Quantitative Analysis on Factors Affecting Crew Productivity : Crew Size

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Abstract

Consideration of factors driving crew productivities is imperative for accurate construction time estimation. Their impacts need to be well understood by estimators. There have been, however, little studies that quantified relationships between crew productivities and factors. This paper quantifies impacts of °ÆCrew size°Ø on crew productivities, for three highway concrete bridge activities, namely Column, Cap, and Deck, based on data compiled from 17 on-going highway projects in Texas State, USA. It was found that, for Bridge Deck operation, an increase of one crew-worker of formwork and rebarwork by one, leads to an increase of the productivity (cy/crew day) by 2.5 and 2.9, respectively. For the other activities, larger crew sizes did not lead to better crew productivities.

Keywords : Factor, Crew, Productivity, Bridge

1. Introduction

Construction time estimation is becoming increasingly important, especially for highway projects. It is important to have reliable productivities data in order to conduct accurate construction time estimation. Moreover, consideration of factors driving productivities is also imperative for time estimation. Their impacts need to be well understood by estimators for accurate estimation, as Herbsman and Ellis (1995) noted that *"a scheduler has to consider a wide rage factors likely to affect highway project duration"*.

There have been, however, little studies that quantified relationship between productivity and factor. One of possible reasons is that there is no such data that can be analyzed with appropriate statistical confidence in order to find out the relations quantitatively.

The aim of the paper is to quantify impacts of 'Crew size' on crew productivities, for three major highway concrete bridge activities, namely Column, Cap, and Deck.

The data used was compiled by the author from 17 on-going highway projects in Texas State, USA, between February, 2002 and November, 2003.

2. Methodology

Research methodology was carefully developed as depicted in Figure 1. First of all, published papers were reviewed in order to develop framework for data collection and analysis. Then data collection preparation was conducted to facilitate data collection process and enhance accuracy of data, which included developing a step-by-step data collection procedure and a data collection tool, and defining scopes of activities. Procedures for selecting and visiting a project as well as for collecting data on a selected project were established. A data collection tool was also developed to guide the data collection process (Huh et al. 2004)[1]. Then data was collected by the author from 17 on-going highway projects, and analyzed by means of regression analysis in order to quantify impact of crew size on crew productivities.

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[1] Readers can find detailed information on the procedures and the data collection tool from the reference paper.

