Production Rate

Factors	Lowest Production Rate	Highest Production Rate
SEASON	Winter	Summer
TEMPERATURE	< 65 & > 85	65 - 85
SOIL TYPE	Heavy Clay	Sandy
LOCATION	Urban	Rural
CONTRACTOR	Varies	Varies
NO OF LANES	2 -lane	8-lane
HIGHWAY TYPE	Asphalt	Concrete
ROUTE	City street	Interstate

Chapter 5

SURVEY ANALYSIS

Two set of questionnaire surveys were sent out to highly experienced ODOT engineers and selected contractors across the State. The main purpose of these surveys is to obtain information on highway production rates of controlling highway activities and compare the results with the findings from the DWR.

5.1 Survey I Analysis

The first survey is intended to identify and rank critical factors affecting production rates of controlling highway activities. A set of questions which consisted of five to six factors were selected for each controlling highway activity. Then, a group of experts which includes one ODOT project scheduler, two senior resident engineers and two representative contractors was organized to identify and rank these critical factors. The development of this survey is based on the findings from literature review and meetings & interviews with ODOT engineers. The questionnaire survey is attached in Appendix C.

The survey was sent out to the research team by mid of November, 2009 and the responses were collected after two weeks. All participating experts responded to the survey. Based on the results from the survey, 83.3 % of the experts reported weather as the most common critical factor affecting production rates of controlling highway activities. On average, more than 74% of the respondents reported quantity of work as another critical factor affecting productivity. Location of a project and soil type accounted for 67%, while traffic condition resulted in 33%. Figures 5.1 and 5.2 illustrate the effect of factors identified from the survey.

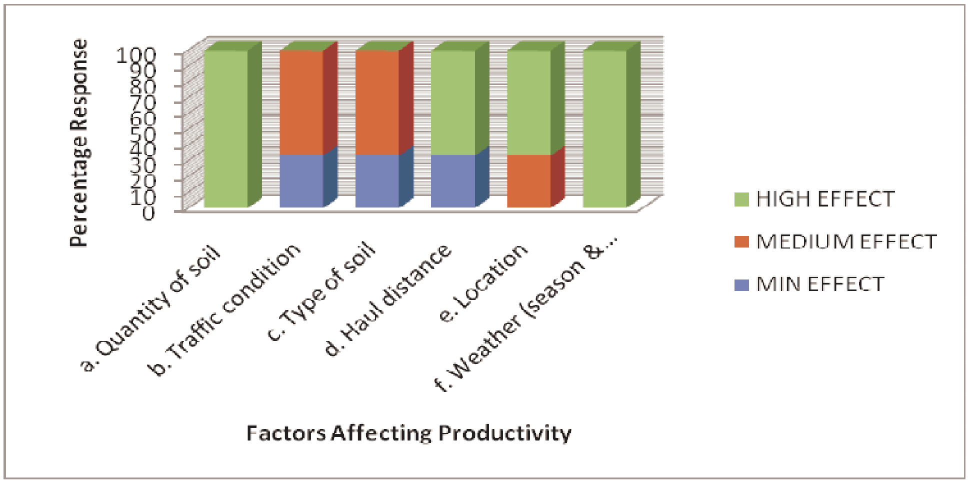


Figure 5.1 Effect of Factors on Unclassified Excavation and Borrow

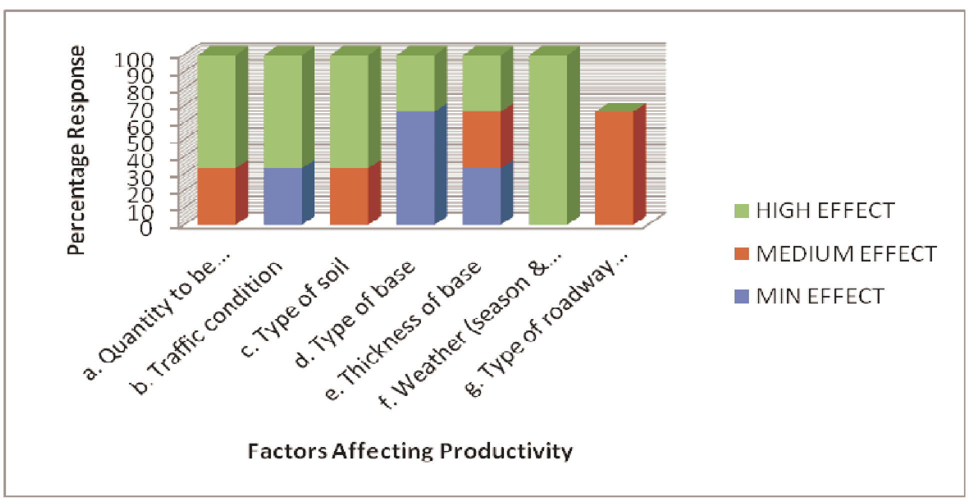


Figure 5.2 Effect of Factors on Sub-grade Modification

As shown in Figure 5.1, quantity of work item and weather account for 100%, while location and haul distance account for 67%, with 33% favoring location for both unclassified excavation and borrow. 67% of the experts agreed that traffic condition and soil type have medium effect compared to weather, location and haul distance. The survey participants fully favored weather as the most critical factor affecting sub-grade modification, while 67% agreed on quantity and type of soil (Figure 5.2).

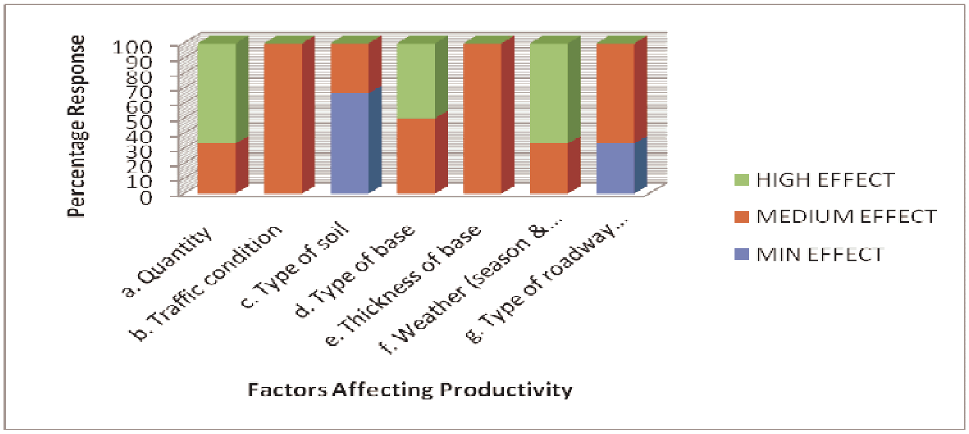


Figure 5.3 Effect of Factors on Aggregate Base

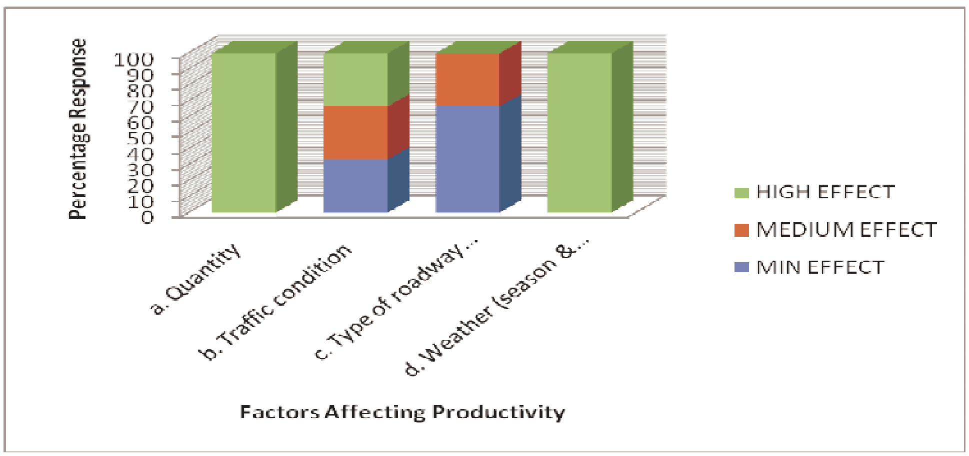


Figure 5.4 Effect of Factors on Dowel Jointed Pavement, Asphaltic Concrete & Bridge Deck Rebar

More than 67% of the respondents reported that weather and quantity as critical factors affecting aggregate base, with type of base accounting for 50% (Figure 5.3). According to the participants, traffic condition and thickness of base has a medium effect on aggregate base. Similarly, quantity and weather are found out to be critical factors for performing dowel jointed pavement, asphaltic concrete and bridge deck rebar with more than 67% of the team favoring it (Figure 5.4). Traffic condition accounts for 100% of the survey response, while quantity, weather and steel can be considered as additional factors affecting the removal of concrete pavement (Figure 5.5).

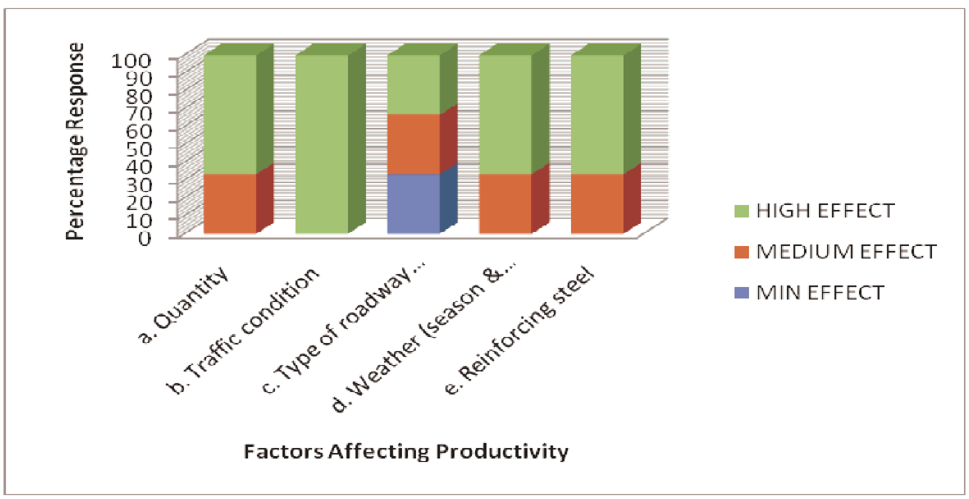


Figure 5.5 Effect of Factors on Removal of Pavement

Based on the participant's response, two to three highly ranked factors are selected for each controlling highway activity. Table 5.1 summarizes the significant factors obtained from the survey.

Table 5.1 Summary of Critical Factors Obtained from Survey

Controlling Activity	Primary Factors
Unclassified Excavation	Weather (season & temperature)
Unclassified Borrow	Quantity of soil
Aggregate Base	Location
Sub-grade Modification, lime/fly ash	Weather (season & temperature) Quantity of soil Soil Type
Dowel Jointed P.C. Pavement Rebar-Bridge Deck 10” Asphalt Pavement Type S-3	Weather (season & temperature) Quantity of Soil
Removal of pavement	Weather (season & temperature) Quantity Traffic Condition

5.2 Survey II Analysis

The second survey is intended to extract highly experienced engineers’ valuable knowledge and experience in estimating highway production rates of controlling highway activities. Based on the findings from survey I, a second survey is prepared with a set of questions which consisted of five different scenarios of project site conditions for each controlling highway activity. The purpose of this is to evaluate and compare the client’s estimate of production rate with the contractors’ perspective. The survey was sent out early December, 2009 to all participants and the responses were collected by mid of January, 2010. The questionnaire survey is attached in Appendix D.

In total, 30 experts, 20 ODOT residencies and 10 selected and highly repetitive contractors were selected for the survey. A total of 17 participants (56%), 11 residencies and 6 contractors responded to the survey. Although the response rate is low, a comparison made between residencies and contractors’ estimate of production rates revealed that there is a 51% increase of residencies productivity over contractors' productivity. Figure 5.6 shows the production rate comparison of residencies and contractors for laying asphaltic pavement type S3 with different scenarios. For instance, for laying more than 30Kton of asphaltic pavement during the summer, contractors estimated a productivity of 163% while residencies estimated a productivity of 213% unit.

Based on the analysis, the contractors' estimate has showed an average percent unit of 98% productivity, while the residencies estimate resulted in 142% unit of productivity. Overall, there is an average increase of more than 40% between contractors and residencies production rate estimate in laying asphalt pavement type S3.

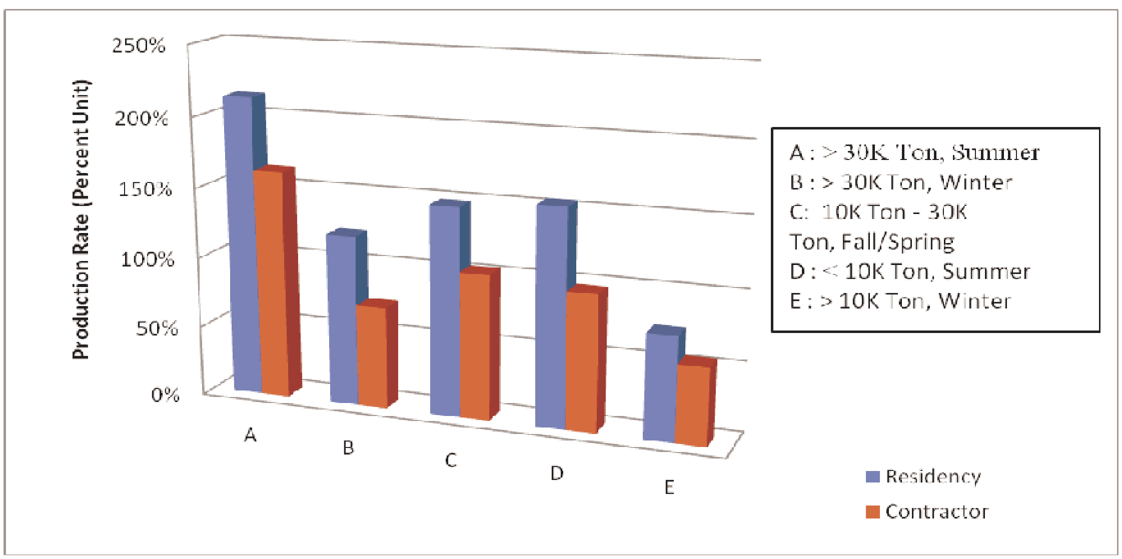


Figure 5.6 Comparison of Contractor Vs Residency Production Rate for Laying Asphaltic Pavement

An overall comparison of the percent unit of production is made for the selected controlling highway activities between residency, DWR, contractor and ODOT production rate estimate (Figure 5.7). The percent unit of production ranges from 50% to an increase of 630%. The highest productivity is observed in residency estimate except for unclassified excavation. DWR has higher productivity than contractors and ODOT chart except for unclassified borrow and excavation. A trend of decrease of productivity is observed in sub-grade modification, aggregate base, asphalt pavement and removal of pavement in the order of residency, DWR, contractor and ODOT. A similar pattern is experienced in dowel pavement and bridge deck except that contractors estimate of productivity is lower than ODOT's chart.

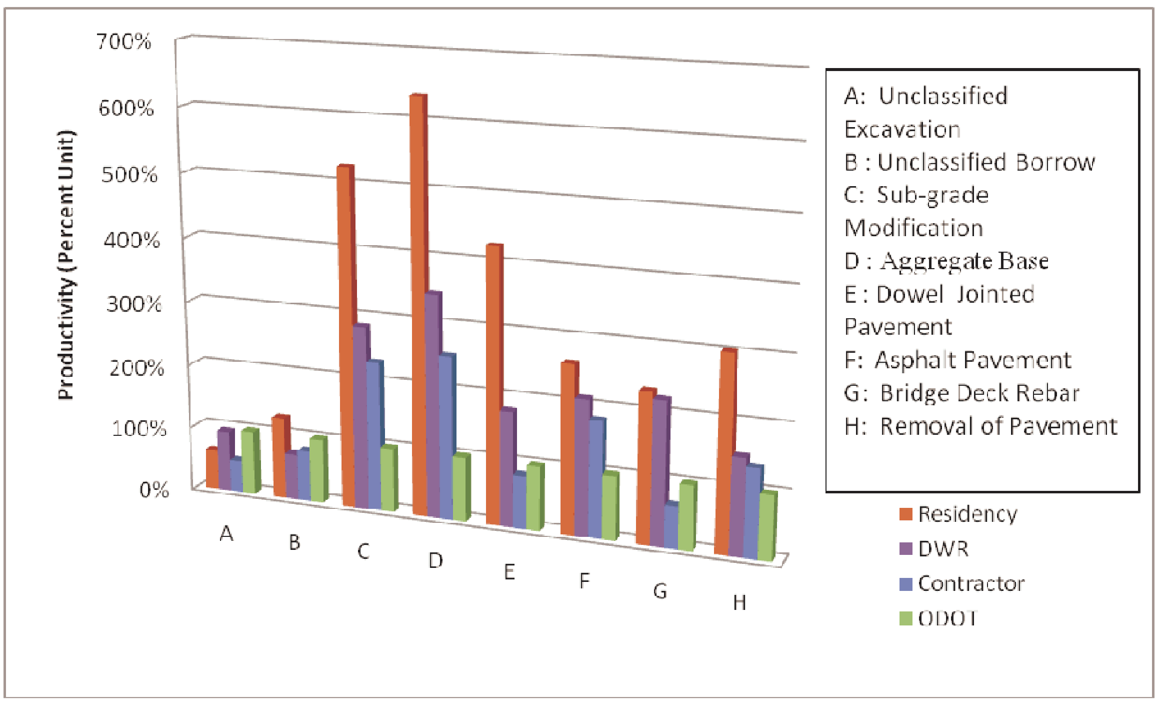


Figure 5.7 Comparison of Production Rate Estimate

This wide range of difference may be attributed to the fact that contractors might not reveal actual productivity data as they would likely keep the data confidential as it is one of their main sources of their competitiveness when bidding highway projects. In addition, it may be difficult to monitor and record some components of factors such as crew size and type of equipment in the preliminary planning of a project. Further, residencies may overestimate the production rates of these activities.

CHAPTER 6

PRODUCTION RATE ESTIMATION MODEL

This chapter discusses production rate prediction models of controlling highway construction activities based on the critical factors affecting productivity. Statistical analysis is first employed to identify the significance of factors and their degrees of impact on production rates of controlling highway activities. Then, prediction models are developed to estimate approximate and reasonable production rates for the selected controlling highway activities.

6.1 Definition

Inferential statistics is the second branch of statistical methods used to draw conclusions and inferences from a research study. Inferential statistics uses patterns in a sample data to draw inferences about the population represented accounting for randomness and uncertainty in the observations (Freund, 2003).

In developing a statistical model, the variables are first classified into independent variables (also called co-variable) and dependent variables (response variable). In this study, all the factors listed in the previous chapter are considered as independent variables except production rate, which is explained by these factors or co-variables.

6.2 Significance of Factors Affecting Production Rate

A pooled t test is employed to test the significance of factors affecting each controlling highway activity. As stated before, a significance level, $\alpha = 0.05$ (95% Confidence Interval) is chosen due to the high variability of factors affecting productivity. Based on the t-test, a p-value of less than 0.05 is considered as significant factor affecting productivity and is used in predicting production rates. P values that lie between 0.05 and 0.1 are considered as secondary factors for this study. Table 6.1 shows the results of the t-test for unclassified excavation.

Table 6.1 Significance of Factors on Unclassified Excavation

Model		Un-standardized Coefficients		Standardized Coefficients	t	P-Value	95% Confidence Interval for B	
		B	Standard Error	Beta			Lower Bound	Upper Bound
1	(Constant)	1814.927	1115.661		1.627	0.108	-408.076	4037.929
	Route No.	297.08	214.537	0.178	1.385	0.17	-130.394	724.553
	Highway Type	-10.864	217.809	-0.006	-0.05	0.96	-444.857	423.129
	No of Lanes	266.105	108.014	0.301	2.464	0.016	50.882	481.328
	AADT	-0.224	0.083	-0.409	-2.682	0.009	-0.39	-0.058
	Soil Data	241.187	127.085	0.203	1.898	0.042	-12.035	494.41
	Seasons	-473.751	174.334	-0.35	-2.717	0.008	-821.119	-126.382
	Temp	8.881	12.968	0.087	0.685	0.496	-16.957	34.72

Number of lanes, AADT, soil type and weather conditions are the most significant factors affecting unclassified excavation. These factors are also significant in unclassified borrow. Weather condition and number of lanes have significant effect on asphalt pavement, while highway type has a moderate effect with P-value of 0.1. The significance of factors for the selected controlling highway activities varies from one to another. Table 6.2 summarizes significant factors obtained from the statistical analysis. The regression analysis for other controlling activities is attached in Appendix H.

Table 6.2 Significant Factors Affecting Highway Production Rates

Controlling Highway Activities	Significant Factors ($p \le 0.05$)	Secondary Factors ($0.1 \le p \le 0.05$)
Unclassified Excavation Unclassified Borrow	Weather (season)	
	Soil Type	
	AADT	
	Number of Lanes	
Aggregate Base	Weather (temperature)	Soil Type
	AADT	
Sub-grade Modification, lime/fly ash	Weather (season & temperature)	Number of Lanes
Asphalt Pavement, Type S-3	Weather (season)	Highway Type
	Number of Lanes	
Removal of pavement	Weather (season)	AADT

The analysis reveals weather as the most significant factor affecting the selected controlling highway activities. The test did not identify statistically any relationship between factors and production rates for dowel jointed pavement and bridge deck rebar. This may be attributed to the low number of data points collected from the DWR. Therefore, a regression model is not developed for dowel jointed pavement and bridge deck rebar.

6.3 Sample Size Determination

Studies have suggested various rules of thumb to determine the minimum number of sample size required for conducting regression analysis. The most widely used rule of thumb is N ≥ 50 + 8m for multiple correlations and N ≥ 104 + m for partial correlation, where N is the number of subjects and m is the number of predictors (Green, 1991). Green (1991) has suggested a sample size determination based on power analysis. Based on his study, four values determine the sample size for conducting a regression analysis. These are α (the probability of making a Type I error), $1-\beta$ (one minus the probability of making a Type II error), R^2, and number of predictors (Chang, 2005). Table 6.3 summarizes the comparison of sample size requirement based on Green's analysis.

