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ECONOMIC ENHANCEMENT THROUGH INFRASTRUCTURE STEWARDSHIP

DEVELOPMENT OF AN IMPROVED SYSTEM FOR CONTRACT TIME DETERMINATION - PHASE III

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16. Abstract

This study developed Daily Work Report (DWR) based prediction models to determine reasonable production rates of controlling activities of highway projects. The study used available resources such as DWR, soil data, AADT and other existing project data from the various divisions of ODOT as primary source in estimating productivity. The study describes the effects and variations of production rates of highway activities to changes in environmental, geographical and project site conditions. The study also includes a relative comparison between a survey of experts' estimate of production rate and DWR based prediction models. An Excel based standalone software program developed for ODOT engineers and schedulers to estimate reasonably accurate production rates is also presented in the study.

The output of this model would allow ODOT engineers and schedulers to improve their accuracy and save their time in determining more reliable production rates of major highway construction activities by easily adjusting site conditions and project factors. The program will help ODOT to determine appropriate contract times of Tier II highway projects which would enhance better planning of resources, reduce construction cost, minimize the construction crew's exposure to traffic, reduce the inconvenience to the public, track project progress and future estimating and bidding guidelines. This study will not only allow ODOT to be equipped with a streamlined procedure for determining production rates of highway construction activities, but will also be a framework and a benchmarking example to other highway agencies.

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SI (METRIC) CONVERSION FACTORS

Approximate Conversions to SI Units

Symbol	When you know	Multiply by	To Find	Symbol
LENGTH				
in	inches	25.40	millimeters	mm
ft	feet	0.3048	meters	m
yd	yards	0.9144	meters	m
mi	miles	1.609	kilometers	km
AREA				
in²	square inches	645.2	square millimeters	mm
ft²	square feet	0.0929	square meters	m²
yd²	square yards	0.8361	square meters	m²
ac	acres	0.4047	hectares	ha
mi²	square miles	2.590	square kilometers	km²
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft³	cubic feet	0.0283	cubic meters	m³
yd³	cubic yards	0.7645	cubic meters	m³
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.4536	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
TEMPERATURE (exact)				
°F	degrees Fahrenheit	(°F-32)/1.8	degrees Celsius	°C
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.448	Newtons	N
lbf/in²	poundforce per square inch	6.895	kilopascals	kPa

Approximate Conversions from SI Units

Symbol	When you know	Multiply by	To Find	Symbol
LENGTH				
mm	millimeters	0.0394	inches	in
m	meters	3.281	feet	ft
m	meters	1.094	yards	yd
km	kilometers	0.6214	miles	mi
AREA				
mm²	square millimeters	0.00155	square inches	in²
m²	square meters	10.764	square feet	ft²
m²	square meters	1.196	square yards	yd²
ha	hectares	2.471	acres	ac
km²	square kilometers	0.3861	square miles	mi²
VOLUME				
mL	milliliters	0.0338	fluid ounces	fl oz
L	liters	0.2642	gallons	gal
m³	cubic meters	35.315	cubic feet	ft³
m³	cubic meters	1.308	cubic yards	yd³
MASS				
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.1023	short tons (2000 lb)	T
TEMPERATURE (exact)				
°C	degrees Celsius	9/5+32	degrees Fahrenheit	°F
FORCE and PRESSURE or STRESS				
N	Newtons	0.2248	poundforce	lbf
kPa	kilopascals	0.1450	poundforce per square inch	lbf/in²

DEVELOPMENT OF AN IMPROVED SYSTEM FOR

CONTRACT TIME DETERMINATION (Phase III)

Final Report

September 30, 2010

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EXECUTIVE SUMMARY

The purpose of this report is to present Daily Work Reports (DWR) based prediction models that would help ODOT engineers and schedulers to estimate reasonably accurate production rates of major highway activities. The report shows how available resources such as DWR, soil data, AADT and other existing project data from the various divisions of ODOT can be used as primary sources in estimating the production rates of major highway activities. A total of 93 Tier II type highway projects and 8 major highway activities were selected to collect production rate data. Weather (temperature and seasonal effects), location & traffic condition, construction firms, quantity of work, type of soil, haul distance, type of highway route, number of lanes, and type of roadway were considered in the report to determine their effects on the production rates of highway activities.

This report summarizes prior research works and relative studies conducted in estimating the production rates of highway constructions; discusses historical project records data collection procedure and technique; quantitatively analyzes significant factors affecting production rates; and presents a DWR based prediction models to estimate the production rates of major highway activities. The report includes a survey conducted with highly experienced engineers' to collect their accumulated knowledge and compare their production rate estimates with DWR based prediction models. Finally, the report presents a standalone software program developed to estimate reasonably accurate production rates of major highway activities.

This developed program would allow ODOT engineers and schedulers to improve their accuracy and save their time in determining more reliable production rates of major highway construction activities by easily adjusting site conditions and project factors. The program will help ODOT to determine appropriate contract times of Tier II highway projects which would enhance better planning of resources, reduce construction cost, minimize the construction crew's exposure to traffic, reduce the inconvenience to the public, track project progress and future estimating and bidding guidelines. This study will not only allow ODOT to be equipped with a streamlined procedure for determining the production rates of highway construction activities, but also will be a framework and a benchmarking example to other highway agencies.

CHAPTER 1
INTRODUCTION

1.1 Introduction:

The production rates of highway construction activities are an important issue in the construction industry. Highway construction production rates are vital to both State Department of Transportations' (DOT) and participants in the construction industry. Research conducted on the process of estimating the contract time of highway projects shows that the 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, reduces delays in completion of a project on time, minimizes 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, to determine the production rates of highway activities, which will be expandable in the future.

1.4 Research Methodology:

The study has employed 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 Production Rate 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 review and meetings with ODOT engineers and contractors. The second stage involves collecting production rate data and identifying critical factors by using Daily Work Reports (DWR) and questionnaire surveys. In addition, the factors

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obtained from the study are statistically analyzed to determine the significance of the 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.

STAGE	INPUT	OUTPUT

Stage I — Conduct Literature Review → Meetings with ODOT Engineers & Contractors

Identify Controlling Highway Activities

Identify Current Practice

Highway Project Selection

Stage II — Collect Historical Data → Daily Work Report (DWR) → Analyze Historical Data; Collect Experienced Engineers Estimate → Questionnaire Survey I, Questionnaire Survey II → Analyze Survey Response

Identify Critical Factors

Collect Productivity Data

Significance of Factors Affecting productivity

Stage III — Compare Historical Data with Survey Response → Is comparison good? → (Yes) Develop Productivity Estimation Model; (No) Discussion with Senior Engineer → Develop Productivity Chart

Comparison of Productivity Data

Estimation Model / Expert System

Standalone Program

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 the production rates of highway construction activities and factors affecting the production rates.

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 the production rates.

1.4.3   Historical Highway Project Data

Once the controlling highway activities and factors are identified, the 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 the production rates of controlling highway activities. The first questionnaire survey is used to identify and rank critical factors affecting the production rates. The second survey is used to extract production rate estimate 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 the production rates 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 Production Rate Estimation Models

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.

1.4.7 Development of a Standalone Program

Based on the estimation models, a standalone software program is developed for estimating the 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.

1.5 Report Organization

Prior studies conducted on the 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 results 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. 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 of an activity. 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.

$$\Pr oductionRa\,te = \frac{Total\ estimated\ quantity\ of\ the\ activity}{ActivityDu\,ration}\ \dots\dots\dots\dots\dots\dots\dots\dots\quad (Eq.\ 2.1.)$$

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. Herbsman 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. 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.
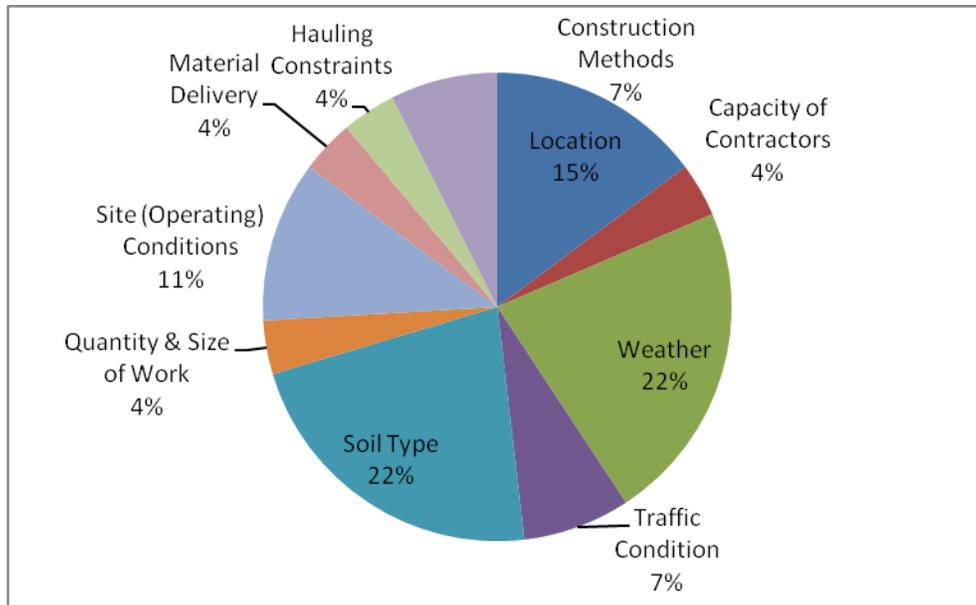
Figure 2.1 Factors Affecting Productivity of Highway Projects

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) method.

The new production rates showed an increase in highway construction productivity. Based on the 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

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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

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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,

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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 several 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.
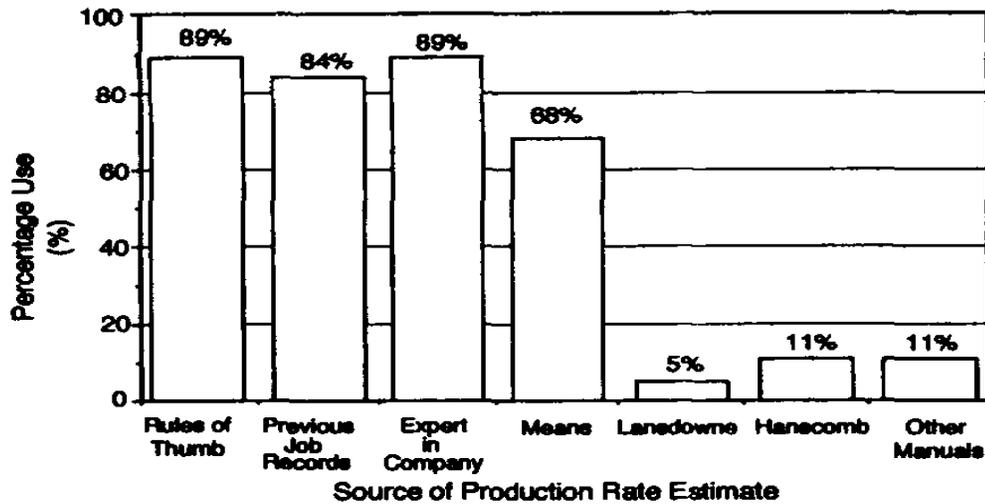
17

Figure 2.2 Sources of Information when Estimating Production Rate (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.

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 Department 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, higher production rates were 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.

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, it is difficult to quantify the uncertainties and assess their significance of the production rates of highway activities. Table 2.5 briefly summarizes these scientific tools or approaches used in determining production rates during the past five decades.