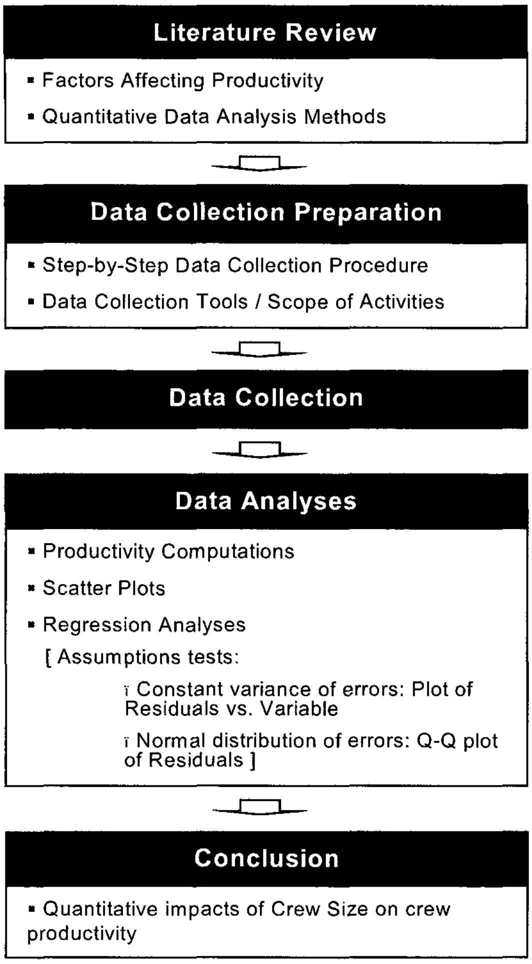

Figure 1. Research Methodology

3. Literature Review

There are numerous factors reported to affect construction labor productivity. Thomas (1989) listed 42 factors under three categories as shown in Table 1.1. Herbsman and Ellis (1995) found 17 factors affecting overall construction duration of a transportation facility project from a survey: weather and seasonal effects; location of a project; traffic impacts; relocation of construction utility; type of project; letting time; special items; night and weekend work; dominant activities; environmental; material delivery time; conflicting construction operation; permits; waiting & delay time; budget & contract payment control; and legal aspects. Furthermore many researchers studied in different ways how those factors affect the productivity and how those are interpreted and/or used for better construction project management.

One of problems in the studies is that there are many factors and the interaction between factors is not well quantitatively understood. It is mainly because there is no such data that can be analyzed with appropriate statistical confidence in order to find out the relations quantitatively. In construction operations, not only is it hard to record detailed daily productivity log, but also a number of within project factors vary from day to day.

Another reason might be methodology of its analysis. Analysis techniques are not always simple. Finding proper analysis approach is actually still a topic of ongoing research in construction industry (Sanders et al. 1989). Fortunately a few of the studies attempted quantitative analysis despite these difficulties in data collection and analysis.

3.1 Crew Size

The effects of crew size on productivity have not been extensively studied. It is well established that as crew size increases productivity (output/input) decreases mainly due to congestion, interferences and conflicts between crews, tools, and materials.

Thomas and Sanders (Thomas et al. 1989, 1990, Sanders et al. 1989) studied 570 workdays of data on 11 commercial masonry projects. They did not find significant relationships between crew size and productivity but suggested that there might be two patterns pertaining crew size; 'Production-oriented work' and 'Piece-meal work'. They reported that, for a 10-person crew, productivity was reduced greatly when the crew shifted from production-oriented work (such as long span of simple masonry wall work) to piece-meal work (such as small section of detailed architectural wall work).

3.2 Congestion and Restricted Access

'Congestion' refers to the situation where a craftsman does not have sufficient space to perform his or her activities effectively. General consensus on the effect of congestion on productivity is that as the area for a workforce is decreased, its productivity is lessened.

Little research has however quantified the actual effects of congestion.

Thomas and Smith (1990) summarized a Mobil Oil Corporation study on the effect of congestion on medium to large refinery projects. The study recommended 200ft^2 per person in order to maximize the productivity; and 110 ft^2 per person was mentioned as a lower limit, which led to 50% reduction in the productivity. The study also mentioned that 25% more space should be provided with subcontractors, and 100ft^2 per person was appropriate for small projects. Smith also suggested that the range be from 110 ft^2 to 320 ft^2 (Smith 1987; Thomas and Smith 1990).

Table 1. Factors Affecting Construction Labor Productvity

Within-Project Factors	Project-to-Project Factors	Regional Factors
Manning Level / Crew Size and staffing practices / Congestion and overcrowding / Absenteeism and turnover / Interruptions and delays / Moral and Motivation of labor force / Remobilization / Working hours (shift and overtime) / Restricted access / Temperature and humidity / Acceleration / Weather events / Change orders / Welfare provisions / Repetition and continuity / Continuity of work for trade / Complexity and constructability / Subcontractor performance / Client relations / Management control / Artificial constraints / Safety and Housekeeping / Rework / Inadequate supervision / Availability of tools and materials / Out-of-sequence work	Size and type of project / Complexity and constructability / Crew composition / Project scope / Work methods / Mechanization and amount of equipment / Quality requirements / Type of contract documents / Quality of supervision	Skill of labor force / Unemployment rate / Union attitudes / Weather / National, local politics

Original Source: "An exploratory study of productivity forecasting using the factor model for masonry", PTI Rep. 9005 (Thomas, H.R., Smith, G. R., Sanders, S. R., 1989)

Sanders concluded from a masonry study that the average loss of efficiency for congestion was 65% which is a bit higher than those reported previously to the industry. One possible explanation is that he focused on congested operations only, whereas the other researchers recorded more or less the average of congested works as well as normal works over a longer period (Thomas et al 1990).