Table 6.3 Sample Size Predictor (Green 1991)

Number of Predictors	Sample Size Based on Power Analysis			Sample Size Based on Rule of Thumb		
	Effect Size			Effect Size		
	R^2 = 0.02	R^2 = 0.13	R^2 = 0.26	Small	Medium	Large
1	390	53	24	400	53	23
2	481	66	30	475	63	27
3	547	76	35	545	73	31
4	599	84	39	610	81	35
5	645	91	42	670	89	38
6	686	97	46	725	97	41
7	726	102	48	775	103	44
8	757	108	51	820	109	47
9	788	113	54	860	115	49
10	844	117	56	895	119	51
15	952	138	67	1045	139	60
20	1066	156	77	1195	159	68
30	1247	187	94	1495	199	85
40	1407	213	110	1795	239	103

For this study, a sample size based on power analysis is considered to conduct regression analysis. A model with a sample squared multiple correlation coefficient, R^2 greater than 0.26 is considered sufficient for developing a production rate estimation model. For instance, in order to conduct a regression model with 6 number of predictors or factors, 46 data points should be acquired. Based on the number of data points obtained from DWR, the selected controlling activities have sufficient data points except bridge deck rebar (39) and dowel jointed pavement (15).

6.4 Goodness of fit test

The goodness-of-fit determines whether a statistical model fits the collected data by analyzing the difference between the observed values and their expected values in the model (Freund & Wilson, 2003). For this study, the goodness-of-fit is assessed quantitatively with a hypothesis test using the Anderson-Darling (AD) test and a probability plot.

Goodness-of-fit tests use the following hypotheses:

H_0: The model adequately describes DWR productivity

H_1: The model does not adequately describe DWR productivity

The Anderson-Darling test compares the empirical cumulative distribution function of the sample data with the expected distribution if the data are normal (Aron, 2001). If the observed difference is sufficiently large, the test rejects the null hypothesis of population normality. The probability plot calculates the cumulative distribution function (cdf) and associated confidence intervals based on parameters estimated from the collected data. Figures 6.1 & 6.2 show the probability plot of production rate for laying asphalt pavement & bridge deck rebar with 95% confidence interval.

As shown in Figure 6.1, the DWR data points fall close to the fitted distribution line. In addition, the p-value for laying asphaltic pavement is 0.274 which is greater than $\alpha = 0.05$, and the Anderson-Darling statistic is small enough. Similarly, the p-value for bridge deck rebar is 0.301 with AD statistic of 0.561. Although there is a slight tendency for these data to be heavier in the tails than a normal distribution because the smallest points are above the line and the largest point is just below the line, we can conclude that the distribution fits the DWR data.

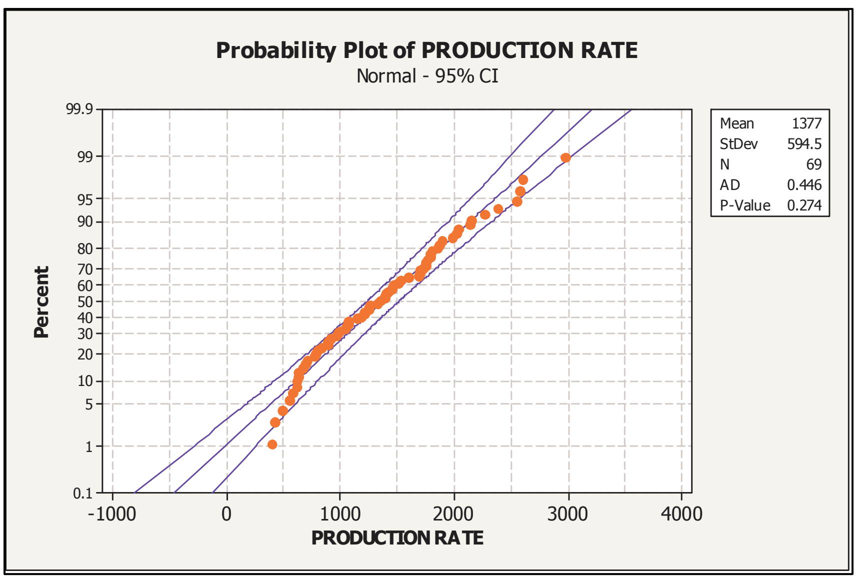


Figure 6.1 Probability Plot of Asphaltic Pavement Type S3

The probability plot for unclassified borrow is shown in Figure 6.3. As shown the AD statistics is over 1.00 and the p-value statistics is below 0.05. This indicates that, at α levels greater than 0.007, there is evidence that the data do not follow a normal distribution. Based on the goodness-of –fit, the distribution fits the DWR data for asphaltic pavement type S3, bridge deck rebar, unclassified excavation, sub-grade modification, removal of pavement and pc dowel jointed pavement. The probability plot for other controlling activities is attached in Appendix H.

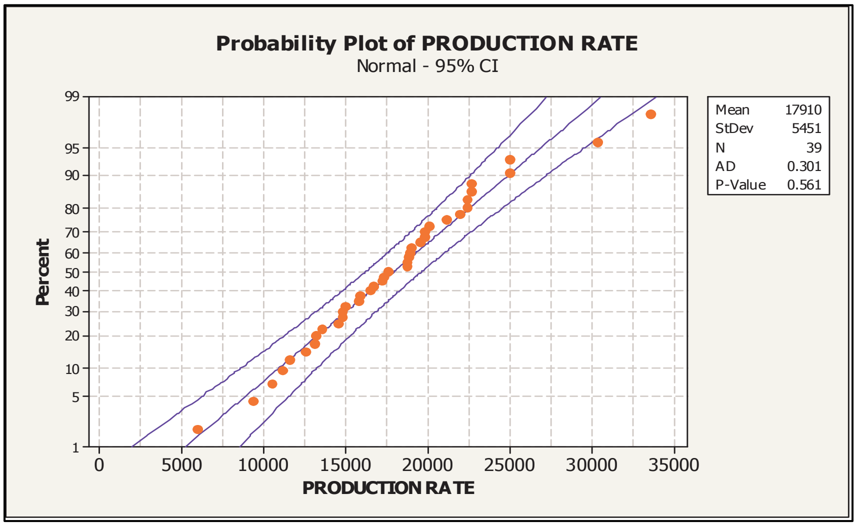


Figure 6.2 Probability Plot of Bridge Deck Rebar

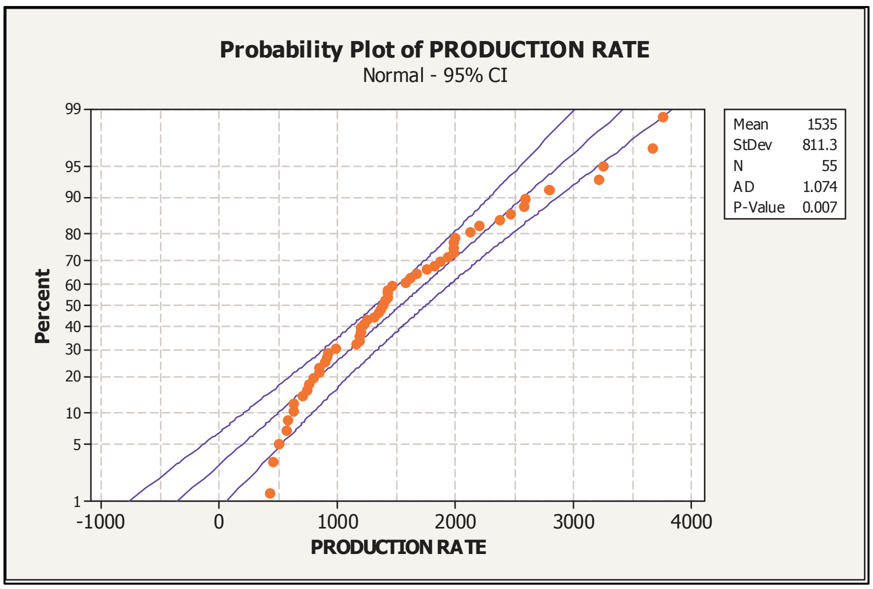


Figure 6.3 Probability Plot of Unclassified Borrow

6.5 Regression Analysis

A multiple linear regression is then used to describe the relationship of factors affecting productivity with a model so that one can predict future highway production rates. Multiple regression is a flexible method of data analysis that may be appropriate whenever a quantitative variable is to be examined in relationship to any other factors (Berger, 2003). Once the relationship and significance of factors are identified, a checking for the sample size of data points must be conducted in order to perform a regression analysis. Freund and Wilson (2003) define regression analysis as a statistical method used for analyzing a relationship between two or more variables in such a manner that one can variable can be predicted or explained by using information on others. A multiple linear regression model can be expressed by Equation 6.1,

$$y = \beta_o + \beta_1 x_1 + \beta_2 x_2 + \ldots\ldots \beta_m x_m + \varepsilon \ldots\ldots\ldots\ldots\ldots \quad (Eq.\ 6.1.)$$

Where, y is the dependent or response variable, and $X_,$, i = 1, 2…m, are the independent variables. The β_i are the parameters or regression coefficients for each independent variables and β_0 is the intercept. ε is the random error. The following assumptions apply in performing regression analysis (Freund and Wilson, 2003),

a. The model has been properly specified
b. The variance of the residuals is σ_2 for all observations.
c. There are no outliers.
d. The error terms are at least approximately normally distributed.

The strength of prediction from a multiple regression equation is measured by the square of the multiple correlation coefficient, R^2. R can be explained mathematically by Equation 6.2.

$$R^2 = \frac{SS.due.to.regression.\mathrm{mod}\,el}{total.SS.for.y.corrected.for.the.mean} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (Eq.\ 6.2.)$$

In other words, R^2 (coefficient of determination) measures the proportional reduction in variability about the mean resulting from the fitting of the multiple regression model (Freund and Wilson, 2003). R^2 is also called the measurement of the goodness of fit of the regression line. Table 6.4 summarizes the values of R^2 for the selected controlling highway activities.

Table 6.4 Coefficient of Determination, R^2

CONTROLLING ACTIVITY	R	R^2	Adjusted R^2	Standard Error of the Estimate
UNCLASSIFIED EXCAVATION	.555a	0.308	0.242	1307.507
UNCLASSIFIED BORROW	.841a	0.707	0.645	520.566
AGGREGATE BASE	.941a	0.886	0.62	210.602
LIME/CEMENTETIOUS STABILIZED SUBGRADE	.762a	0.58	0.265	1275.04
(SP)ASPHALT CONCRETE TYPE S3	.751a	0.563	0.474	464.059
DOWEL JOINTED CONCRETE PAVEMENT	.991a	0.982	0.926	289.914
BRIDGE DECK REBAR	.514a	0.264	-0.012	5970.373
REMOVAL OF CONCRETE PAVEMENT	.842a	0.709	0.553	428.014

All controlling activities fall within 95% confidence interval with R^2 greater than 0.26. Bridge deck rebar does not represent a good fit of the regression line. Based on the sample size predictor and coefficient of determination, a regression equation is developed for controlling highway activities. A summary of the regression equations is given in Table 6.5.

Table 6.5 Regression Equations

Unclassified Excavation	$PR = 297.X_1 - 11.X_2 + 266.X_3 - 0.22.X_4 + 241.X_5 - 474.X_6 + 9.X_7 + 1815$
Unclassified Borrow	$PR = 258.X_1 - 244.X_2 + 260.X_3 - 0.19.X_4 + 740.X_5 - 375.X_6 - 3.X_7 + 354$
Sub-grade Modification	$PR = 745.X_1 + 757.X_3 + 0.35.X_4 + 548.X_5 - 83X_6 + 21.X_7 + 1123$
Aggregate Base	$PR = -78.X_1 + 90.X_2 - 55.X_3 - 4.X_5 - 278.X_6 + 3.X_7 + 984$
Asphalt Pavement, Type S-3	$PR = -294.X_1 + 471.X_2 - 587.X_3 + 3633$
Removal of pavement	$PR = -123.X_1 + 82.X_2 + 117.X_3 - 154.X_5 - 500.X_6 - 11.X_7 + 4190$

Where, X1, X2, X3, X4, X5, X6 and X7 represent Type of Route, Highway Type, Number of Lanes, AADT, Soil Type, Season and Temperature respectively. For instance, production rate for unclassified excavation can be calculated as:

Production Rate = 297 * Route Type - 11 * Highway Type + 266 * Number of Lanes – 0.22 * AADT + 241 * Soil Type - 474 * Season + 9 * Temperature + 1815.

6.6 Sensitivity Analysis

Once the regression equations are developed, a sensitivity analysis based on scenarios is conducted to validate significant factors obtained from statistical analysis.

The study uses this concept of sensitivity analysis in identifying influential factors. Sensitivity analysis begins with a base-case situation, which is developed using the expected values for each input. Each variable or factor is changed by several percentage points above and below the expected value, holding all other variables constant (Brigham, 2008). Then a new production rate is calculated using each of these values. Finally, the set of production rates is plotted to show how sensitive production rate is to variation in factors. Figure 6.4 illustrates the sensitivity graph for unclassified excavation.

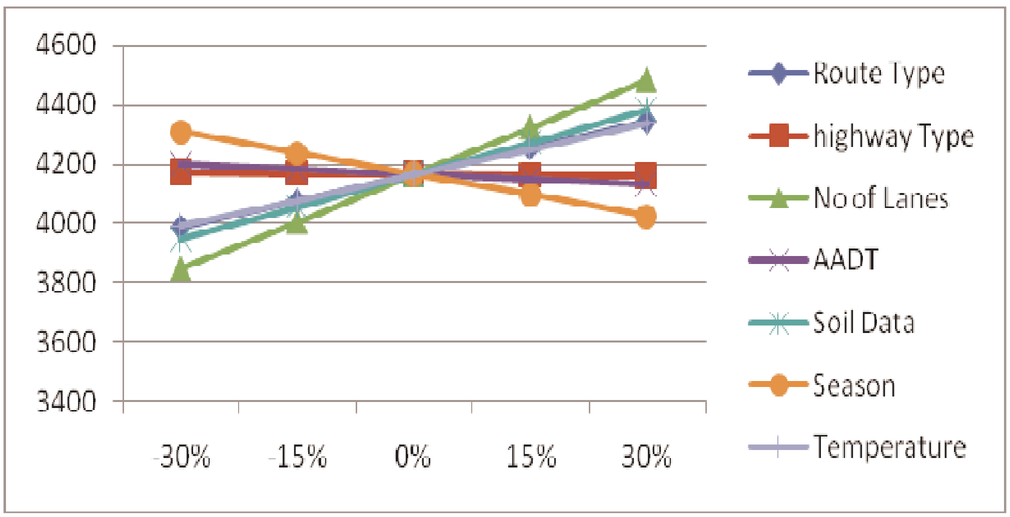


Figure 6.4 Sensitivity Analysis for Unclassified Excavation

The slopes of the lines in the graph show how sensitive production rate is to changes in each of the inputs: The steeper the slope, the more sensitive the production rate is to a change in the variable (Brigham, 2008). Figure 6.4 shows that production rate is very sensitive to number of lanes, soil type and weather condition, fairly sensitive to route type and not very sensitive to highway type and AADT. Similarly a sensitivity analysis for aggregate base shows that, it is very sensitive to number of lanes, weather condition and soil type, fairly sensitive to route type, AADT and not very sensitive to highway type and season. The sensitivity analysis for other controlling activities is attached in Appendix J.

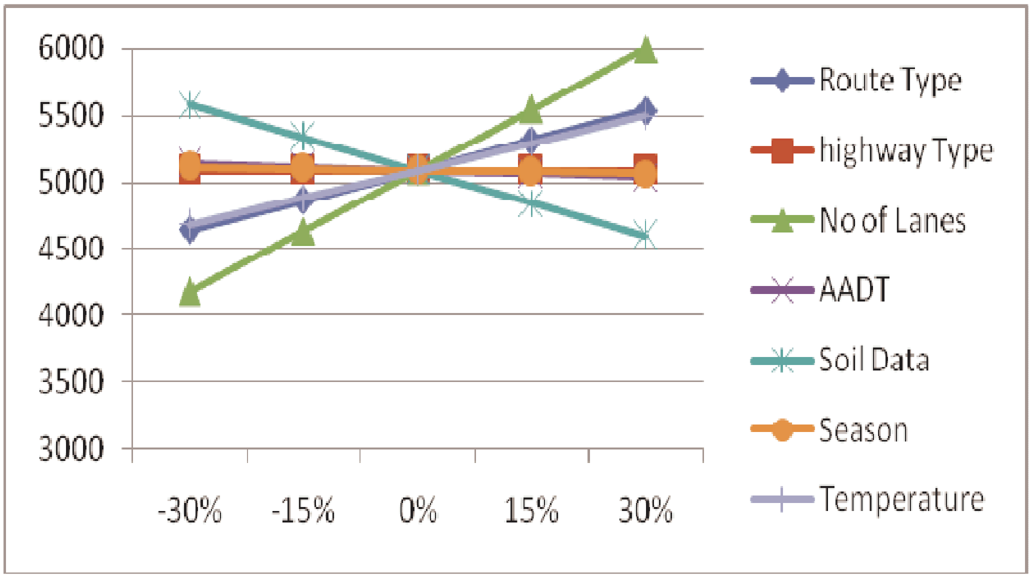


Figure 6.4 Sensitivity Analysis for Aggregate Base

Sensitivity analysis is a technique that indicates how much a base unit will change in response to a given change in an input variable, other things held constant (Brigham, 2008). When limited amount of project data is available, there is a need to get more accurate information about sensitive variables in order to predict a more reliable production rate. Therefore, the sensitivity analysis has proved that the significant factors obtained from regression analysis gives a reliable estimate of production rates of controlling highway activities.

CHAPTER 7

DEVELOPMENT OF A STANDALONE PROGRAM

A standalone software program is developed for estimating production rates of controlling highway activities based on engineers' estimate and the regression models as described in chapter 5 and 6 respectively. The software incorporates all factors identified from Daily Work Reports (DWR) and engineers' survey for the selected controlling highway activities. The system is called Oklahoma Production Rate Estimator (OPRE). It is developed using Visual Basic in Microsoft Excel program to make the system a user friendly program.

The system consists of two sections: an input section and an output section. The input section of the model or the front end model involves the user to select project conditions (factors) for a particular controlling activity, while the output section or back end model provides a reasonable production rate estimate based on the selected criterion. Finally, the validation of the program is conducted.

7.1 Front End of the Model

The front end model allows the user to select the source of production rate estimate and accompanying factors or project conditions for controlling highway activities. The front end model consists of three parts. The first part allows the user to select the source for estimating production rate, either DWR or engineers estimate. Figure 7.1 shows a screen shot of OPRE program.

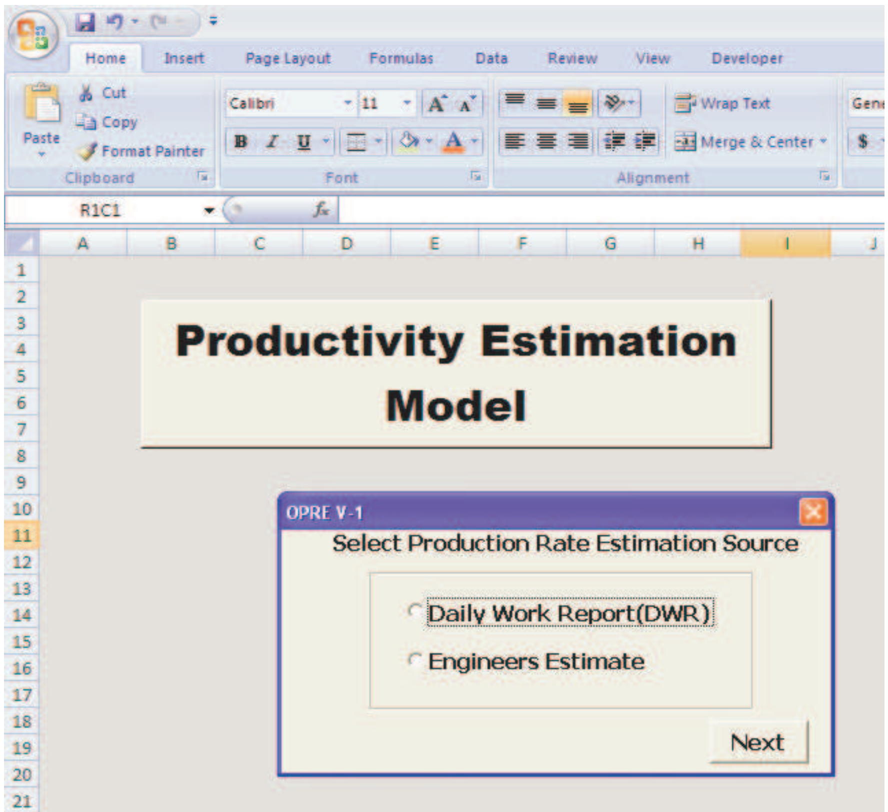


Figure 7.1 OPRE Front Screen

The second part allows the user to select the required controlling highway activity. In case of engineers' estimate, a drop down menu which lists controlling highway activities is developed. In addition, the user has an option to choose production rate estimate either from contractors' perspective or residencies. Figures 7.2 and 7.3 show the selection of controlling highway activities. Finally, the user can select the project conditions for a particular controlling highway activity. For the DWR selection, the user has the option to select only critical or significant factors or may add additional factors (Figure 7.4). The significant factors are mandatory to produce an output of production rate estimate. In case of engineers' estimate, the program lists the factors in a drop down menu (Figure 7.5). For missing data points, the system leaves a blank space or puts a hyphen sign.

