MODELING FOR THE ESTIMATION OF WORK DURATION AND MANAGEMENT OF LABOR RESOURCES FOR THE FACILITIES DEPARTMENT AT UPRM

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ABSTRACT

The purpose of this research was to obtain estimation models for the time duration of maintenance and repair activities performed at selected sections of the Facilities Department at the University of Puerto Rico in Mayaguez (UPRM) and design a database using these models. These sections were Electricity, Refrigeration and Plumbing. Tasks performed by these sections were divided into activities and then classified as either constant or variable. The estimation models were a result of a combination of the times of both constant and variable activities. The time estimates database allows the user to estimate the total man-hours required to process a work order and obtain a Productivity Index (PI). A survey was conducted in the studied sections to determine opportunities for productivity and methods improvement taking into consideration the search for materials, material handling equipment, transportation, the setup activity, and the repair or service activity.

RESUMEN

El propósito de esta investigación fue obtener modelos para la estimación de tiempos de reparación y mantenimiento realizadas por el Departamento de Facilidades de la UPRM y diseñar una base de datos para almacenar estos modelos. Las secciones seleccionadas fueron Electricidad, Refrigeración y Plomería. Las tareas que realizaba cada sección fueron divididas en actividades, las cuales fueron subdivididas en constantes o variables. Los modelos de estimación de tiempos fueron obtenidos de una combinación de los tiempos de estos dos tipos de actividades. La base de datos de tiempos estimados permite al usuario estimar las horas-hombre totales por órden de trabajo y un Índice de Productividad asociado a esta. Se suministró una encuesta entre los empleados de las secciones estudiadas para determinar oportunidades de mejora en términos de productividad y métodos de trabajo.

This research is dedicated to my parents, Alfonso Cesari Rosado and Rosario López Ruiz, for their unconditional love and support. Thanks for teaching me to never give up on my dreams.
I love you both very much!

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"No matter how difficult the challenge, when we spread our wings of faith and allow the winds of God's spirit to lift us, no obstacle is too great to overcome".

Roy Lessin

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LIST OF SYMBOLS AND ABBREVIATIONS

A/C: Air Conditioner

CI: Confidence Interval

FD: Facilities Department

FT: Fluorescent Tubes

PI: Productivity Index

UPRM: University of Puerto Rico, Mayagüez Campus

V/A: Verification/Activation

WF: Water Fountains

WO: Work Orders

MODELING FOR THE ESTIMATION OF WORK DURATION AND MANAGEMENT OF LABOR RESOURCES FOR THE FACILITIES DEPARTMENT AT UPRM

Chapter 1: Introduction

The Facilities Department (FD) of the University of Puerto Rico at Mayagüez has recently reengineered the procedure to submit and process a work order. As part of this new method they have improved their labor reporting in terms of hours of work per employee. However, the Facilities Department still does not have a reliable system for the estimation of labor standards and the measurement of labor efficiency.

The main objective of this research was the development of a labor standards database for the tasks performed by employees in critical sections as identified by the management of the Facilities Department. The chosen sections were Electricity, Plumbing and Refrigeration. The database consisted of regression models as a function of the units being serviced in the work order. For example, in the case of the refrigeration section the regression model estimated labor requirements for a number of refrigeration units.

Another objective of this research was the identification of opportunities for the improvement of their work methods. These included the search for materials, material handling equipment, transportation, the setup activity, and the repair or service activity.

The labor standards in the database will be used by the supervisor of the sections under study to estimate the total man-hours required to process a work order. This estimate will facilitate the assignment of employees to work orders. Another benefit from the database will be its capability of measuring work order labor efficiency.

This project required communication with the management of the Facilities Department, supervisors and workers. These workers are organized under a labor union. Past initiatives involving the participation of unionized labor were taken into consideration to facilitate cooperation and agreement among researchers, workers and management.

The contributions of this project to the FD can be summarized as follows:

1. Development of a labor standards database for the tasks performed by the Facilities Department critical sections.
2. Improvement of the labor requirements estimation and management process of the facilities department.
3. Improvement of the Facilities Department employee's productivity performance through improvement of the labor standards estimation process.

The primary objectives of this project are as follows:

1. Analysis of the activities performed and time spent on work order completion in selected Facilities Department sections.
2. Development of regression models for the estimation of work duration.
3. Development of a database for the calculation and reporting of section productivity.
4. Identification of areas of opportunity for improving the activities required for work order completion.
5. Further improvement of data collection and reporting tools.