4. Impact of 'Crew Size' on Crew Productivity

4.1 Data Collection and Overview

Data collected as part of the study comes from 17 highway projects under construction in Texas during 2002 ~ 2003. The projects were located across five different counties in Texas State, USA. The contract amounts of the projects range from one million to 261 million dollars. Table 2 and Table 3 show overview of the projects and the data points.

Table 2. Overview of Projects

Districts Visited	Dates Visited	Total No. of Projects	No. of Data Points Collected		
			Column-Rectangle	Cap	Bridge Deck
San Antonio	3/1/02 ~ 7/31/02	1	0	0	1
Austin	9/1/02 ~ 2/10/03	3	7	16	6
Dallas	11/7/02 ~ 2/25/03	5	8	5	7
Houston	3/20/03 ~ 10/16/03	7	3	11	7
Lubbock	9/16/03 ~ 11/06/03	1	0	0	1
	Total	17	18	32	22

Table 3. Overview of Data Points

Activity	No.of Data Points	Total Quantity	No. of Work Days	No.of District	No. of Project
Column-Rectangle	18	31 columns	65.5	3	4
Cap	32	43caps	195	3	11
Bridge Deck	22	32,224M2	428.5	5	14

4.2 Productivity Computation

Crew productivity was defined as '[2]CY completed/ Crew Work Day'. Calculating productivities as defined requires two input values; 'Output' and 'Crew work days'. The 'Output' value represents quantity of work completed during a certain number of work days and is measured as 'CY of concrete'. While a minimal effort was needed to measure the 'Output', clear guidelines were required on assessing 'Crew work days'.

If, in a given day, delay effect caused by any of factors, such as weather, material unavailability, traffic accident, machine downtime, etc., amounts to less than two hours, the day is considered one work day. When the delay is less than or equal to five hours but greater than two, the day is counted as a half-work day. Otherwise, it is counted as a non-work day. A work day having more than 2 hours of overtime was also adjusted based on actual overtime hours. Non-working days, for example, holidays and non-working weekends, are not counted at all.

Table 4 shows specific scope of each activity for which data was collected. Work elements included in the scopes of the activities were those that most directly represent actual production of the work operation (Huh et al. 2004).

4.3 Regression Analysis

The Simple linear regression method was employed to quantify impacts of crew sizes on crew productivities. A value of R^2, coefficient of determination, for a regression model, indicates how

[2] CY= Cubic Yard

Table 4 Scope of Activity Observation for Productivity Data

Activity	Observation Starting Node	Observation Ending Node
Column-Rectangle	False work or form work, whichever starts first	Concrete placement is completed
Cap	False work or form work, whichever starts first	Concrete placement is completed
Bridge Deck	Setting of pre-cast panel / Permanent Metal Deck starts	Concrete placement is completed

well observed data fit into the predicted model.

When R^2 is reasonably high enough, the impact can be determined by a value of regression coefficient, provided its *p*-value is higher than a statistically significant level of *p*- value. The *p*-value is seen to be the probability of observing a sample value assuming the null hypothesis (Ho), which for this case is that the coefficient equals zero, is true. In other words, if *p*-value of the regression coefficient is larger than the given α value, it can be concluded that the effect of the independent variable (crew size) on the dependent variable (productivity) is not statistically significant at the given significance level α (Wonnacott et al. 1986; Sakamoto 2002).

The following are three assumptions to be tested for better interpretation of a regression model (Albright 2003; Thomas 2003).