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......)		*	*	*

Chapter 3
DATA COLLECTION

This study uses historical recorded data of previously completed projects as its primary sources with the addition of experienced engineers' estimates in predicting production rates of controlling highway activities and updating the 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.

```
┌─────────────────────────┐
│  Meetings & Interviews  │
└─────────────────────────┘
         │   ├─ Identify Controlling Highway Activities
         │   ├─ Identify Critical Factors
         │   └─ Select Highway Projects
         ▼
┌─────────────────────────┐
│ Historical Highway      │
│ Project Data            │
└─────────────────────────┘
         │   └─ Collect Production Rate Data
         ▼
┌─────────────────────────┐
│  Questionnaire Survey   │
└─────────────────────────┘
             ├─ Survey I (Identify & Rank Critical Factors)
             └─ Survey II (Production Rate Data)
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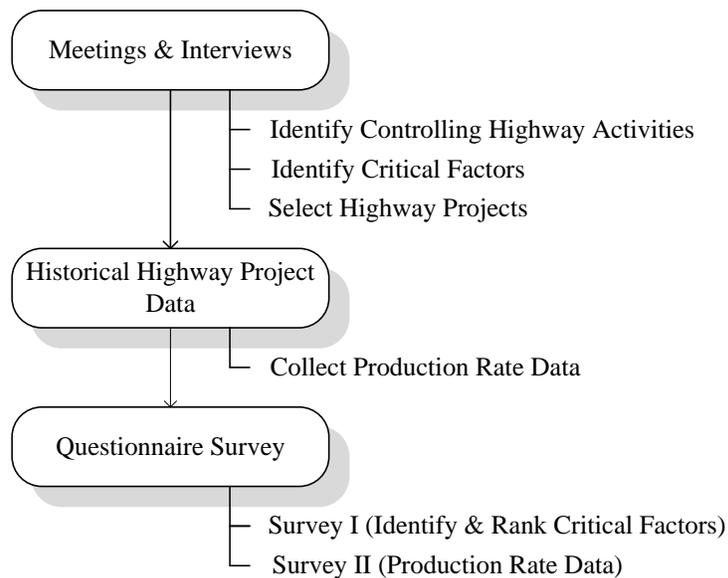
Figure 3.1 Data Collection Methodology

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

No.	ITEM NO.	PAY-ITEM DESCRIPTION	UNIT
A.	202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY
B.	202(C) 0184	UNCLASSIFIED BORROW, RDY	CY
C.	303 0192	AGGREGATE BASE, RDY	CY
D.	414(A1) 5755	10" P.C. DOWEL JOINTED CONCRETE PAVEMENT , RDY	SY
E.	326(E) 4240	(SP) CEMENTETIOUS STABILIZED SUBGRADE, RDY	SY
F.	511(B) 6010	EPOXY COATED REINFORCING STEEL	LB
G.	411(S3) 5945	(SP)ASPHALT CONCRETE TYPE S3	TON
H.	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.
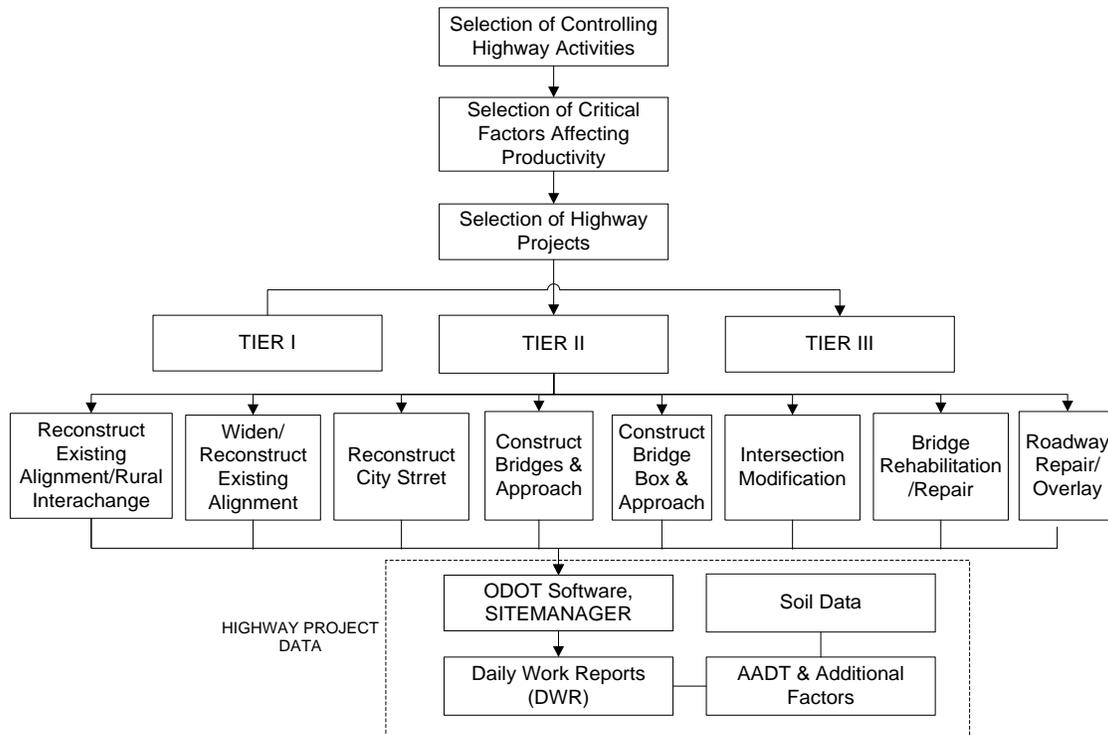
Figure 3.2 Data Collection Process

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.

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 and compare it with DWR based production rate of 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 and compare it with DWR based production rate 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 employs 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 factors 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. The data analysis procedure is illustrated in Figure 4.1.
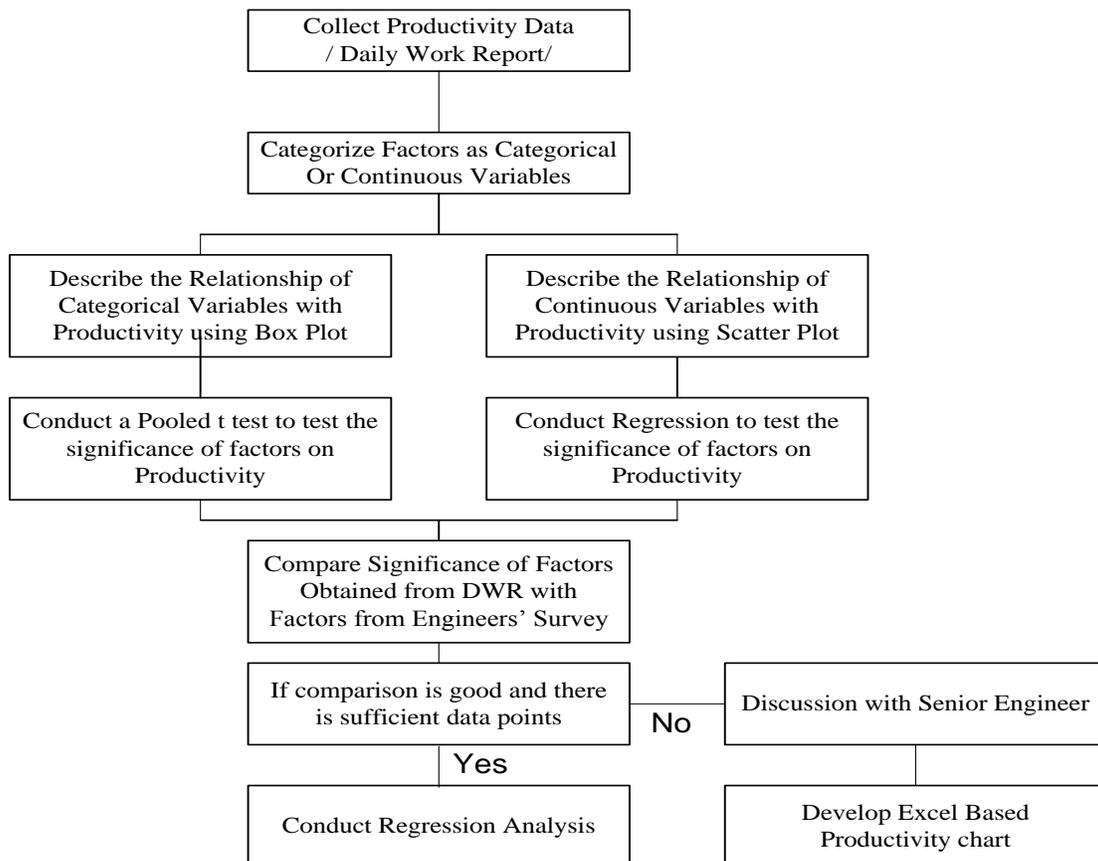
Figure 4.1 Data Analysis Procedure

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.
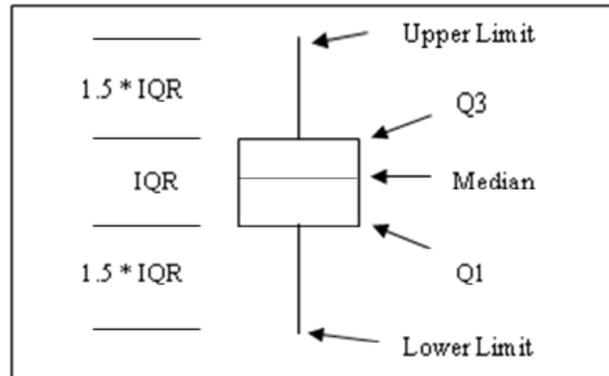
Figure 4.2 Box Plot Diagram (Freund, 2003)

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. Table 4.1 summarizes the breakdown of these factors investigated in this study.

Table 4.1 Break-down of Factors

Factors	Sub-factors
Soil Type	Heavy clay, Lean Clay, Sandy/Sandy loam
Roadway Type	Concrete pavement, asphalt pavement, composite
Temperature	$(20-29^oF)$, $(30-39^oF)$, $(40-49^oF)$, $(50-59^oF)$, $(60-69^oF)$, $(70-79^oF)$, $(80-89^oF)$, $(90-99^oF)$, and $(100-109^oF)$
Season	Spring, Summer, Fall, and Winter
Location and Traffic condition	Flat, Rolling, Mountainous, Central business district (CBD), Fringe of CBD, outlying business district, Residential
Number of lanes	1-Lane 1-Way, 2-Lane 2-Way, 2/3-Lane 1-Way, 2/3-Lane 2-Way, 4-Lane, 6-Lane, 8-Lane
Highway Route	Interstate, State Highway, US Highway, Turnpike, City Street
Construction Firms	A, B,C,…, J.

Weather:

As many studies already identified, weather is one of the factors affecting productivity of construction operations (Smith (1999), El-Rayes & Moselhi (2001), (Pan (2005), Jiang and Wu (2007)). Weather condition includes precipitation (rainfall), moisture, temperature, seasonal changes and humidity. Extreme weather conditions result in delay of work operations, lower production rates 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 4.2.

a. 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.

b. 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.

c. 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.

d. Central Business District (CBD) – includes downtown area of city characterized by large number of pedestrians, loading zones and high parking demand.

e. Fringe CBD – represents areas adjacent to CBD with light industry, warehouses, auto service and low activity.

f. Outlying Business district – includes business districts located outside the CBD.

g. Residential Area – includes areas predominately used for dwelling.

Table 4.2 Terrain or Area Type

Terrain Type	Classification
Flat	Rural Area
Rolling	
Mountainous	
Central Business District (CBD)	Urban Area
Fringe of Central Business District	
Outlying Business District	
Residential	

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 production rate 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 production rates of construction activities. 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 production rates. The effect of quantity of work can be explained by the economies of scale. As the quantity of work increases, better equipments, resources, and construction methods is utilized to decrease the average cost of construction which in turn increases production rates of construction operations.

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 distances greater than 1,000ft 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 it 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 4.3

Table 4.3 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. Based on the collected data, the 70% of the construction projects 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 Appendix E.

4.6 Effect of Factors on Production Rates of Highway Activities

Once factors affecting production rates of highway activities have been categorized, box plot and scatter plot are employed in analyzing the effects of these factors to determine their significance on production rates. The concept of 'percent unit' has been developed and used throughout the study. 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)

$$\text{Percent Unit}_i = \frac{\text{Mean Production Rate}_{DWR}}{\text{Mean Production Rate}_{ODOT\ PRC}} * 100 \ldots\ldots\ldots (\text{Eq. 1})$$