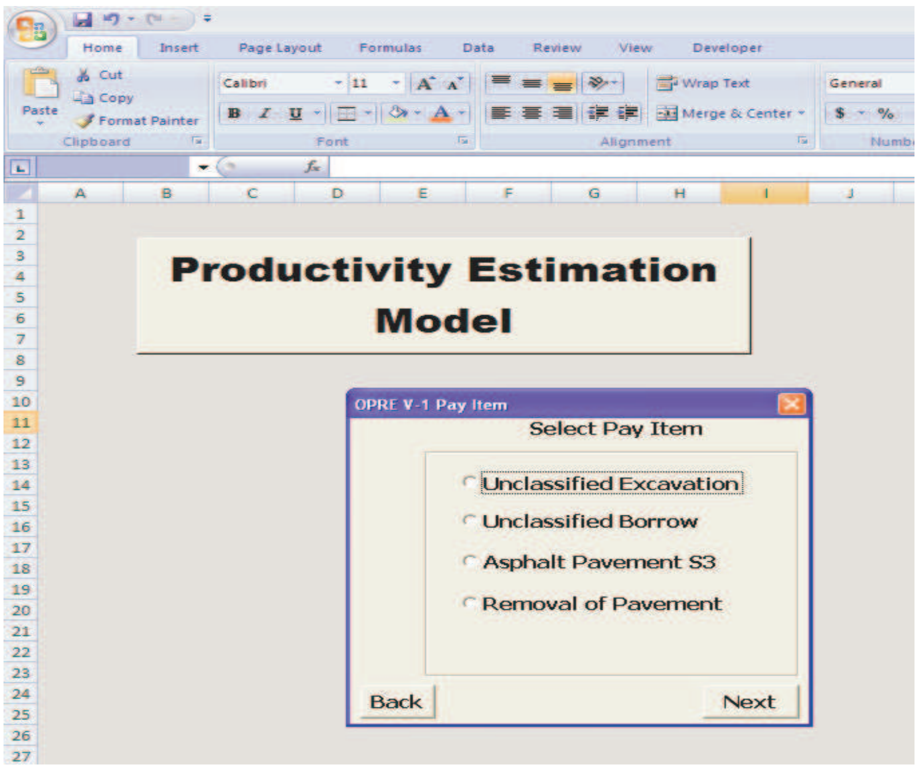


Figure 7.2 Selection of Controlling Highway Activity (DWR)

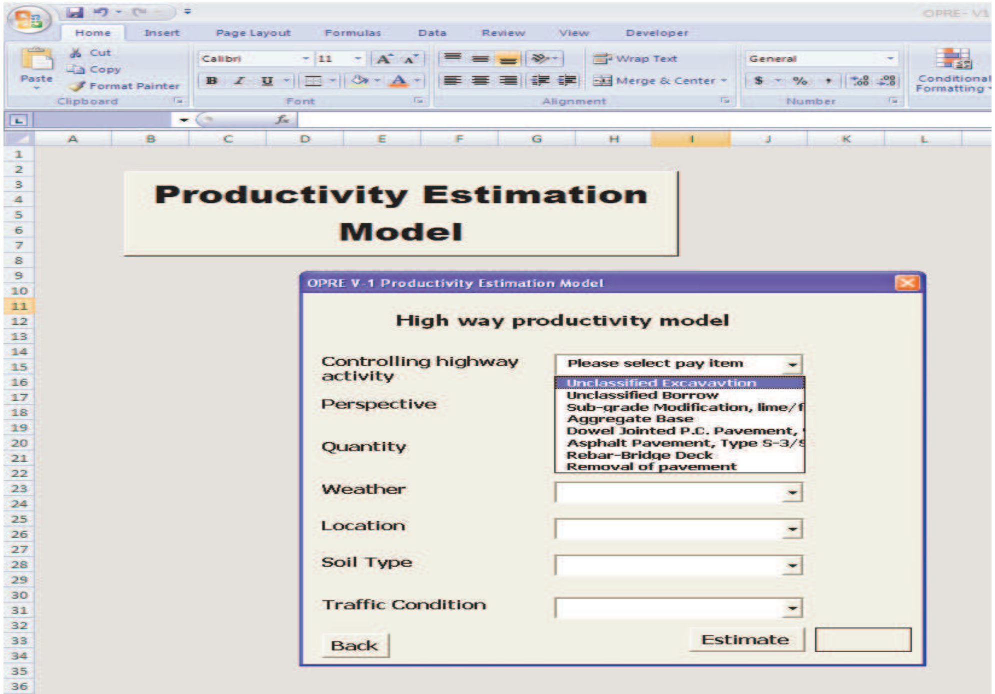


Figure 7.3 Selection of Controlling Highway Activity (Engineers' Estimate)

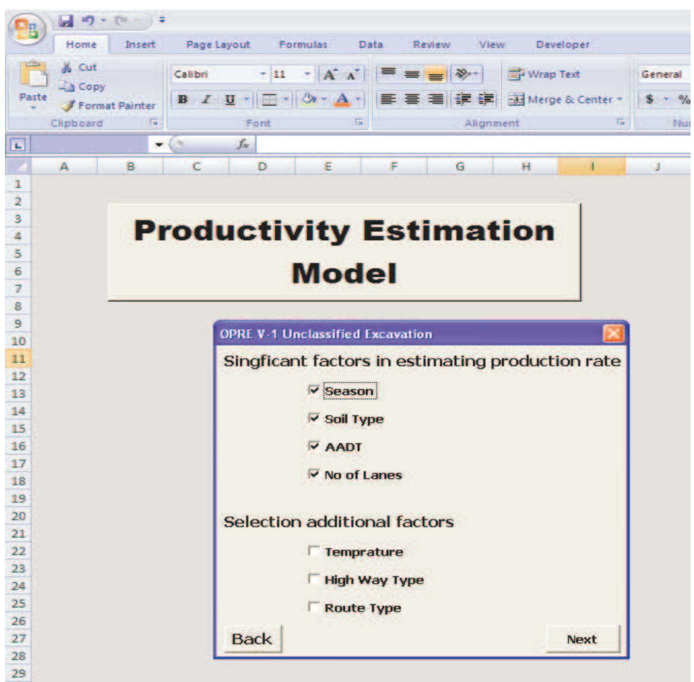


Figure 7.4 Selection of Factors (DWR)

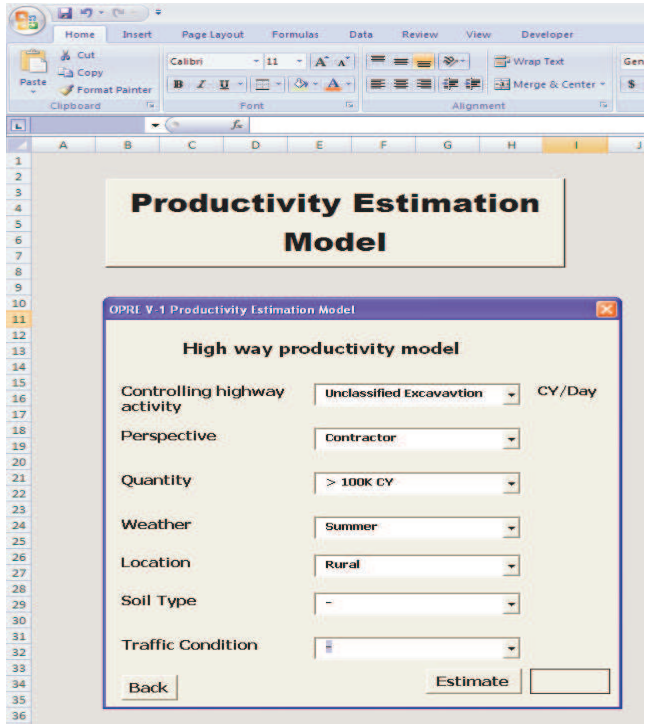


Figure 7.5 Selection of Factors (Engineers' Estimate)

7.2 Back End of the Model

Once the required inputs are fed, the back end model estimates a reasonable production rate based on the factors obtained from DWR and engineers survey. The system allows the user to go back at any stage to further change project conditions before requesting for production rate estimate. The system uses an average 8-hr per day of standardized work hours. A screen shot of the output model is shown on the same page as the factor or project condition selection (Figure 7.6). For instance, for unclassified excavation with quantity of work greater than 100,000 CY, during the summer time, where the project site is located in the rural area, a contractor's average estimate of productivity is 2460CY per day.

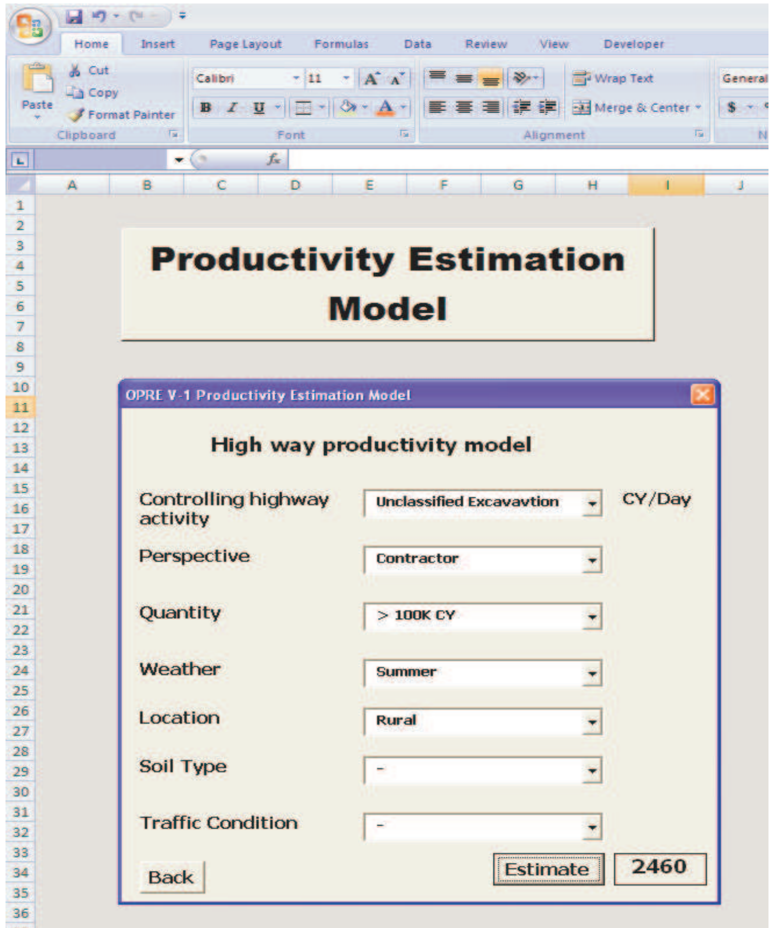


Figure 7.6 Production Rate Estimate

7.3 Validation of the OPRE

Once the OPRE was completed, a validation of the program was conducted by randomly taking two construction activities and testing the production rate estimates with the DWR regression model for controlling activities with significant amount of data points and with survey database for activities with insufficient data points. In order to conduct unclassified excavation, during summer, under 2-lane highway with AADT of 1000 and which encountered heavy clay soil, the regression model estimated 1894Cy/day while the program estimated 1890.57Cy/day. This difference resulted due to the rounding of coefficients. A residency estimate for laying aggregate base of more than 15,000Cy during summer, in rural area resulted in 2050Cy/day which is the same as the engineers' estimate. Table 7.1 illustrates the results of the validation.

Table 7.1 Comparison of Production Rate

Controlling Activity	Factors		DWR Regression Model	OPRE	Survey Database
Unclassified Excavation	Season	Summer	1894	1890.573	
	Soil Type	Heavy Clay			
	AADT	1000			
	No. of Lanes	2			
Aggregate Base	Season	Summer		2050	2050
	Perspective	Residency			
	Quantity	> 15K Cy			
	Location	Rural			

Further testing of the program will also be conducted for other controlling activities. In addition, it will be sent to ODOT engineers and residencies to fully prove its reliability before sending out to engineers' and consultants across Oklahoma.

CHAPTER 8

CONCLUSIONS & RECOMMENDATIONS

8.1 Summary

The objectives of this study are to identify major factors affecting highway construction production rates and asses their relationship with controlling highway activities, to develop production prediction models for selected controlling highway activities, and to develop a standalone software program. These objectives have been accomplished through three main tasks.

The first task of the study identified controlling highway activities; studied current approaches practiced by State DOTs and prior studies conducted on productivity; and selected ongoing and recently completed highway projects, through extensive literature reviews and a series of meetings with ODOT engineers and contractors. The second task of the study identified major factors; collected productivity data and assessed the relationship of factors with controlling highway activities by collecting historically recorded data; conducted two set of questionnaire surveys and applied statistical methods. The third task has compared different productivity data; developed production prediction models or regression models for controlling highway activities with significant number of data points and prediction models based on subjective data from surveys for activities with insufficient data points; and developed a standalone software program using Microsoft Excel program.

8.2 Findings and Contributions

The study has selected a) unclassified excavation; b) unclassified borrow; c) aggregate base; d) sub-grade modification, e) asphaltic concrete; f) dowel jointed pavement; g) bridge deck rebar; and h) removal of pavement as controlling highway activities. Based on the statistical analysis, it was concluded that the major factors affecting production rates are weather conditions (temperature and seasonal changes); geographic location of highway projects; traffic condition; quantity of work; size of contractor; and soil type for earthwork activities. In addition, type of route, number of lanes and type of roadway are major factors affecting production rates of controlling highway activities.

Higher production rates were observed when highway projects are constructed during summer at temperature between 65˚F and 85˚F; under sandy/sandy loam soil condition; project located in rural area; concrete pavement; Interstate highway of 8-lane roadway. A survey of productivity data among contractors and residencies resulted in a much lower contractors' production rate when compared to residencies because contractors likely keep their data confidential for the purpose of bidding.

Scatter plot and box plot were used to describe the relationship of factors with production rates. Further, a pooled t-test and regressions were used to determine the significance of factors on productivities of each controlling activity. The goodness of fit test was conducted to test whether the statistical model fit the DWR productivity data and the data fits the model for more than 90% of the controlling activities. Based on the square of the multiple correlation coefficient a multiple regression model is developed for controlling highway activities. Finally, standalone software which predicts production rates of controlling highway activities have been developed based on engineers' estimate and DWR's regression model using Microsoft Excel (Visual basic).

The study implemented the FHWA guide for Contract Time Determination procedure in establishing production rates to be used for determining contract time. The study followed ODOT's tier classification of highway projects in selecting highway projects. Historical records (Daily Work Reports) of recently completed projects were used as primary source in the determination of production rates in order to obtain the most accurate production rate data. In addition, questionnaire surveys with highly experienced engineers were conducted to capture their accumulated knowledge and experience on productivity of controlling highway activities. The study also conducted a sensitivity analysis in identifying significant factors in order to predict a more reliable production rate.

8.3 Lessons Learned

ODOT should bid projects by early January so that construction projects can start by mid of March or early of April in order to have longer duration of work hours and efficient productivity of highway activities during the summer and fall seasons. Highway construction projects should be designed in large scale to increase the efficiency in production rates of highway activities. Mass production and increased scale of operation leads to an increase in highway construction production rates. In addition, the selection of efficient and specialized construction firms will also increase the productivity of highway construction activities. Further, it is concluded that full lane closure of both rehabilitation projects or construction of new highway projects have higher production rates of highway construction activities than half lane closure. Although the advancement in technology (material, equipment & machineries), and better management systems are difficult to statically analyze the effects on production rates in preliminary scheduling of highway projects, they should be incorporated in project control and progress tracking of highway projects.

Therefore, engineers and schedulers should take these factors into consideration in estimating production rates of highway activities. Engineers and schedulers can use the developed system for progress tracking and future estimating & bidding guidelines.

8.4 Recommendation for Future Work

ODOT stores a huge amount of project data in its contract administration software, SITEMANAGER. Daily work reports (DWR) of highway construction projects is part of the data stored in this software. However there is no standard format for collecting and recording this daily work reports (DWR). The problems associated with recording the DWR in such a manner include: a) inspectors are spending a huge amount of time every day in recording this data (spend one and a half to three hours per day) b) most of these stored data are linguistic data and c) the data is inconsistent as remarks are written differently by different inspectors. These problems make DWR a time consuming process for project managers and schedulers to extract production rate and other important information. Moreover, important information might be missed while recording these data. The DWR is a tool both for managing the current project and planning future projects. Therefore an innovative and standardized framework of data collection, storage, and record keeping should be developed. This can be achieved by:

1. Planning and controlling the level of detail of data collection should be determined considering the efficiency of data handling.
2. Study of highway construction projects in order to breakdown construction activities into the desired level, categorize, and synchronize information required to be stored as DWR.

REFERENCES

1.AbouRizk, S., Knowles, P., and Hermann, U.R., “Estimating Labor Production Rates for industrial Construction Activities”, Journal of Construction Engineering and Management, Vol. 127, No. 6, pg. 0502-0511, Novemeber/Decemeber 2001.

2.Chao, Li-Chung, and Skibniewski, Miroslaw J., “Estimating Construction Productivity: Neural-Network-Based Approach”, Journal of Computing in Civil Engineering, Vol. 8, No. 2, pg. 234-251, April 1994.

3. Chong, Wai Kiong, “Construction Production Rate Information System for Highway Projects”, Dissertation for PHD at the University of Texas at Austin, May 2005.

4. Christian, John and Hachey, Daniel, “Effects of Delay Times on Production Rates in Construction”, Journal of Construction Engineering and Management, Vol. 121, No. 1, pg. 0020-0026, March 1995.

5.El-Rayes, Khaled and Moselhi, Osama, “Impact of Rainfall on the Productivity of Highway Construction”, Journal of Construction Engineering and Management, Vol. 127, No. 2, pg. 0125-0131, March/April 2001.

6.Green, S. B. (1991). “How Many Subjects Does It Take to Do A Regression Analysis?” Multivariate Behavioral Research, Lawrence Erlbaum Associates, 26(3), 499-510.

7.Hancher, D. E., McFarland, W. F., and Alabay, R. T. (1992) “Construction Contract Time Determination” Texas Department of Transportation Research Report.

8.Herbsman, Z. J., and Ellis, R., “Determination of Contract Time for Highway Construction Projects.”, National Cooperative Highway Research Program Synthesis of Highway Practice 215, Transportation Research Board, National Research Council, Washington, DC, 43PP, October,1995.

9. Jiang, Yi and Wu, Hongbo, “Production Rates of Highway Construction Activities”, International Journal of Construction Education and Research, Vol. 3, pg. 81-98, May 2007.

10. Lee, Eul-Bum, Lee, Hojung, and Ibbs, C.W., “Productivity Aspects of Urban Freeway Rehabilitation with Accelerated Construction”, Journal of Construction Engineering and Management, Vol. 133, No. 10, pg. 798-806, October 2007.

11. O’Connor, James and Huh, Youngki, “Crew Production Rates for Contract Time Estimation: Bent Footing, Column, and Cap of Highway Bridges”, Journal of Construction Engineering and Management, Vol. 131, No. 9, pg. 1013-1020, September 2005.

12. O’Connor, James and Huh, Youngki, “Crew Production Rates for Contract Time Estimation: Beam Erection, Deck, and Rail of Highway Bridges”, Journal of Construction Engineering and Management, Vol. 132, No. 4, pg. 408-415, September 2006.

13.Pan, Nang-Fei, “Assessment of Productivity and Duration of Highway Construction Activities subject to Impact of Rain”, Expert systems with Applications, Vol. 28, pg. 331-326, 2005.

14.Smith, Simon D., “Earthmoving Productivity Estimation Using Linear Regression Techniques”, Journal of Construction Engineering and Management, Vol. 125, No. 3, pg. 0133-0141, May/June 1999.

15. Thomas, H. R. and Zavrski, I. (1999), "Construction Baseline Productivity: Theory and Practice", Journal of Construction Engineering and Management, 125 (5), pp 295-303.

16. US Department of Transportation, Federal Highway Administration (FHWA), "FHWA Guide for construction contract time determination procedures", (10/15/02: replaces TA 5080.15, dated 10/11/91).