Chapter 2: Literature Review

The literature review presented in this section focuses on estimation models for service activities, metrics for productivity measurement, and the process of establishing labor standards in unionized environments.

2.1 Service Activities Time Estimation Models

Productivity improvement relies mainly on work study. Work study comprises two areas: methods study and work measurement. The concept of work measurement has been used for many years. The concept of time studies was proposed in the US by Frederick W. Taylor and the principles of methods studies were proposed by Frank and Lillian Gilbreth. [11]

The main purpose of work measurement techniques is to plan the work activities, measure performance, and estimate costs [11]. Work activities can be classified as direct labor and indirect labor. Direct labor is work applied to the product that produces a change and advances it toward its final specifications [12]. On the other hand, indirect labor is work that is not directly applied to the product, but is necessary to support its manufacture [12].

2.1.1 Work Measurement Techniques for Direct Labor

There are a significant amount of time measurement techniques available that can be applied to direct labor. Some of them are presented next.

Time Studies with Stopwatch

Time study is a methodology used to estimate work duration using stopwatches. A well trained operator must be selected to be studied. The methodology followed by the operator as well as the tools and materials should be analyzed. The job must be divided into well described elements (a portion of the job that can be measured with specific endpoints). A preliminary sample of times should be taken and the sample size determined using these preliminary times. When the study is completed, a standard time is determined from the results. Allowances for personal needs, fatigue and unavoidable delays are included.

The advantage of this method is that the division of the activity into elements facilitates the process of identifying areas of opportunity for improvement..

It is recommended that the analyst observe as much cycles as possible to get acquainted with the operation. Also, the elements should be of short duration, however larger than 2.4 seconds.

The two stopwatch methods are snapback and the continuous method. In the snapback method it is difficult to time very short elements since the stopwatch has to be returned to zero after each element. On the other hand, the clerical time is minimal since it is not necessary to subtract the times from the previous lecture. In the continuous method it is necessary to subtract the previous lecture from the current lecture. However, it is more precise since the watch does not have to be to zero after every timed element. [12].

Predetermined Time Systems (PTS)

The first predetermined time system was developed by A. B. Segur and it was called MTA (Motion Time Analysis). He worked with Gilbreth during World War I in developing methods for training of blind people and other handicapped workers [2]. His system was available on a consulting basis although no evidence to support his data was published. The first researches were conducted in the Industrial Engineering Laboratory at the University of IOWA in 1930's and 1940's.

At the present time, the International Labor Organization (ILO) has classified more than 200 pre-determined time systems. These methods consist on the study of fundamental or grouped motions that cannot be precisely evaluated with ordinary stopwatch time study procedures. They are also the result of studying a large sample of diversified operations with a timing device capable of measuring very short elements. Basically, the PTS are sets of motion-time tables with explanatory rules and instructions on the use of motion-time values [12].

It is required that the operation under study be divided into basic motions specified by each particular system. PTS do not include allowances so these should be added as in any time study.

The application of these PTS has increased as people have gained understanding of them. The most important advantage that these systems have over time study is that it is possible to determine the standard time of a job if the motion pattern is known. Different workplace layouts and methods can also be evaluated beforehand.

Although these systems are superior to time study because judgment of the analyst is not required in evaluating the pace of the worker, it is very important that all people establishing time standards be trained to use the data in the same way.

Among the most commonly used are:

- MTM (Methods Time Measurement): This method was developed in 1946 by Maynard, Stegemerten and Schwab using movies of drilling operations performed in Westinghouse. The time standards were published in 1948. They developed the concept of the normal operator based on a study at Westinghouse. It is defined as a procedure which analyzes any manual operation or method based on the basic motions required to perform it, and assigns to those motions a predetermined time value based on the nature and conditions under which it is performed [2]. It gives time values for fundamental motions such as: reach, move, turn, grasp, position, disengage and release [12]. Among the MTM systems there are:
  - MTM-1 designed for highly repetitive tasks requiring a significant amount of details in the documentation of the activity.
  - MTM-2 for activities requiring fewer details in their documentation.
  - MTM-C, is used for the analysis of clerical tasks such as keypunching, filing, data entry and typing.
  - MTM-GDP (general purpose data) has been derived from MTM-1. This is a "building block process" for the development of standard data [2].
  - MTM-V was designed for use with machine tool operations including setting machine tools, handling tools and work pieces.
  - MTM-M was designed for the analysis and measurement of manual assembly work performed under stereoscopic magnification of 5 to 30 power.
  - 4D DATA (Micro-Matic Methods and Measurement) is the use of MTM-1 with computers. The computer simplifies the work of the analyst and assists in standard development, recalling elements and mass changing standards [2].