Where i = activity i, DWR = Daily Work Reports, and ODOT PRC = Oklahoma Department of Transportation Production Rate Chart [Eq. 1].

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 might be 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

No.	Major Controlling Activity	Unit	DWR Mean Production Rate	ODOT Average Production Rate	Percent Unit
A.	Unclassified Excavation, Rdy	Cy	3330	3500	95%
B.	Unclassified Borrow, Rdy	Cy	1535	2150	71%
C.	Aggregate Base, Rdy	Cy	475.5	310	345%
D.	(SP) Asphalt Concrete Type S3	Ton	1377.3	900	211%
E.	Lime/Cementetious Stabilized Subgrade, Rdy	Sy	4638	2400	285%
F.	10 " Dowel Jointed Concrete Pavement, Rdy	Sy	2936	1640	179%
G.	Bridge Deck Rebar	Lb	17910	8050	222%
H.	Removal of Concrete Pavement	Sy	2222	1475	151%

4.6.1 Effect of Weather

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 4.3 and 4.4.
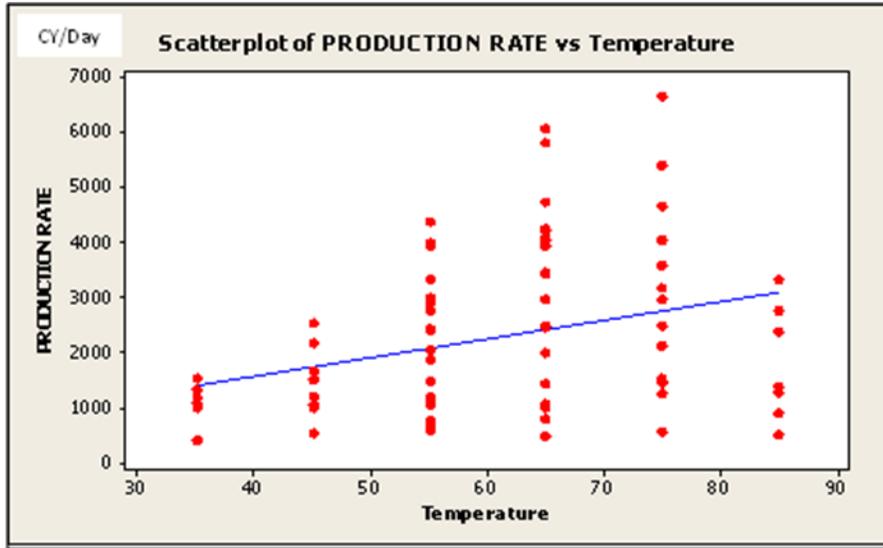
Figure 4.3 Scatter Plot of Production Rate against Temperature (Unclassified Excavation)
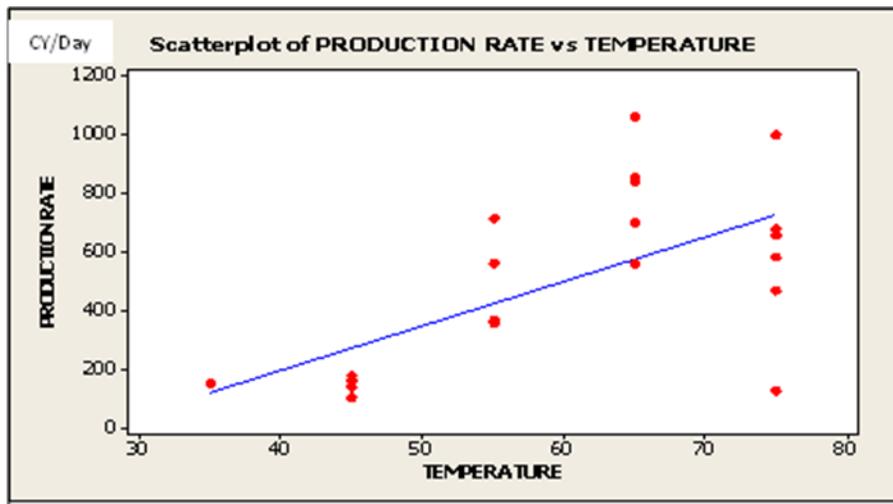
Figure 4.4 Scatter Plot of Production Rate against Temperature (Aggregate base)

Although the plots are scattered, 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 65^0F and 85^0F. Similarly, Figure 4.5 shows a trend of increase in the percent unit of production rate with an increase in temperature up to 85^0F and tends to decrease beyond that. This trend of productivity is observed in aggregate base, bridge deck rebar, and removal of pavement. For instance, for aggregate base the percentage unit increases from 50% at 35F to 185% at 85^0F. A trend of decrease in production rate at 85^0F is observed with an increase in temperature for unclassified excavation, asphaltic concrete, stabilized sub-grade and dowel

35

jointed pavement. This decrease in productivity at temperature 85^0F is attributed to the fact that other factors play role in lowering production rates at higher temperatures. Although there is not a distinct trend observed for unclassified borrow, a favorable temperature for operating construction activities may be taken as between 65^0F and 85^0F.
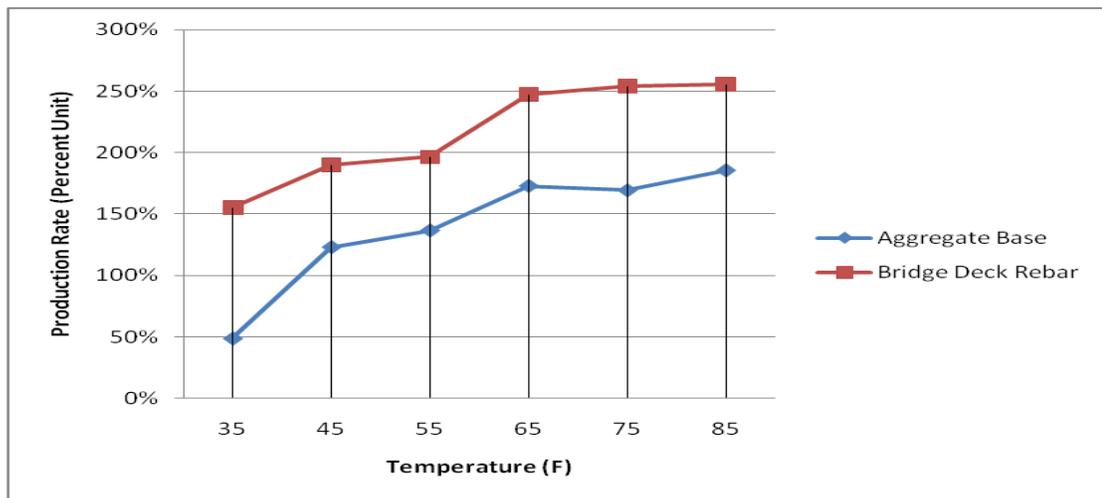
Figure 4.5 Effect of Temperature on Production Rate

A box plot of production rate for Asphaltic pavement against seasonal changes is shown in Figure 4.6. 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 up to 2800Ton/Day during summer 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.
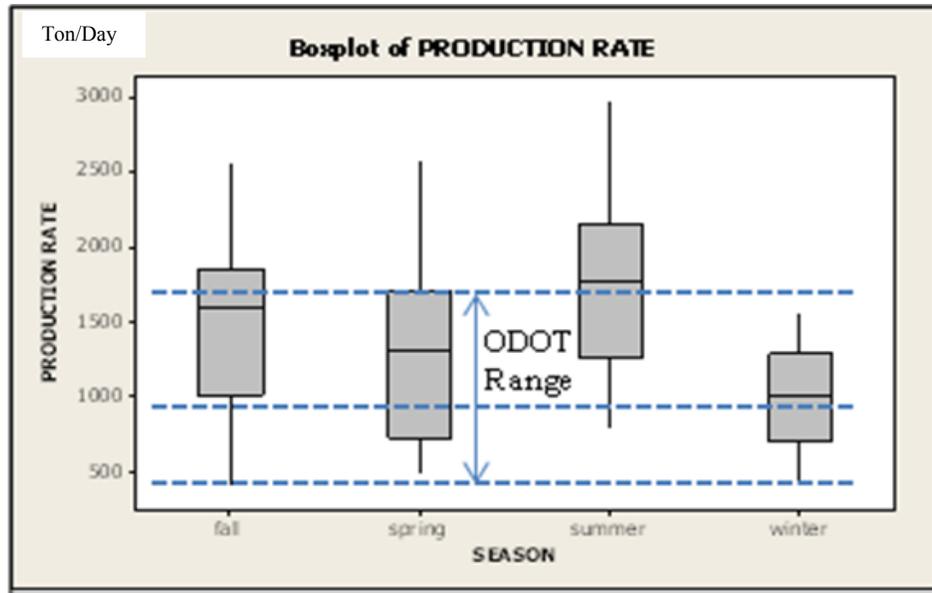
Figure 4.6 Box Plot of Production Rate against Season (Asphaltic Pavement)

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 4.7). In the second trend, production rate is higher in spring rather than fall (Figure 4.8). The first trend is observed in unclassified excavation, asphaltic concrete, stabilized sub-grade and dowel jointed pavement and the second is observed 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 Appendices F & G.
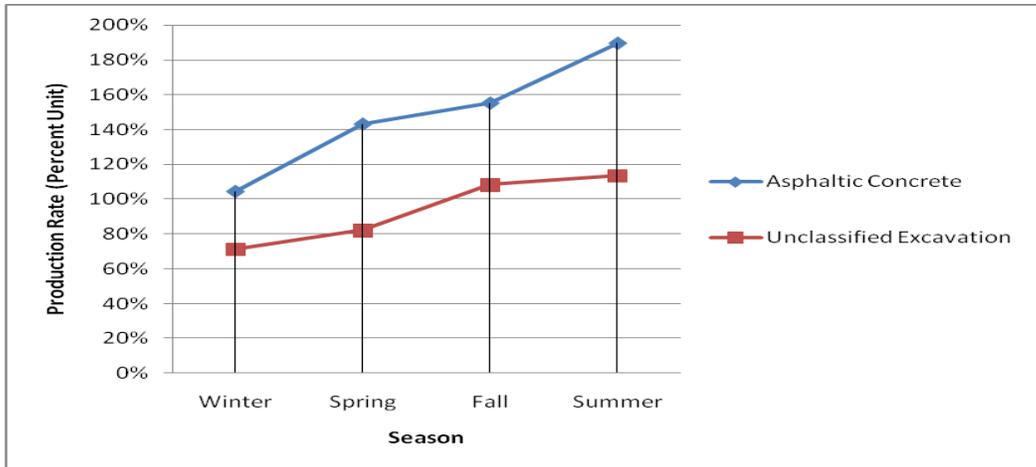
Figure 4.7 Effect of Seasonal Change on Production Rate (Trend 1)

Lower production rates of controlling highway activities may be attributed to the extreme weather conditions (temperature and seasonal changes) which lead to 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).
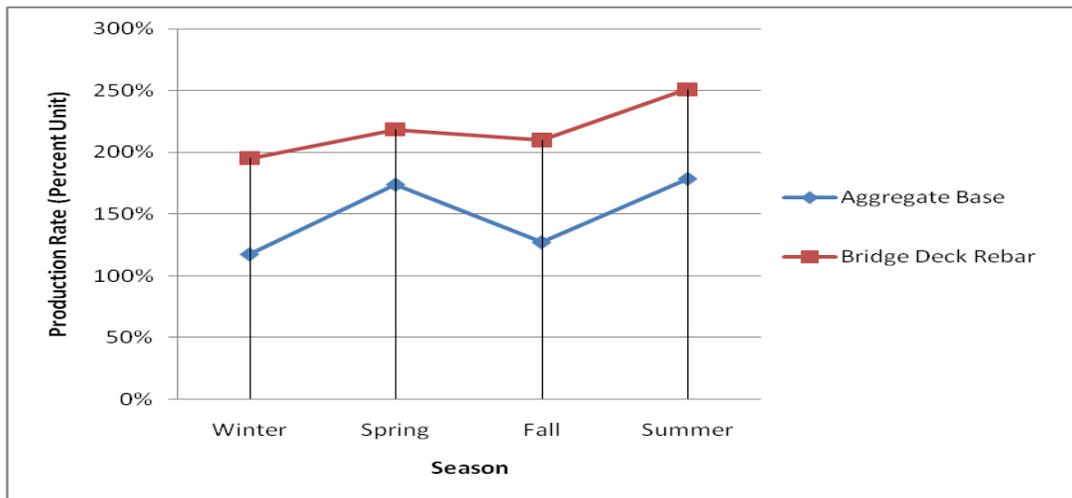
Figure 4.8 Effect of Seasonal Changes on Production Rate (Trend 2)

4.6.2 Effect of Soil Type

The effect of soil on productivity of laying an aggregate base is explained in Figure 4.9. Although the production rates range is wide, the median reveals that higher productivity is

achieved for projects which encountered loam/sandy soil. A comparison made between ODOT's minimum (160 Cy/day), average (310Cy/day) and maximum (775 Cy/day) production rate with DWR based maximum production rate of heavy clay, lean clay and sandy soils respectively, shows that ODOT's production rate chart are lower by more than one third when compared to DWR based production rates.
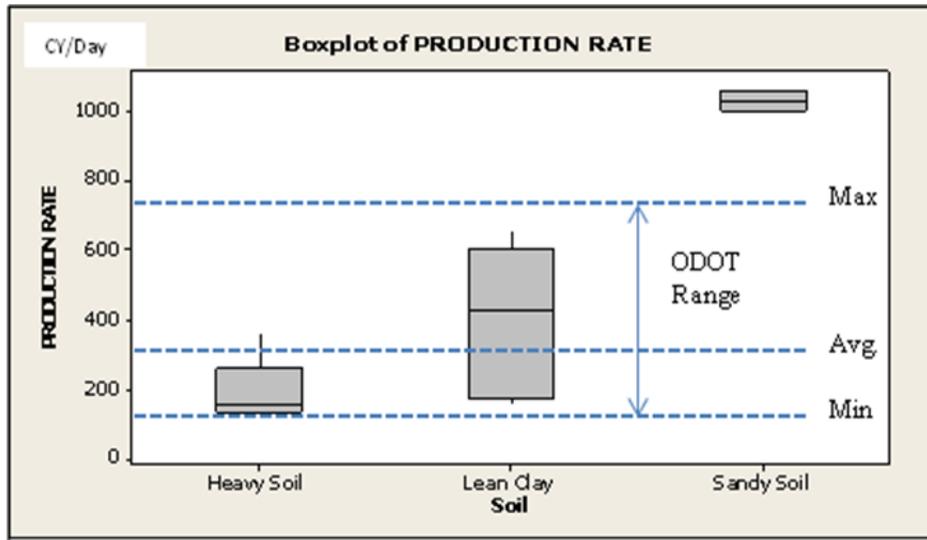
Figure 4.9 Box Plot of Production Rate against Soil Type (Aggregate Base)

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. Production rate increases are observed in the order of heavy soil, lean clay and sandy soil for unclassified excavation, unclassified borrow, and aggregate base (Figure 4.10). This is probably attributed to the fact that sandy soil has a better drainage and offers better maneuverability of equipment and machineries than lean and heavy clay.
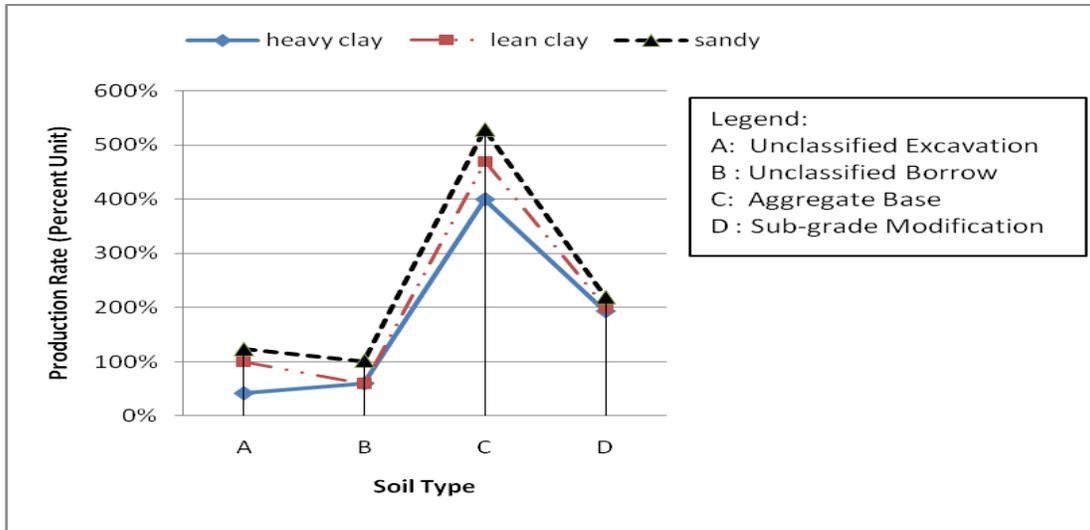
Figure 4.10 Effect of Soil Type on Production Rate

4.6.3 Effect of location & Traffic Condition

The location of projects is classified into rural and urban areas based on Annual Average Daily Traffic (AADT) and Terrain or Area type. Figure 4.11 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 may affect material delivery and supply, traffic condition, accessibility to the site and time periods of construction which results in lower productivity. In addition, Figure 4.12 illustrates the reduction in the production rate of laying asphalt pavement with an increase in the annual average daily traffic (AADT).
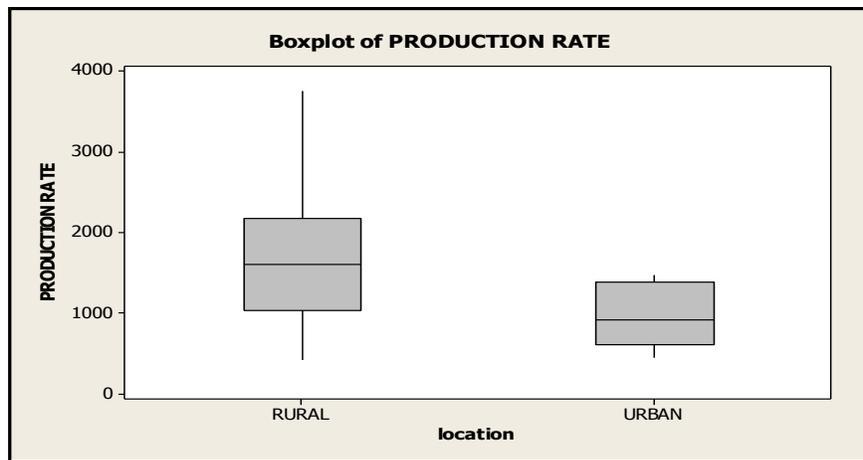
Figure 4.11 Box Plot of Production Rate against Location (Unclassified Borrow)

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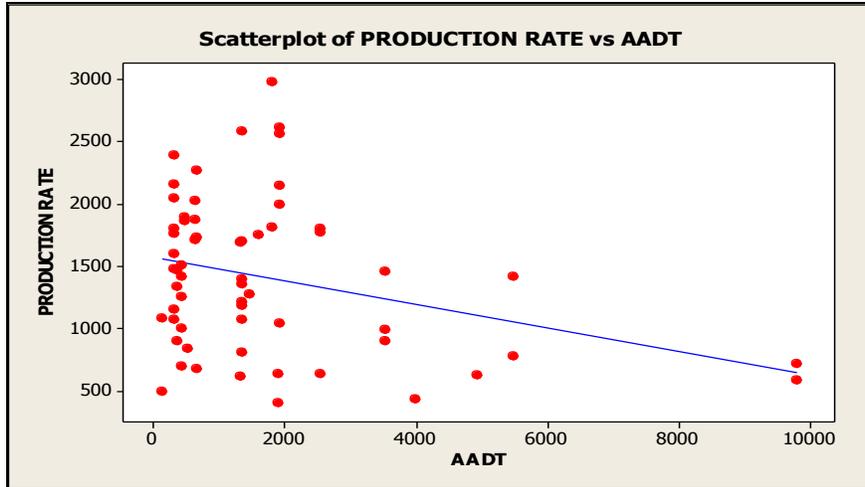
Figure 4.12 Scatter Plot with Regression for Laying Asphaltic Pavement (AADT)

Figures 4.13 further illustrates the differences in the percent unit of production for urban and rural areas. Although the degree of sensitiveness varies, the same trend of percent unit production is observed in the other controlling activities. It is observed that unclassified borrow and aggregate base are much sensitive to location of a project while asphaltic pavement and removal of pavement are relatively sensitive to project site location.
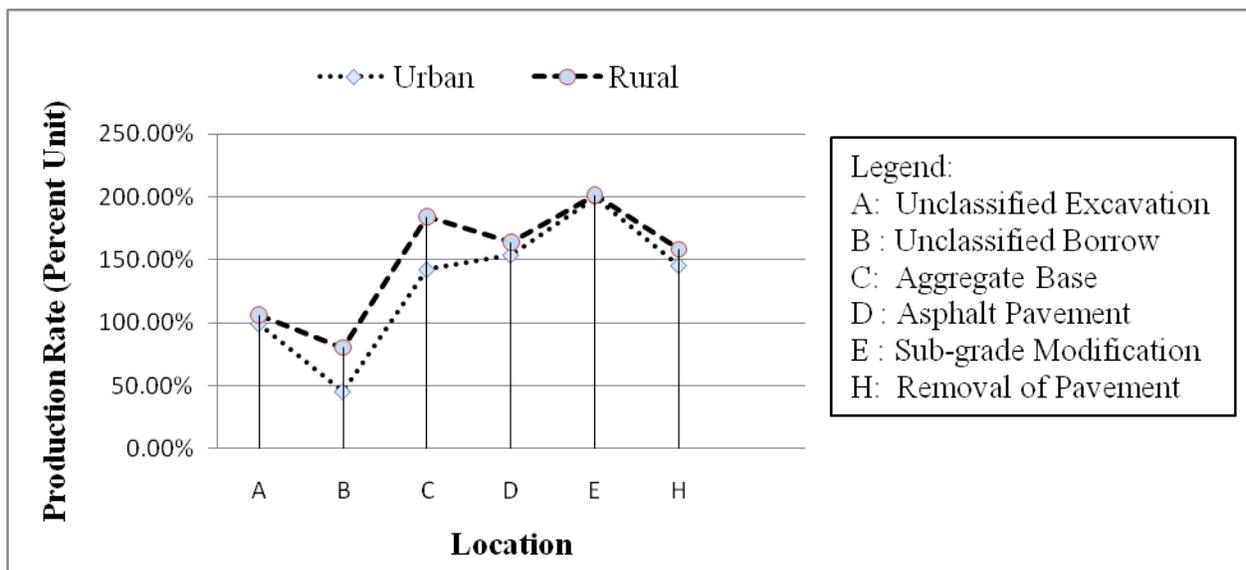
Figure 4.13 Effect of Location on Production Rates

4.6.4 Effect of Contractors