- Linear model is appropriate
- Constant variance of errors
- Normal distribution of errors

The first assumption can be tested by inspecting scatter plot. The second and third assumptions are tested by means of scatter plot of residuals vs. independent variable and normal Q-Q plot of residuals, respectively. The 'Q-Q Plot' plots standardized values of data set vs. values that would be expected if the data was perfectly normally distributed. If data tends to be normally distributed, values will fall on or near a straight line (Albright 2003; Thomas 2003)

Although multiple regression method is a widely accepted statistical application to build a prediction model and shows the net effect of each independent variable, (while controlling all other variables,) simple regression is only employed for this research mainly because of sample sizes limits. The number of data points collected and used for the analyses is mostly less than 30 per work item, which is believed to be insufficient to develop a reliable multiple regression model, as Stevens (2002) stated that "for social science research, about 15 subjects (*data points*) per predictor (*independent variable*) are needed for a reliable equation."

Furthermore, nonlinear regression analyses were also attempted to find better explanations of the relationships. However, the results were marginally same or even worse than liner models. One possible explanation might be that Crew Size (X values in plots) is limited in a real life and so linear models are good enough for explaining relationships between variables within given X ranges.

4.4. Analyses Results: Column-Rectangle and Cap

Each set of productivities data of two activities, Column-Rectangle and Cap, was regressed on total crew size, that is a total number of form-workers plus rebar-workers, and results are presented in Figures 2 and 3. The middle straight line in the graphs is a linear regression line and the curved two lines represent the 95% confidence interval of predicted productivity values.

Although concrete pouring work was included in the productivity scope, concreting-crew size was excluded in the analyses, since the operation is to some extent machine, such as crane or pump car, driven. In order words, concreting-crew size, to a little extend, does not affect the duration of concreting operations, and so not crew productivity of 'output/crew days.' No observation was made on one concreting-crew operating with more than two pieces of equipment.

For both cases, perhaps surprisingly, larger crew sizes did not lead to better crew productivities. Moreover, regression models with each

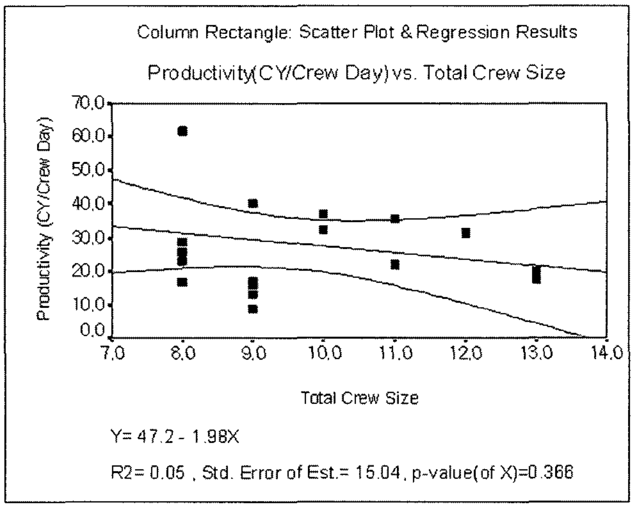

Figure 2. Scatter Plot and Regression Results; Column-Rectangle vs. Total Crew Size