17. Zar, J. H., "Bio-statistical Analysis", Second Edition, Prentice Hall, Inc., New Jersey, 1996

APPENDICES

APPENDIX A: DATA COLLECTION SHEET

CONT_ID	ROUTE	DESCRIPTION	COUNTY	DIVISION	ROUTE	HIGHWAY	CONTRACT AMOUNT	CONTRACTOR	ITM_CD	DESC1	UNIT	TEMPERATURE	QUANTITY	DURATIO	PRODUCT	SOIL	SEASON	AADT	TERRAIN	NO OF	Functiona	REMARKS
040104	US-75	GRADE, DRAIN SURFACE AND BRIDGE	Washington County	08	US-75	COMB	$13,883,410.19	APAC-OKLAHOMA, INC.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	78.5	9555	3	3185.0	0	summer	1440	2	4	3	
040104	US-75	GRADE, DRAIN SURFACE AND BRIDGE	Washington County	08	US-75	COMB	$13,883,410.19	APAC-OKLAHOMA, INC.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	75	28309	6	4662.0	0	summer	1440	2	4	3	
040104	US-75	GRADE, DRAIN SURFACE AND BRIDGE	Washington County	08	US-75	COMB	$13,883,410.19	APAC-OKLAHOMA, INC.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	74.8	4571	8	571.0	0	summer	1440	2	4	3	side works
040104	US-75	GRADE, DRAIN SURFACE AND BRIDGE	Washington County	08	US-75	COMB	$13,883,410.19	APAC-OKLAHOMA, INC.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	73.6	40966	4	10242.0	0	fall	1440	2	4	3	
040211	I-35	RESURFACE AND BRIDGE REPLACEMENT	Logan County	04	I-35	CONC	$4,866,609.27	DUIT CONSTRUCTION COMPANY, INC.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	47	4803	9	534.0	Lean Clay	spring	2915	1	4	1	
040220	SH-3	GRADE, DRAIN, SURFACE AND BRIDGE	Pushmataha County	02	SH-3	COMB	$2,198,058.54	MUSKOGEE BRIDGE COMPANY, INC.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	52.75	644	1	644.0	Lean Clay	spring	3976	1	4	3	
040339	SH-51	GRADE, DRAIN, SURFACE AND EROSION CONTROL	Creek County	08	SH-51	ASPH	$4,738,169.40	BECCO CONTRACTORS, INC.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	33	1080	1	1080.0	0	winter	1330	7	4	4	
040339	SH-51	GRADE, DRAIN, SURFACE AND EROSION CONTROL	Creek County	08	SH-51	ASPH	$4,738,169.40	BECCO CONTRACTORS, INC.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	44	2898	1	2898.0	0	winter	1330	7	4	4	
040339	SH-51	GRADE, DRAIN, SURFACE AND EROSION CONTROL	Creek County	08	SH-51	ASPH	$4,738,169.40	BECCO CONTRACTORS, INC.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	51	4174	1	4174.0	0	winter	1330	7	4	4	
040339	SH-51	GRADE, DRAIN, SURFACE AND EROSION CONTROL	Creek County	08	SH-51	ASPH	$4,738,169.40	BECCO CONTRACTORS, INC.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	50	6066	1	6066.0	0	winter	1330	7	4	4	
040339	SH-51	GRADE, DRAIN, SURFACE AND EROSION CONTROL	Creek County	08	SH-51	ASPH	$4,738,169.40	BECCO CONTRACTORS, INC.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	64	4050	1	4050.0	0	winter	1330	7	4	4	
040339	SH-51	GRADE, DRAIN, SURFACE AND EROSION CONTROL	Creek County	08	SH-51	ASPH	$4,738,169.40	BECCO CONTRACTORS, INC.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	41	2770	1	2770.0	0	winter	1330	7	4	4	
040339	SH-51	GRADE, DRAIN, SURFACE AND EROSION CONTROL	Creek County	08	SH-51	ASPH	$4,738,169.40	BECCO CONTRACTORS, INC.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	48	3330	1	3330.0	0	spring	1330	7	4	4	
040339	SH-51	GRADE, DRAIN, SURFACE AND EROSION CONTROL	Creek County	08	SH-51	ASPH	$4,738,169.40	BECCO CONTRACTORS, INC.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	70	3444	1	3444.0	0	spring	1330	7	4	4	
040339	SH-51	GRADE, DRAIN, SURFACE AND EROSION CONTROL	Creek County	08	SH-51	ASPH	$4,738,169.40	BECCO CONTRACTORS, INC.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	65	2968	1	2968.0	0	spring	1330	7	4	4	
040349	SH-3	GRADE, DRAIN, SURFACE AND BRIDGE	Pushmataha County	02	SH-3	ASPH	$1,676,139.56	WITTWER CONSTRUCTION CO., INC.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	57	2111	2	1056.0	Sandy	spring	335	2	4	3	
040380	US-75	GRADING, DRAINAGE, SURFACING & BRIDGE	Tulsa County	08	US-75	CONC	$15,608,000.51	SHERWOOD CONSTRUCTION CO., INC.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	46.72	48576	9	5397.0	Lean Clay	winter	4920	6	4	2	
040380	US-75	GRADING, DRAINAGE, SURFACING & BRIDGE	Tulsa County	08	US-75	CONC	$15,608,000.51	SHERWOOD CONSTRUCTION CO., INC.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	49.3	66661	10	6666.0	Lean Clay	spring	4920	6	4	2	
040380	US-75	GRADING, DRAINAGE, SURFACING & BRIDGE	Tulsa County	08	US-75	CONC	$15,608,000.51	SHERWOOD CONSTRUCTION CO., INC.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	51.06	96994	8	12124.0	Lean Clay	spring	4920	6	4	2	
040380	US-75	GRADING, DRAINAGE, SURFACING & BRIDGE	Tulsa County	08	US-75	CONC	$15,608,000.51	SHERWOOD CONSTRUCTION CO., INC.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	55.875	63494	4	15874.0	Lean Clay	spring	4920	6	4	2	
040380	US-75	GRADING, DRAINAGE, SURFACING & BRIDGE	Tulsa County	08	US-75	CONC	$15,608,000.51	SHERWOOD CONSTRUCTION CO., INC.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	59.17	83138	6	13856.0	Lean Clay	spring	4920	6	4	2	
040380	US-75	GRADING, DRAINAGE, SURFACING & BRIDGE	Tulsa County	08	US-75	CONC	$15,608,000.51	SHERWOOD CONSTRUCTION CO., INC.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	66.83	123387	9	13710.0	Lean Clay	spring	4920	6	4	2	
040380	US-75	GRADING, DRAINAGE, SURFACING & BRIDGE	Tulsa County	08	US-75	CONC	$15,608,000.51	SHERWOOD CONSTRUCTION CO., INC.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	72.08	157740	12	13145.0	Lean Clay	spring	4920	6	4	2	
040396	CITY STREETS/	GRADE, DRAIN, SURFACE AND BRIDGE	Garfield County	04	CITY STREETS/	COMB	$2,842,029.38	THE CUMMINS CONSTRUCTION CO., INC.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	31.75	1240	3	413.0	Lean Clay	spring	9800	6	4	3	ditches
040396	CITY STREETS/	GRADE, DRAIN, SURFACE AND BRIDGE	Garfield County	04	CITY STREETS/	COMB	$2,842,029.38	THE CUMMINS CONSTRUCTION CO., INC.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	61	480	1	480.0	Lean Clay	spring	9800	6	4	3	ditches
040396	CITY STREETS/	GRADE, DRAIN, SURFACE AND BRIDGE	Garfield County	04	CITY STREETS/	COMB	$2,842,029.38	THE CUMMINS CONSTRUCTION CO., INC.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	58	636	1	636.0	Lean Clay	spring	9800	6	4	3	ditches
040396	CITY STREETS/	GRADE, DRAIN, SURFACE AND BRIDGE	Garfield County	04	CITY STREETS/	COMB	$2,842,029.38	THE CUMMINS CONSTRUCTION CO., INC.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	54.25	1210	2	605.0	Lean Clay	4	spring	6	4	3	
040396	CITY STREETS/	GRADE, DRAIN, SURFACE AND BRIDGE	Garfield County	04	CITY STREETS/	COMB	$2,842,029.38	THE CUMMINS CONSTRUCTION CO., INC.	202(C) 0184	UNCLASSIFIED BORROW, RDY	CY	66.5	450	1	450		5	spring				
040396	CITY STREETS/	GRADE, DRAIN, SURFACE AND BRIDGE	Garfield County	04	CITY STREETS/	COMB	$2,842,029.38	THE CUMMINS CONSTRUCTION CO., INC.	202(C) 0184	UNCLASSIFIED BORROW, RDY	CY	77	1350	1	1350		6	summer				
040396	CITY STREETS/	GRADE, DRAIN, SURFACE AND BRIDGE	Garfield County	04	CITY STREETS/	COMB	$2,842,029.38	THE CUMMINS CONSTRUCTION CO., INC.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	82	1010	2	505.0	Lean Clay	6	summer	6	4	3	
040396	CITY STREETS/	GRADE, DRAIN, SURFACE AND BRIDGE	Garfield County	04	CITY STREETS/	COMB	$2,842,029.38	THE CUMMINS CONSTRUCTION CO., INC.	202(C) 0184	UNCLASSIFIED BORROW, RDY	CY	84	1425	1	1425		9	fall				
040436	I-35	GRADE, DRAIN, SURFACE/RESURFACE &	Love County	07	I-35	CONC	$24,831,744.31	DUIT CONSTRUCTION COMPANY, INC.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	76.125	5018	4	1255.0	0	5	spring	1	4	1	
040436	I-35	GRADE, DRAIN, SURFACE/RESURFACE &	Love County	07	I-35	CONC	$24,831,744.31	DUIT CONSTRUCTION COMPANY, INC.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	66	3937	1	3937.0	0	10	fall	1	4	1	
040436	I-35	GRADE, DRAIN, SURFACE/RESURFACE &	Love County	07	I-35	CONC	$24,831,744.31	DUIT CONSTRUCTION COMPANY, INC.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	70.5	9284	6	1547.0	0	10	fall	1	4	1	
040436	I-35	GRADE, DRAIN, SURFACE/RESURFACE &	Love County	07	I-35	CONC	$24,831,744.31	DUIT CONSTRUCTION COMPANY, INC.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	64	7997	4	1999.0	0	11	fall	1	4	1	
040461	I-35	GRADE, DRAIN, SURFACE AND BRIDGE	Adair County	03	I-35	CONC	$18,731,485.81	HASKELL LEMON CONSTRUCTION CO.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	72.5	17771	6	2962.0	0	10	fall	1	4	1	
040461	I-35	GRADE, DRAIN, SURFACE AND BRIDGE	Adair County	03	I-35	CONC	$18,731,485.81	HASKELL LEMON CONSTRUCTION CO.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	39	27577	7	3940.0	0	11	fall	1	4	1	

APPENDIX B: QUESTIONNAIRE SURVEY I

Assessment of Factors Affecting Productivity of Highway Activities

Dear survey participant,

Oklahoma State University is working on a research project entitled "Determination of Production Rates of Highway Activities". The research is focused on developing a system to estimate reasonably accurate production rates for controlling activities. Actual production rates in the field depend on many factors such as weather, topography, project size, soil conditions, etc. For most of the time, the actual impact of these factors on the production rates is very difficult to be accurately forecasted. The purpose of this research is to identify the critical factors affecting production rates of highway activities.

We would like you to participate in the survey and provide us with your valuable opinions for the determination of production rates of highway activities. The time required to complete this form is approximately 5 minutes. You can return the completed survey form in the following ways. Please return the completed forms by **November 17th 2009**.

Electronic Copy	Mail Copy: Dr. David Jeong, Assistant Professor
Please e-mail to:asreged@okstate.edu Or fax to: 405-744-7554	Oklahoma State University
	Civil & Environmental Engineering Dept.
	207 Engineering South
	Stillwater, OK 74078

If you have any questions, please feel free to contact me, via phone or e-mail. All data provided for this survey will be considered company confidential.

We appreciate your support.

Sincerely,

David Jeong, Ph.D.
Assistant Professor
207 Engineering South
School of Civil and Environmental Engineering
Oklahoma State University
Stillwater OK 74078-5033
Telephone: 405-744-7073/Fax: 405-744-7554
Email: david.jeong@okstate.edu

1. Provide Company Name:
2. Please provide:

Contact Person Name: Position:

Work Experience: Name of County:

Phone: Ext: Email Address:

3. In your opinion, what are the critical factors affecting the productivity of **Unclassified Excavation** (please rate each factor):

Factors	1=Strongly Disagree, 3= Neutral & 5=Strongly Agree
a. Quantity of soil	☐1 ☐2 ☐3 ☐4 ☐5
b. Traffic condition	☐1 ☐2 ☐3 ☐4 ☐5
c. Type of soil	☐1 ☐2 ☐3 ☐4 ☐5
d. Haul distance	☐1 ☐2 ☐3 ☐4 ☐5
e. Location	☐1 ☐2 ☐3 ☐4 ☐5
f. Weather (season & temperature)	☐1 ☐2 ☐3 ☐4 ☐5
g. If other, please specify	☐1 ☐2 ☐3 ☐4 ☐5

4. In your opinion, what are the critical factors affecting the productivity of **Unclassified Borrow** (please rate each factor):

Factors	1=Strongly Disagree, 3= Neutral & 5=Strongly Agree
a. Quantity of soil	☐1 ☐2 ☐3 ☐4 ☐5
b. Traffic condition	☐1 ☐2 ☐3 ☐4 ☐5
c. Type of soil	☐1 ☐2 ☐3 ☐4 ☐5
d. Haul distance	☐1 ☐2 ☐3 ☐4 ☐5
e. Location	☐1 ☐2 ☐3 ☐4 ☐5
f. Weather (season & temperature)	☐1 ☐2 ☐3 ☐4 ☐5
g. If other, please specify	☐1 ☐2 ☐3 ☐4 ☐5

5. In your opinion, what are the critical factors affecting the productivity of **Sub-grade Modification, lime/fly ash** (please rate each factor):

Factors	1=Strongly Disagree, 3= Neutral & 5=Strongly Agree
a. Quantity to be modified	☐1 ☐2 ☐3 ☐4 ☐5
b. Traffic condition	☐1 ☐2 ☐3 ☐4 ☐5
c. Type of soil	☐1 ☐2 ☐3 ☐4 ☐5
d. Type of base	☐1 ☐2 ☐3 ☐4 ☐5
e. Thickness of base	☐1 ☐2 ☐3 ☐4 ☐5
f. Weather (season & temperature)	☐1 ☐2 ☐3 ☐4 ☐5
g. Type of roadway (US/city street/SH/IS)	☐1 ☐2 ☐3 ☐4 ☐5
h. If other, please specify	☐1 ☐2 ☐3 ☐4 ☐5

6. In your opinion, what are the critical factors affecting the productivity of **Aggregate Base** (please rate each factor):

Factors	1=Strongly Disagree, 3= Neutral & 5=Strongly Agree
a. Quantity	☐1 ☐2 ☐3 ☐4 ☐5
b. Traffic condition	☐1 ☐2 ☐3 ☐4 ☐5

1

c. Type of soil	☐1 ☐2 ☐3 ☐4 ☐5
d. Type of base	☐1 ☐2 ☐3 ☐4 ☐5
e. Thickness of base	☐1 ☐2 ☐3 ☐4 ☐5
f. Weather (season & temperature)	☐1 ☐2 ☐3 ☐4 ☐5
g. Type of roadway (US/city street/SH/IS)	☐1 ☐2 ☐3 ☐4 ☐5
h. If other, please specify	☐1 ☐2 ☐3 ☐4 ☐5

7. In your opinion, what are the critical factors affecting the productivity of **Dowel Jointed P.C. Pavement, 9"/10"** (please rate each factor):

Factors	1=Strongly Disagree, 3= Neutral & 5=Strongly Agree
a. Quantity	☐1 ☐2 ☐3 ☐4 ☐5
b. Traffic condition	☐1 ☐2 ☐3 ☐4 ☐5
c. Type of roadway (US/city street/SH/IS)	☐1 ☐2 ☐3 ☐4 ☐5
d. Weather (season & temperature)	☐1 ☐2 ☐3 ☐4 ☐5
e. If other, please specify	☐1 ☐2 ☐3 ☐4 ☐5

8. In your opinion, what are the critical factors affecting the productivity of **Asphalt Pavement, Type S-3/S-4** (please rate each factor):

Factors	1=Strongly Disagree, 3= Neutral & 5=Strongly Agree
a. Quantity	☐1 ☐2 ☐3 ☐4 ☐5
b. Traffic condition	☐1 ☐2 ☐3 ☐4 ☐5
c. Type of roadway (US/city street/SH/IS)	☐1 ☐2 ☐3 ☐4 ☐5
d. Weather (season & temperature)	☐1 ☐2 ☐3 ☐4 ☐5
e. If other, please specify	☐1 ☐2 ☐3 ☐4 ☐5

9. In your opinion, what are the critical factors affecting the productivity of **Rebar-Bridge Deck** (please rate each factor):

Factors	1=Strongly Disagree, 3= Neutral & 5=Strongly Agree
a. Quantity	☐1 ☐2 ☐3 ☐4 ☐5
b. Traffic condition	☐1 ☐2 ☐3 ☐4 ☐5
c. Type of roadway (US/city street/SH/IS)	☐1 ☐2 ☐3 ☐4 ☐5
d. Weather (season & temperature)	☐1 ☐2 ☐3 ☐4 ☐5
e. Reinforcing steel	☐1 ☐2 ☐3 ☐4 ☐5
f. If other, please specify	☐1 ☐2 ☐3 ☐4 ☐5

10. In your opinion, what are the critical factors affecting the productivity of **Rebar- Abutments/Pier Caps** (please rate each factor):

Factors	1=Strongly Disagree, 3= Neutral & 5=Strongly Agree
a. Quantity	☐1 ☐2 ☐3 ☐4 ☐5
b. Traffic condition	☐1 ☐2 ☐3 ☐4 ☐5
c. Type of roadway (US/city street/SH/IS)	☐1 ☐2 ☐3 ☐4 ☐5
d. Weather (season & temperature)	☐1 ☐2 ☐3 ☐4 ☐5
e. If other, please specify	☐1 ☐2 ☐3 ☐4 ☐5

11. In your opinion, what are the critical factors affecting the productivity of **Removal of pavement** (please rate each factor):

Factors	1=Strongly Disagree, 3= Neutral & 5=Strongly Agree
a. Quantity	☐1 ☐2 ☐3 ☐4 ☐5
b. Traffic condition	☐1 ☐2 ☐3 ☐4 ☐5
c. Type of roadway (US/city street/SH/IS)	☐1 ☐2 ☐3 ☐4 ☐5
d. Weather (season & temperature)	☐1 ☐2 ☐3 ☐4 ☐5
e. Reinforcing steel	☐1 ☐2 ☐3 ☐4 ☐5
f. If other, please specify	☐1 ☐2 ☐3 ☐4 ☐5

12. Please provide additional comments regarding factors affecting production rates in determining productivity of highway activities in the space here:

APPENDIX C: QUESTIONNAIRE SURVEY II

Assessment of Productivity of Critical Highway Activities

Dear survey participant,

Oklahoma State University is working on a research project entitled "Determination of Production Rates of Highway Activities". The research is focused on developing a system to estimate reasonably accurate production rates for controlling highway activities. Actual production rates in the field depend on many factors such as weather, topography, project size, soil conditions, etc. For most of the time, the actual impact of these factors on the production rates is very difficult to be accurately forecasted. But based on your experience and knowledge, the research team can develop a system to estimate a reliable production rates for controlling highway activities. Therefore we would like you to participate in the survey and provide us with your valuable estimates of production rates for the selected highway activities.

You can return the completed survey form in the following ways. Please return the completed forms by **December 17th 2009**.

Electronic Copy	Mail Copy: Dr. David Jeong, Assistant Professor
Please e-mail to:asreged@okstate.edu	Oklahoma State University
Or fax to: 405-744-7554	Civil & Environmental Engineering Dept.
	207 Engineering South
	Stillwater, OK 74078

If you have any questions, please feel free to contact me, via phone or e-mail. All data provided for this survey will be considered company confidential. Individual company data will not be communicated in any form to another party.

We appreciate your support.

Sincerely,

David Jeong, Ph.D.
Assistant Professor
207 Engineering South
School of Civil and Environmental Engineering
Oklahoma State University
Stillwater OK 74078-5033
Telephone: 405-744-7073/Fax: 405-744-7554
Email: david.jeong@okstate.edu

1. Unclassified Excavation

		Quantity	Weather	Location	Production Rate (CY/Day)	Remark
1	Ideal Condition	> 100K CY	Summer	Rural		
2		> 100K CY	Winter	Rural		
3	Average Condition	20K Cy - 100K CY	Fall/Spring	Urban		
4		< 20K CY	Summer	Urban		
5	Less than Average	< 20K CY	Winter	Urban		

Remarks:

2. Unclassified Borrow

		Quantity	Weather	Location	Production Rate (CY/Day)	Remark
1	Ideal Condition	> 100K CY	Summer	Rural		
2		> 100K CY	Winter	Rural		
3	Average Condition	20K Cy - 100K CY	Fall/Spring	Urban		
4		< 20K CY	Summer	Urban		
5	Less than Average	< 20K CY	Winter	Urban		

Remarks:

1

3. Sub-grade Modification, lime/fly-ash

		Quantity	Weather	Soil Type	Production Rate (SY/Day)	Remark
1	Ideal Condition	> 70K SY	Summer	Loam/Sandy Loam		
2		> 70K SY	Winter	Loam/Sandy Loam		
3	Average Condition	20K SY - 70K SY	Fall/Spring	lean Clay		
4		< 20K SY	Summer	Heavy Clay/Rock		
5	Less than Average	< 20K SY	Winter	Heavy Clay/Rock		

Remarks: ______________________________

4. Aggregate Base

		Quantity	Weather	Location	Production Rate (CY/Day)	Remark
1	Ideal Condition	> 15K CY	Summer	Rural		
2		> 15K CY	Winter	Rural		
3	Average Condition	3K Cy - 15K CY	Fall/Spring	Urban		
4		< 3K CY	Summer	Urban		
5	Less than Average	< 3K CY	Winter	Urban		

Remarks: ______________________________

2

5. Dowel Jointed P.C. Pavement, 9/10"

		Quantity	Weather	Production Rate (SY/Day)	Remark
1	Ideal Condition	> 70K SY	Summer		
2		> 70K SY	Winter		
3	Average Condition	20K SY - 70K SY	Fall/Spring		
4		< 20K SY	Summer		
5	Less than Average	< 20K SY	Winter		

Remarks:

6. Asphalt Pavement, Type S-3/S-4

		Quantity	Weather	Production Rate (Tons/Day)	Remark
1	Ideal Condition	> 30K Ton	Summer		
2		> 30K Ton	Winter		
3	Average Condition	10K Tons - 30K Tons	Fall/Spring		
4		< 10K Ton	Summer		
5	Less than Average	< 10K Ton	Winter		

Remarks:

3

7.BridgeDeckRebar

		Quantity	Weather	Production Rate (LB/Day)	Remark
1	Ideal Condition	> 75K Lb	Summer		
2		> 75K Lb	Winter		
3		< 75K Lb	Summer		
4	Less than Average	< 75K Lb	Winter		

Remarks:

8. Concrete Pavement Removal

		Quantity	Weather	Traffic Condition	Production Rate (SY/Day)	Remark
1	Ideal Condition	> 70K SY	Summer	No Traffic		
2		> 70K SY	Winter	Under Traffic		
3	Average Condition	20K SY - 70K SY	Fall/Spring	Light Traffic		
4		< 20K SY	Summer	No Traffic		
5	Less than Average	< 20K SY	Winter	Under Traffic		

Remarks:

1. Provide Company Name:
2. Please provide:

Contact Person Name: Position:

Work Experience: County:

Phone: Ext: Email Address:

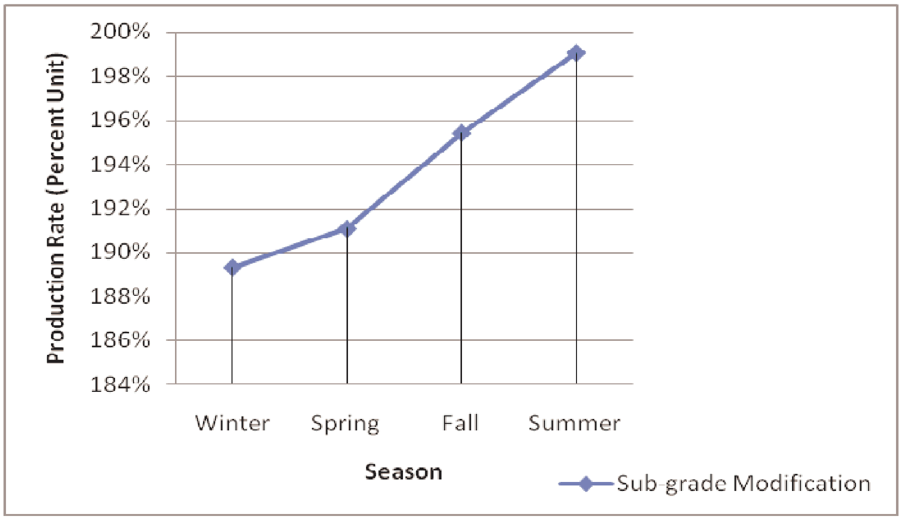
N. B. - Standard Performance day is considered as 8hrs.