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,

$$H_o : \mu_1 - \mu_2 = \delta_0$$
$$H_1 : \mu_1 - \mu_2 \neq \delta_0 \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(Eq.4.2)$$

We use the test statistic,

$$t = \frac{(\overline{y_1} - \overline{y_2}) - \delta}{\sqrt{(S_p^2 / n_1) + (S_p^2 / n_2)}} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(Eq.4.3)$$

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

$$S_p{}^2 = \frac{SS_1 + SS_2}{n_1 + n_2 - 2} \qquad ....(Eq.4.4)$$

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 4.14 and 4.15 respectively. The result of the pooled t-test is shown in Appendix H.
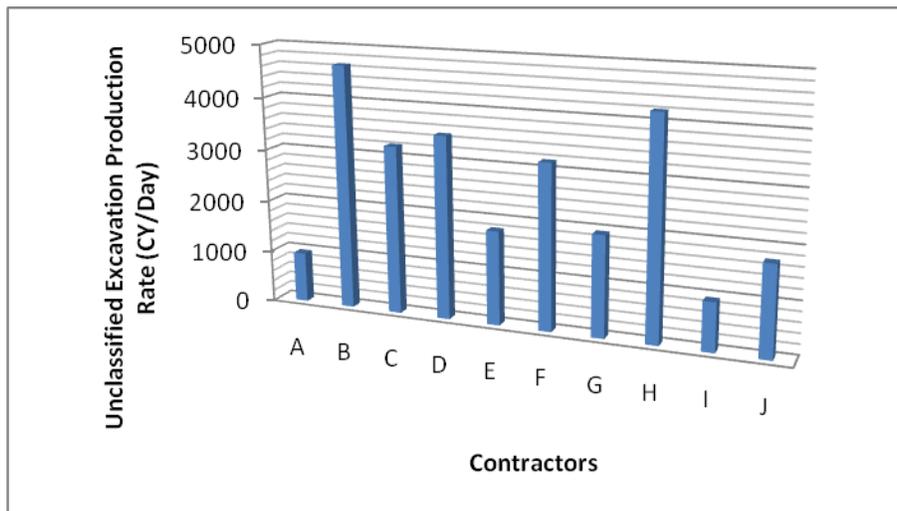
Figure 4.14 Comparison of Production Rate Among Contractors (Unclassified Excavation)

For instance, in Figure 4.14, 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 4.15. 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 observed in all controlling activities. The effect of contractors on other controlling activities is shown in Appendix I.
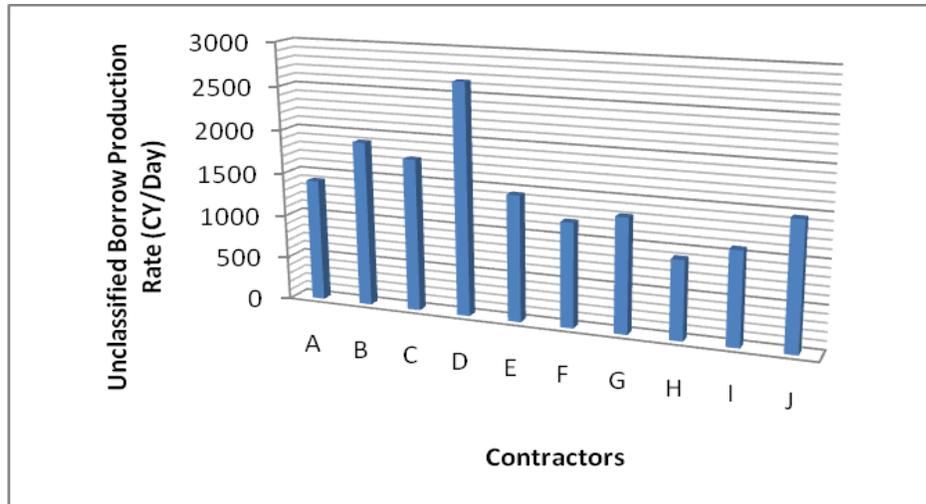
Figure 4.15 Comparison of Production Rate Among Contractors (Unclassified Borrow)

4.6.5 Effect of Number of Lanes

Figure 4.16 illustrates the relationship between the number of lanes and production rates for laying asphaltic pavement. Higher production rate is achieved in 8-lane highways compared to 2-lane highways. Figure 4.17 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. The quantity of work (economies of scale), the availability of materials, and selection of construction methodology may attribute to the higher productivity of 8-lane highways compared to 2-lane highways.
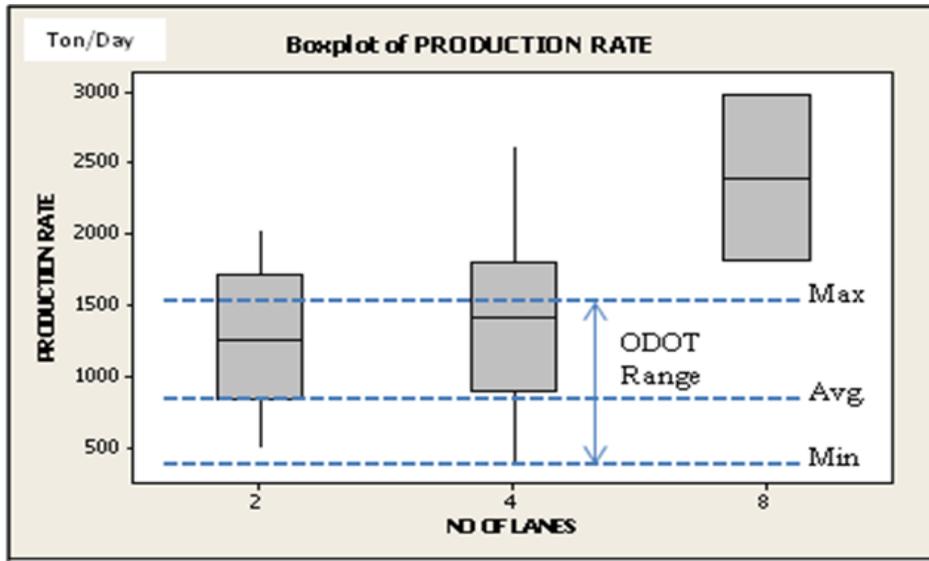
Figure 4.16 Box Plot of Production Rate against No of Lanes (Asphaltic Pavement)
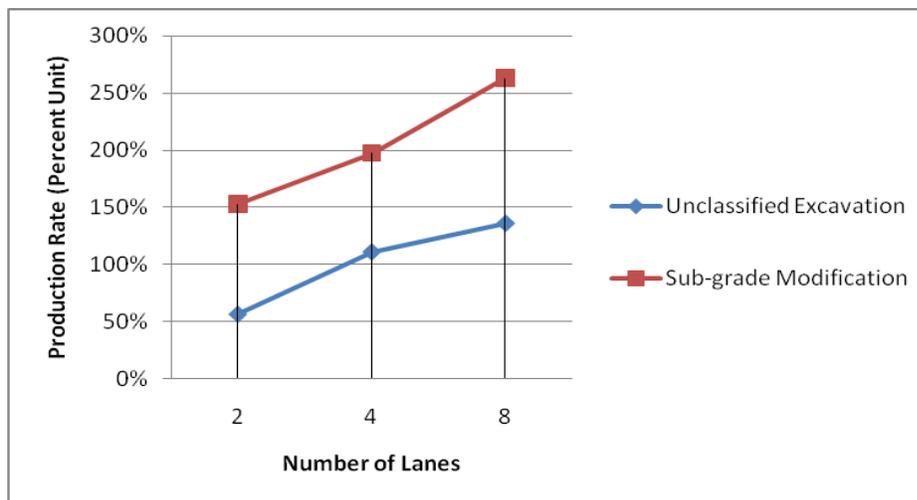
Figure 4.17 Effect of Number of Lanes on Productivity

4.6.6 Effect of Highway Type on Productivity

The effect of highway type on production rates is explained in Figure 4.18. 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. Asphaltic pavements can be turned over to traffic as it does need curing time, but concrete pavements can be placed much quicker than asphalt pavements.

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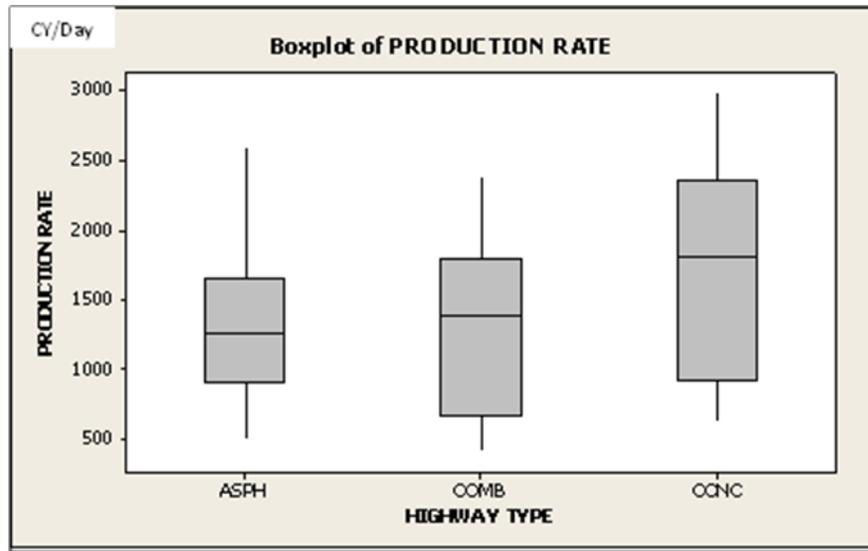
Figure 4.18 Box Plot of Production Rate against Highway Type (Aggregate Base)

4.6.7 Effect of Route Type

A box plot of removal of concrete pavement against route type is shown in Figure 4.19. 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 might be 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 4.20 shows the effect of route type for asphaltic concrete and unclassified borrow. This order is observed in all controlling activities except unclassified excavation and aggregate base, where US Highway's percent unit of production is higher than Interstate (Figures 4.21). This may be due to economies of scale (quantity of work) and the fact that interstate projects are usually located in rural areas where there are less operational constraints and traffic flow which would enhance better material delivery and supply and higher safety of construction workers. The effect of route type for the remaining controlling activities is shown in Appendix E.

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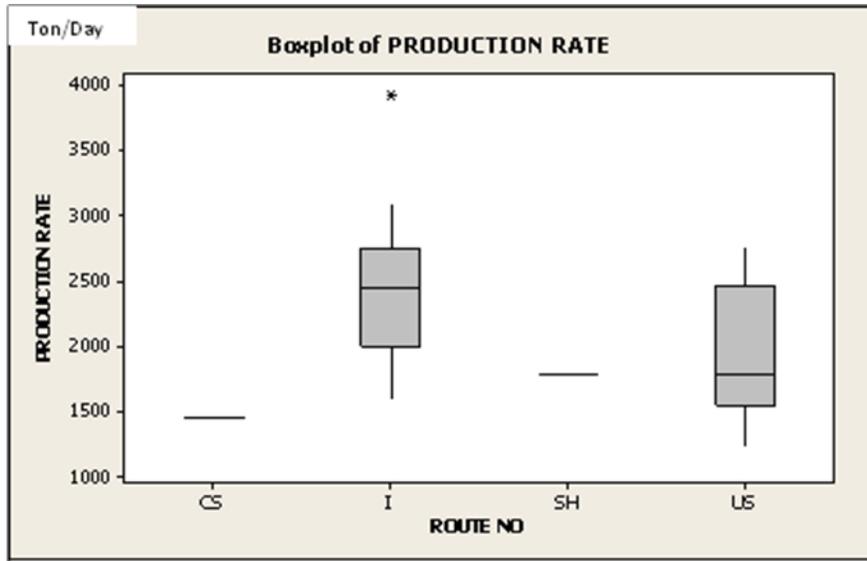
Figure 4.19 Box Plot of Production Rate against Route Type (Removal of Pavement)
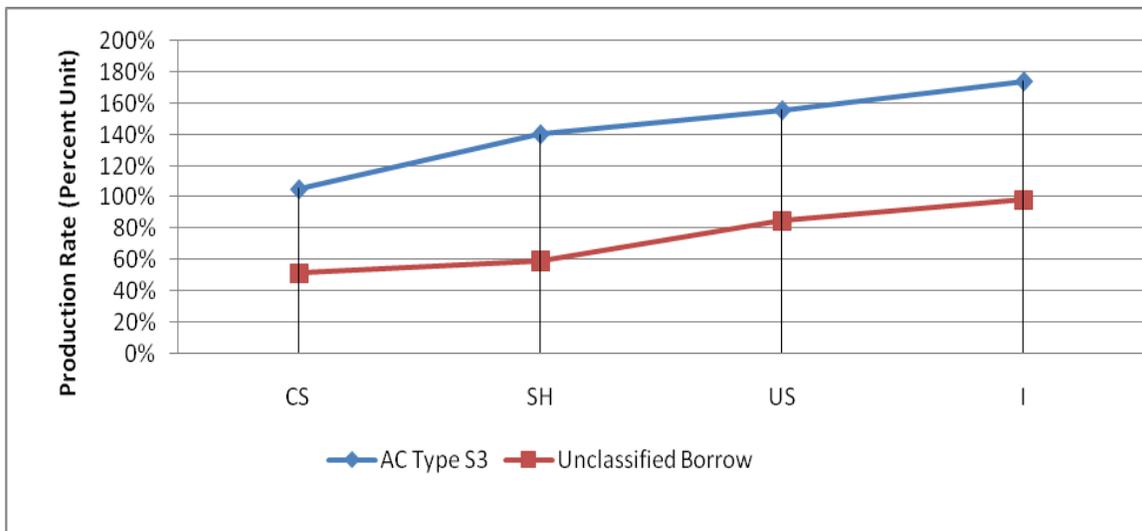
Figure 4.20 Effect of Type of Route Type on Production Rate (Trend 1)

47
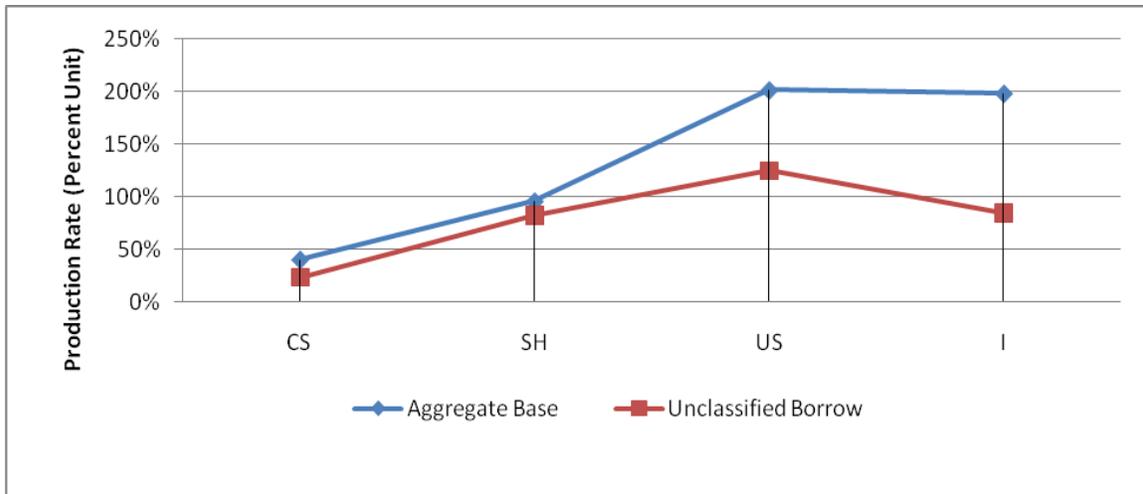
Figure 4.21 Effect of Route Type on Production Rate (Trend 2)

Based on the statistical analysis, Table 4.5 summarizes the effect of factors 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 Effects of Factors on Production Rate

Factors	Lowest Production Rate	Highest Production Rate
SEASON	Winter	Summer
TEMPERATURE	$< 65^0F$ & $> 85^0F$	$65\ ^0F - 85^0F$
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 by the research team in 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.
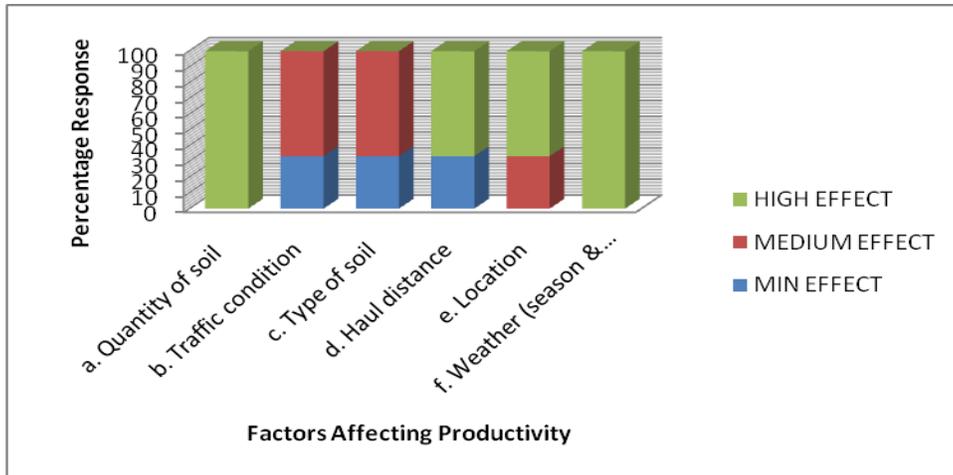
Figure 5.1 Effect of Factors on Unclassified Excavation and Borrow
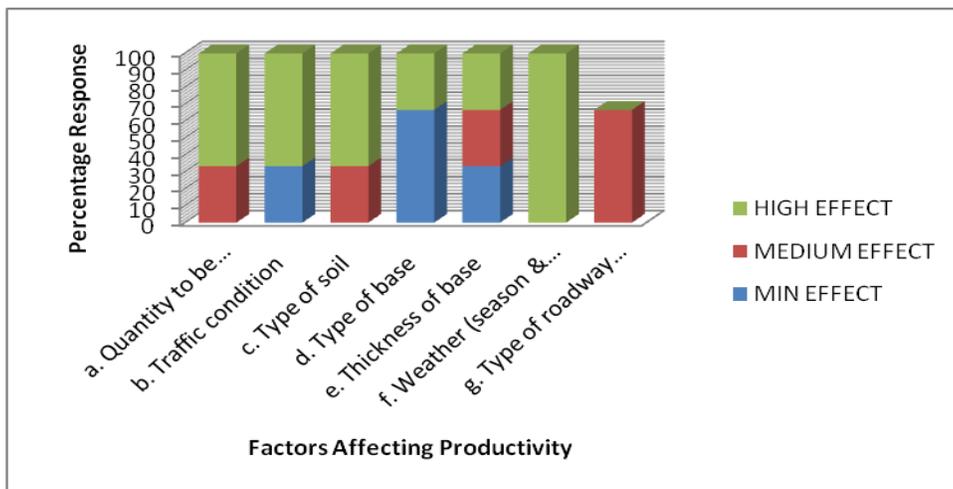
Figure 5.2 Effect of Factors on Sub-grade Modification

As shown in Figure 5.1, quantities of work and weather are the most significant factors identified by the experts, while location and haul distance are relatively significant. 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).

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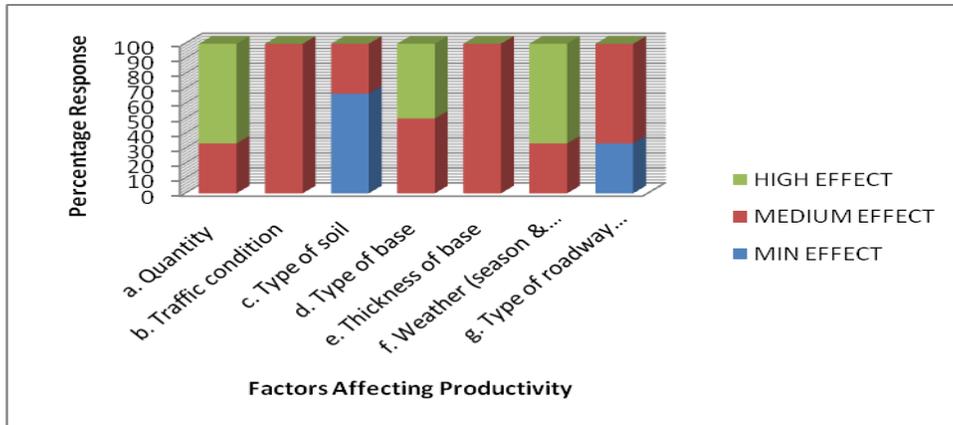
Figure 5.3 Effect of Factors on Aggregate Base
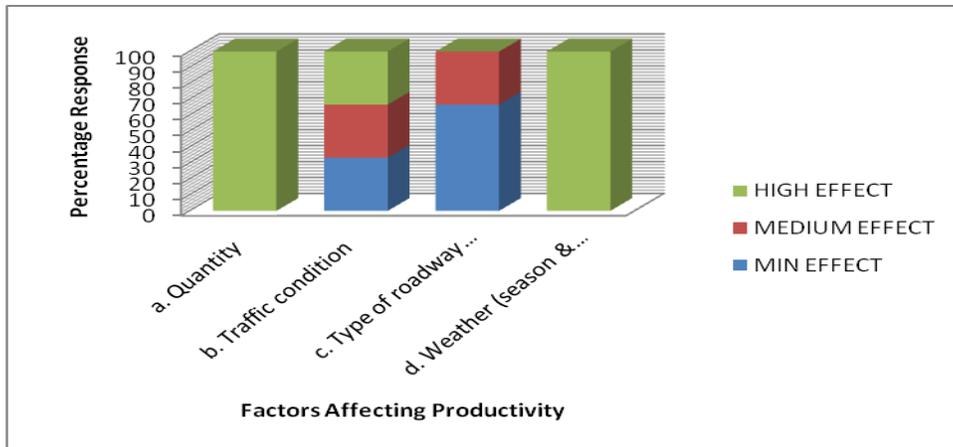
Figure 5.4 Effect of Factors on Dowel Jointed Pavement, Asphaltic Concrete & Bridge Deck Rebar

More than 67% of the respondents reported that weather and quantity as critical factors affecting aggregate base, with type of base being relatively significant (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 experts' favoring it (Figure 5.4). Traffic condition is observed to be a critical factor, while quantity, weather and steel can be considered as additional factors affecting the removal of concrete pavement (Figure 5.5).
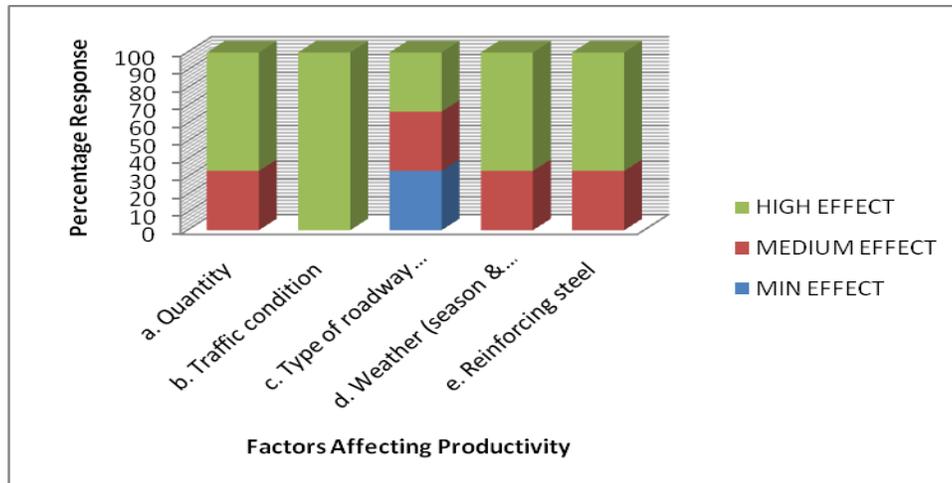
Figure 5.5 Effect of Factors on Removal of Pavement

Based on the survey participants' responses, 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	Weather (season & temperature)
Rebar-Bridge Deck	
10" Asphalt Pavement Type S-3	Quantity of Soil
Removal of pavement	Weather (season & temperature)
	Quantity
	Traffic Condition

5.2 Survey II Analysis

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 second survey is intended to extract highly experienced engineers' valuable