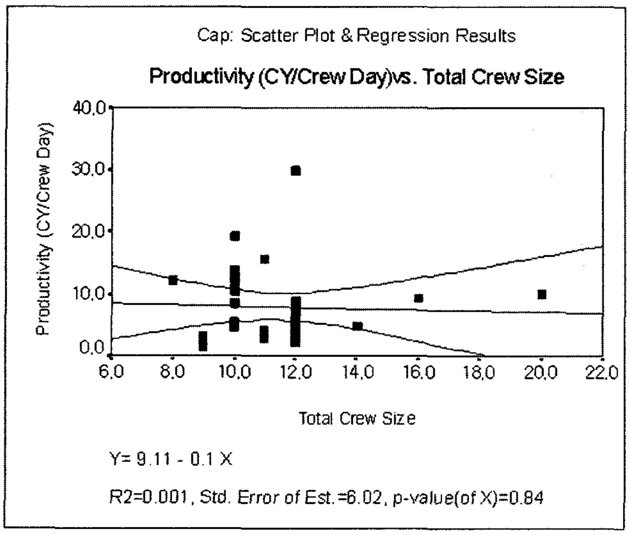

Figure 3. Scatter Plot and Regression Results; Cap vs. Total Crew Size

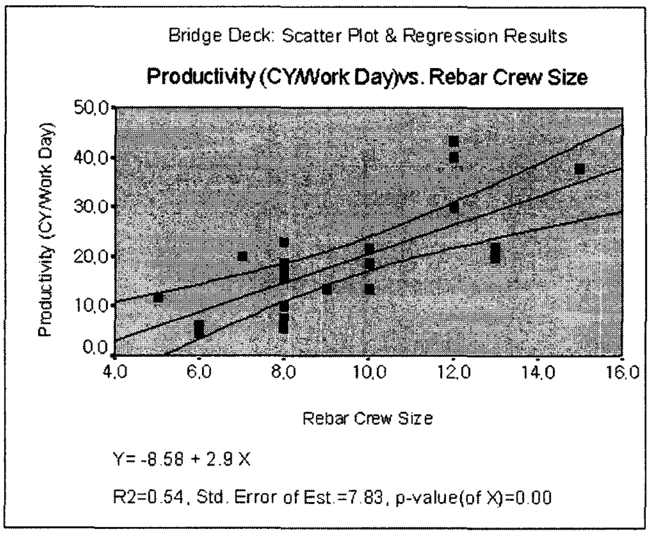

Figure 5. Scatter Plot and Regression Results; Bridge Deck vs. Rebar work Crew Size

size of the two crews, formwork crew and rebarwork crew, showed the same conclusion. None of their R^2 was higher than 0.1. In many cases, the crew size of such an activity had an insignificant impact on its crew productivities. One possible explanation would be that a larger crew size of such an activity helps only to deal with its larger scale and/or higher complexity, rather than to produce more units of work, resulting in the productivity remaining about the same.

4.4. Analyses Results: Bridge Deck

In contrast to the other two activities, Bridge Deck activity has considerable variation in productivity with crew size, as shown in

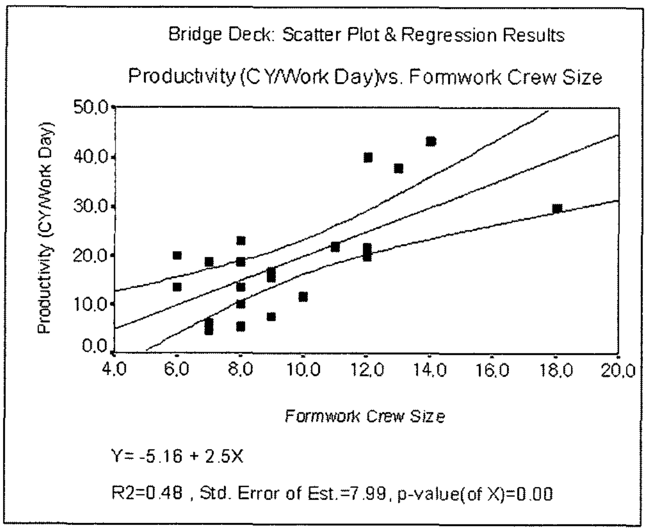

Figure 4. Scatter Plot and Regression Results; Bridge Deck vs. Formwork Crew Size

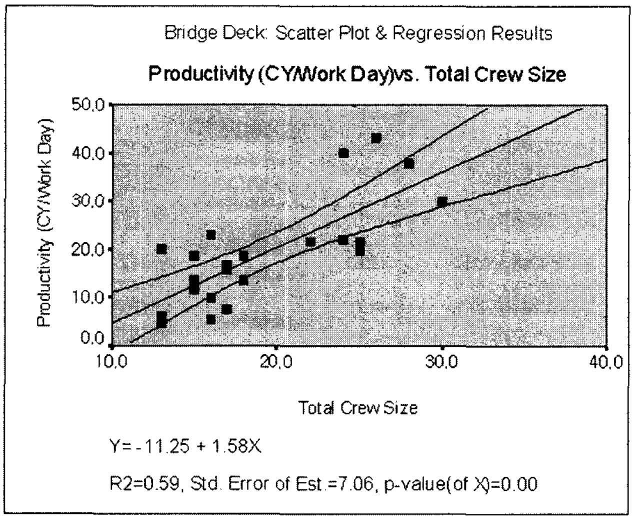

Figure 6. Scatter Plot and Regression Results; Bridge Deck vs. Total Crew Size

Figures 4, 5, and 6. The regression analyses results reveled that an increase of one-crew-worker of formwork, rebarwork, and total by one, lead to