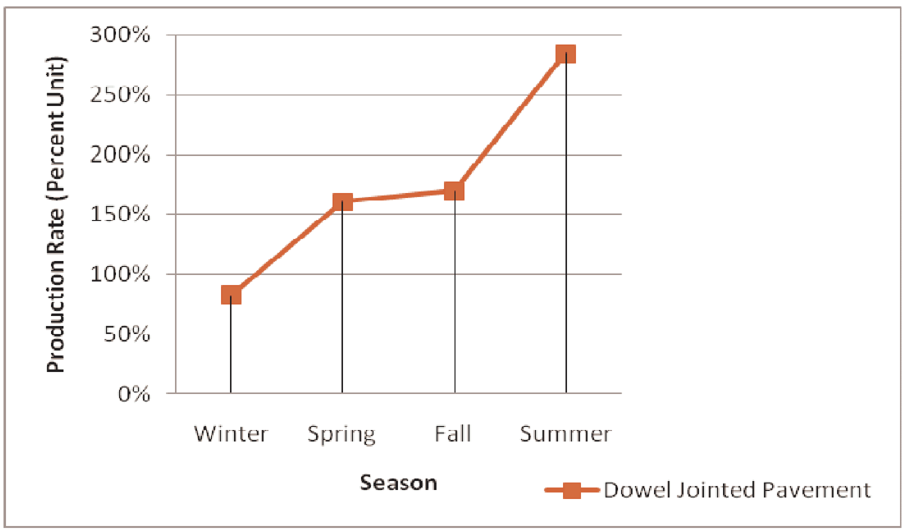
APPENDIX D: UNIFIED SOIL CLASSIFICATION SYSTEM (ASTM STANDARD)

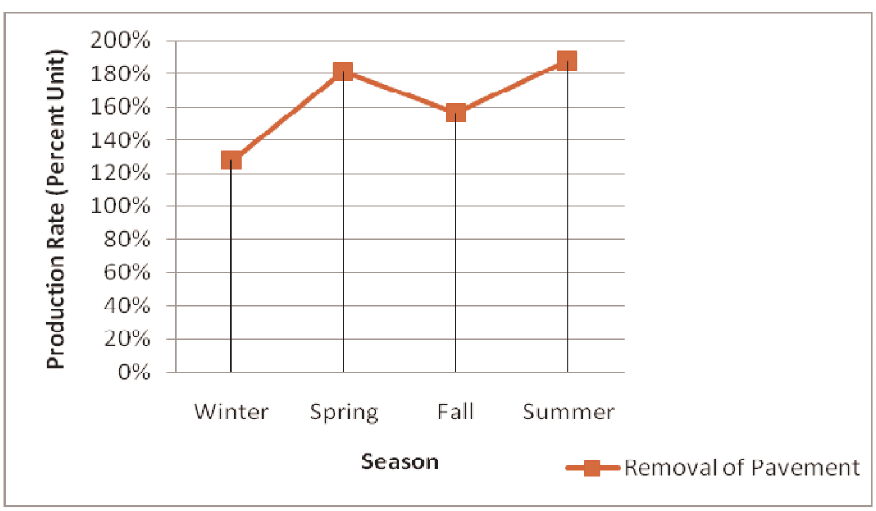
Criteria for Assigning Group Symbols and Group Names Using Laboratory Tests[A]				Soil Classification: Group Symbol	Soil Classification: Group Name[B]
COARSE-GRAINED SOILS	Gravels	Clean Gravels	Cu ≥ 4 and 1 ≤ Cc ≤ 3[C]	GW	Well-graded gravel[D]
More than 50 % retained on No. 200 sieve	More than 50 % of coarse fraction retained on No. 4 sieve	Less than 5 % fines[E]	Cu < 4 and/or 1 > Cc > 3[C]	GP	Poorly graded gravel[D]
		Gravels with Fines	Fines classify as ML or MH	GM	Silty gravel[D,F,G]
		More than 12 % fines[E]	Fines classify as CL or CH	GC	Clayey gravel[D,F,G]
	Sands	Clean Sands	Cu ≥ 6 and 1 ≤ Cc ≤ 3[C]	SW	Well-graded sand[H]
	50 % or more of coarse	Less than 5 % fines[I]	Cu < 6 and/or 1 > Cc > 3[C]	SP	Poorly graded sand[H]
	fraction passes No. 4 sieve	Sands with Fines	Fines classify as ML or MH	SM	Silty sand[F,G,H]
		More than 12 % fines[I]	Fines classify as CL or CH	SC	Clayey sand[F,G,H]
FINE-GRAINED SOILS	Silts and Clays	inorganic	PI > 7 and plots on or above "A" line[J]	CL	Lean clay[K,L,M]
50 % or more passes the No.	Liquid limit less than 50		PI < 4 or plots below "A" line[J]	ML	Silt[K,L,M]
200 seive		organic	Liquid limit – oven dried / Liquid limit – not dried < 0.75	OL	Organic clay[K,L,M,N]
				OL	Organic silt[K,L,M,O]
	Silts and Clays	inorganic	PI plots on or above "A" line	CH	Fat clay[K,L,M]
	Liquid limit 50 or more		PI plots below "A" line	MH	Elastic silt[K,L,M]
		organic	Liquid limit – oven dried / Liquid limit – not dried < 0.75	OH	Organic clay[K,L,M,P]
					Organic silt[K,L,M,Q]
HIGHLY ORGANIC SOILS	Primarily organic matter, dark in color, and organic odor			PT	Peat

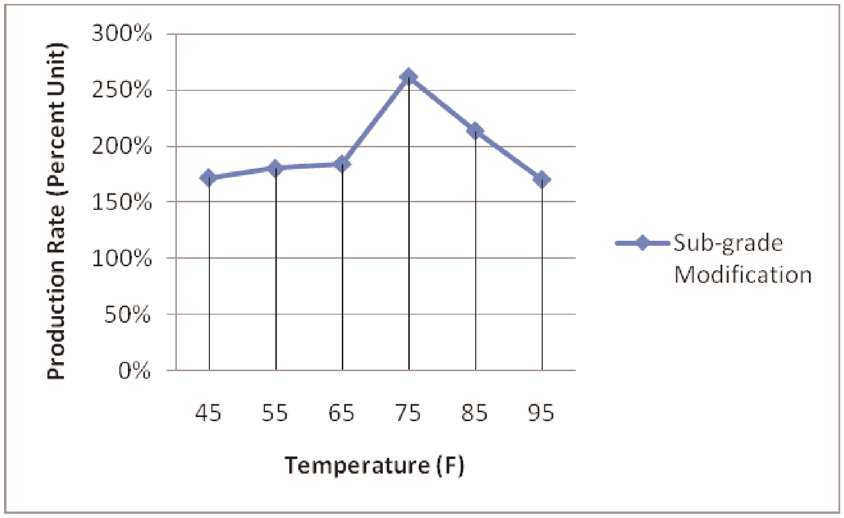
[A] Based on the material passing the 3-in. (75-mm) sieve.
[B] If field sample contained cobbles or boulders, or both, add "with cobbles or boulders, or both" to group name.
[C] $Cu = D_{60}/D_{10}$ $Cc = (D_{30})^2 / D_{10} \times D_{60}$
[D] If soil contains ≥15 % sand, add "with sand" to group name.
[E] Gravels with 5 to 12 % fines require dual symbols:
GW-GM well-graded gravel with silt
GW-GC well-graded gravel with clay
GP-GM poorly graded gravel with silt
GP-GC poorly graded gravel with clay
[F] If fines classify as CL-ML, use dual symbol GC-GM, or SC-SM.
[G] If fines are organic, add "with organic fines" to group name.
[H] If soil contains ≥15 % gravel, add "with gravel" to group name.
[I] Sands with 5 to 12 % fines require dual symbols:
SW-SM well-graded sand with silt
SW-SC well-graded sand with clay
SP-SM poorly graded sand with silt
SP-SC poorly graded sand with clay
[J] If Atterberg limits plot in hatched area, soil is a CL-ML, silty clay.
[K] If soil contains 15 to 29 % plus No. 200, add "with sand" or "with gravel," whichever is predominant.
[L] If soil contains ≥30 % plus No. 200, predominantly sand, add "sand " to group name.
[M] If soil contains ≥30 % plus No. 200, predominantly gravel, add "gravelly" to group name.
[N] PI ≥ 4 and plots on or above "A" line.
[O] PI < 4 or plots below" A" line.
[P] PI plots on or above "A" line.
[Q] PI plots below "A" line.

APPENDIX E: EFFECT OF TEMPERATURE, SESONAL CHANGE, NUMBER OF LANES & ROUTE TYPE ON PRODUCTION RATE

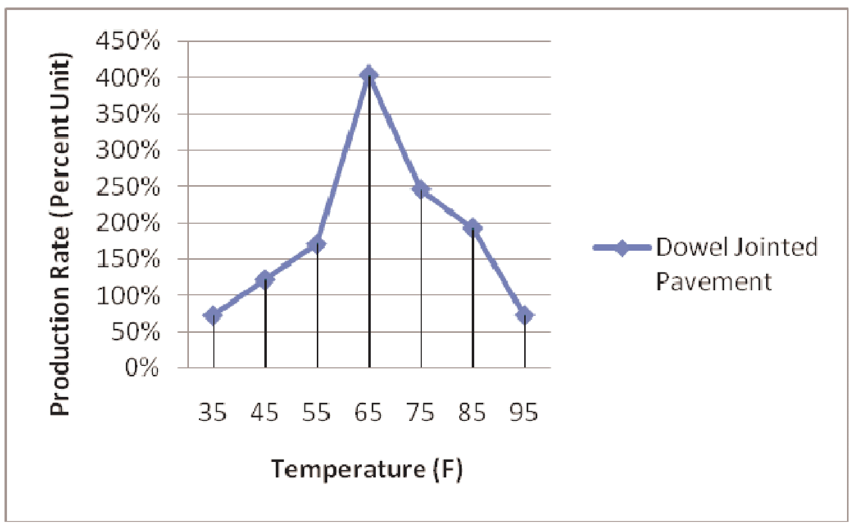

200%
198%
196%
194%
192%
190%
188%
186%
184%
Production Rate (Percent Unit)
Winter
Spring
Fall
Summer
Season
Sub-grade Modification


300%
250%
200%
150%
100%
50%
0%
Production Rate (Percent Unit)
Winter
Spring
Fall
Summer
Season
Dowel Jointed Pavement

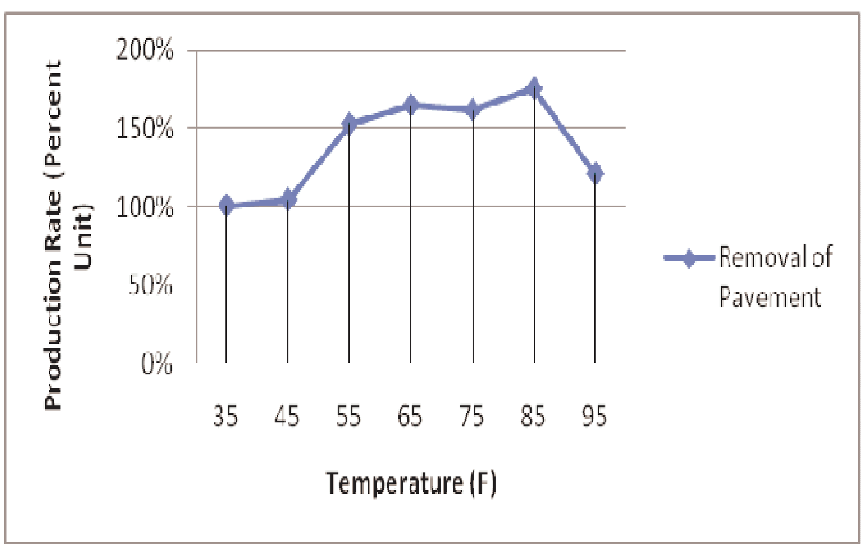

200%
180%
160%
140%
120%
100%
80%
60%
40%
20%
0%
Production Rate (Percent Unit)
Winter
Spring
Fall
Summer
Season
Removal of Pavement



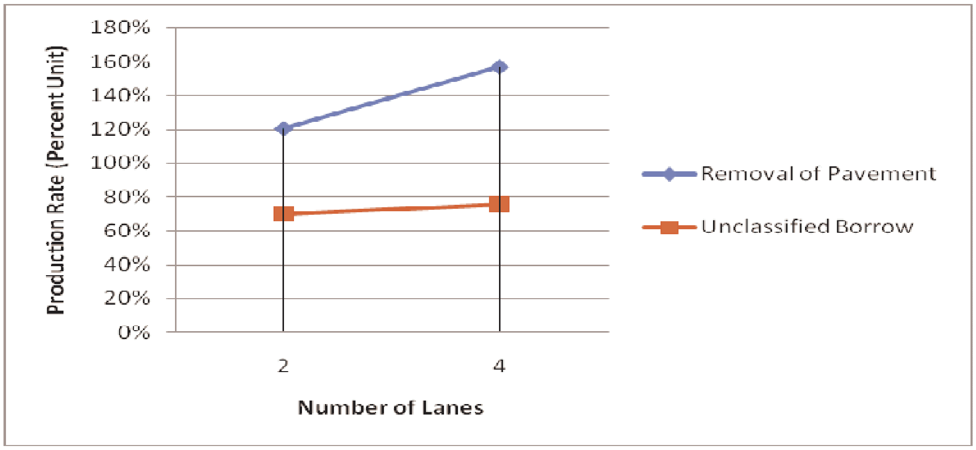
300%
250%
200%
150%
100%
50%
0%
45
55
65
75
85
95
Production Rate (Percent Unit)
Temperature (F)
Sub-grade Modification



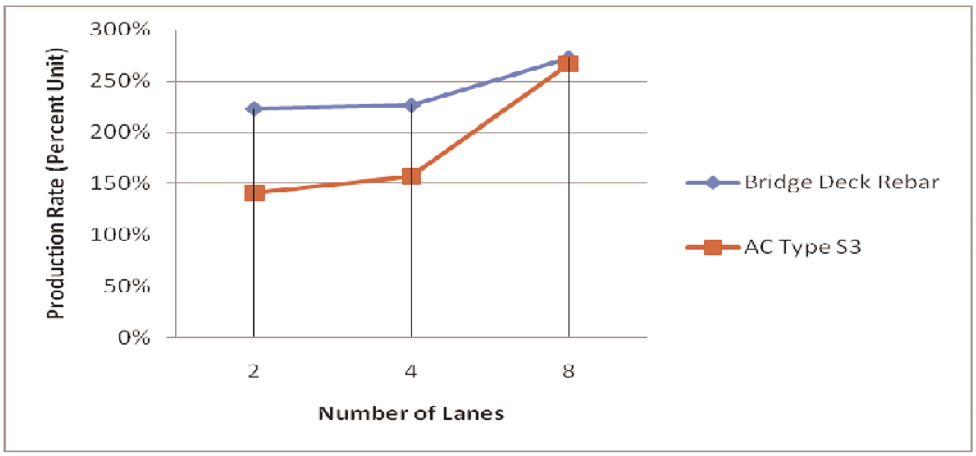
450%
400%
350%
300%
250%
200%
150%
100%
50%
0%
35
45
55
65
75
85
95
Production Rate (Percent Unit)
Temperature (F)
Dowel Jointed Pavement



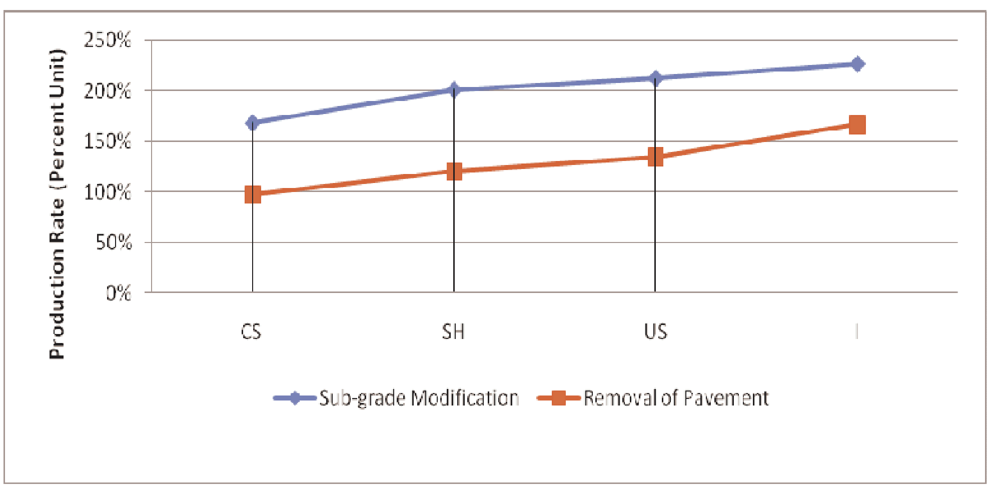
200%
150%
100%
50%
0%
35
45
55
65
75
85
95
Production Rate (Percent Unit)
Temperature (F)
Removal of Pavement



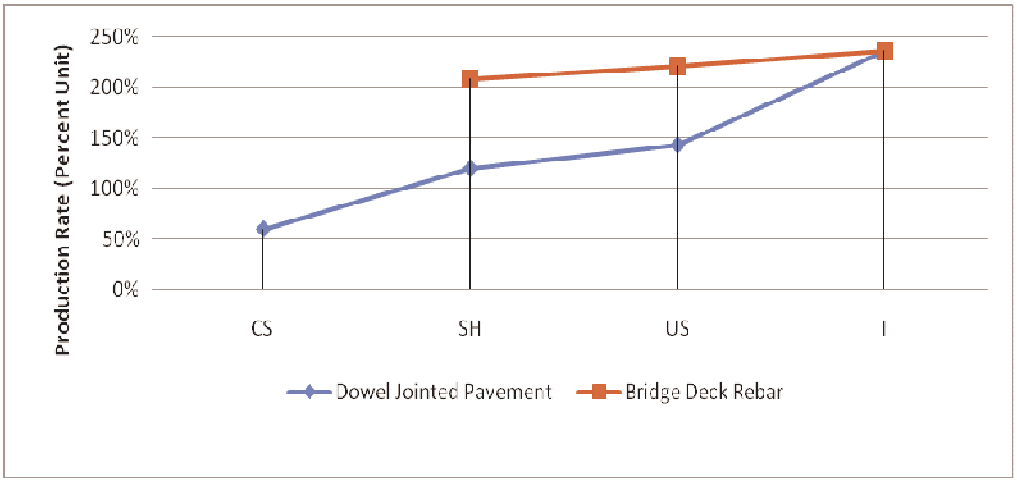
180%
160%
140%
120%
100%
80%
60%
40%
20%
0%
Production Rate (Percent Unit)
2
4
Number of Lanes
Removal of Pavement
Unclassified Borrow



300%
250%
200%
150%
100%
50%
0%
Production Rate (Percent Unit)
2
4
8
Number of Lanes
Bridge Deck Rebar
AC Type S3

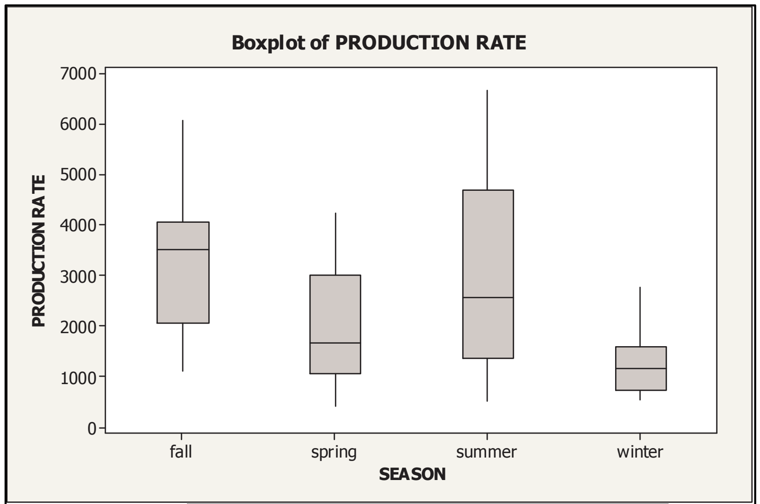


250%
200%
150%
100%
50%
0%
Production Rate (Percent Unit)
CS
SH
US
I
Sub-grade Modification
Removal of Pavement

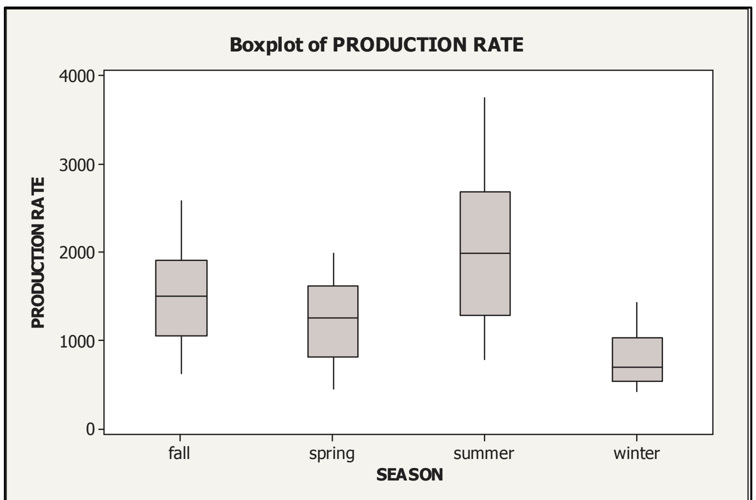


Production Rate (Percent Unit)
250%
200%
150%
100%
50%
0%
CS
SH
US
I
Dowel Jointed Pavement
Bridge Deck Rebar