- MOST (Maynard Operation Sequence Technique): It was developed in late 60's by Kjell B. Zandin when working for the Swedish division of H. B. Maynard and Company and introduced to the US in 1975. MTM was the database used in the development of MOST. However, MOST is much simpler to use. Analysts can establish standards 40 to 50 times faster than with MTM-1. Within MOST there are four systems: Mini MOST, Basic MOST, Maxi MOST, and Clerical MOST.
    - Mini MOST is used to analyze highly repetitive operations with very small reaching distances and low levels of muscular forces. It is also used on operations requiring very detailed documentation.
    - Basic MOST is used in the analysis of operations with higher levels of muscular force, longer reaching distances, and a high level of detailed documentation.
    - Maxi MOST is used in the analysis of operations in which a high level of documentation is not a requirement.
    - Clerical MOST is an extension of Basic MOST used in the analysis of clerical activities [6].

In general, MOST describes work through three basic sequence models: general move, controlled move and tool use, using larger blocks of fundamental motions [12].

- MODAPTS (Modular Arrangement of Predetermined Time Systems): It was developed in the 60's by G. C. Heyde, member of the International MODAPTS Directors Committee. It is based on MTM-2 System.

- Micro and Macro Motion Analyses: Developed by Standards, International. Its purpose was to improve the times obtained with MTM and Work Factor in certain operations where the times obtained were not adequate.
    - Micro Motion Analyses – Normal Times for methods with precise specifications. It is based on Work Factor.
    - Macro Motion Analyses – General Standard Data based on MTM.

2.1.2 Work Measurement Techniques for Indirect Labor

Fewer techniques are available for the measurement of indirect labor. Some of the techniques found in the literature review are described next.

Work Sampling

Work Sampling is a technique used to investigate the proportions of total time devoted to the various activities that constitute a job or work situation. This technique was first applied in the British textile industry. It was later brought to US with the name of ratio delay.

The results of work sampling can be effectively used to estimate time standards for indirect labor such as material handling and office tasks. It helps determine the machine and personnel utilization, allowances applicable to the tasks and can also be used to estimate labor time standards. Work sampling can provide the same information as a time study on a faster and less costly way. To perform a work sampling study, a large amount of observations representing typical conditions must be taken randomly.

Some of the advantages of this method are that it does not require continuous observations for prolonged time, it requires less clerical effort, total time required by the analyst is usually less, the operator does not have to be subject to constant stopwatch observations and more than one operator can be studied by one analyst simultaneously [12].

The theory of work sampling is based on the fundamentals of probability. Every observation is a Bernoulli trial where:

$Y_i = 0$ (failure)
The operator is not performing the task of interest.

$Y_i = 1$ (success)

The operator is performing the task of interest.

The probability of x occurrences of an event *P(x)* in n observations follows a binomial distribution as shown below:

$$P(x) = \binom{n}{x} p^x (1-p)^{n-x} \qquad x = 0, 1, 2, \ldots, n$$

where:

p = probability of observing the operator performing the task of interest in a visit to the area of study during any day

$(1-p) = q$ = probability of observing the operator not performing the task of interest in a visit to the area of study during any day

n = number of observations

The mean and variance of any random variable with binomial distribution is:

$$\mu = Np$$
$$\sigma^2 = Npq$$

According to statistics, when n becomes large, the binomial distribution approaches the normal distribution:

$$X \approx N(Np, Npq)$$

It is desired to estimate P = X/N. If X follows a normal distribution, then P follows the normal distribution too with μ_p and σ_p as follows:

$$\mu_p = \frac{1}{N} * Np = p$$

$$\sigma_p = \sqrt{\frac{pq}{n}}$$

After the estimate of p for the selected task is obtained, the standard time of any task i is calculated by multiplying the total number of hours worked by the employees by p_i and dividing this amount by the number of units of activity i completed during the worked hours.