knowledge and experience and compare it with DWR based production rates of controlling highway activities. The survey was sent out early in December, 2009 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' estimates of production rates revealed that there is a 51% increase of residencies' productivity over contractors' production rates estimates. 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 30,000ton of asphaltic pavement during the summer, contractors estimated a production rate of 163% while residencies estimated a production rate of 213% unit.

Based on the analysis, the contractors' estimate has showed an average percent unit of 98% unit, while the residencies estimate resulted in 142% unit of production rate. Overall, there is an average increase of more than 40% between contractors and residencies production rate estimate in laying asphalt pavement type S3.
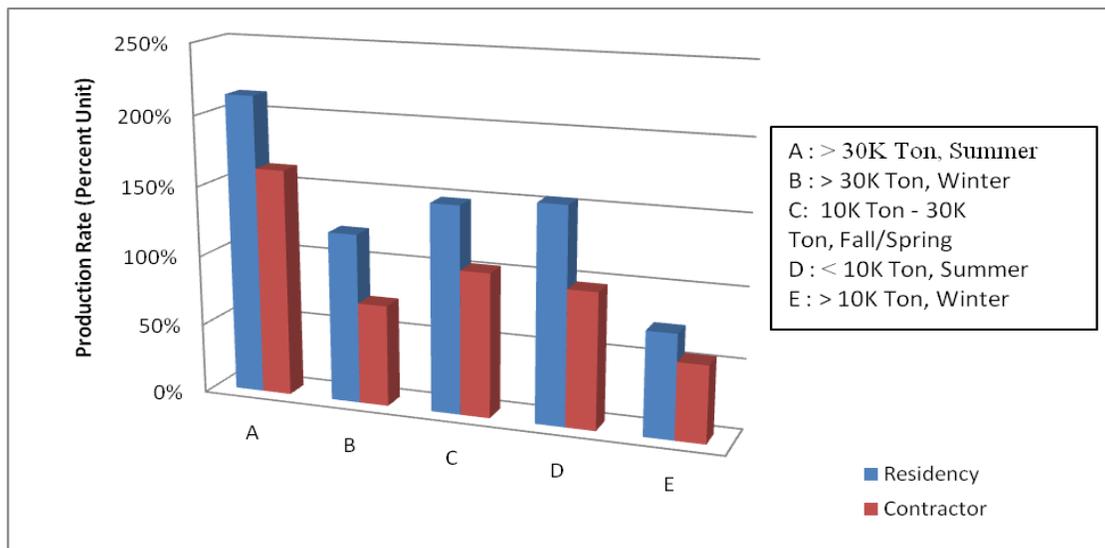
Figure 5.6 Comparison of Contractor Vs Residency Production Rate for Laying Asphaltic Pavement

An overall comparison of the percent unit of production is made for the selected controlling highway activities between residencies' estimates, DWR based production rate, contractors' estimates and ODOT's production rate chart estimates (Figure 5.7). The percent unit of production ranges from 50% to 630%. The highest production rate is observed in residencies' estimates except for unclassified excavation. DWR has higher productivity than contractors and ODOT chart except for unclassified borrow and excavation. A general trend of decrease of percent unit of production rate is observed in the order of residencies' estimates, DWR based production rate, contractors' estimates and ODOT's production rate chart estimates.
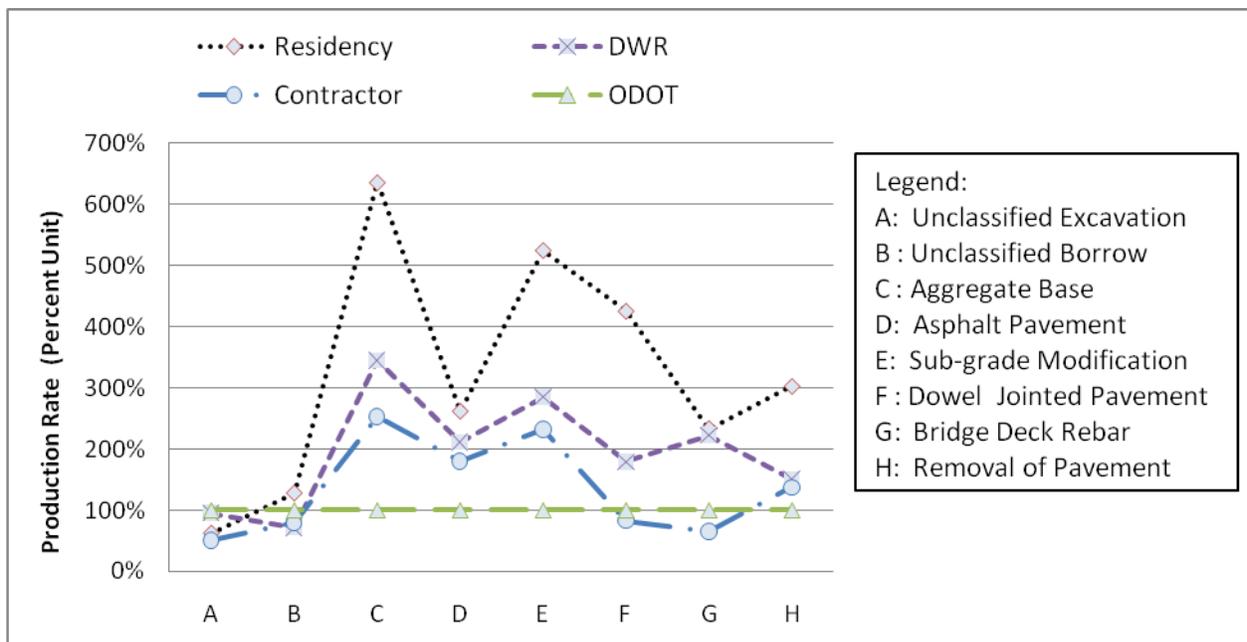
Figure 5.7 Comparison of Production Rate Estimate

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 MODELS

This chapter discusses production rate prediction models of controlling highway construction activities based on identified critical factors. Statistical analysis is employed to identify the significance of factors and their degrees of impact on production rates of controlling highway activities. 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.

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. For instance, weather conditions, soil type, route type and number of lanes, and AADT are the most significant factors affecting unclassified excavation. The significance of factors for the selected controlling highway activities varies from one to another. Table 6.1 summarizes significant factors obtained from the statistical analysis. The significance of factors for other controlling activities is attached in Appendix J.

Table 6.1 Significant Factors Affecting Highway Production Rates

Major Controlling Highway Activities	# of Data Points	Significant Factors	P-value (p ≤ 0.05)	Secondary Factors	P-value (0.1 ≤ p ≤ 0.05)
Unclassified Excavation	90	Weather (season)	0.008	-	-
		Soil Type	0.013		
		Route Type	0.009		
		Number of Lanes	0.016		
Unclassified Borrow	55	Weather (season)	0.0072	-	-
		Soil Type	0.028		
		Route Type	0.010		
		Number of Lanes	0.034		
Aggregate Base	46	Weather (temperature)	0.002	Soil Type	0.068
		AADT	0.017		
Sub-grade Modification, lime/fly ash	31	Weather (season)	0.016	Number of Lanes	0.057
		Weather (temperature)	0.043		
Asphalt Pavement, Type S-3	59	Weather (season)	0.01	-	-
		Number of Lanes	0.001		
Removal of pavement	42	Weather (season)	0.003	AADT	0.071

The analysis reveals weather, soil type and number of lanes as the most common significant factors affecting production rates of 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 (15, 31) respectively collected from the DWR. Therefore, a regression model is not developed for dowel jointed pavement and bridge deck rebar.

6.3 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. Figure 6.1 shows the probability plot of production rate for laying asphalt pavement 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. 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. A similar result is observed in the other activities (Appendix K).
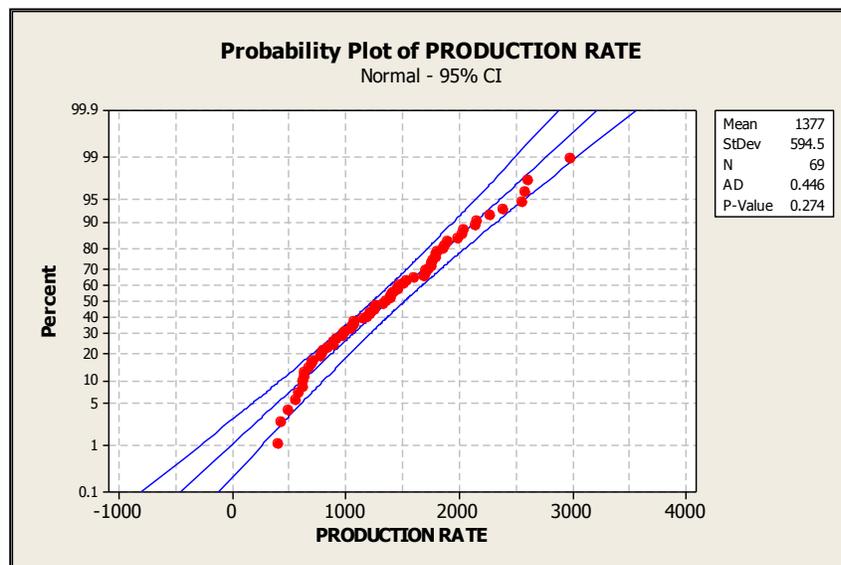
Figure 6.1 Probability Plot of Asphaltic Pavement Type S3

6.4 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 variable can be predicted or explained by using information on others. A multiple linear regression model can be expressed by Equation 6.1,

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

Where, y is the dependent or response variable, and X_i, i = 1, 2…m, are the independent variables. The β_i are the parameters or regression coefficients for each independent variable 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.

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

    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). Table 6.2 summarizes the values of R^2 for the selected controlling highway activities.

Table 6.2 Coefficient of Determination, R^2

No.	Major Controlling Highway Activity	Unit	R	R^2	Standard Error of the Estimate
A.	Unclassified Excavation, Rdy	Cy	.555a	0.308	1307.507
B.	Unclassified Borrow, Rdy	Cy	.841a	0.707	520.566
C.	Aggregate Base, Rdy	Cy	.941a	0.886	210.602
D.	(SP) Asphalt Concrete Type S3	Ton	.751a	0.563	1275.04
E.	Lime/Cementetious Stabilized Subgrade, Rdy	Sy	.762a	0.58	464.059
H.	Removal of Concrete Pavement	Sy	.842a	0.709	428.014

Where, a. Predictors: (Constant), Temperature, Highway Type, Route No., Soil Type, Number of Lanes, Season and AADT

R^2 has a value ranging from 0 to 1. The closer the R^2 value is to 1, the higher possibility that the regression line perfectly fits the DWR based production rate data. All controlling activities fall within 95% confidence interval with R^2 greater than 0.55 except for unclassified excavation. Based on the coefficient of determination, a regression equation is developed for controlling highway activities. A summary of the regression equations is given in Table 6.3.

Table 6.3 Regression Equations

A. $PR_{UE} = 297X_1 - 11X_2 + 266X_3 - 0.22X_4 + 214X_5 - 474X_6 + 9X_7 + 1814.....(Eq.2)$

B. $PR_{UB} = 258X_1 - 244X_2 + 260X_3 - 0.19X_4 + 740X_5 - 375X_6 - 3X_7 + 354....(Eq.3)$