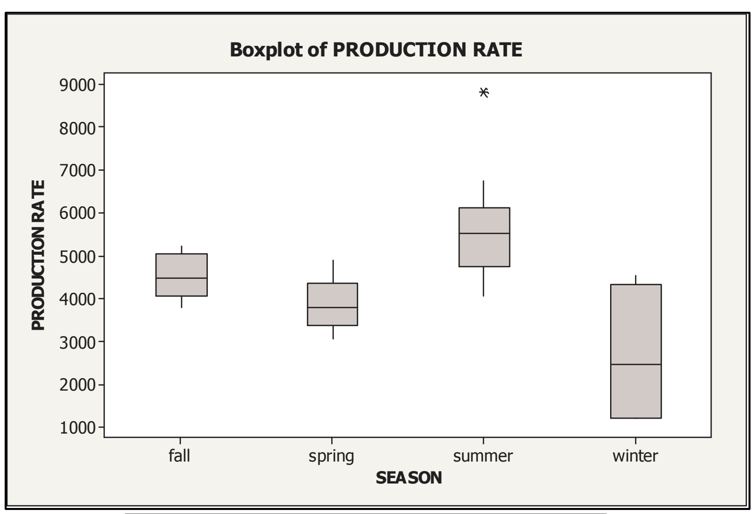
APPENDIX F: BOX PLOT & SCATTER PLOT OF SELECTED FACTORS



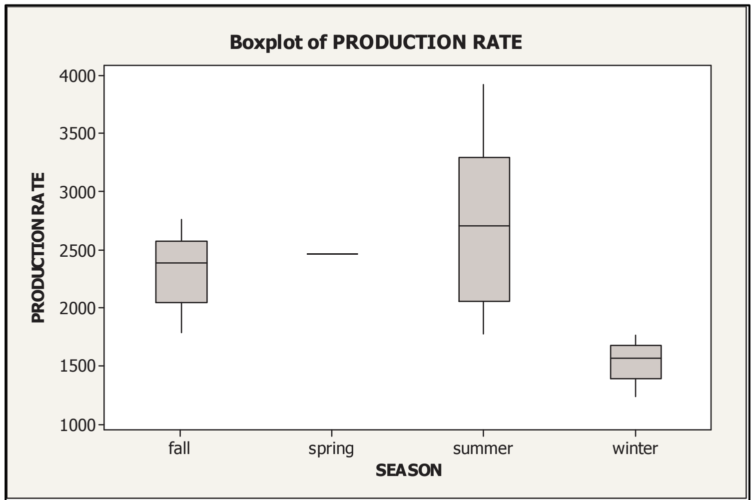
Unclassified Excavation (Season)



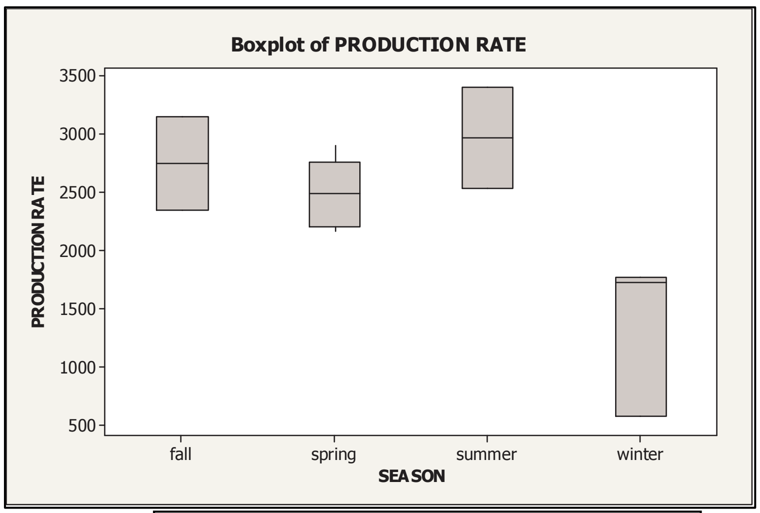
Unclassified Borrow (Season)



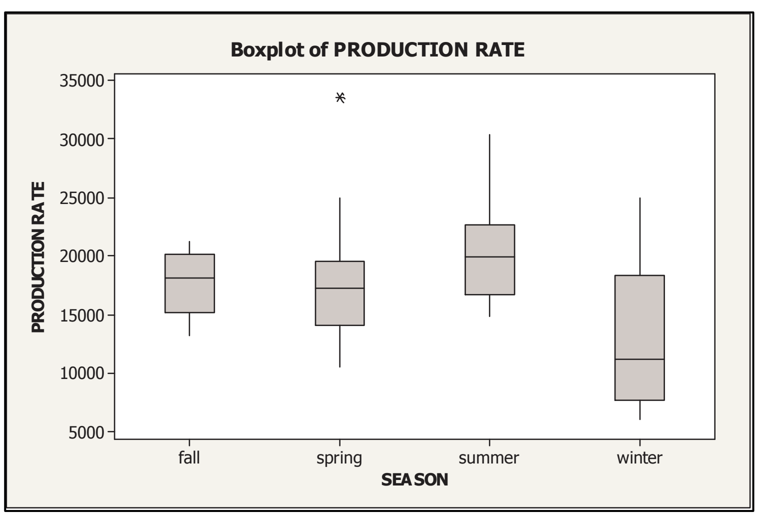
Sub-grade Modification (Season)



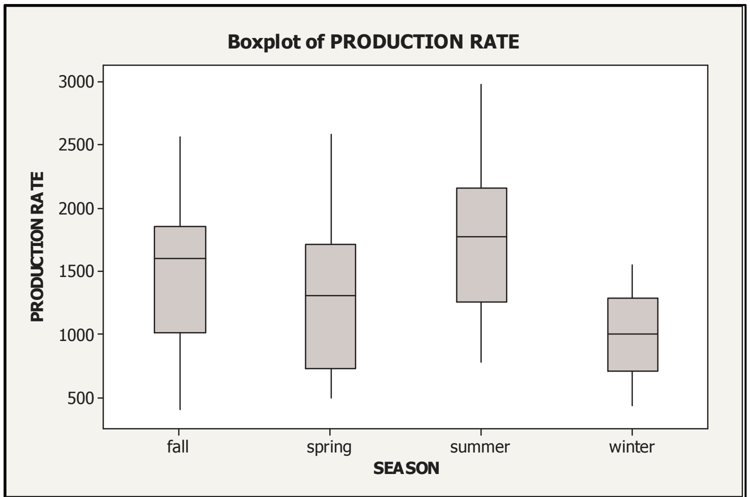
Removal of Pavement (Season)



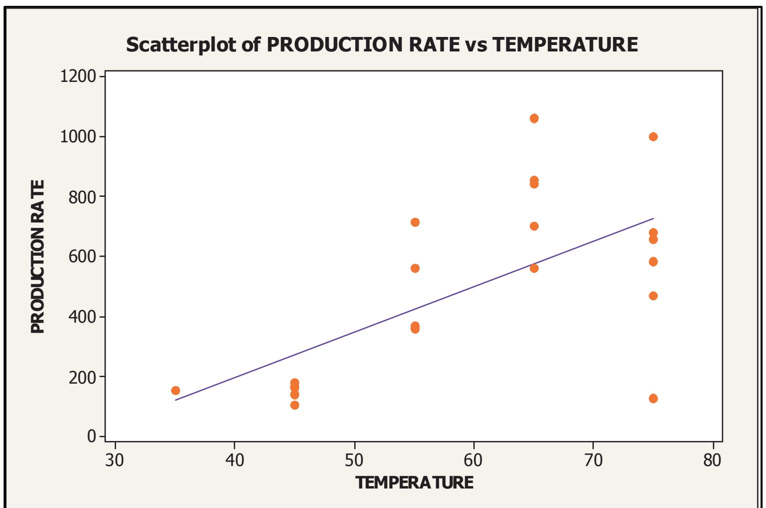
PC Dowel Jointed Pavement (Season)



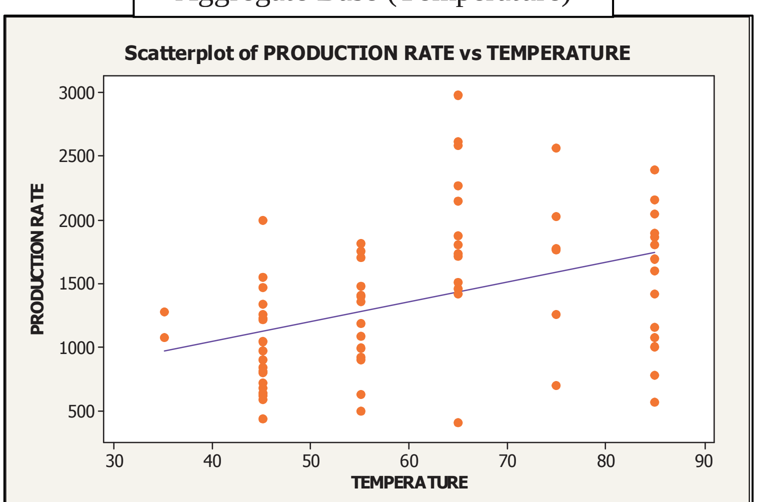
Bridge Deck Rebar (Season)



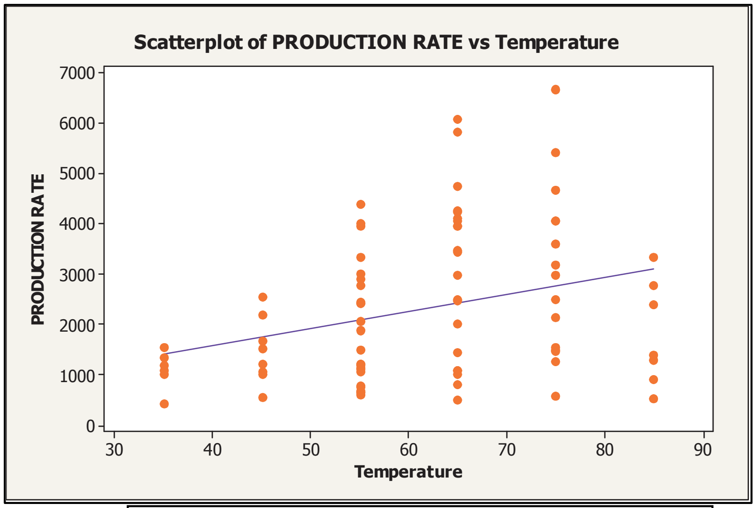
Asphaltic Pavement (Season)



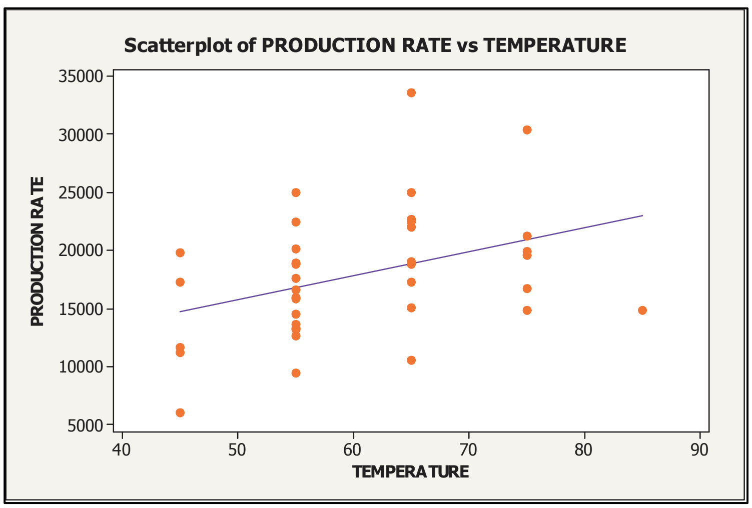
Aggregate Base (Temperature)



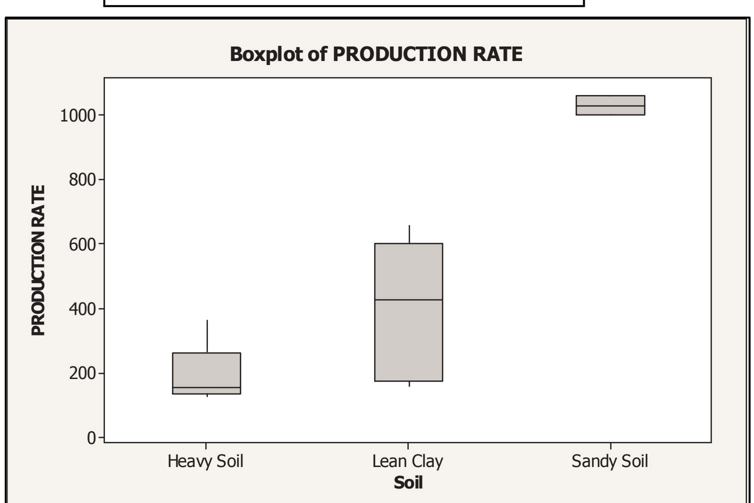
Asphaltic Concrete (Temperature)



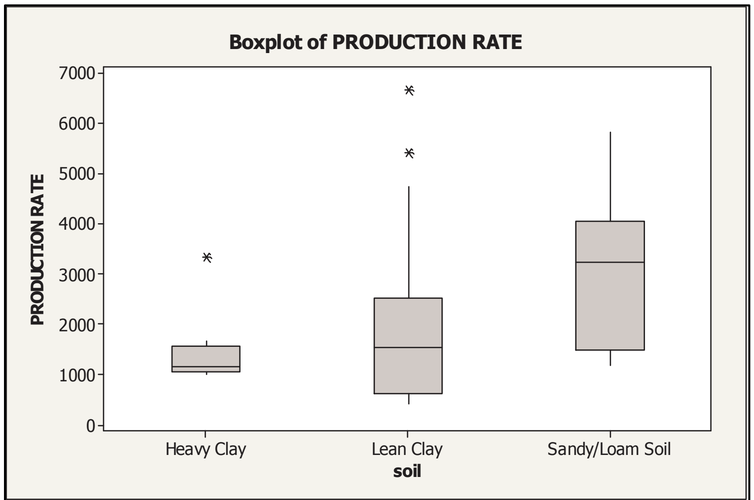
Unclassified Excavation (Temperature)



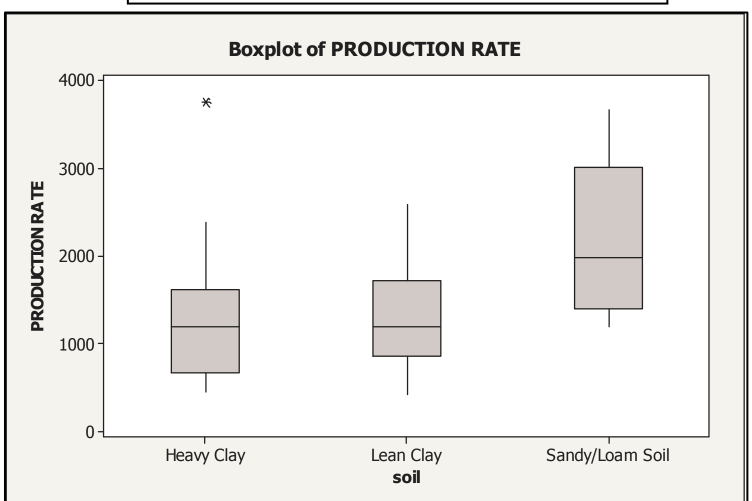
Bridge Deck Rebar



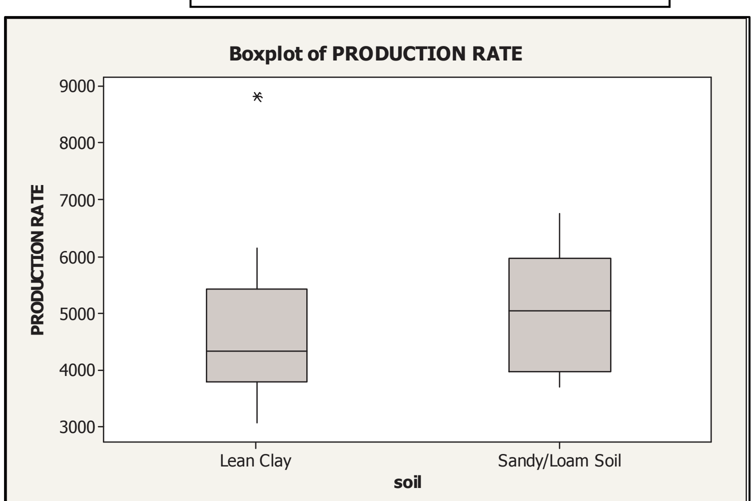
Aggregate Base (Soil Type)



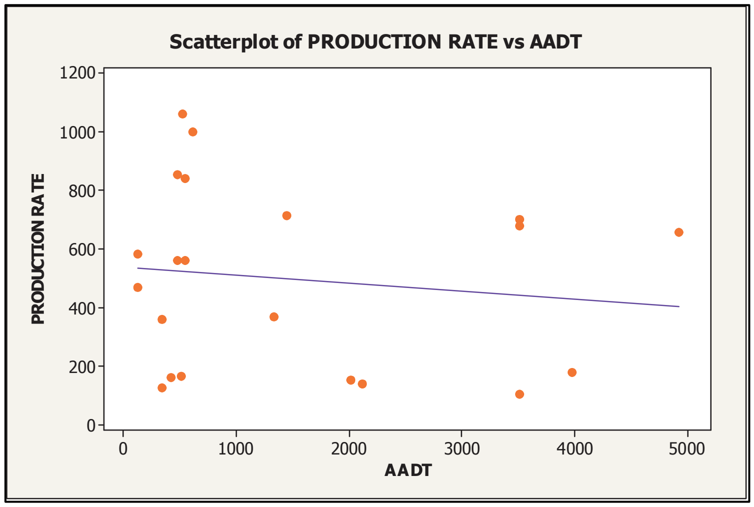
Unclassified Excavation (Soil Type)



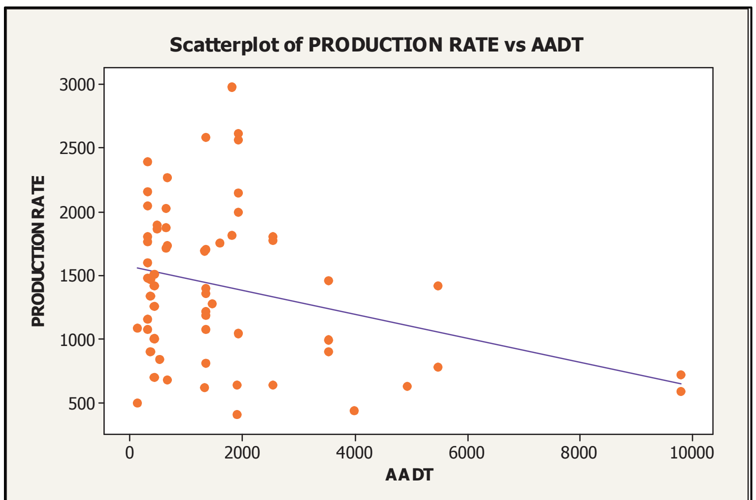
Unclassified Borrow (Soil Type)



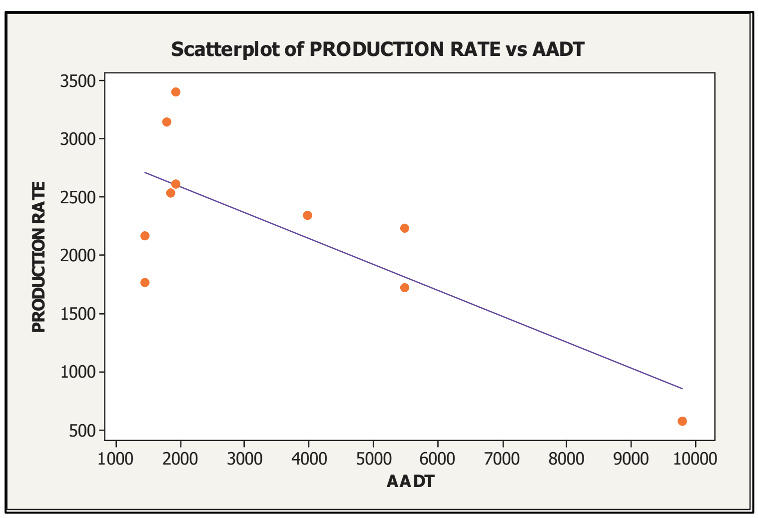
Sub-grade Modification (Soil



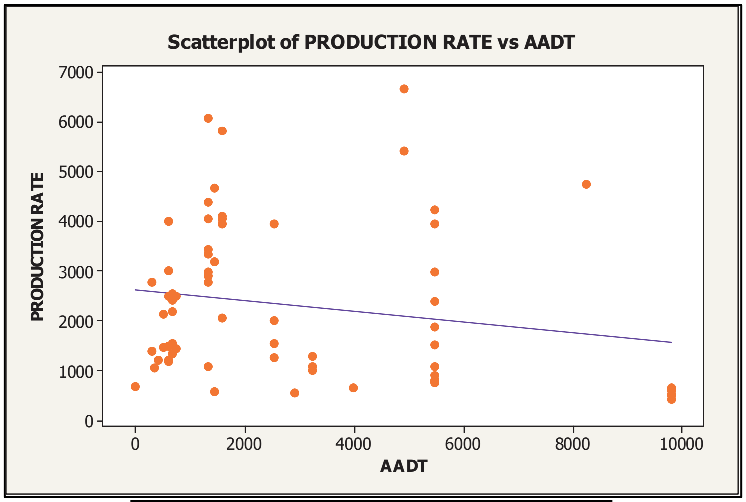
Aggregate Base (AADT)