Formula Application

The application of formulas has been very useful in non repetitive work, in which it is impractical to establish standards for each job using time study. This methodology has been used in service operations such as office tasks, maintenance work, painting, grass cutting, etc. It involves the design of an algebraic expression that establishes a time standard by substituting known values peculiar to the job for the variable elements [12].

Some of the advantages of using formulas to calculate time standards include: more consistent time standards; duplicate time studies on similar operations are eliminated; time standards are established faster and can be calculated by less experienced and/or less trained personnel.

Some disadvantages are that caution has to be exercised in the development of the formula to avoid treating more elements than the necessary as constants. Also, in the desire to estimate standards faster, some analysts use formulas that are not applicable to the case, resulting in incorrect values. Formulas should be reliable. That means that they should estimate the individual standards used in its development by ±5 percent. Formulas should also be clear, concise and simple. [12]

The steps to construct a formula begin with the determination of the type of work to be studied. Once this has been determined the next step is to collect the data. It is very important to establish consistent endpoints, being sure to select the same starting and ending point for each observation. All gathered data is analyzed and the constant and variable elements are identified. The constant values are added and the variables are either expressed algebraically or graphically. Following this should be a synthesis where the development of the formula should be explained in detail to interested parties. After that, the formula should be thoroughly checked for any possible error. If the prevailing conditions change, a new study should be performed, breaking down tasks into like elements with consistent endpoints.

Basic Queuing Theory

The Basic Queuing Theory is a useful tool for estimating waiting times which occur when the flow of arriving traffic (people, facilities and so on) establishes a random demand for service at facilities with a limited service capacity [11]. There must be an economic balance between waiting times and service capabilities. The following characteristics define a queuing problem:

- Pattern of arrival rates which may be either constant or random.
- Pattern of the service rate which may be either constant or random.
- Number of servicing units.
- Pattern of selection for service, usually follows the first-come, first-served basis but it can also be random or following a set of given priorities.

Solutions to queuing problems and estimation of waiting times can be obtained analytically or through a computer simulation model.

Standard Manning Level Method Proposed by Jack A. Wu and Nesa L. Wu

Jack and Nesa Wu [29] used the concepts of *key tasks* and *standard manning level (SML)*. *Key tasks* are the main activities of the job under study and *SML* is the amount of workers needed to perform the job at a specific level during a certain period of time. An example of these two concepts will be provided later.

The first step of their methodology is to perform a time delay analysis. The job under study is divided into elements that are classified as either *productive* or *non-productive*. The *productive time elements* are those activities that serve the overall production goal (example: service equipment, unload a truck). On the other hand, the *non-productive time elements* are subdivided into avoidable or unavoidable delays. Avoidable delays are elements that are not part of the job (do not serve the production goal but can be avoided). Unavoidable delays are the elements that do not serve the production goal but are not under the control of the operator (example: waiting for parts). The proper identification of these unavoidable delays is very important when determining indirect labor standards.

The next step is to determine the key tasks. The key task should be a productive work element that best represents the job under study. In many cases several small tasks are combined into one key task. Examples of key tasks are: the inspection of a unit and the replacement of bulbs.

Once the key tasks are identified, one must proceed to divide them into elements and identify such elements as repetitive or non-repetitive. The time value for both types of elements should be obtained and combined into a single time to represent the average time required to perform one unit of the key task.

Following the division of key tasks, it is necessary to determine the frequency or number of occurrences of each key task during a specific period of time. Then, the standard manning level (SML) is calculated. The SML consists of a constant part (C) and a variable part (V). The constant part of the job does not depend on the number of units being serviced or produced. The variable part is dependent on the frequency of the key task and its time standard. Then the total time required (T) is obtained from:

$$T = C + V$$

From the literature review it is concluded that most time estimation techniques are developed for situations where repetitive tasks are performed (example: manufacturing environments). Since this project was focused on repair activities that are usually non-repetitive, the Standard Manning Level technique was used to develop models to predict time durations of specific jobs at the Facilities Department.

2.2 Productivity Measurement

The globalization of the economy has challenged every economic sector. It has become of great importance the estimation of operating costs and business efficiency. Also, important to companies is achieving the maximum utilization of intangible resources such as intellectual capital and motivation, among others. This new way of viewing business helps them create the environment necessary for innovation; an important characteristic for improving productivity [1].