C. $PR_{AB} = -78X_1 + 90X_2 - 55X_3 - 4X_5 - 278X_6 + 3X_7 + 984 ....(Eq.4)$

D. $PR_{AP} = -294X_1 + 471X_2 - 587X_3 + 3633 ....(Eq.5)$

E. $PR_{SG} = 745X_1 + 757X_2 + 0.35X_4 + 548X_5 - 83X_6 + 21X_7 + 1123 ....(Eq.6)$

H. $PR_{RP} = -123X_1 + 82X_2 + 117X_3 - 154X_5 - 500X_6 - 11X_7 + 4190 ....(Eq.7)$

Where, X_1 = Route Type, X_2 = Highway Type, X_3 = No. of Lanes, X_4 = AADT, X_5 = Soil Type, X_6 = Season, and X_7 = Temperature.

PR_{UE} = Production Rate (PR) of Unclassified Excavation, PR_{UB} = PR of Unclassified Borrow, PR_{AB} = PR of Aggregate Base, PR_{AP} = PR of Asphalt pavement, PR_{SG} = PR of Stabilized Sub-grade, and PR_{RP} = PR of Removal of Pavement

6.5 Sensitivity Analysis

Once the regression equations are developed, a sensitivity analysis based on scenarios is conducted. The study uses this concept of sensitivity analysis to validate significant 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 6.2 illustrates the sensitivity graph for unclassified excavation.
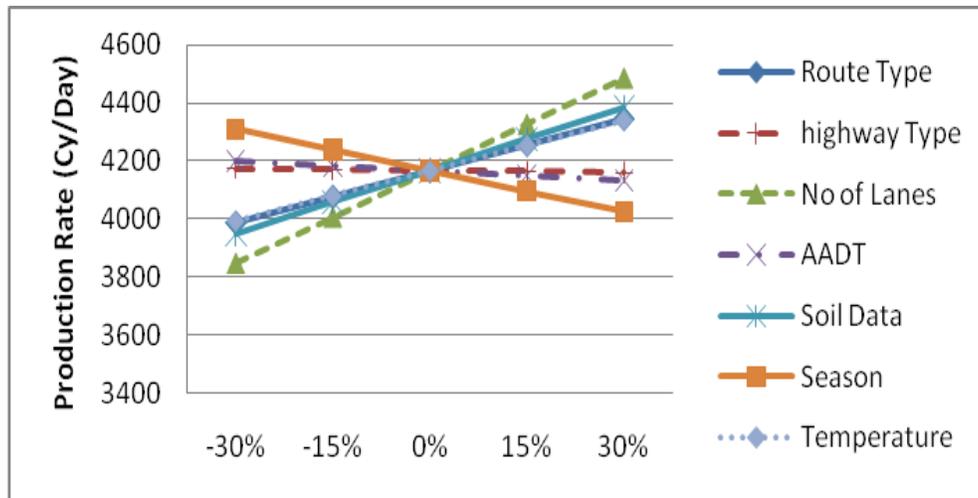
Figure 6.2 Sensitivity Analysis for Unclassified Excavation

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. Figure 6.2 shows that production rate is very sensitive to number of lanes, soil type and weather condition, fairly sensitive to route type, highway type and AADT. A sensitivity analysis for unclassified borrow is shown in Figure 6.3. The sensitivity analysis for other controlling activities is attached in Appendix L.
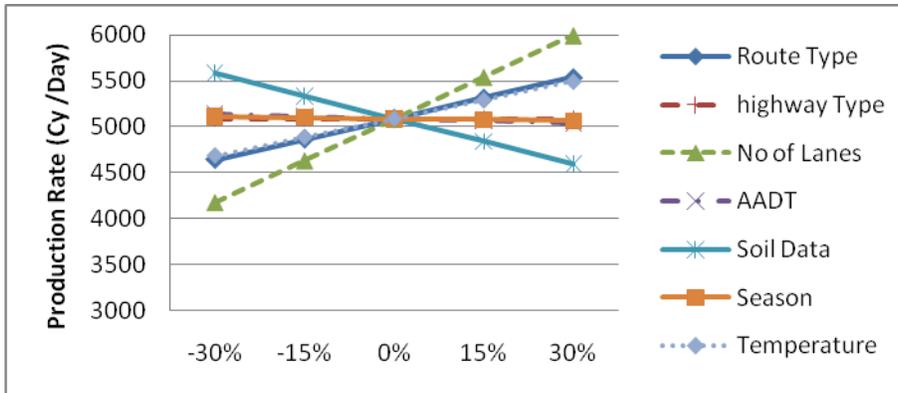
Figure 6.3 Sensitivity Analysis for Unclassified Borrow

CHAPTER 7

DEVELOPMENT OF A STANDALONE PROGRAM

A standalone software program is developed for estimating production rates of controlling highway activities based on the regression models and engineers' estimates. The software incorporates all factors identified from Daily Work Reports (DWR) and engineers' survey for the selected controlling highway activities. The program 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.
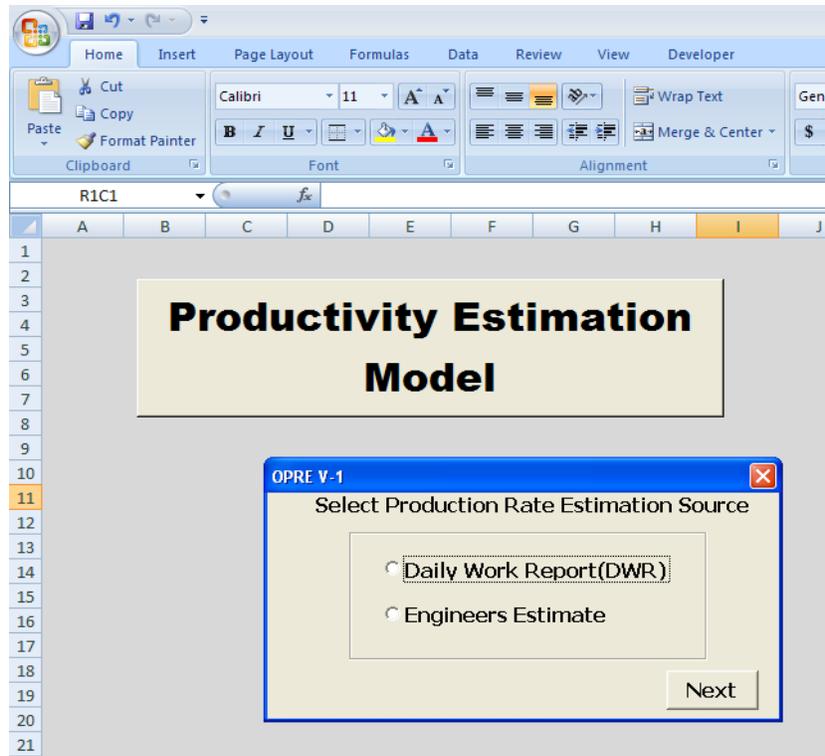
Figure 7.1 OPRE Front Screen

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.
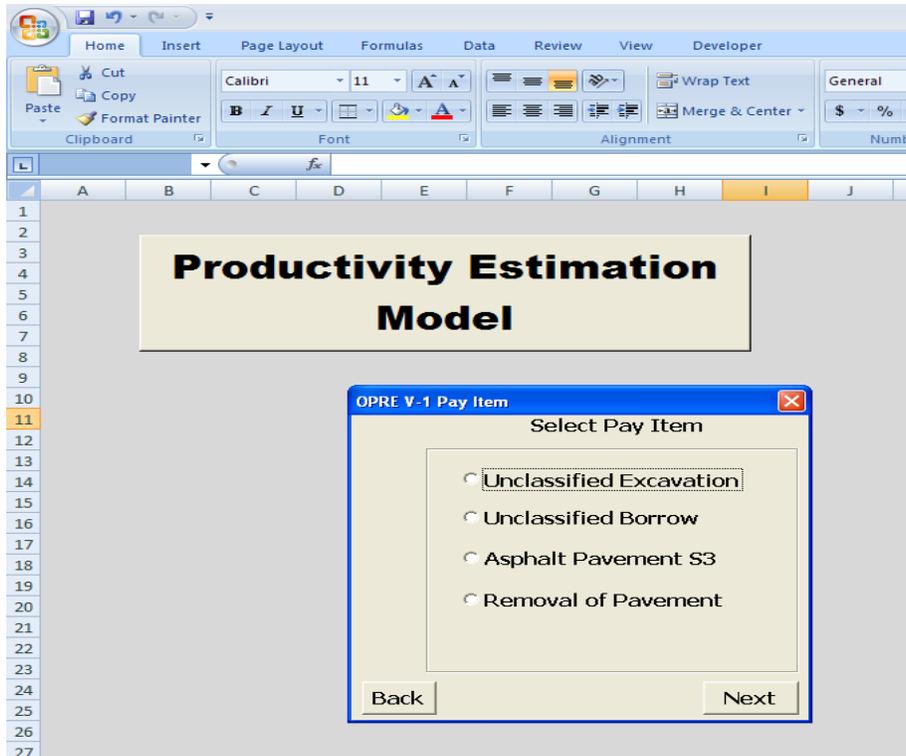
Figure 7.2 Selection of Controlling Highway Activity (DWR)
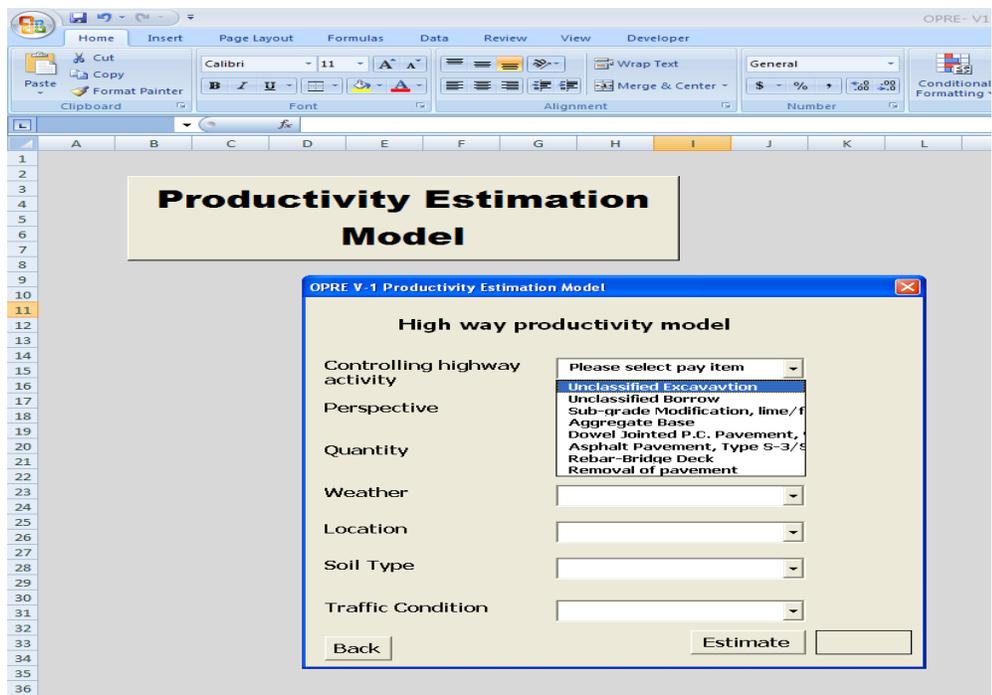
Figure 7.3 Selection of Controlling Highway Activity (Engineers' Estimate)
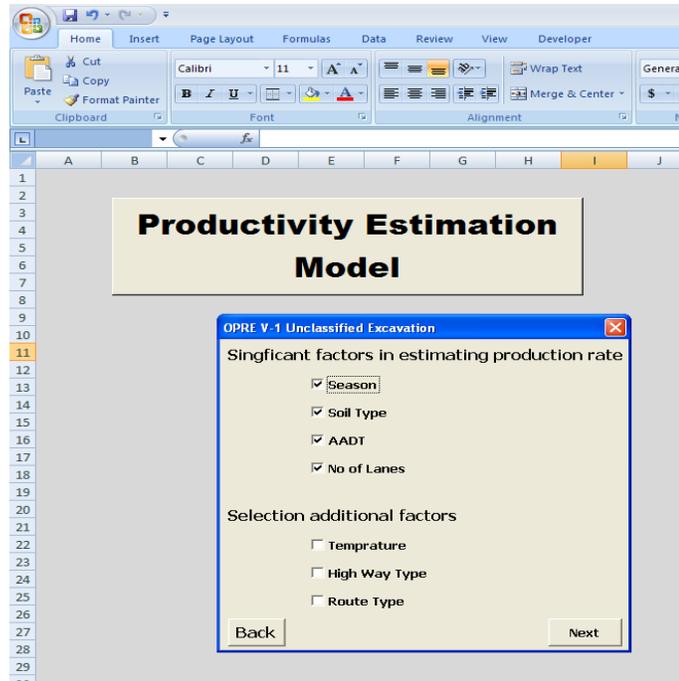
Figure 7.4 Selection of Factors (DWR)
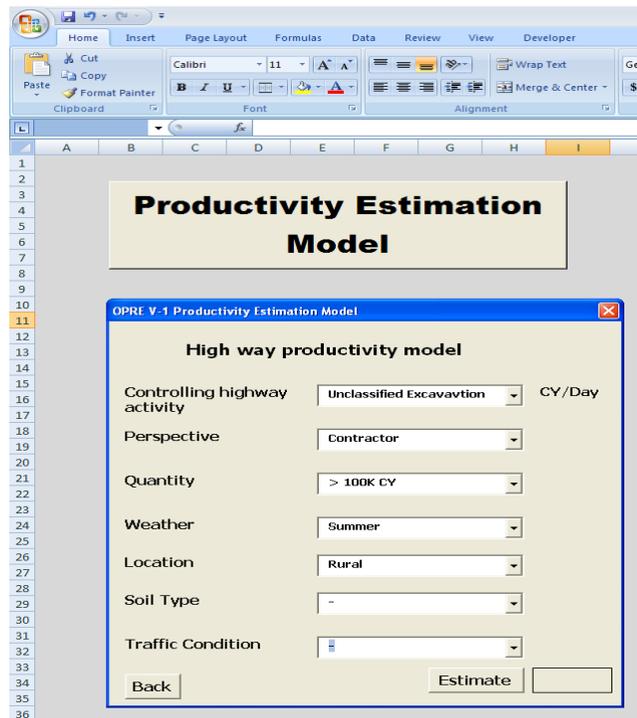
Figure 7.5 Selection of Factors (Engineers' Estimate)

7.2 Back End of the Model

Once the required inputs are fed, the back end model estimates a reasonable production rate. 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.
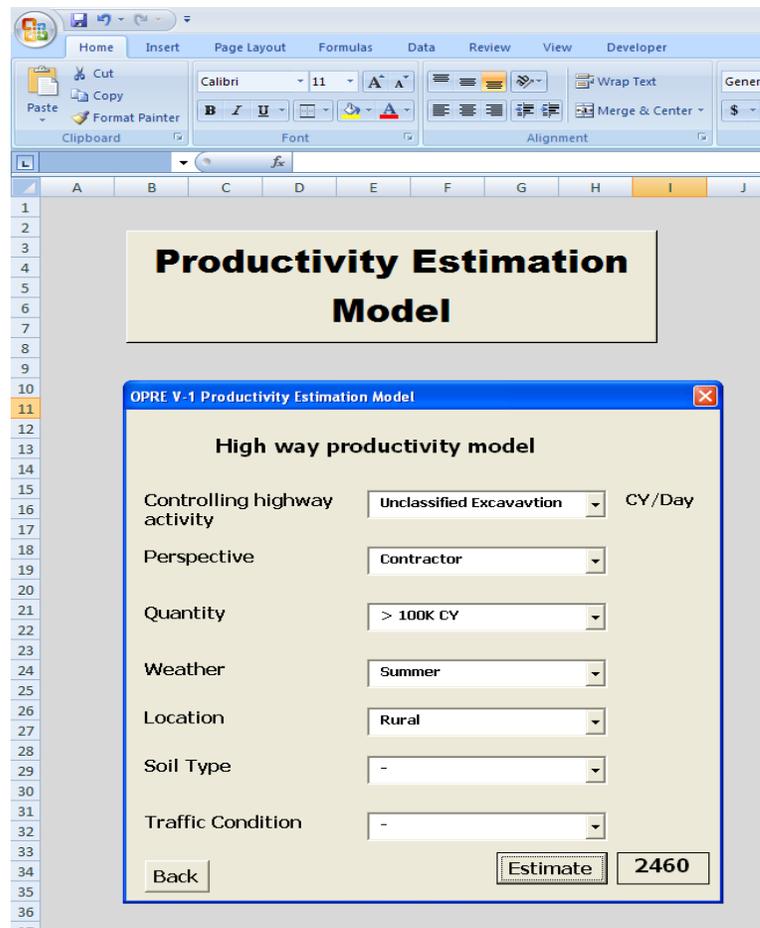
Figure 7.6 Production Rate Estimate

7.3 Validation of the OPRE

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 Rates

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			

CHAPTER 8

CONCLUSIONS & RECOMMENDATIONS

8.1 Summary

The project developed Daily Work Reports (DWR) based prediction models to estimate reasonably accurate production rates of major highway activities. The study used available resources such as DWR, soil data, AADT and other existing project data from the various divisions of ODOT as primary source in estimating production rates. A total of 93 Tier II type highway projects and 8 major highway activities were selected to collect production rate data. Weather (temperature and seasonal effects), location & traffic condition, construction firms, quantity of work, type of soil, haul distance, type of highway route, number of lanes, and type of roadway were considered in the study to determine their effects on production rates of highway activities. The significance of these factors was quantitatively analyzed and production rate prediction models were developed by utilizing statistical tools. A survey was conducted with experts to capture their accumulated knowledge and compare it with DWR based production rates. Finally, the study developed a standalone software program to estimate reasonably accurate production rates of selected major highway activities.

8.2 Findings and Contributions

The study 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. The study showed that production rate prediction models for major highway activities can be developed with available resources and at low cost by utilizing Daily Work Reports (DWR) and existing project data. Weather conditions, soil type and number of lanes were found out to be the most common critical factors affecting major highway activities. Based on the study, ODOT should let projects by early January so that construction projects can commence 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. Mass production and increased scale of operation leads to an increase in highway construction production rates. In addition, DWR based production rates are

significantly different from ODOT's production rate chart, experienced residencies estimates and contractors' estimates.

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 based 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 called OPRE, which predicts production rates of controlling highway activities have been developed based on engineers' estimate and DWR's regression models 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.

8.3 Implementation

OPRE program will allow ODOT engineers and schedulers to improve their accuracy and save their time in determining more reliable production rates of major highway construction activities by easily adjusting site conditions and project factors. The program will help ODOT to determine appropriate contract times of Tier II highway projects which would enhance better planning of resources, reduce construction cost, minimize the construction crew's exposure to traffic, reduce the inconvenience to the public, track project progress and future estimating and bidding guidelines. This study will not only allow ODOT to be equipped with a streamlined procedure for determining production rates of highway construction activities, but also will allow ODOT to be a framework and a benchmarking example to other highway agencies.