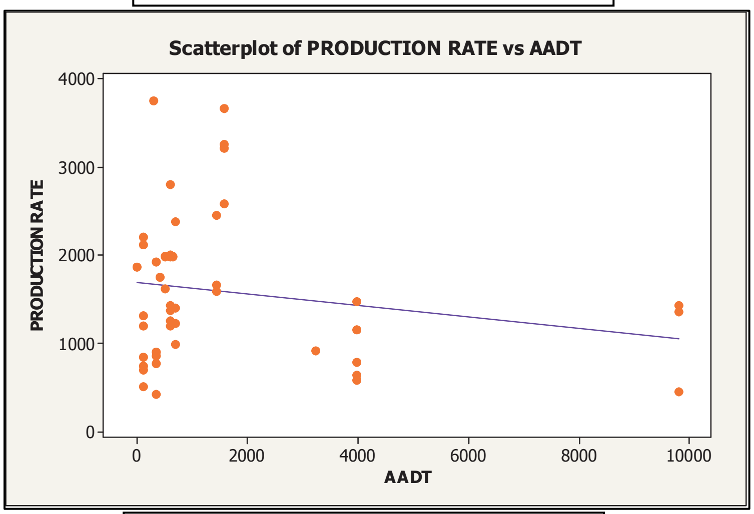
Asphaltic Pavement (AADT)



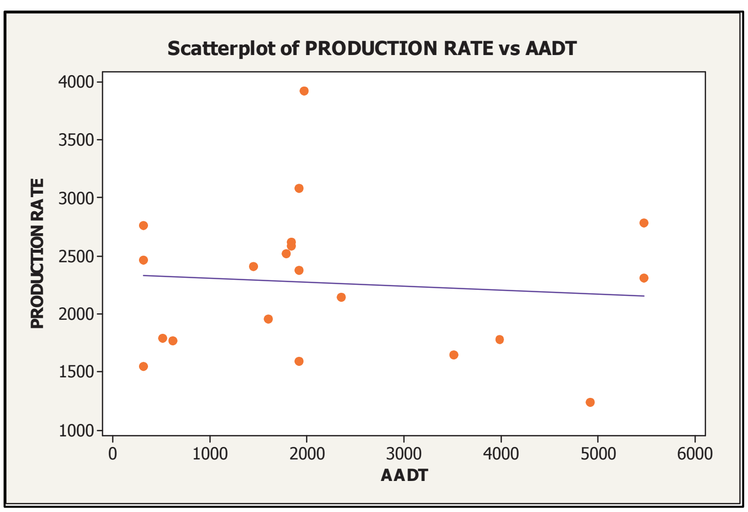
PC Dowel Jointed pavement



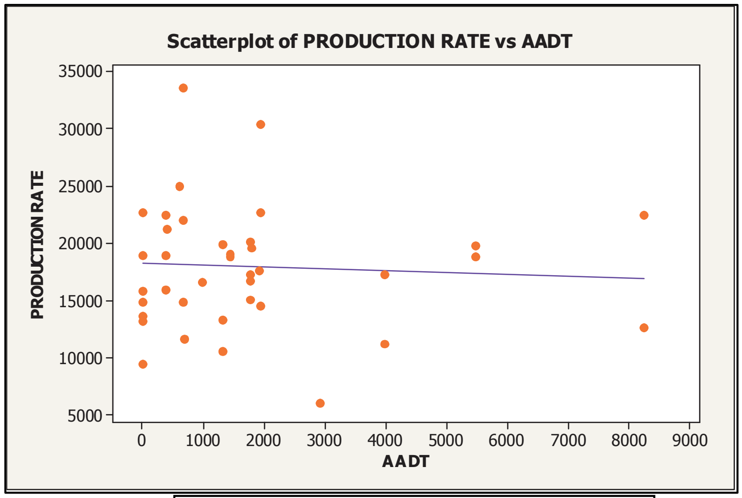
Unclassified Excavation (AADT)



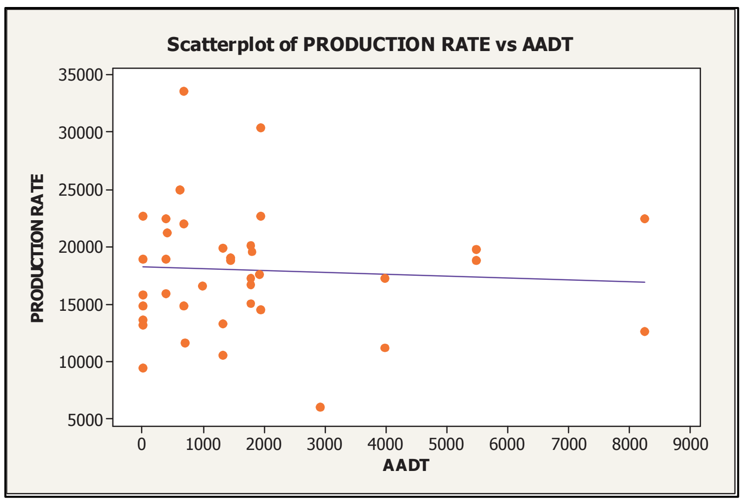
Unclassified Borrow (AADT)



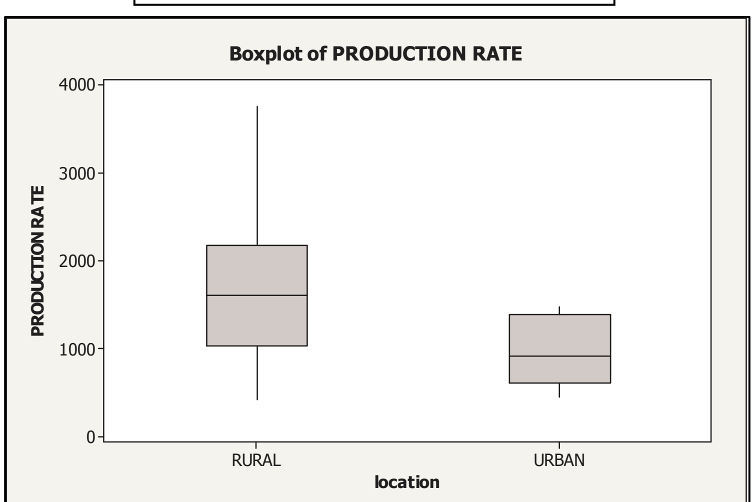
Removal of Pavement (AADT)



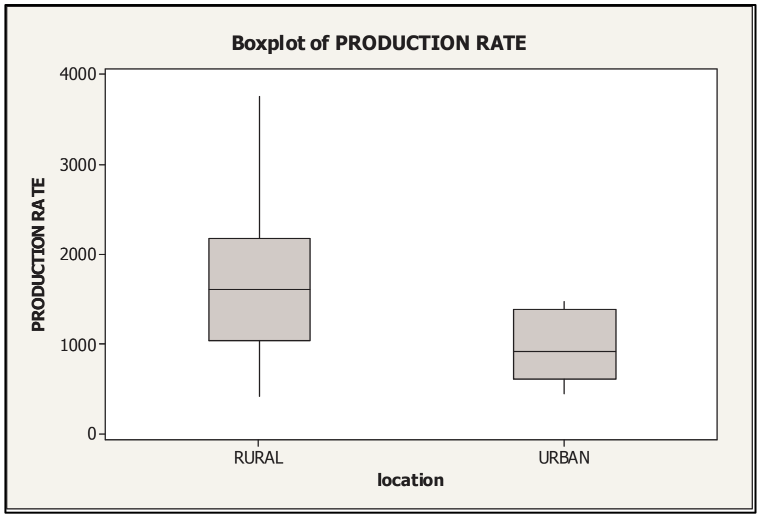
Sub-grade Modification (AADT)



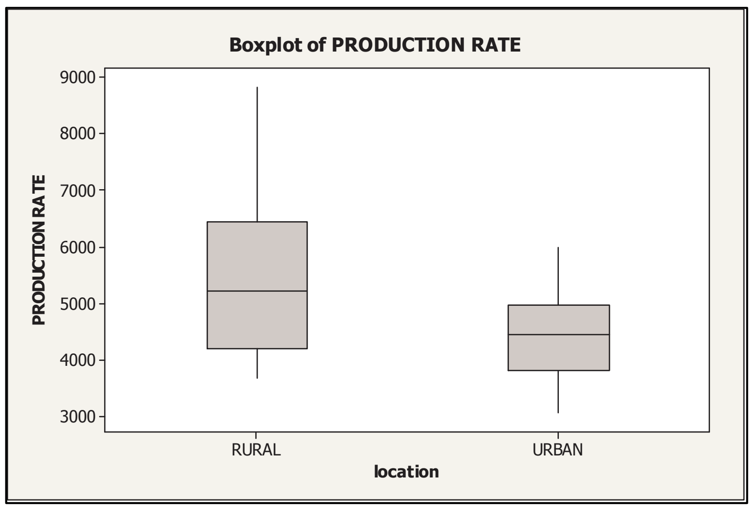
Bridge Deck Rebar (AADT)



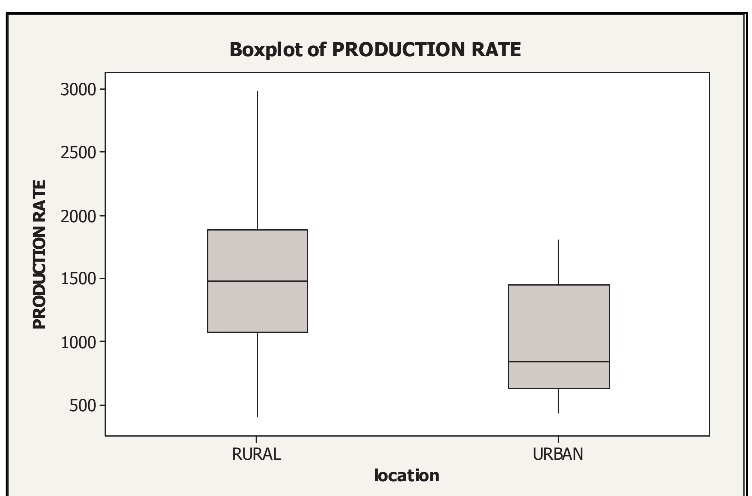
Unclassified Excavation



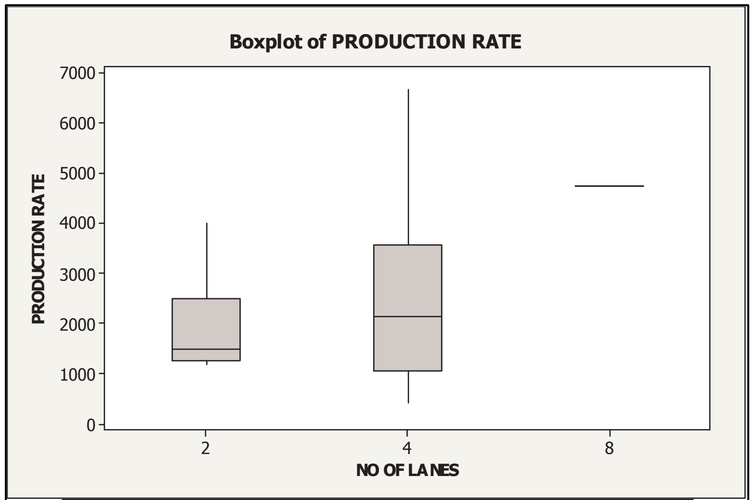
Unclassified Borrow (Location)



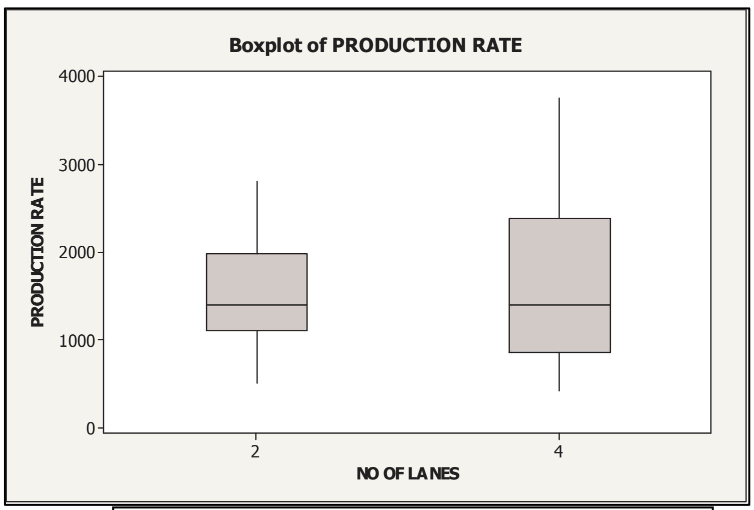
Sub-grade Modification (Location)



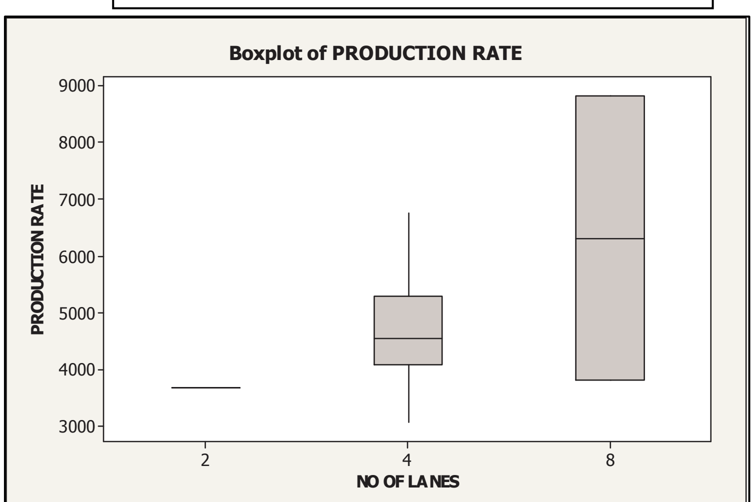
Asphaltic Concrete (Location)



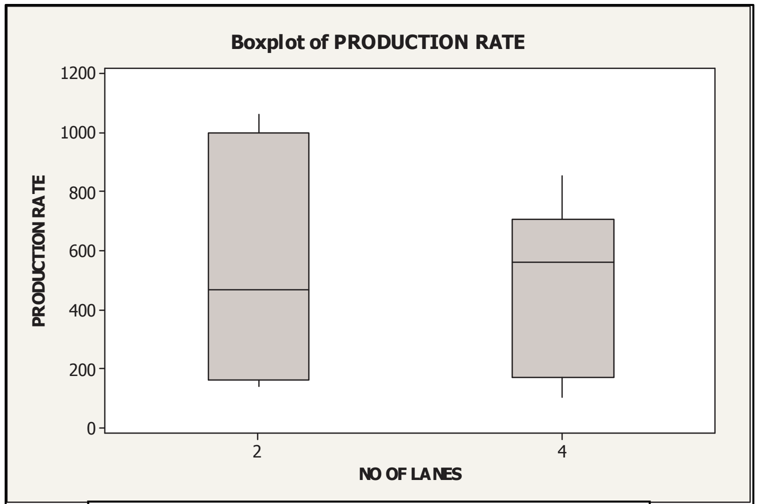
Unclassified Excavation (Number of Lanes)



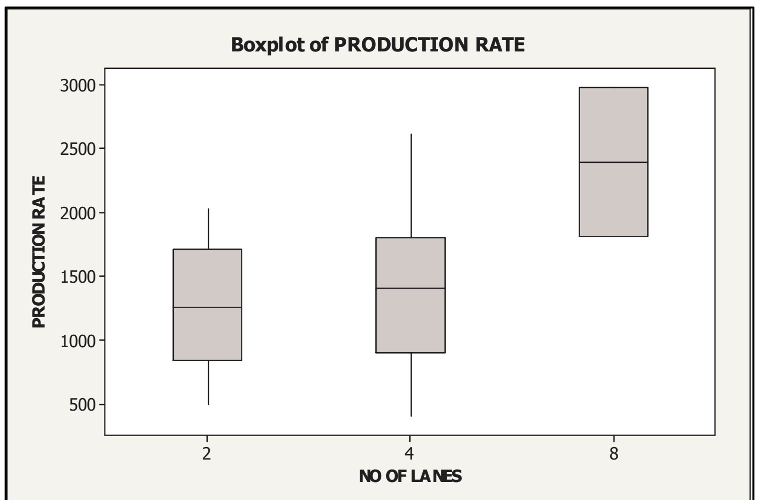
Unclassified Borrow (Number of Lanes)



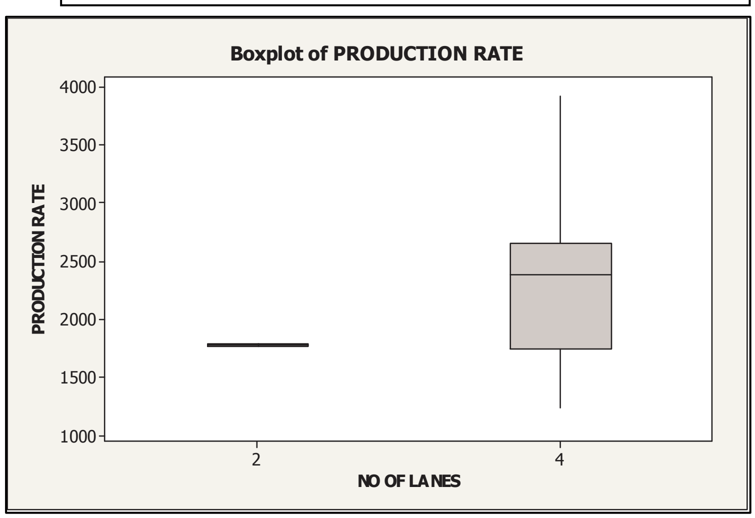
Sub-grade Modification (Number of Lanes)



Aggregate Base (Number of Lanes)

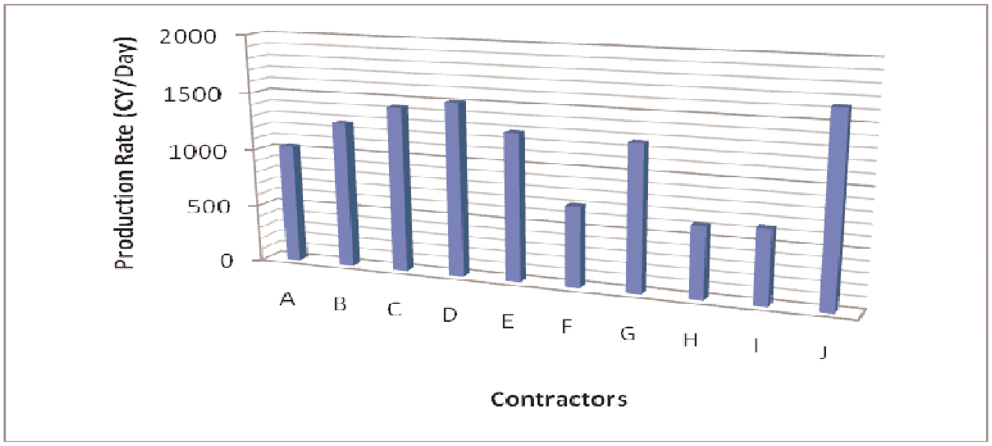


Asphaltic Pavement S-3 (Number of Lanes)

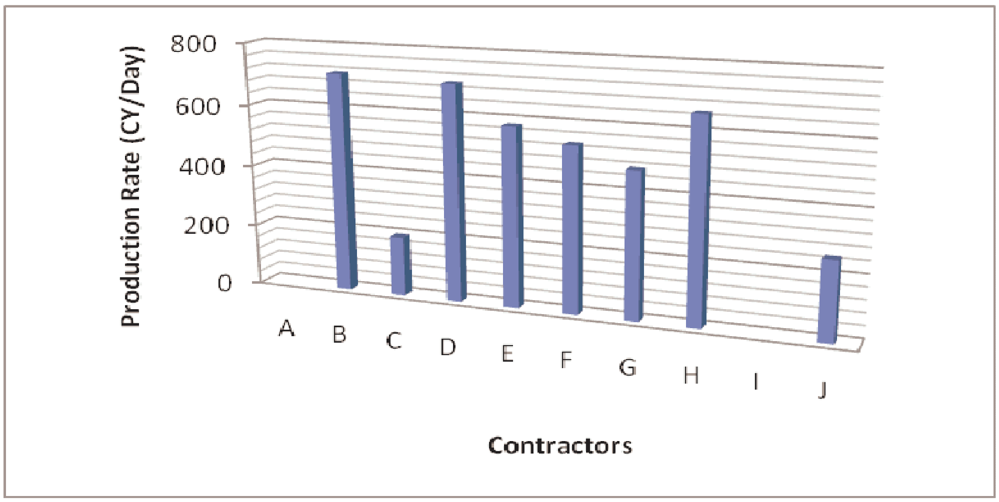


Removal of Asphaltic Pavement (Number of Lanes)

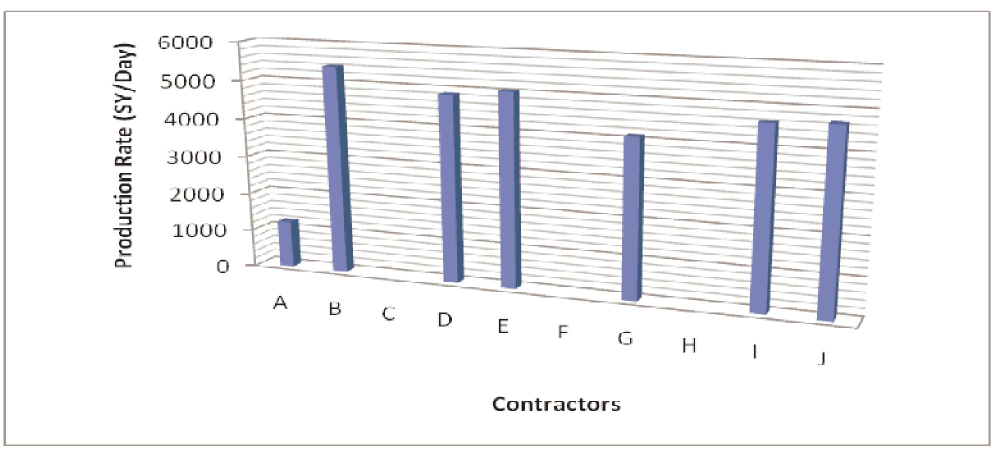
APPENDIX G: PRODUCTION VARIATION AMONG CONTRACTORS