For the manufacturing sector, the measurement of labor productivity can be obtained fairly straightforward. One metric commonly used is output per unit of labor input, measured as:

$$\text{Productivity} = \frac{\text{Total Amount of Units Manufactured in a Given Period of Time}}{\text{Total Amount of Direct Labor Input}}$$

Other metrics are financial, such as the total value produced in a given period of time divided by the man hours used to produce it.

The measurement of productivity on the service sector is quite a challenge. Productivity models based on manufacturing assumes that the alteration of the configuration of the inputs does not change the quality of the output, the constant quality assumption. This assumption can not be used in the service sector. In the service sector the most important factor is the way the customer perceives the service. If the productivity of the service industry is measured as it is in the manufacturing sector (number of output units), an improvement in productivity might lead to a decrease in service quality. This concept is crucial to this sector because a decrease in customer value leads to a decrease in profits, meaning that the resources are not used in an efficient way. On the other hand, if customers perceive that they are receiving equal or better service than with the previous configuration of inputs, then it can be considered that the productivity has increased [1].

Existing measurement instruments for productivity do not take into account the interrelationship between productivity and perceived quality. C. Grönroos and K. Ojasalo [9] evaluate three alternative ways of measuring service productivity and conclude that the most effective one is based on financial measurements as follows:

$$\text{Service productivity} = \frac{\text{revenues from a given service}}{\text{costs of producing this service}}$$

They concluded that this method incorporates the variations in quality due to the configuration of services and the effect of the quality perceived by the customer reflected on their participation in the process. However, these assumptions should be managed carefully because prices not always reflect the quality perceived by the customer. Revenue is also not a good output for business with regulated prices, monopolistic competitions or in a very competitive situation [1].

Another method to measure productivity is using Multifactor Productivity. This method measures the change in the relationship between the quantities of an industry's output in terms of the quantity of inputs consumed in producing that output. Such inputs are capital, labor, energy, materials and purchased services:

$$\text{Multifactor Productivity} = \frac{\text{Output}}{\text{KLEMS}}$$

Where,

K – Capital

L – Labor

E – Energy

M – Materials

S – Purchased business services

The Multifactor productivity method of computing productivity has been used with success in the manufacturing sector. However, in sectors where the output is difficult to define such as construction or financial services, this method should be used with caution [19].

There is another method commonly used to evaluate the performance of workers known as the Performance Index. This Index takes into account the ratio of the estimated time to perform a specific job over the actual time taken to complete it. This can be shown in the following equation:

$$PI = \frac{ET}{AT} * 100$$

Where:

PI = Performance Index for a specific job

ET = Estimated Time for the specific job

AT = Actual Time for the specific job

One of the objectives of this project was to develop a model to estimate the time durations of specific jobs. Therefore, it was appropriate to use the Performance Index (PI) method to evaluate workers performance.

2.3 Estimation of Labor Standards in Union Environments

Unions can severely limit the managerial decision-making through work rules, seniority systems and provisions on outsourcing, among others [14]. This effect tends to be overlooked when a firm wants to adopt changes. Most of the time, unions limit managerial discretion, although there are specific situations when the rate of adoption of change might increase [4]. Through negotiation, management and union representatives agree on some specific rules that must be followed, although union contracts are often very inflexible regarding changes of any sort.

It is imperative to understand the priorities of today's unions in order to accomplish successful negotiations. In past years, union negotiations were focused on wages and better working conditions. At the present time, union members want job security and better quality of work life. During slow economy growth and global competition, keeping the job has become more important. Union leaders have learned that partnering with management is critical for improved competitiveness, which assures jobs. For this reason union employees are accepting working conditions they never would have considered before [3].

Pagell and Handfield [14] made comparisons between unionized and non-unionized firms in different areas. They established four hypothesis to compare between unionized and non-unionized firms in terms of flexibility, outsourcing and shop floor performance. They concluded that it is very important for unionized firms to develop a partnership with its union. They noted that unions have a great impact on either the success or failure of its operational strategies. This is specially seen on the assimilation of new ways of doing things. The result of their research suggests that firms without unions tend to be more successful implementing new initiatives than the unionized firms. From the results of their research it can be noted that products spend more time in queues in unionized firms and have longer lead times (almost three times longer). Since longer lead times are associated with higher inventories and higher capital expenses, it is possible that non-unionized firms within the same industrial sector have a competitive advantage.