8.4 Recommendation for Future Work

This study considered only 8 major controlling highway activities, but production rate estimation models must be carefully developed for all other controlling highway activities. In addition, production rate 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: a) planning and controlling the level of detail of data that needs to be collected should be determined by considering efficient data handling mechanisms, and b) 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.

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APPENDICES

APPENDIX A: DATA COLLECTION SHEET

CONT_ID	ROUTE NO	DESCRIPTION	COUNTY	DIVISION	ROUTE	HIGHWAY TYPE	CONTRACT AMOUNT	CONTRACTOR	ITM_CD
040194	US-75	GRADE, DRAIN SURFACE AND BRIDGE	Washington County	08	US-75	COMB	$3,883,410.19	APAC-OKLAHOMA, INC.	202(A) 0183
040194	US-75	GRADE, DRAIN SURFACE AND BRIDGE	Washington County	08	US-75	COMB	$3,883,410.19	APAC-OKLAHOMA, INC.	202(A) 0183
040194	US-75	GRADE, DRAIN SURFACE AND BRIDGE	Washington County	08	US-75	COMB	$3,883,410.19	APAC-OKLAHOMA, INC.	202(A) 0183
040194	US-75	GRADE, DRAIN SURFACE AND BRIDGE	Washington County	08	US-75	COMB	$3,883,410.19	APAC-OKLAHOMA, INC.	202(A) 0183
040211	I-35	RESURFACE AND BRIDGE REPLACEMENT	Logan County	04	I-35	CONC	$4,866,609.27	DUIT CONSTRUCTION COMPANY, INC.	202(A) 0183
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
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
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
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
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
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
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
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
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
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
040349	SH-3	GRADE, DRAIN, SURFACE AND BRIDGE	Pushmataha County	02	SH-3	ASPH	$3,676,139.56	WITTWER CONSTRUCTION CO., INC.	202(A) 0183
040380	US-75	GRADING, DRAINAGE, SURFACING & BRIDGE	Tulsa County	08	US-75	CONC	$15,603,000.51	SHERWOOD CONSTRUCTION CO., INC.	202(A) 0183
040380	US-75	GRADING, DRAINAGE, SURFACING & BRIDGE	Tulsa County	08	US-75	CONC	$15,603,000.51	SHERWOOD CONSTRUCTION CO., INC.	202(A) 0183
040380	US-75	GRADING, DRAINAGE, SURFACING & BRIDGE	Tulsa County	08	US-75	CONC	$15,603,000.51	SHERWOOD CONSTRUCTION CO., INC.	202(A) 0183
040380	US-75	GRADING, DRAINAGE, SURFACING & BRIDGE	Tulsa County	08	US-75	CONC	$15,603,000.51	SHERWOOD CONSTRUCTION CO., INC.	202(A) 0183

ITM_CD	DESC1	UNIT	TEMPERATURE	QUANTITY	DURATION	PRODUCTION RATE	SOIL DATA	SEASON	AADT	TERRAIN AREA	NO OF LANES	Functional Classification	REMARKS
202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	78.5	9555	3	3185.0	0	summer	1440	2	4	3	
202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	75	23309	5	4662.0	0	summer	1440	2	4	3	
202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	74.8	4571	8	571.0	0	summer	1440	2	4	3	side works
202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	73.6	40966	4	10242.0	0	fall	1440	2	4	3	
202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	47	4803	9	534.0	Lean Clay	spring	2915	1	4	1	
202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	52.75	644	1	644.0	Lean Clay	spring	3976	1	4	3	
202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	33	1080	1	1080.0	0	winter	1330	7	4	4	
202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	44	2898	1	2898.0	0	winter	1330	7	4	4	
202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	51	4374	1	4374.0	0	winter	1330	7	4	4	
202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	50	6066	1	6066.0	0	winter	1330	7	4	4	
202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	64	4050	1	4050.0	0	winter	1330	7	4	4	
202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	41	2770	1	2770.0	0	winter	1330	7	4	4	
202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	48	3330	1	3330.0	0	spring	1330	7	4	4	
202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	70	3444	1	3444.0	0	spring	1330	7	4	4	
202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	65	2968	1	2968.0	0	spring	1330	7	4	4	
202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	57	2111	2	1056.0	Sandy	spring	335	2	4	3	
202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	46.72	48576	9	5397.0	Lean Clay	winter	4920	6	4	2	
202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	49.3	66661	10	6666.0	Lean Clay	spring	4920	6	4	2	
202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	51.06	96994	8	12124.0	Lean Clay	spring	4920	6	4	2	
202(A) 0183	UNCLASSIFIED EXCAVATION, RDY	CY	59.875	63494	4	15874.0	Lean Clay	spring	4920	6	4	2	

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	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.

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

2

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:

3

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: _____

_____

_____

4

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.

5

APPENDIX D: UNIFIED SOIL CLASSIFICATION SYSTEM (ASTM STANDARD)

Criteria for Assigning Group Symbols and Group Names Using Laboratory Tests[A]				Soil Classification	
				Group Symbol	Group Name[B]
COARSE-GRAINED SOILS	Gravels	Clean Gravels	$Cu \geq 4$ and $1 \leq Cc \leq 3$[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	,urule;1>GC	Clayey gravel[D,F,G]
	Sands	Clean Sands	$Cu \geq 6$ and $1 \leq Cc \leq 3$[C]	SW	Well-graded sand[H]
	50 % or more of coarse fraction passes No. 4 sieve	Less than 5 % fines[I]	$Cu < 6$ and/or $1 > Cc > 3$[C]	SP	Poorly graded sand[H]
		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. 200 seive	Liquid limit less than 50		PI < 4 or plots below "A" line[J]	ML	Silt[K,L,M]
		organic	Liquid limit – oven dried> < 0.75	OL	Organic clay[K,L,M,N]