an increase of productivity (cy/crew day) by 2.5, 2.9, and 1.58, respectively. Relatively longer period[3] of activity, larger crew size and wider work area might be reasons, comparing with two other activities. Plots used for testing assumptions of the analyses can be found in Appendix A.

[3] As Bridge Deck includes more sub-activities and quantities than the others, its works normally take longer.

5. Conclusions

Many papers have been reviewed and summarized in order to gain quantifiable insight on the effects of two factors; Crew size, and Congestion and restricted access. It is not surprising that there are little quantitative analysis researches that can be used effectively by management with confidence. This is largely because it is very difficult to isolate an effect caused by one factor due to the nature of construction operation.

Simple regression analyses were conducted in order to quantify the impacts of 'Crew Size' on three major bridge work activities, based on data compiled from 17 highway ongoing projects during 2002 ~ 2003 in Texas State, USA. It was found that, for Bridge Deck operation, an increase of one-crew-worker of formwork, rebarwork, and total by one lead to an increase of productivity (cy/crew day) by 2.5, 2.9, and 1.58, respectively. For Column-Rectangle and Cap activities, larger crew sizes did not lead to better crew productivities. One possible explanation would be that a larger crew size of such an activity helps only to deal with its larger scale and/or higher complexity, rather than to produce more units of work, resulting in the productivity remaining about the same.

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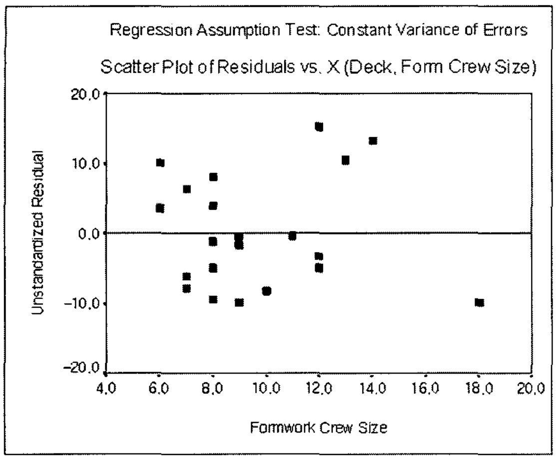
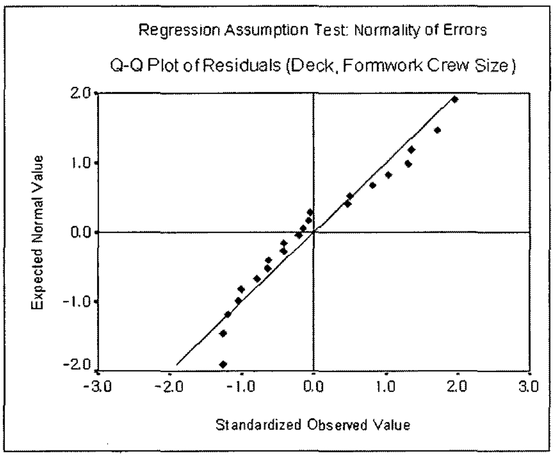
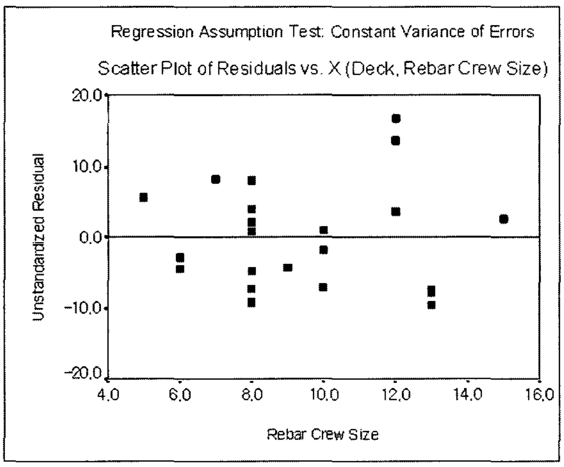
Appendix A