Usually, union members, as well as any non-unionized employees, tend to perceive that any change is positive if the management is seriously involved. Since this project intend to implement a method to estimate time durations for specific jobs performed by the Facilities Department at the UPRM, it was imperative to have both management and union members support. An effective communication was essential to accomplish it, resulting in a minimization of the impact the labor union had during the implementation process.

Chapter 3: Methodology

The methodology followed for the completion of this project work is in Figure 1.

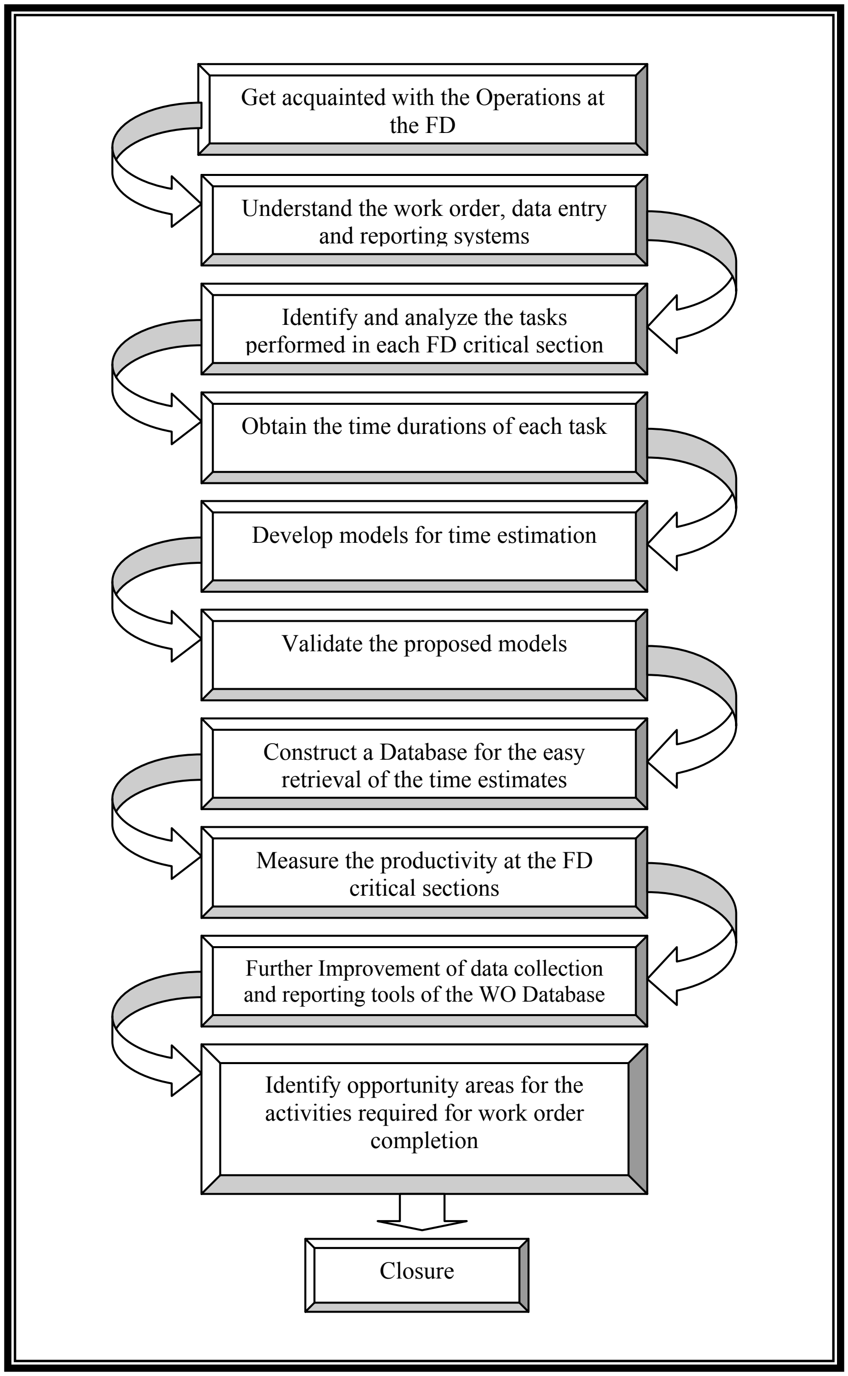

Figure 1: Flowchart of the Followed Methodology

3.1 *Get acquainted with the operations at the Facilities Department (FD)*

The first step of the methodology was to get familiarized with the operations of the FD. The familiarization process began with meetings conducted with the Manager of the FD. During these meetings a general understanding of the labor of each facilities section was gained. Through this process expected results and project scope were established. Also the sections to be studied in the project were identified based on management needs.