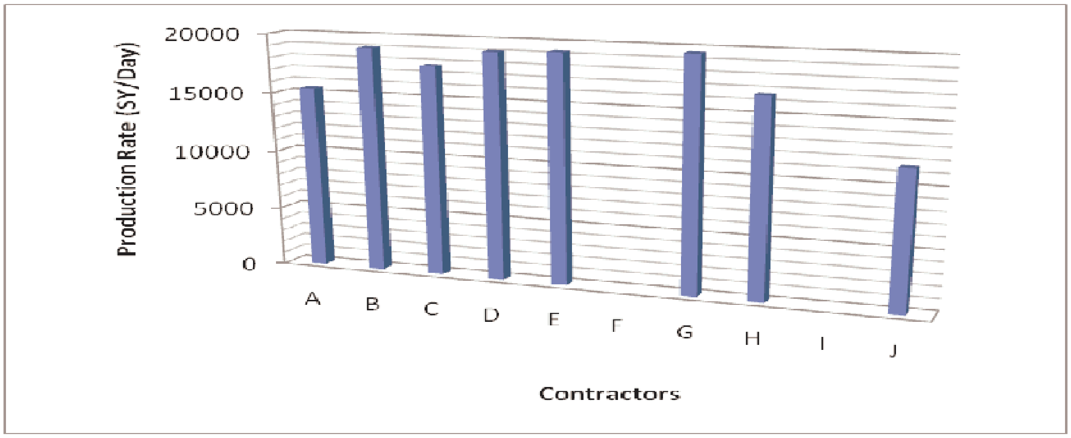
Production Rate Among Contractors (Aggregate Base)



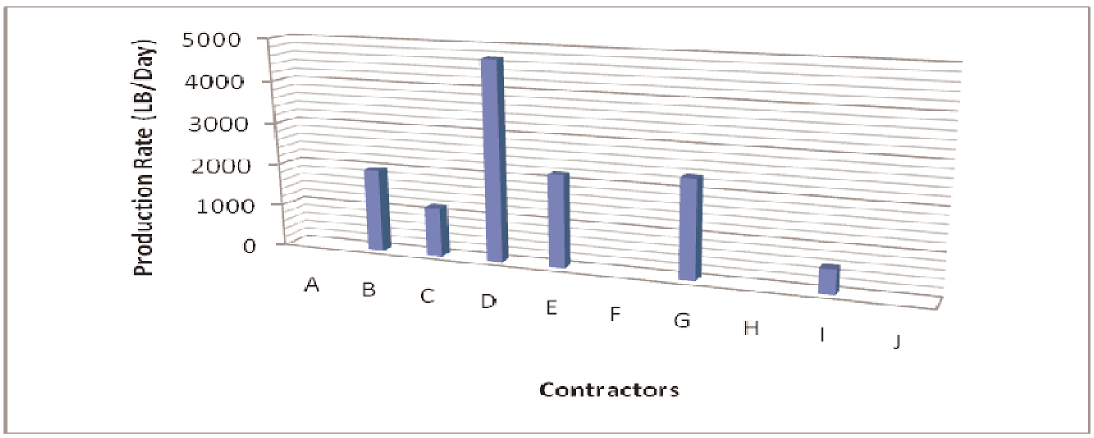
Production Rate Among Contractors (Asphaltic Concrete)



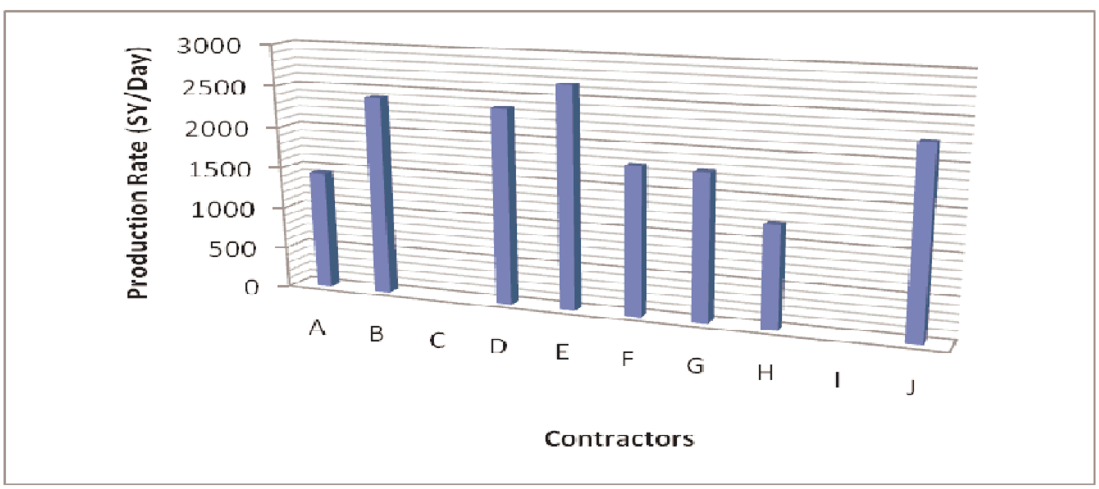
Production Rate Among Contractors (Sub-grade Modification)



Production Rate Among Contractors (Dowel Jointed Pavement)



Production Rate Among Contractors (Bridge Deck rebar)



Production Rate Among Contractors (Removal of Pavement)

APPENDIX H: REGRESSION MODEL

Model		Un-standardized Coefficients		Standardized Coefficients	t	P-Value	95% Confidence Interval for B	
		B	Standard Error	Beta			Lower Bound	Upper Bound
1	(Constant)	353.598	1850.37		0.191	0.85	-3411.01	4118.205
	Route No.	257.858	139.291	0.303	1.851	0.073	-25.532	541.248
	Highway Type	-244.405	225.629	-0.254	-1.083	0.287	-703.451	214.641
	No of Lanes	260.463	185.532	0.3	2.404	0.017	-117.005	637.932
	AADT	-0.192	0.05	-0.573	-3.831	0.001	-0.294	-0.09
	Soil Data	739.637	280.867	0.552	2.633	0.013	168.208	1311.065
	Seasons	-374.634	111.08	-0.491	-3.373	0.002	-600.629	-148.64
	Temp	-2.658	8.303	-0.041	-0.32	0.751	-19.551	14.234

Unclassified Borrow

Model		Un-standardized Coefficients		Standardized Coefficients	t	P-Value	95% Confidence Interval for B	
		B	Standard Error	Beta			Lower Bound	Upper Bound
1	(Constant)	984.12	1743.478		0.564	0.612	-4564.4	6532.644
	Route No.	-78.056	81.321	-0.239	-0.96	0.408	-336.855	180.742
	Highway Type	89.786	275.571	0.181	0.326	0.766	-787.203	966.775
	No of Lanes	-55.039	143.076	-0.163	-0.385	0.726	-510.372	400.294
	AADT	0.091	0.151	0.444	2.604	0.023	-0.39	0.573
	Soil Data	-4.265	305.124	-0.009	-0.014	0.99	-975.307	966.777
	Seasons	-278.025	286.774	-0.911	-0.969	0.404	-1190.67	634.619
	Temp	2.734	12.465	0.117	2.34	0.016	-36.936	42.404

Aggregate Base

Model		Un-standardized Coefficients		Standardized Coefficients	t	P-Value	95% Confidence Interval for B	
		B	Standard Error	Beta			Lower Bound	Upper Bound
1	(Constant)	637.424	927.365		0.687	0.497	-1247.21	2522.057
	Route No.	-80.129	100.942	-0.122	-0.794	0.433	-285.269	125.011
	Highway Type	196.056	115.777	0.273	1.693	0.1	-39.231	431.343
	No of Lanes	237.308	61.233	0.489	3.876	0	112.868	361.748
	AADT	-0.024	0.054	-0.08	-0.444	0.66	-0.133	0.085
	Soil Data	247.981	152.937	0.287	1.621	0.114	-62.825	558.788
	Seasons	-246.739	90.183	-0.455	-2.736	0.01	-430.012	-63.466
	Temp	-3.89	7.827	-0.088	-0.497	0.622	-19.796	12.015

Asphalt Pavement

Model		Un-standardized Coefficients		Standardized Coefficients	t	P-Value	95% Confidence Interval for B	
		B	Standard Error	Beta			Lower Bound	Upper Bound
1	(Constant)	1123.202	3930.057		0.286	0.782	-7939.53	10185.93
	Route No.	745.136	593.165	0.677	1.256	0.244	-622.705	2112.976
	No of Lanes	756.608	314.615	0.788	2.405	0.043	31.105	1482.111
	AADT	-0.351	0.242	-0.924	-1.447	0.186	-0.909	0.208
	Soil Data	-547.888	1061.024	-0.153	-0.516	0.62	-2994.61	1898.838
	Seasons	-83.153	683.341	-0.05	-2.645	0.008	-1658.94	1492.634
	Temp	20.793	34.985	0.233	-2.717	0.007	-59.883	101.469

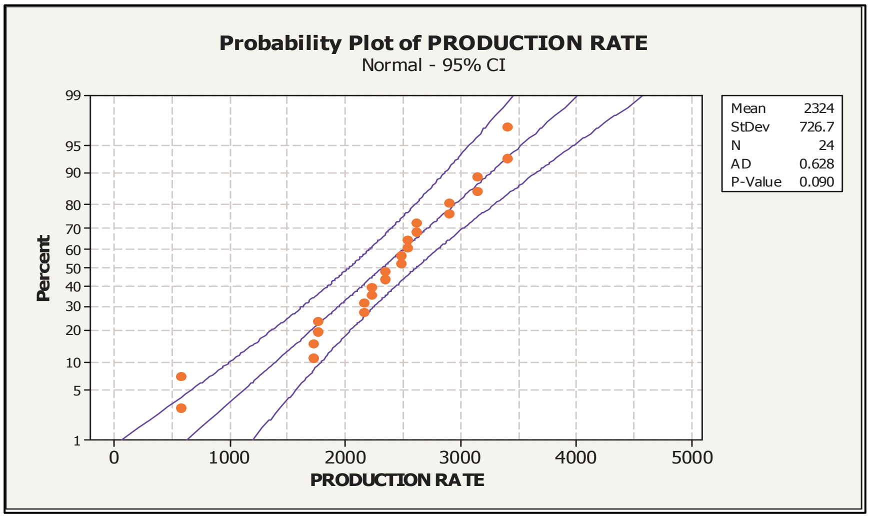
Sub-grade Modification

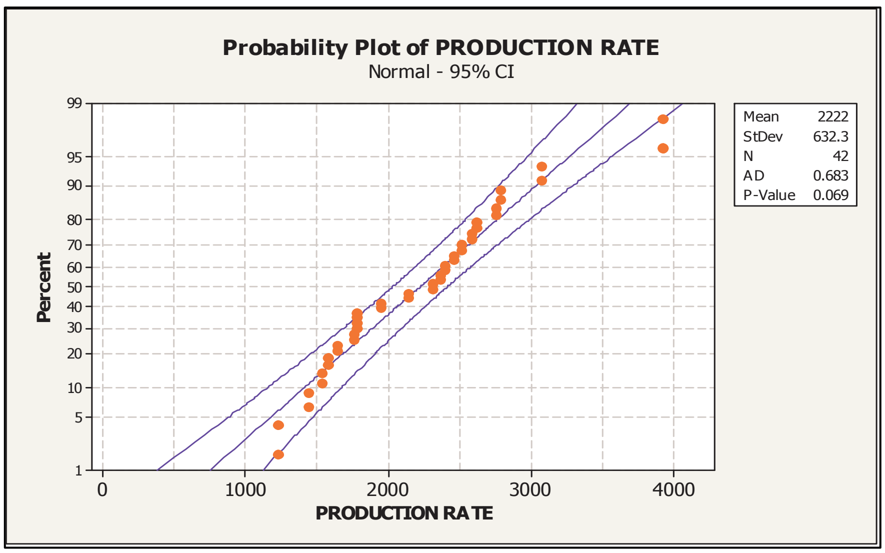
Model		Un-standardized Coefficients		Standardized Coefficients	t	P-Value	95% Confidence Interval for B	
		B	Standard Error	Beta			Lower Bound	Upper Bound
1	(Constant)	4190.194	1471.089		2.848	0.014	1012.1	7368.288
	Route No.	-123.282	173.532	-0.144	-0.71	0.49	-498.175	251.611
	Highway Type	82.278	200.462	0.095	0.41	0.688	-350.793	515.35
	No of Lanes	116.675	180.015	0.187	0.648	0.528	-272.223	505.572
	AADT	-0.14	0.083	-0.367	-1.87	0.013	-0.319	0.038
	Soil Data	-153.858	94.071	-0.291	-1.636	0.126	-357.087	49.371
	Seasons	-500.416	134.404	-0.936	-3.723	0.003	-790.777	-210.054
	Temp	-11.297	8.384	-0.309	-1.347	0.201	-29.41	6.816

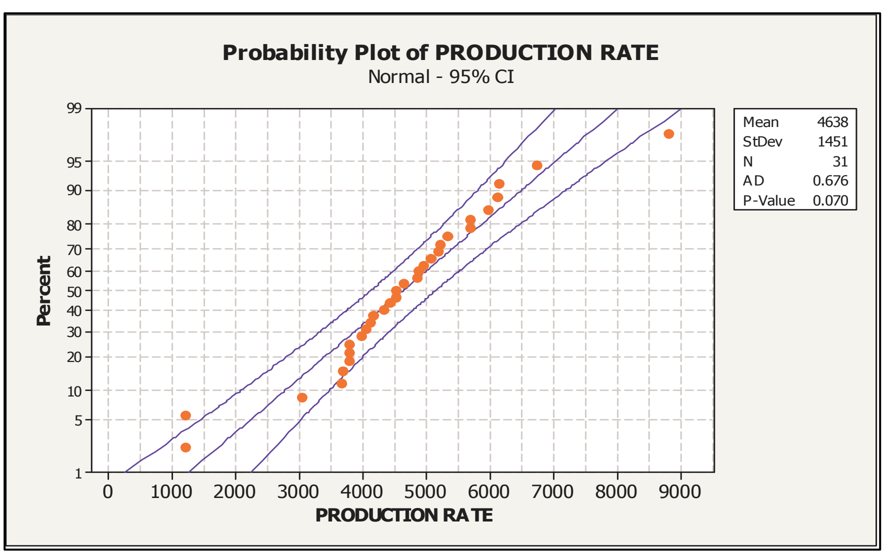
Removal of Pavement

APPENDIX I: PROBABILITY PLOT

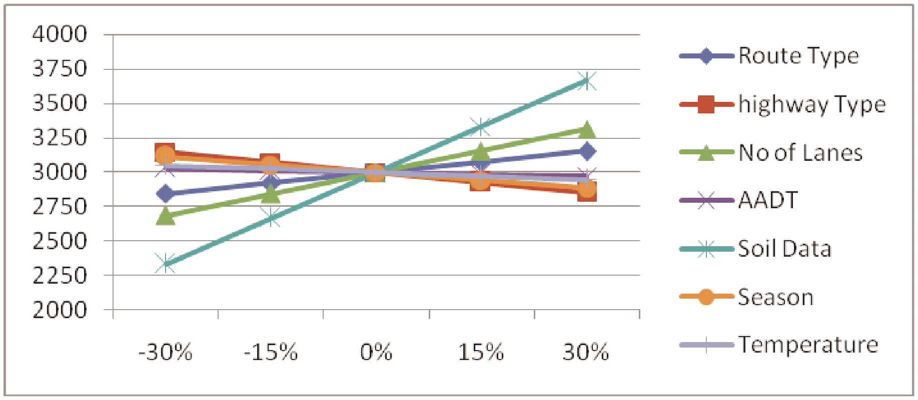
Dowel Jointed, Removal of Pavement & Sub-grade Modification respectively



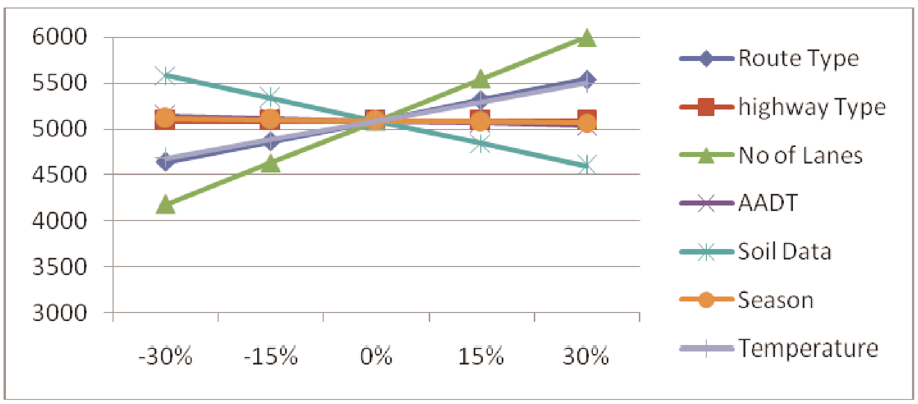




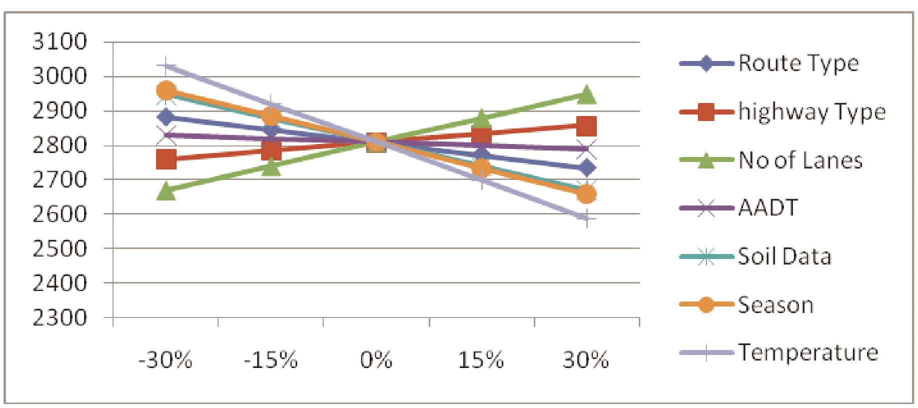
APPENDIX J: SENSISTIVITY ANALYSIS



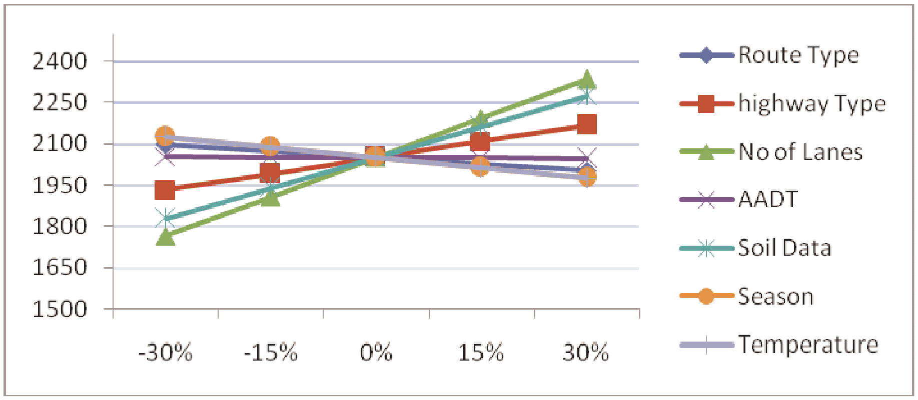
Unclassified Borrow



Sub-grade Modification



Removal of Pavement



Asphaltic Pavement

VITA

Asregedew Kassa Woldesenbet

Candidate for the Degree of

Master of Science

Thesis: ESTMATION MODELS FOR PRODUCTION RATES OF HIGHWAY CONSTRUCTION ACTIVITIES

Major Field: Civil Engineering

Biographical:

Education:
Completed the requirements for the Master of Science in Civil Engineering at Oklahoma State University, Stillwater, Oklahoma in May, 2010. . Received Bachelor of Science in Civil Engineering at Bahir Dar University, Bahir Dar, Ethiopia in July, 2005

Experience:
Structural Engineer and Construction Supervisor October 2005 - July 2008

Professional Memberships:
Golden Key International Honor Society October 2009 – Present
Student member, Project Management Institute (PMI), US July 2008 – Present
Student member, American Society of Civil Engineers (ASCE), US September 2008 – Present
Graduate member, Institute of Civil Engineers (ICE) UK October 2002 – Present

Name: Asregedew Kassa Woldesenbet Date of Degree: May, 2010

Institution: Oklahoma State University Location: OKC or Stillwater, Oklahoma

Title of Study: ESTMATION MODELS FOR PRODUCTION RATES OF HIGHWAY CONSTRUCTION ACTIVITIES

Pages in Study: 144 Candidate for the Degree of Master of Science

Major Field: Civil Engineering

Scope and Method of Study:

The study has identified controlling highway activities; studied current approaches practiced by State DOTs and prior studies conducted on productivity; and selected ongoing and recently completed highway projects, through extensive literature reviews and a series of meetings with ODOT engineers and contractors. It has identified major factors; collected productivity data and assessed the relationship of factors with controlling highway activities by collecting historically recorded data; conducting two set of questionnaire surveys and applying statistical methods. In addition, it has developed production prediction models (regression models) for controlling activities with significant number of data and prediction models based on subjective data from surveys for activities with insufficient data points; and a standalone software program

Findings and Conclusions:

It was concluded that the major factors affecting production rates are weather conditions (temperature and seasonal changes); geographic location of highway projects; traffic condition; quantity of work; size of contractor; and soil type. In addition, type of route, number of lanes and type of roadway are major factors affecting production rates of controlling highway activities. Higher production rates were observed when highway projects are constructed during summer at temperature between 65F and 85F; under sandy/sandy loam soil condition; project located in rural area; concrete pavement; Interstate highway of 8-lane roadway. A survey of productivity data among contractors resulted in a much lower contractors' production rate when compared to residencies as for the reason that contractors would likely keep their data confidential for the purpose of bidding. Clients should bid projects by early January so that construction projects can start by mid of March or early of April in order to have longer duration of work hours and efficient productivity of highway activities during the summer and fall season. In addition, the selection of efficient and specialized construction firms also increase the productivity of highway construction activities. Further, it was concluded that full lane closure of rehabilitation projects or construction of new highway project have higher production rates of highway construction activities than half lane closure.

ADVISER'S APPROVAL: Dr David Jeong