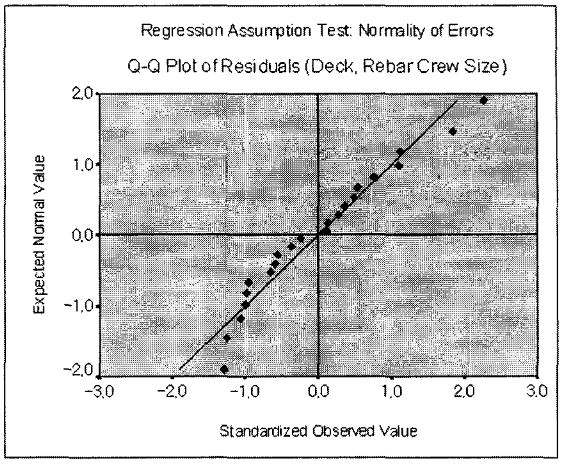
Appendix A-1 Regression Assumption Test- Constance Variance of Errors; Bridge Deck vs. Formwork Crew Size



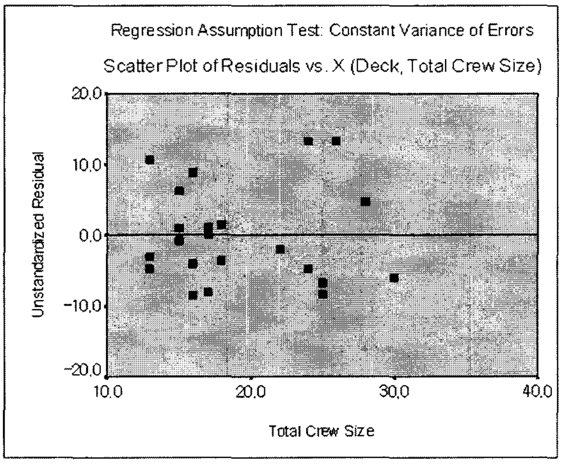
Appendix A-2 Regression Assumption Test- Normality of Errors; Bridge Deck vs. Formwork Crew Size



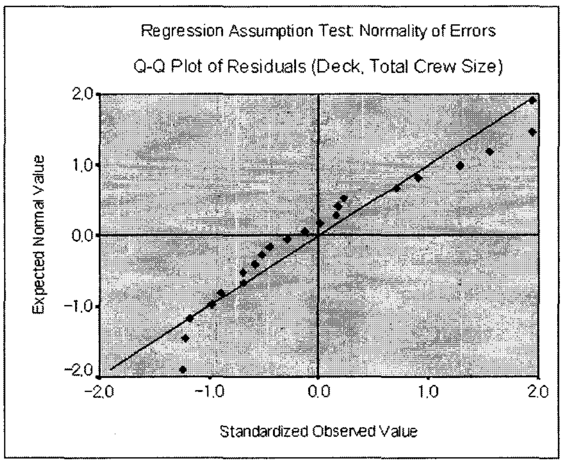
Appendix A-3 Regression Assumption Test- Constance Variance of Errors; Bridge Deck vs. Rebarwork Crew Size



Appendix A-4 Regression Assumption Test- Normality of Errors; Bridge Deck vs. Rebarwork Crew Size



Appendix A-5 Regression Assumption Test- Constance Variance of Errors; Bridge Deck vs. Total Crew Size



Appendix A-6 Regression Assumption Test- Normality of Errors; Bridge Deck vs. Total Crew Size