Once the sections to be studied were selected, the people to be involved in the process were identified:

- Supervisors and employees of each selected section
- Secretaries from the selected sections
- Data Administrator

Individual interviews were held with the supervisors of the sections previously identified by the manager. These interviews helped the researcher to understand in more detail the jobs performed by the selected sections.

3.2 *Understand the work order, data entry and reporting systems*

The work orders managed by the FD are allocated in a computer database, so it was necessary to gain access to it. Since the database was designed in Microsoft Access® the researcher had to learn to use this software.

The learning process continued with the understanding of the design of the database itself. It is divided into different levels and each level is assigned to certain group of users. The first level provides general information of each section. Clients can make requests for maintenance jobs through the Internet. These job requests are stored in the database and can be access by the second level users. The second level is assigned to the secretaries of the sections. Work requests can also be made by phone and entered in the database by the secretaries.

The third level is completed by the supervisors of each section. They assign the employees to the specific work orders and print a work order form. These forms are filled by the assigned employees.

The forth level is owned by the Data Administrator who digitalizes the information submitted by the employees and closes the work orders.

The work orders database did not have accurate data. The FD management established the need to retrieve accurate reports from the database to identify percentages of open and closed work orders on specific dates.

3.3 *Identify and analyze the tasks performed in each FD critical section*

The selected FD sections were evaluated and the most important tasks performed by them were identified in each section (example: repair air conditioner, install bulb, etc.). Then it was established the measurement unit (parameter) for each task.

The tasks were divided into activities. These activities were classified based on the contribution they make to the completion of the task. The classifications are: productive (referring to a key activity that leads to the completion of the task); unavoidable (referring to activities that are necessary for the completion of the task but do not add value to the process); and avoidable (referring to activities that are not necessary to complete the task and do not add value to the process).

3.4 *Obtain the time duration for each task*

Employees reported the time consumed to complete all the activities of the assigned tasks. The work orders generated for key tasks identified for the selected sections were evaluated and the time for each activity was recorded.

3.5 *Develop models for time estimates*

This step included the development of a mathematical model to estimate time requirements given the work parameters. The times reported for productive activities of key tasks were evaluated in terms of the number of units completed.

The time required (TR) to complete the task is determined by:

- A constant part (C_j)
- A variable part (V_i)

The constant part (C_j) consists of activities within the tasks that are not related to the amount of units of the task. These activities can include transportation of workers to the location, among others. The variable part (V_i) includes those activities within the tasks that are a function of the amount of units in the tasks. An example of these activities is the time consumed to repair an Air Conditioner. The total repairing time is a function of the total amount of Air Conditioning units repaired.

All the activities within the studied tasks were classified into either constant or variable activities. The constant part (C_j) was estimated by calculating the weighted averages of the constant activities. The variable part (V_i) was estimated by regression analyses performed to the variable activities. The estimation model for the Time Required (TR) was obtained through *Equation 1*:

$$TR_k = \left[\sum_{j=1}^{m} C_{(j)k} + \sum_{i=1}^{n} V[x]_{(i)k} \right] \qquad \textit{(Equation 1)}$$

Where:

i: a specific variable activity

j: a specific constant activity

k: a specific maintenance or repairing task

$C_{j(k)}$: time to perform constant activity j on task k

$V_{i(k)}$: time to perform variable activity j on task k

x: number of units

m: total number of constant activities in task k

n: total number of variable activities in task k

Some assumptions need to be considered in the use of regression analysis. Regression model residuals have to satisfy the following:

- Constant variance
- Mean value of zero
- Be independent from one another
- Normally distributed

3.6 *Validate the proposed models*

This involved the statistical analysis of the Normality of the residuals of the regression models of each variable activity of each task. The Variances of these residuals were tested to verify its equality at each level of x.

A graphic of Calculated Times vs. Estimated Times was constructed to offer a visual comparison between both.

3.7 *Construct a database for the easy retrieval of the time estimates*

A labor standards database was designed with the models proposed in section 3.5 for each key task. The software used for this purpose was Microsoft Access®.