			Liquid limit – not dried	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 < 0.75	OH	Organic clay[K,L,M,P]
			Liquid limit – not dried	OH	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: 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)

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

98
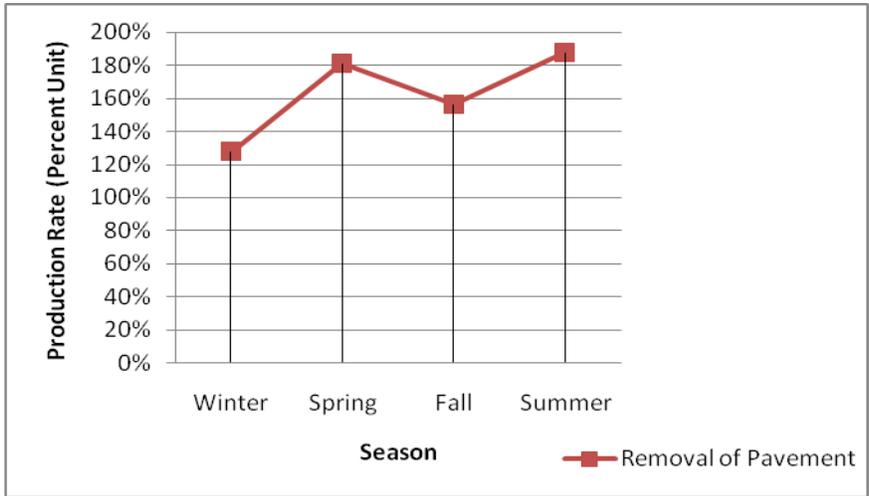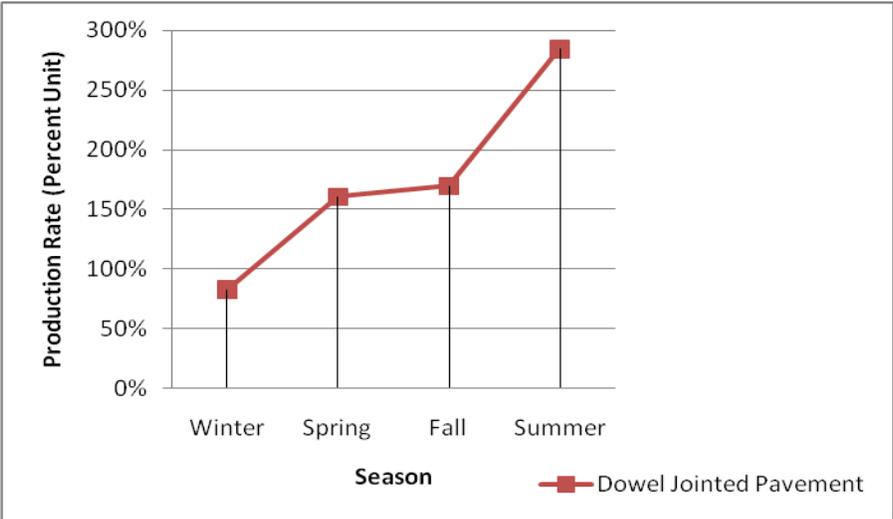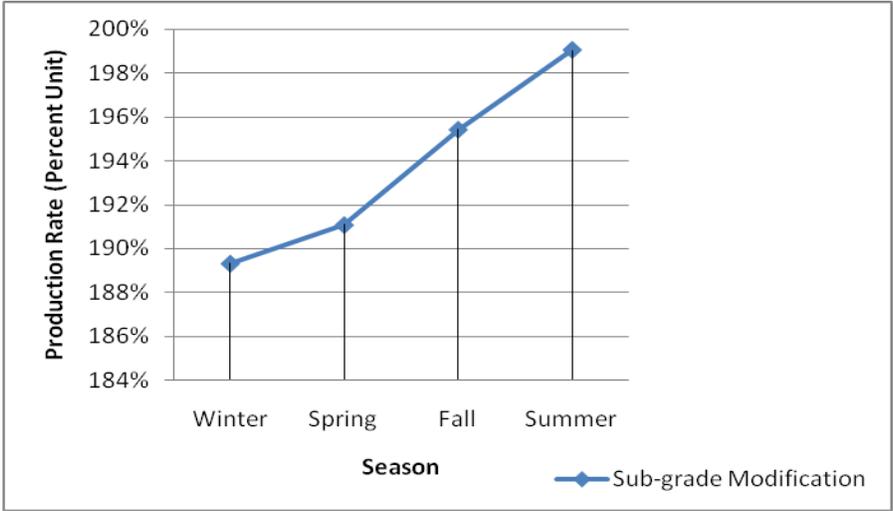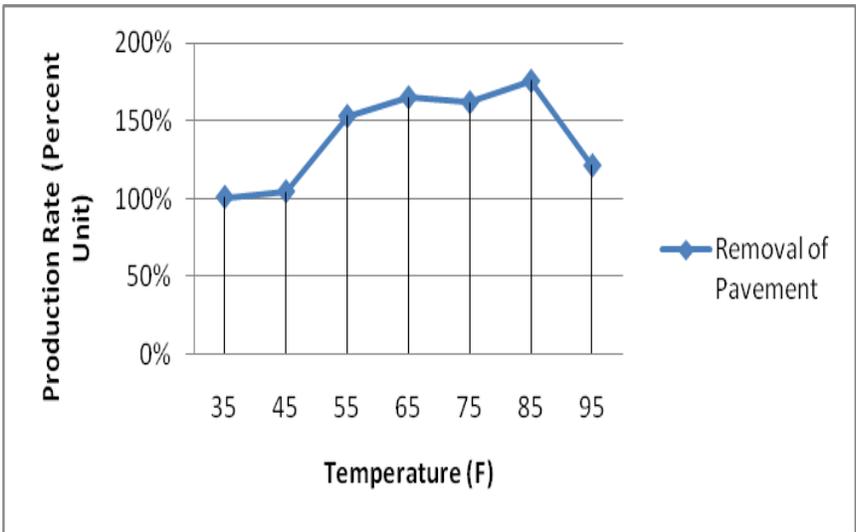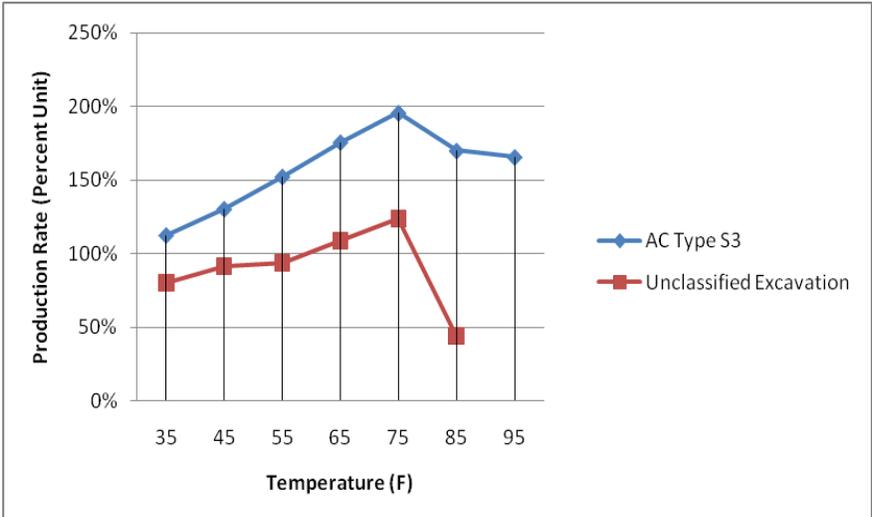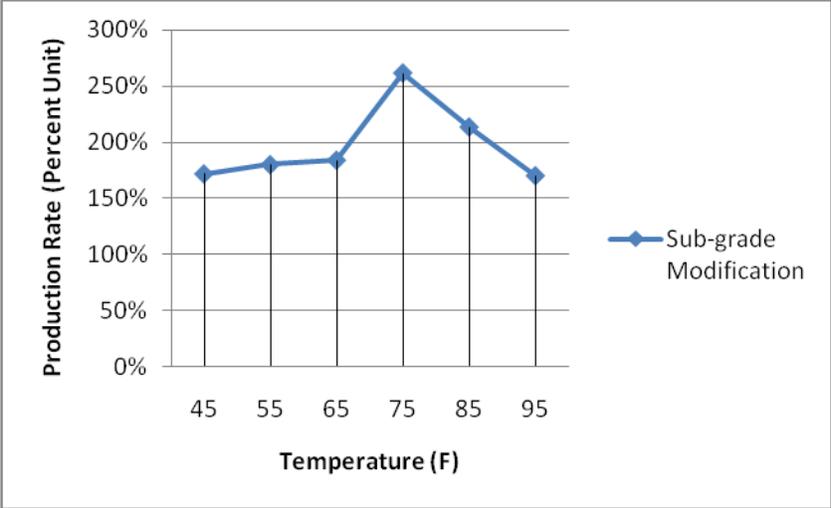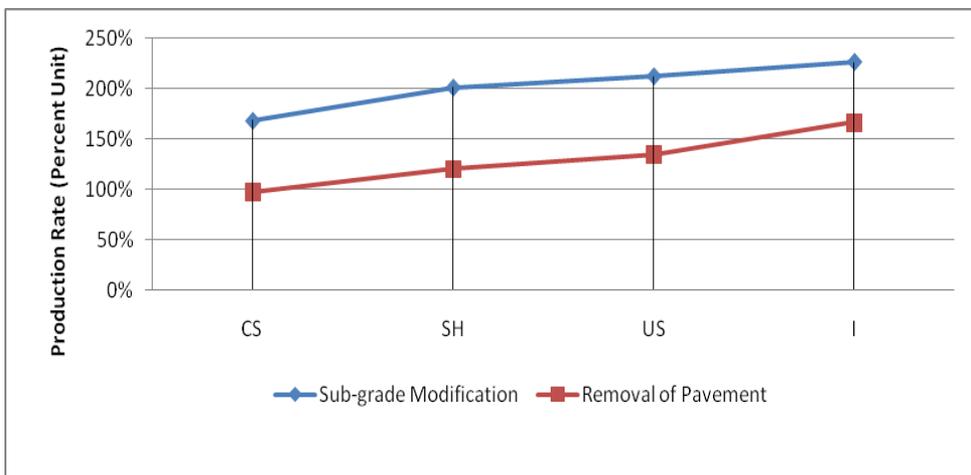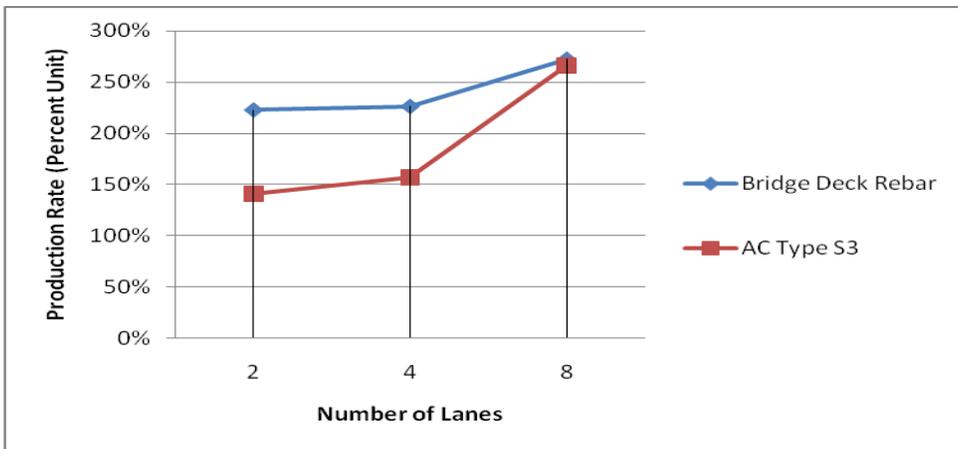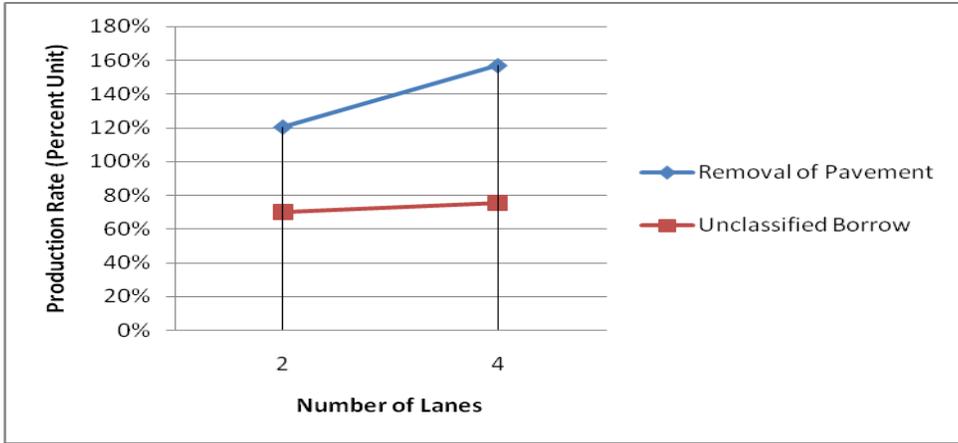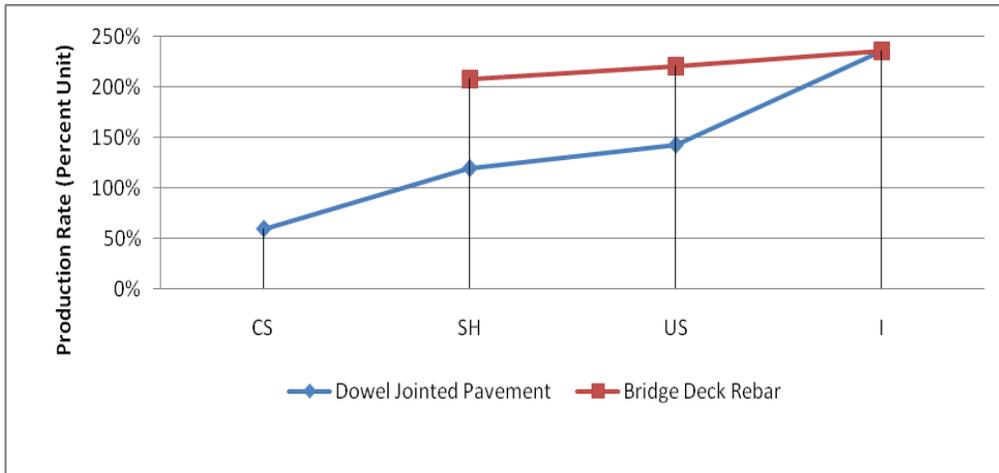
APPENDIX G: BOX PLOT & SCATTER PLOT OF FACTORS AFFECTING PRODUCTION
RATES

Boxplot of PRODUCTION RATE

Unclassified Excavation (Season)

Boxplot of PRODUCTION RATE

Unclassified Borrow (Season)

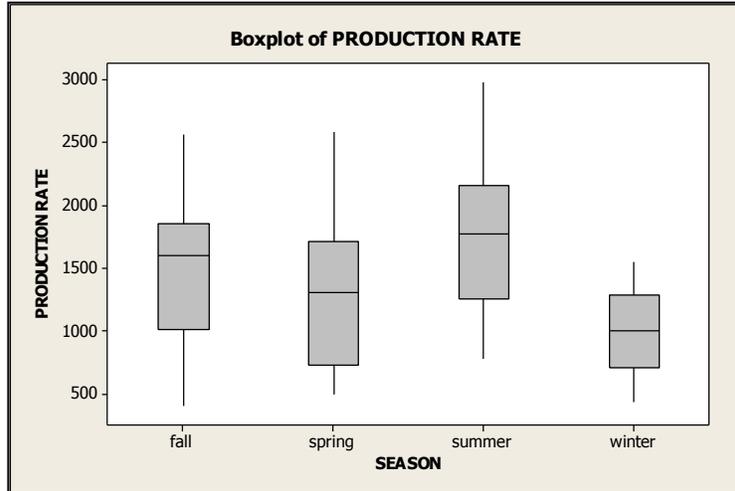**Boxplot of PRODUCTION RATE**
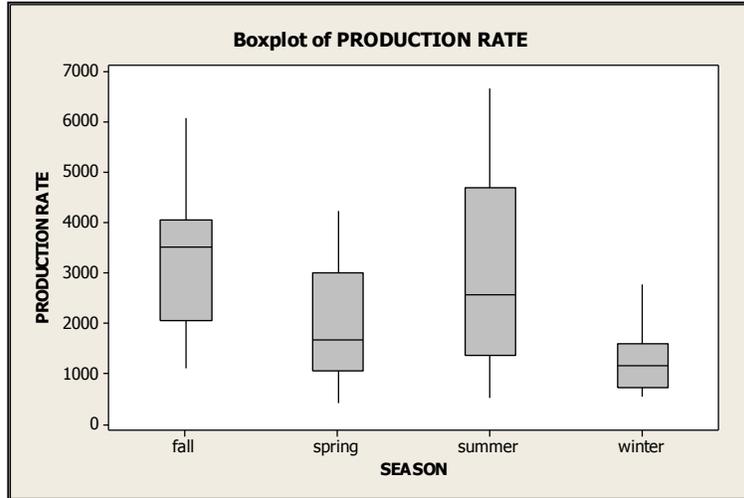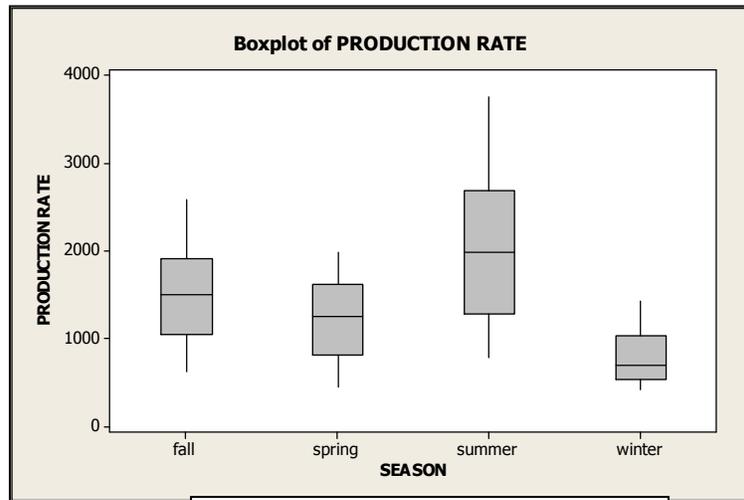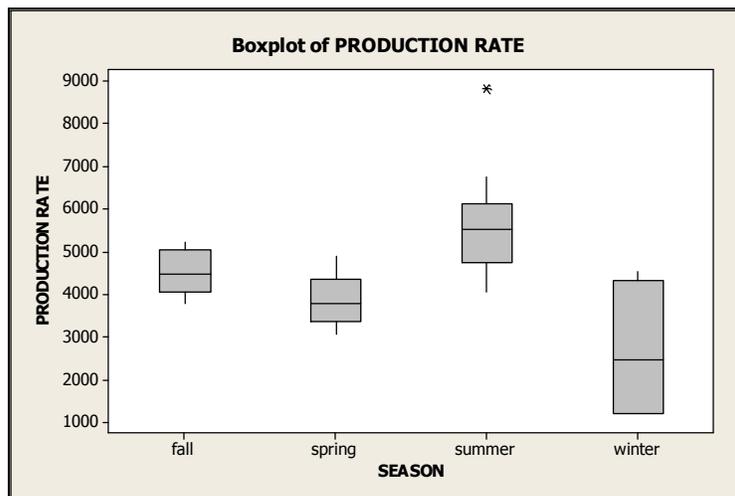
Sub-grade Modification (Season)

100
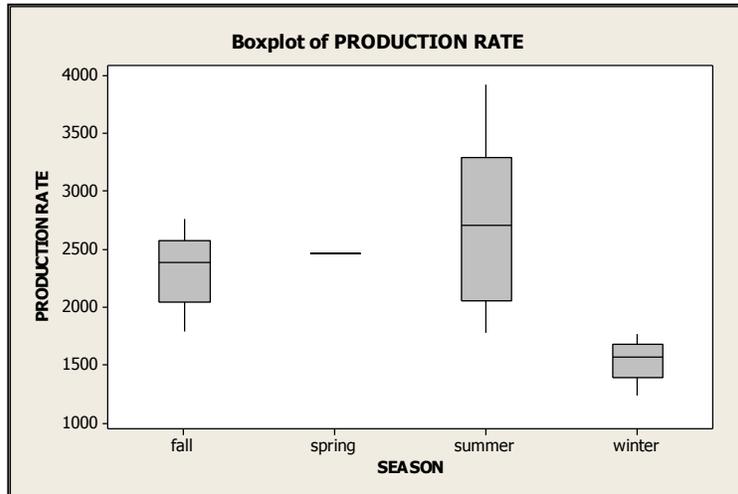
Removal of Pavement (Season)
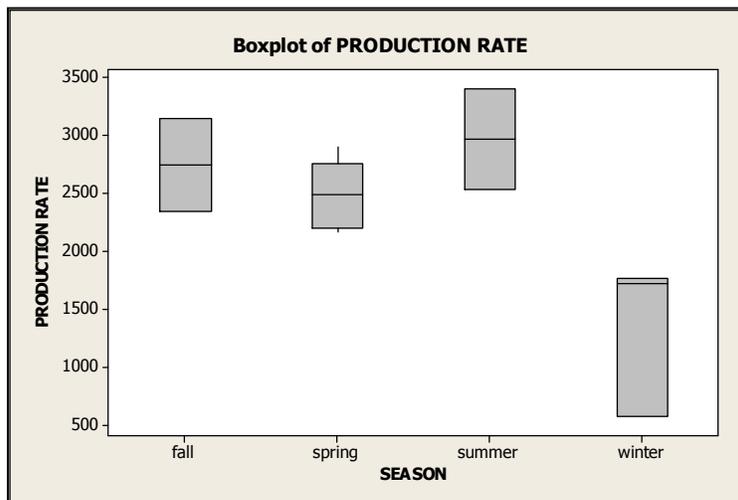
PC Dowel Jointed Pavement (Season)
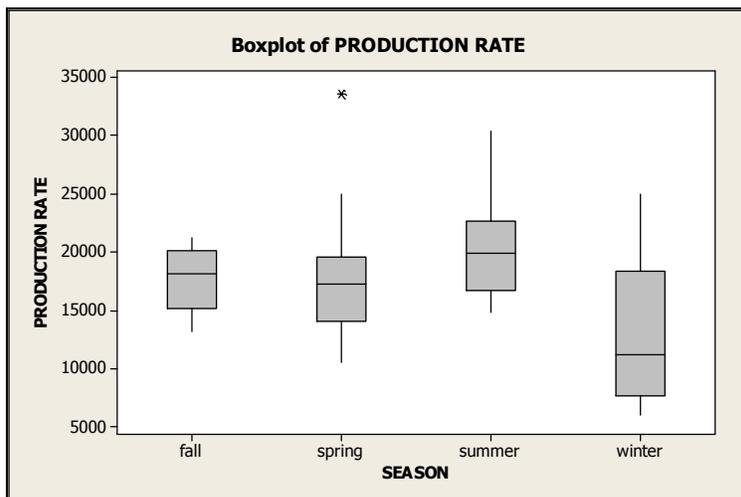
Bridge Deck Rebar (Season)

101

Asphaltic Pavement (Season)
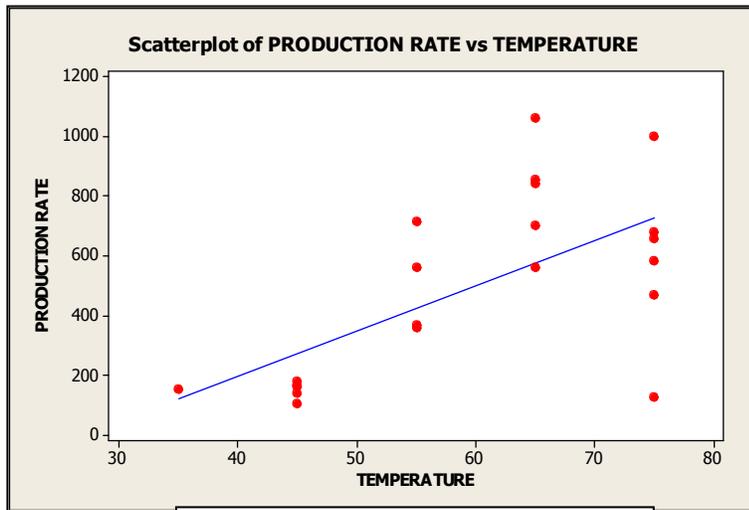
Aggregate Base (Temperature)
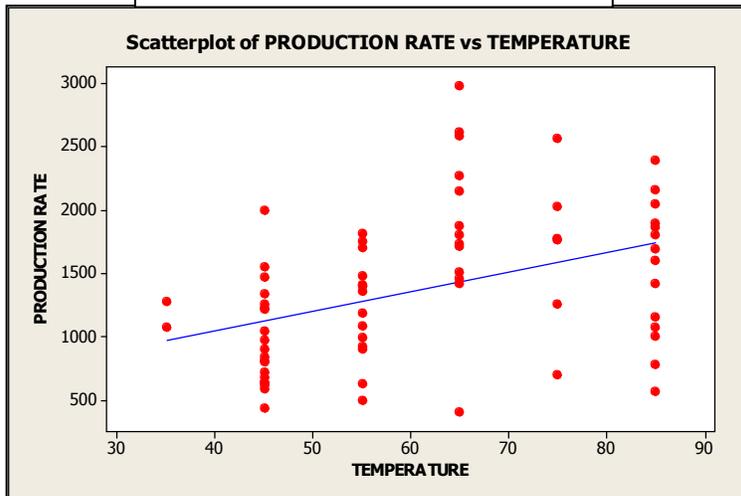
Asphaltic Concrete (Temperature)
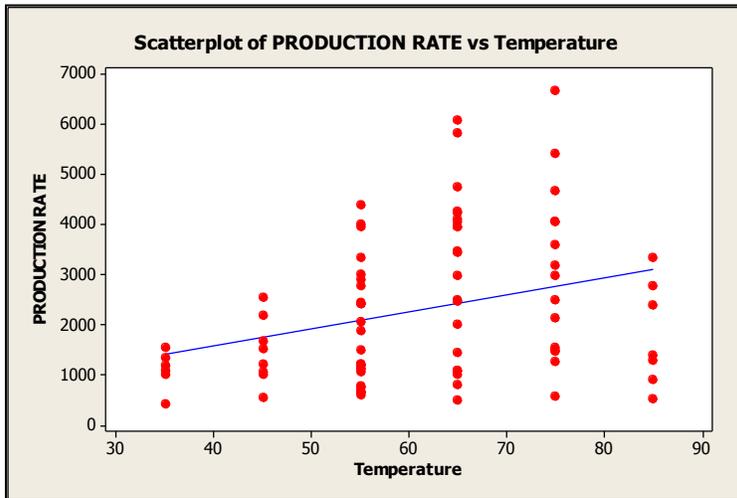
Unclassified Excavation (Temperature)
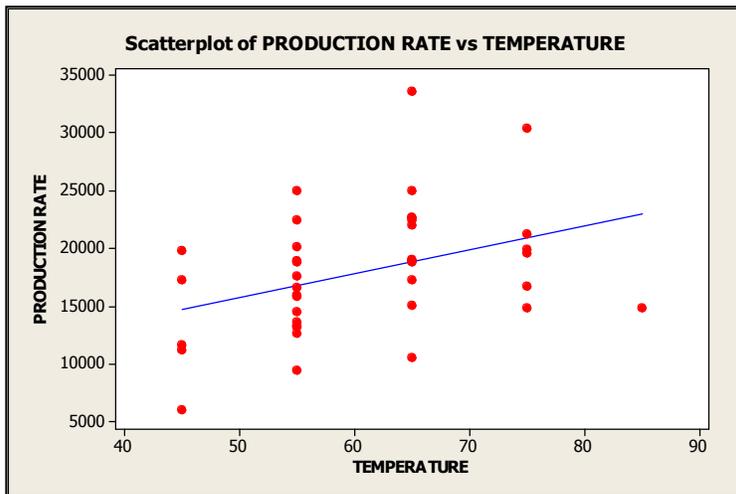
Bridge Deck Rebar
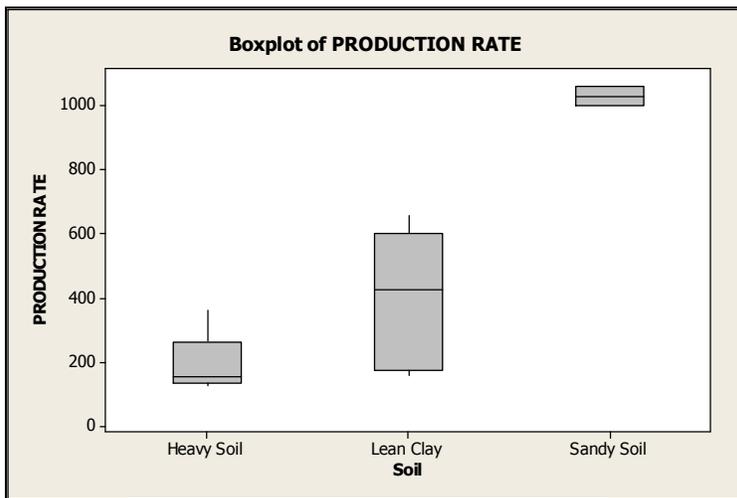
Aggregate Base (Soil Type)

103

Boxplot of PRODUCTION RATE
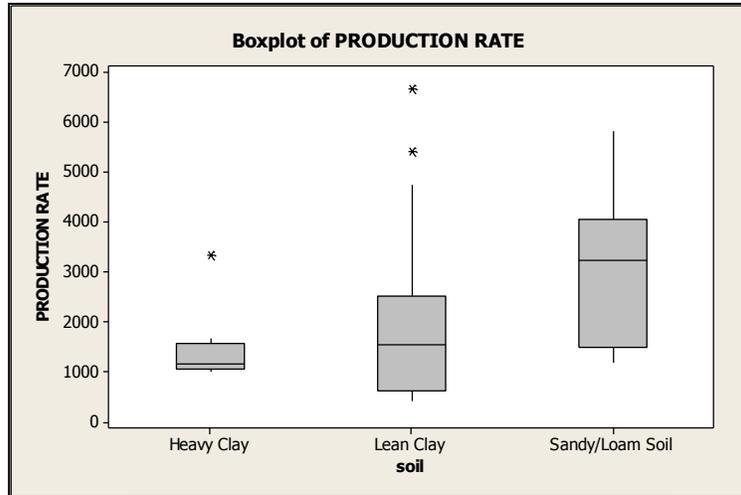
Unclassified Excavation (Soil Type)

Boxplot of PRODUCTION RATE
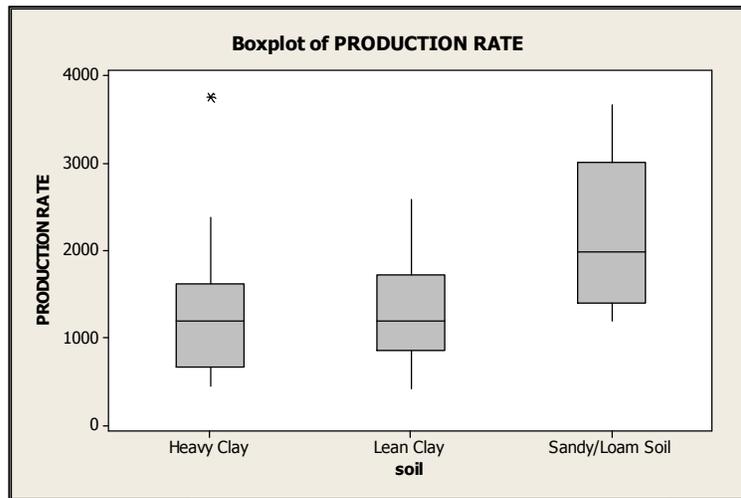
Unclassified Borrow (Soil Type)

Boxplot of PRODUCTION RATE
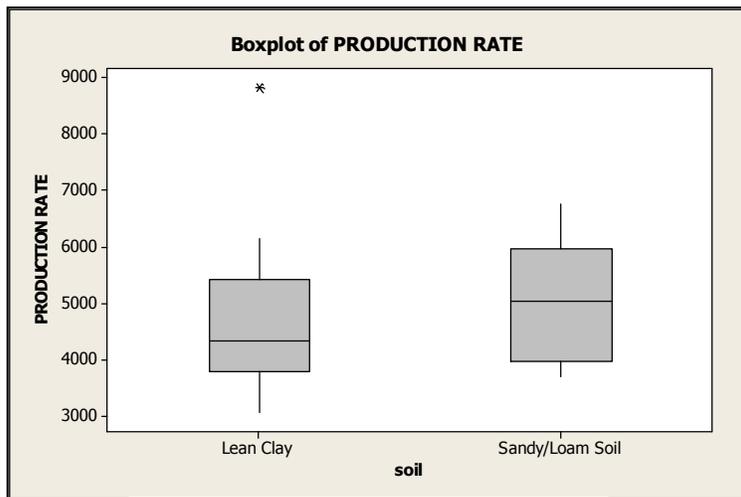
Sub-grade Modification (Soil
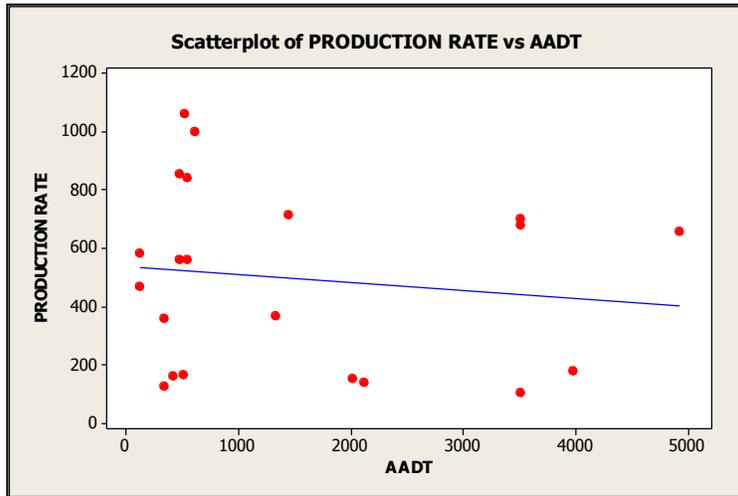
Aggregate Base (AADT)
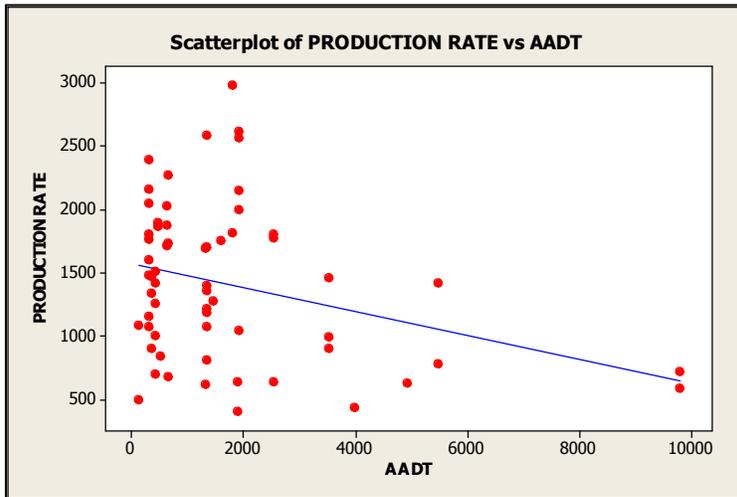
Asphaltic Pavement (AADT)
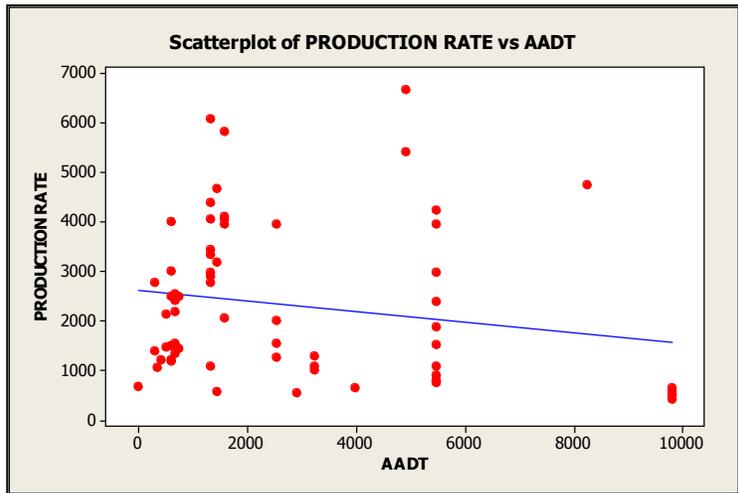
Unclassified Excavation (AADT)

105
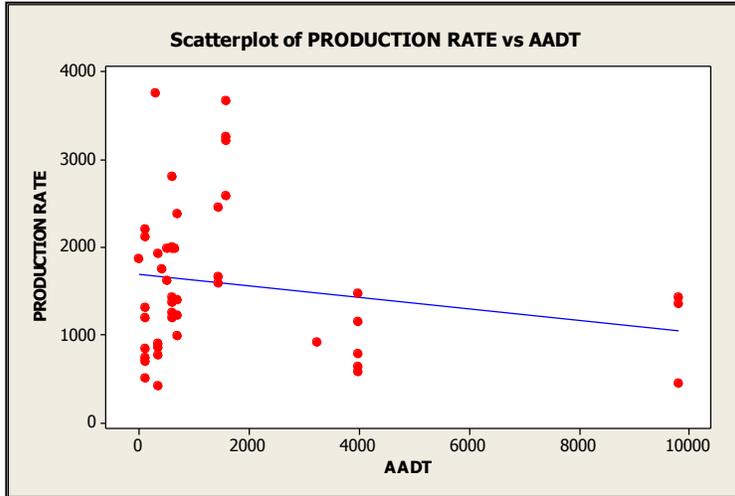
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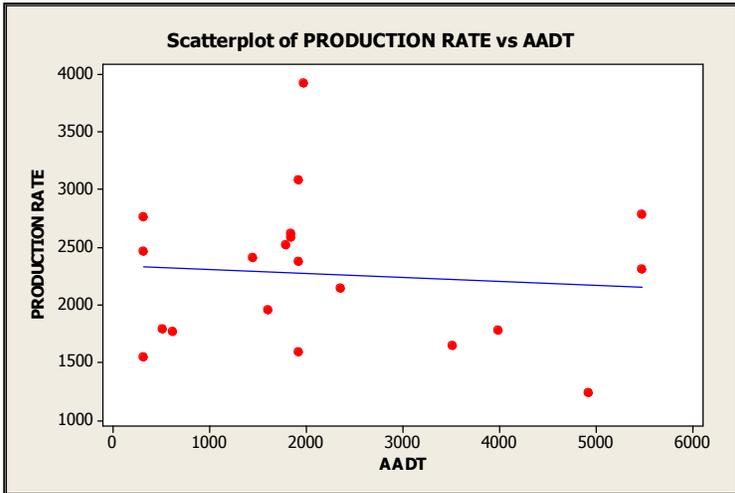
Removal of Pavement (AADT)
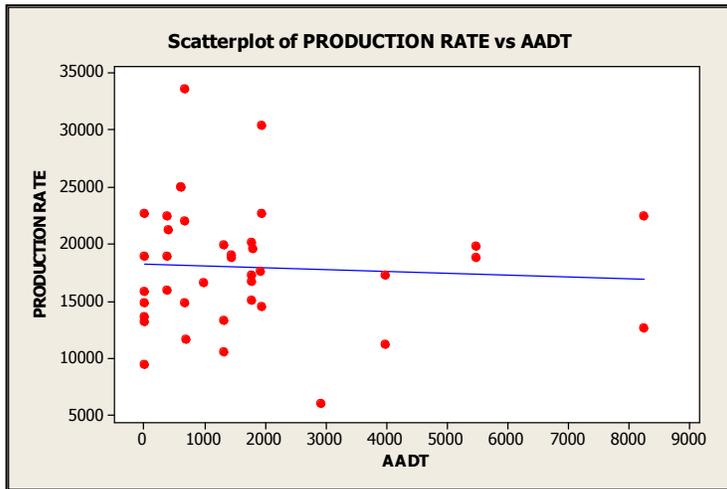
Sub-grade Modification (AADT)
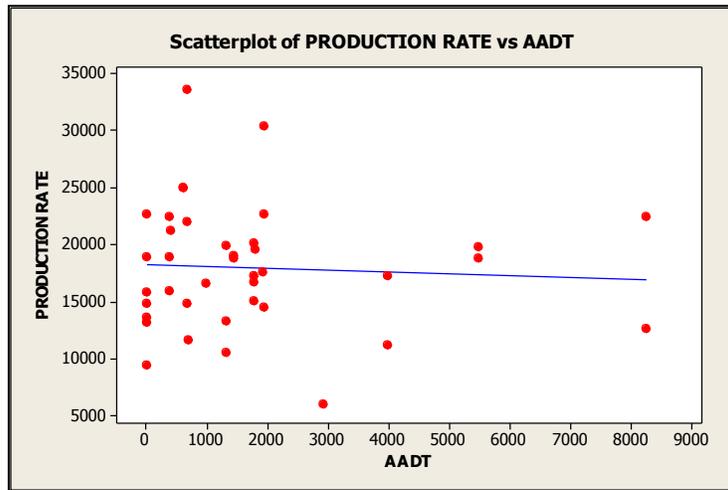
Bridge Deck Rebar (AADT)
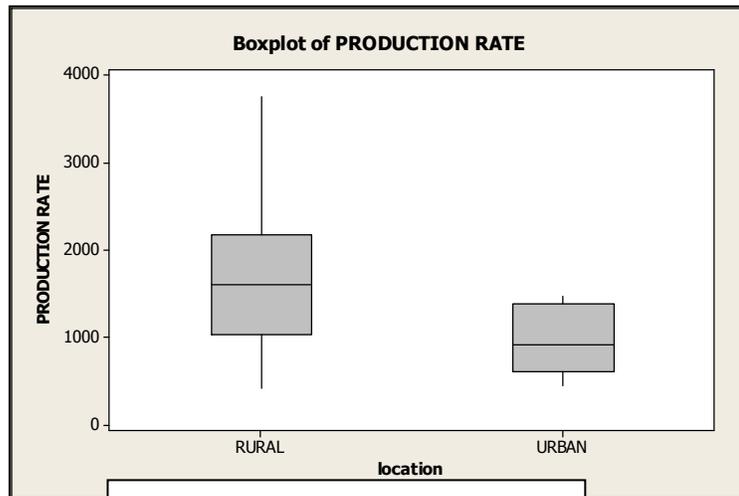
Unclassified Excavation
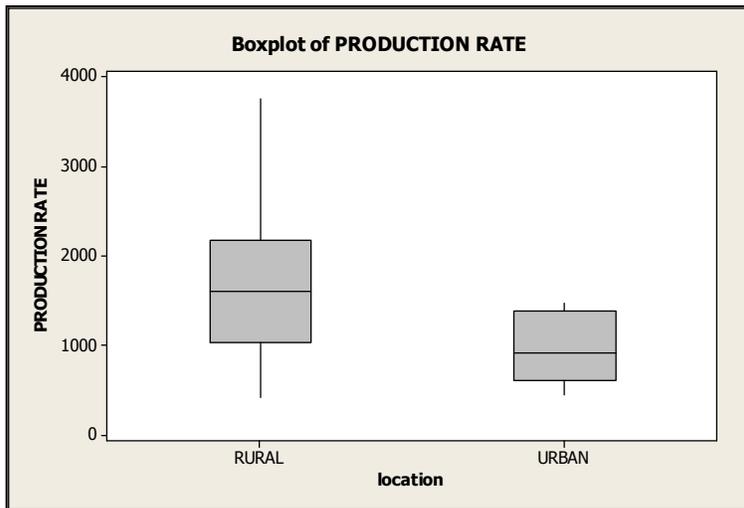
Unclassified Borrow (Location)

107
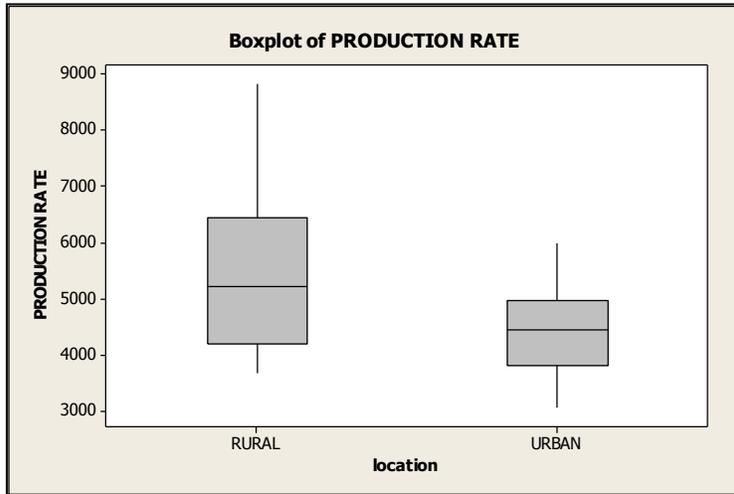
Sub-grade Modification (Location)
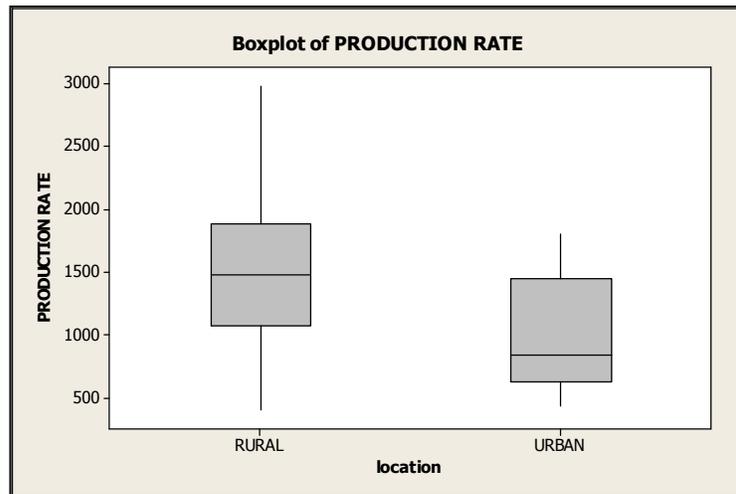
Asphaltic Concrete (Location)
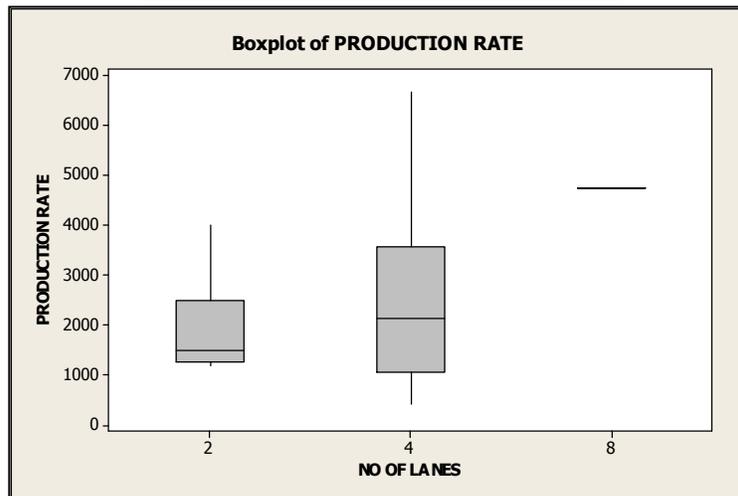
Unclassified Excavation (Number of Lanes)

Boxplot of PRODUCTION RATE
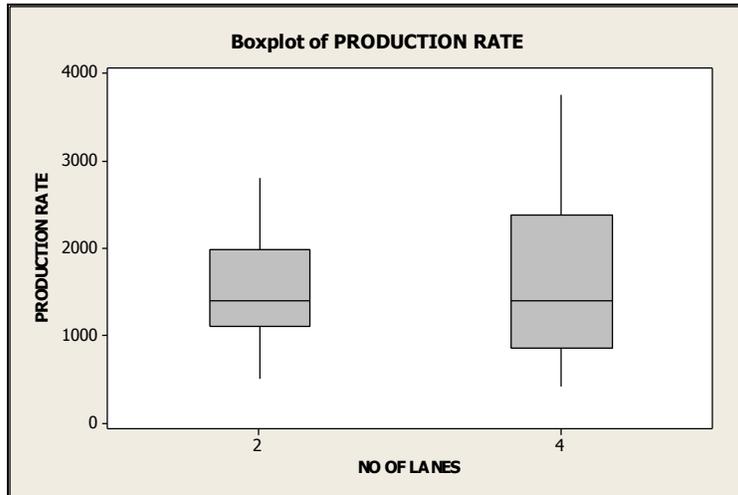
Unclassified Borrow (Number of Lanes)

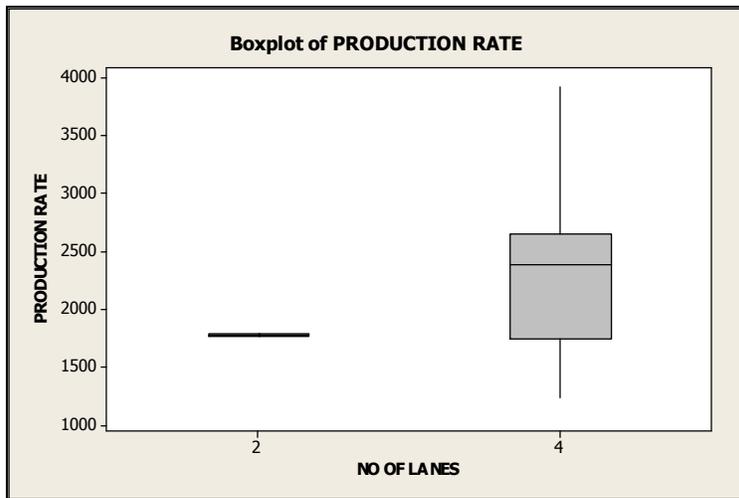**Boxplot of PRODUCTION RATE**
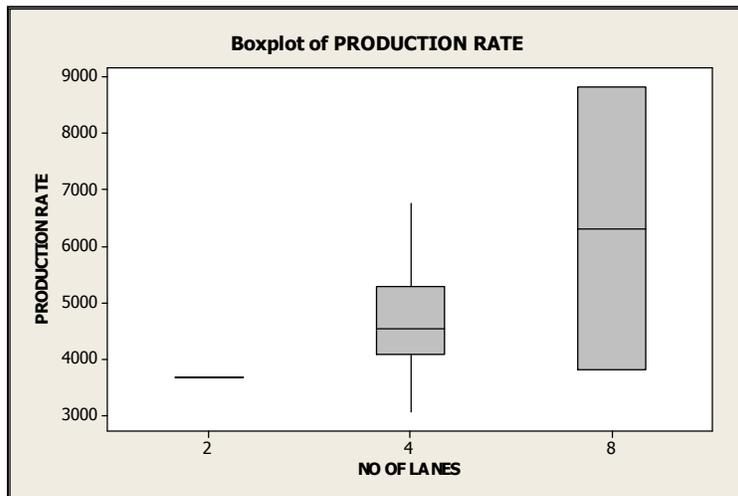
Sub-grade Modification (Number of Lanes)

Boxplot of PRODUCTION RATE
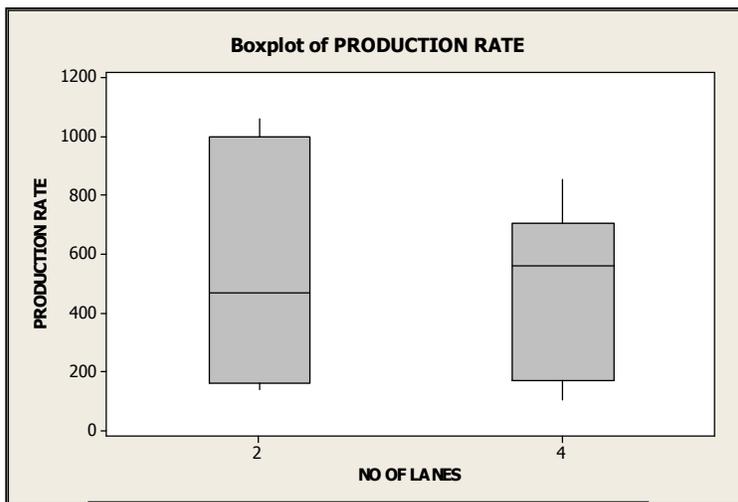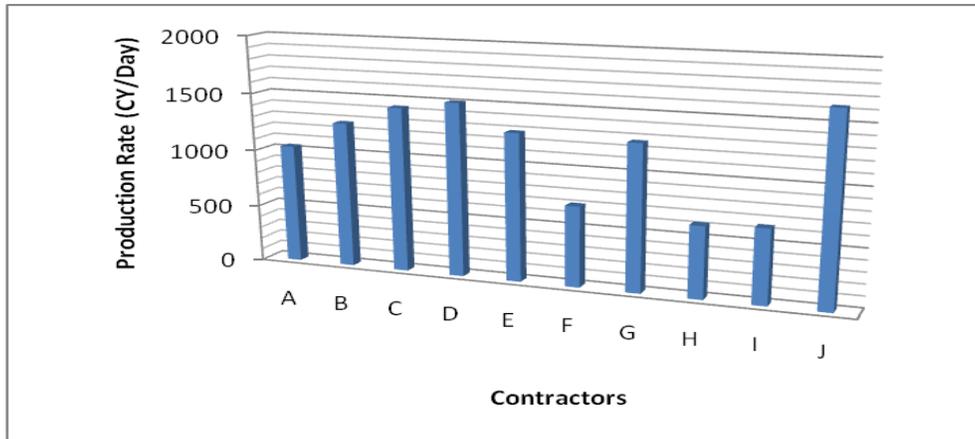
Aggregate Base (Number of Lanes)
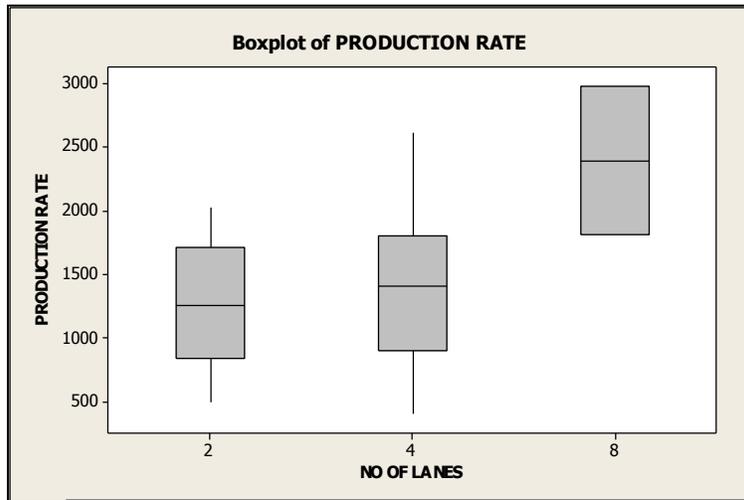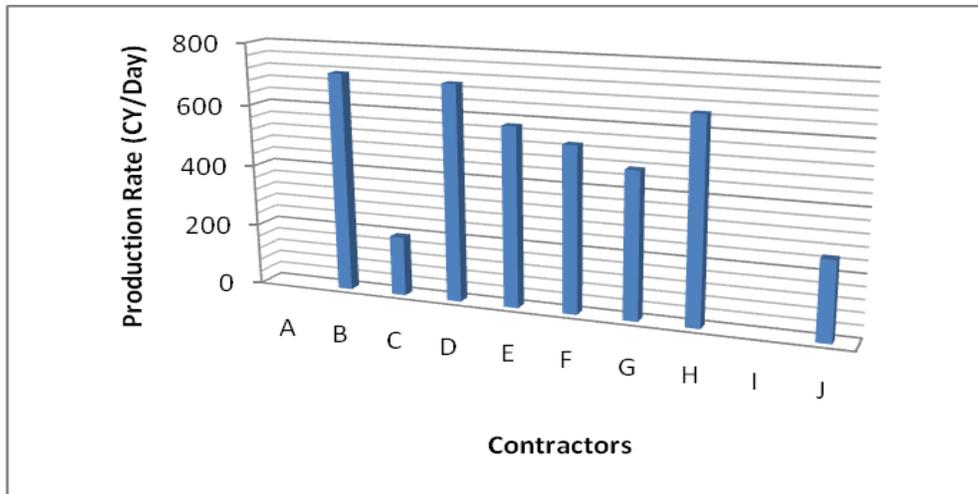
Asphaltic Pavement S-3 (Number of Lanes)

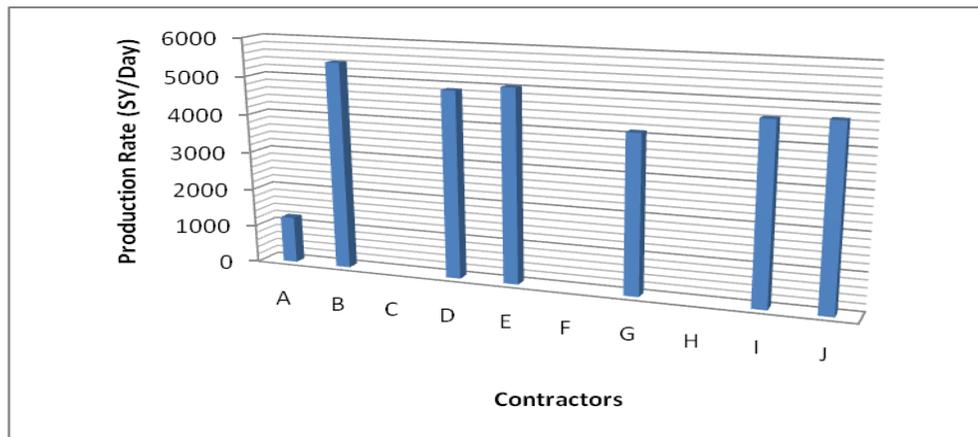Removal of Asphaltic Pavement (Number of Lanes)

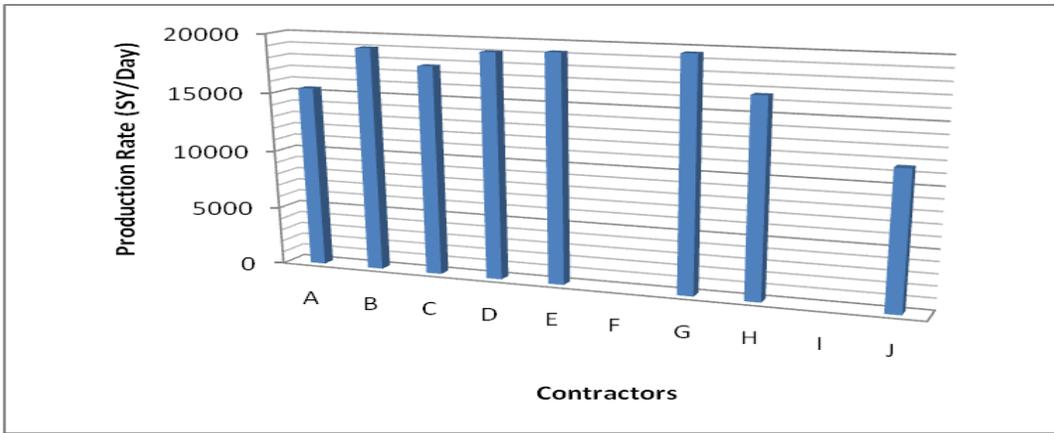APPENDIX I: PRODUCTION VARIATION AMONG CONTRACTORS

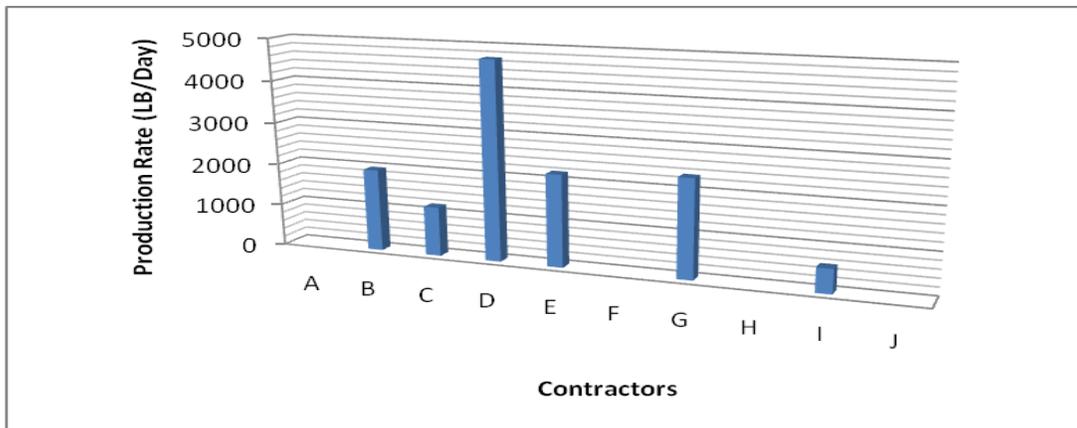Production Rate Among Contractors (Aggregate Base)

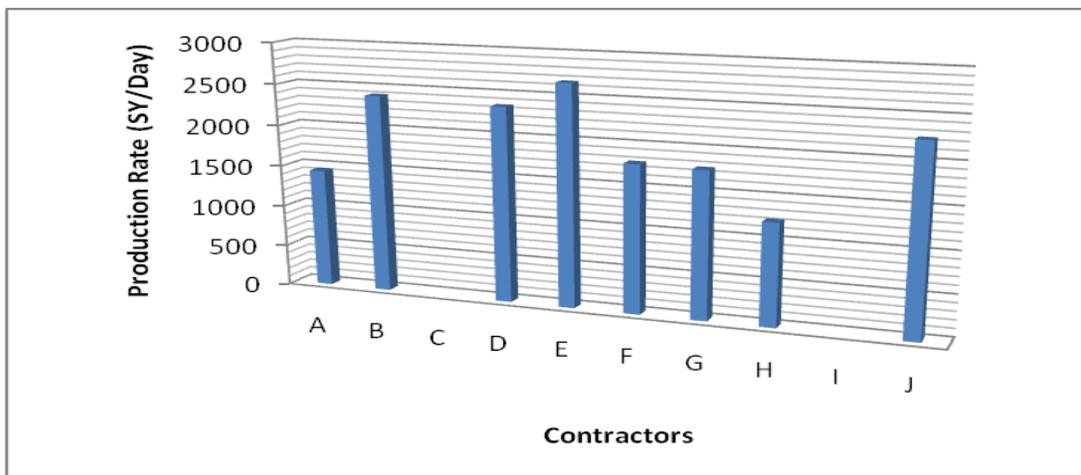Production Rate Among Contractors (Asphaltic Concrete)

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 J: REGRESSION MODELS

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)	353.598	1850.37		0.191	0.85	-3411.01	4118.205
	Route No.	257.858	139.291	0.303	1.851	0.01	-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	0.034	-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	0.028	168.208	1311.065
	Seasons	-374.634	111.08	-0.491	-3.373	0.0072	-600.629	-148.64
	Temp	-2.658	8.303	-0.041	-0.32	0.751	-19.551	14.234

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)	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	0.017	-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	0.002	-36.936	42.404

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)	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	0.12	-39.231	431.343
	No of Lanes	237.308	61.233	0.489	3.876	0.001	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

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)	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	0.057	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	0.0016	-1658.94	1492.634
	Temp	20.793	34.985	0.233	-2.717	0.0043	-59.883	101.469

Removal of 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)	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

APPENDIX K: PROBABILITY PLOT

Aggregate Base, Removal of Pavement & Sub-grade Modification respectively

Probability Plot of PRODUCTION RATE
Normal - 95% CI

Mean	2324
StDev	726.7
N	24
AD	0.628
P-Value	0.090

Probability Plot of PRODUCTION RATE
Normal - 95% CI

Mean	2222
StDev	632.3
N	42
AD	0.683
P-Value	0.069

Probability Plot of PRODUCTION RATE
Normal - 95% CI

Mean	4638
StDev	1451
N	31
AD	0.676
P-Value	0.070

119
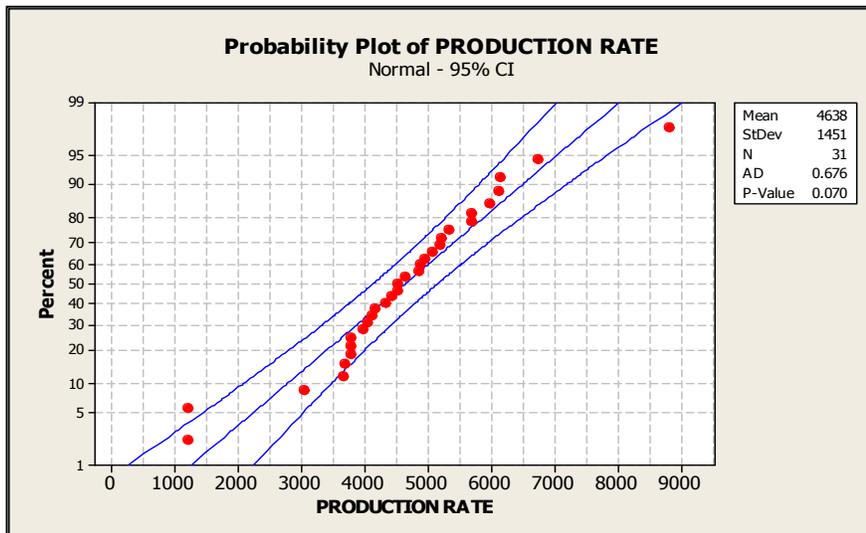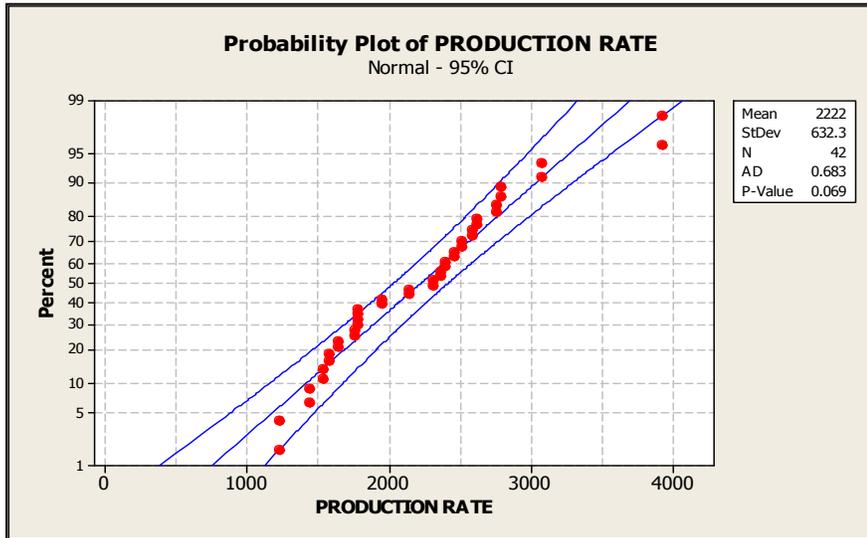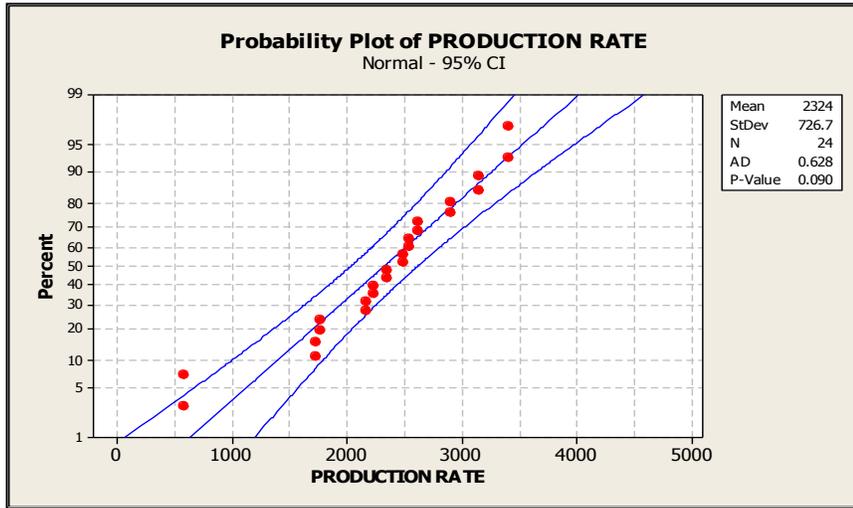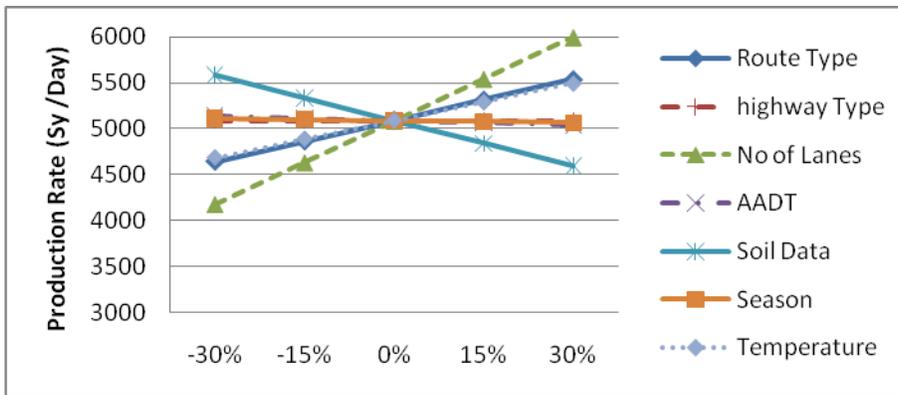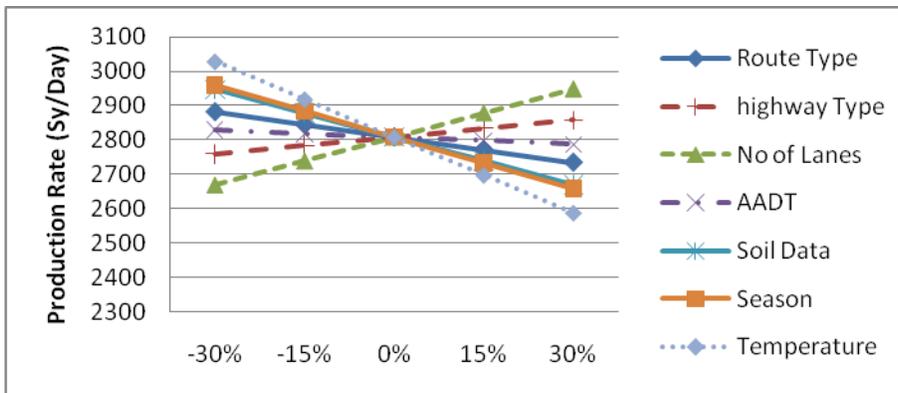
Unclassified Excavation & Unclassified Borrow
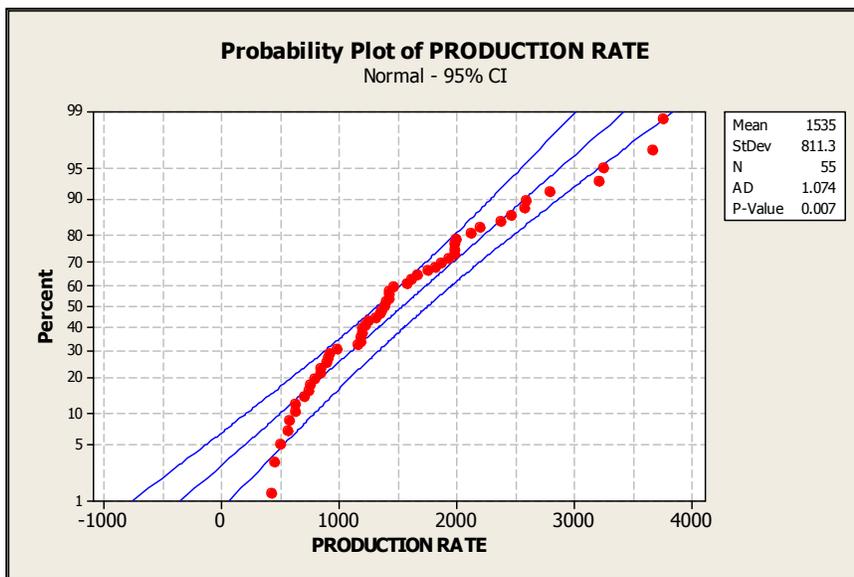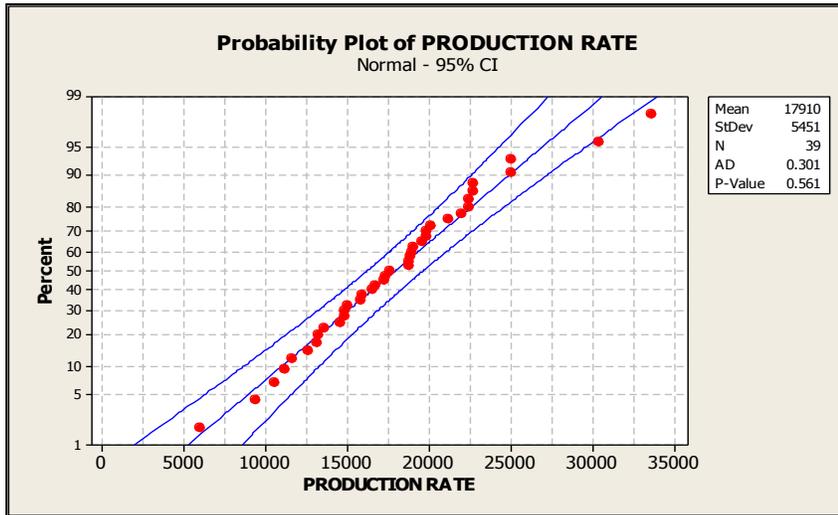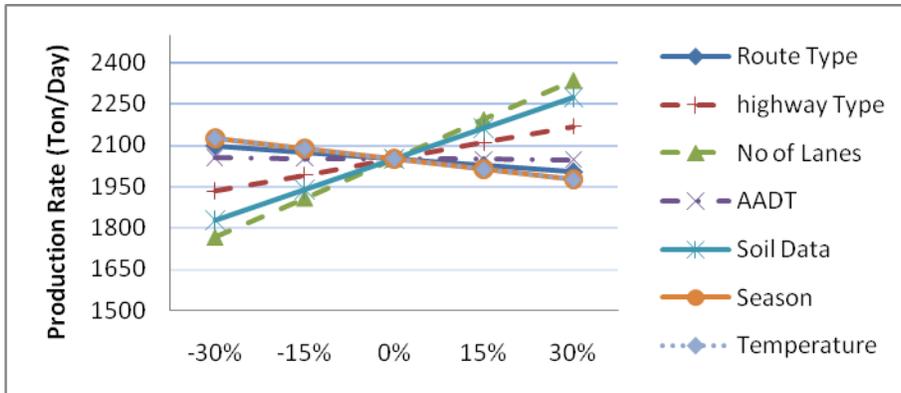
APPENDIX L: SENSISTIVITY ANALYSIS
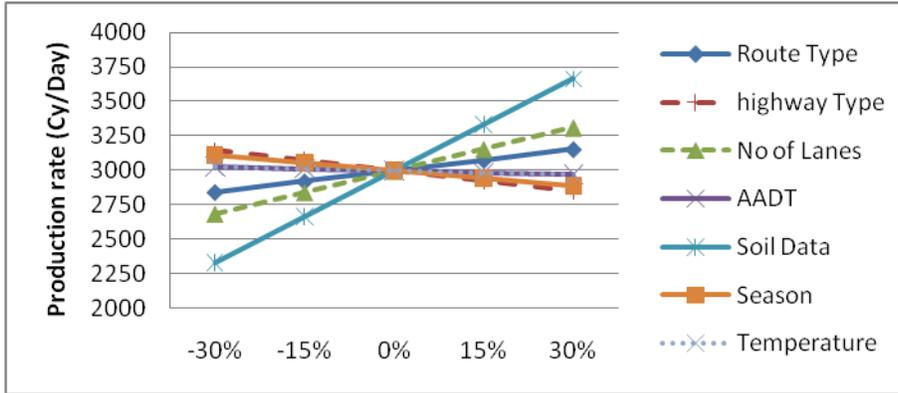
Aggregate Base

Sub-grade Modification

Removal of Pavement

Asphaltic Pavement