3.8 *Measure the productivity at the FD critical sections*

The calculation of the Performed Index (PI) was included in the Time Estimates Database. It allows the measurement of the productivity of the FD critical sections. This index takes into account the ratio of the estimated time to perform a specific task over the actual time taken to complete it. This is shown in the following equation:

$$PI = \frac{ET}{AT} * 100 \qquad \textit{(Equation 2)}$$

Where:
PI = Performance Index for a specific task
ET = Estimated Time for the specific task
AT = Actual Time for the specific task

3.9 *Improvement of data collection and reporting tools at the WO Database*

There were some areas of the Work Orders Database used by the FD that required changes to make it more effective. This was especially necessary on the reports generated by the database. Also, other minor changes requested by the FD management were implemented.

3.10 *Opportunity areas for the activities required for WO completion*

Due to the nature of the tasks performed by the FD, it was impossible to perform a detailed job analysis from observation. A questionnaire was developed and administered to the employees to gather information on the mayor obstacles faced when performing their tasks. Recommendations were given based on the results obtained.

3.11 *Closure*

Conclusions and recommendations were given after completion of the project.

Chapter 4: Results

4.1 Analysis of the tasks performed in the FD critical sections

The FD critical sections were selected by management based on their needs. The selected sections were Refrigeration, Electricity and Plumbing.

4.1.1 Refrigeration Section

The refrigeration section is in charge of the maintenance of air conditioners at UPRM and other equipment used for refrigeration purposes.

Based on the work orders generated for this section, the main tasks performed by the personnel at the refrigeration section are:

a. Repair of A/Cs
b. Cleaning of A/C Filters
c. Repair of Water Fountains
d. Repair of Extractors

4.1.1.1 Repairing of A/Cs

Tasks performed on the repairing of A/Cs were analyzed from the information gathered by the employees. The work orders for the repairing of A/Cs involve four activities as follows:

- Initial Visit: The employees visit the area to gain information about the amount of A/Cs to be repaired and the tools or equipment required.
- Repairing of an A/C unit: Involves the activity of repairing the A/C
- Documentation: Includes the recording of the activities in the order form.

- ❖ Revision by Supervisor: Total time elapsed from the completion of the order to the verification and approval by the supervisor.

These activities were classified into productive, avoidable and unavoidable.

Table 1: Classification of the Repairing of A/Cs Activities

Activity Description	**Classification (Productive, NP-Avoidable, NP-Unavoidable)**	**Constant or Variable**
Initial Visit	A	Not to be considered
Repairing of A/Cs	P	V
Documentation	UA	C
Revision by Supervisor	UA	C

The initial visit is classified as an avoidable activity (A) because usually the employees that will be completing the task know beforehand the number of A/C units to be repaired. The documentation and the revision by the supervisor are unavoidable activities (UA) required for the completion of the task. Repair of A/Cs is the only productive (P) activity because it is the only activity that actually adds value to the task.

The unavoidable activities were classified as constant (C), those not dependent on the amount of units in the work order. The productive activity was classified as variable (V), since it is dependent on the amount of units in the work order.

To compute an estimate of time for the repair of A/Cs, the weighted average of the times of the constant activities (C) was obtained. The original data is given in Table 17. Table 1 summarizes the information of the activities identified in the repair of A/Cs task.

Table 2: Summary of Activities for Repairing of A/Cs Task

Activities	Time to Document	Revision by Supervisor
Standard Deviation=	1.498	5.059
Average=	10.083	7.409

Total Average=	17.492

On the other hand, the times of the variable activity were used to compute a regression model. After considering different regression models which included linear, quadratic and cubic models, the one that best described the behavior of the data is:

$$y = 13.68 + 41.56\,x + 9.641\,x^2 \qquad \textit{(Equation 3)}$$

Where:

y: The estimated time for the repairing of A/Cs activity

x: The amount of A/Cs

The Analysis of Variance (ANOVA) yielded the following results:

```
S = 19.9372   R-Sq = 77.8%   R-Sq(adj) = 77.7%


Analysis of Variance

Source       DF      SS      MS       F      P
Regression    2  415199  207599  522.28  0.000
Error       298  118452     397
Total       300  533651
```

Figure 2: Analysis of Variance for the Repairing of A/Cs Activity

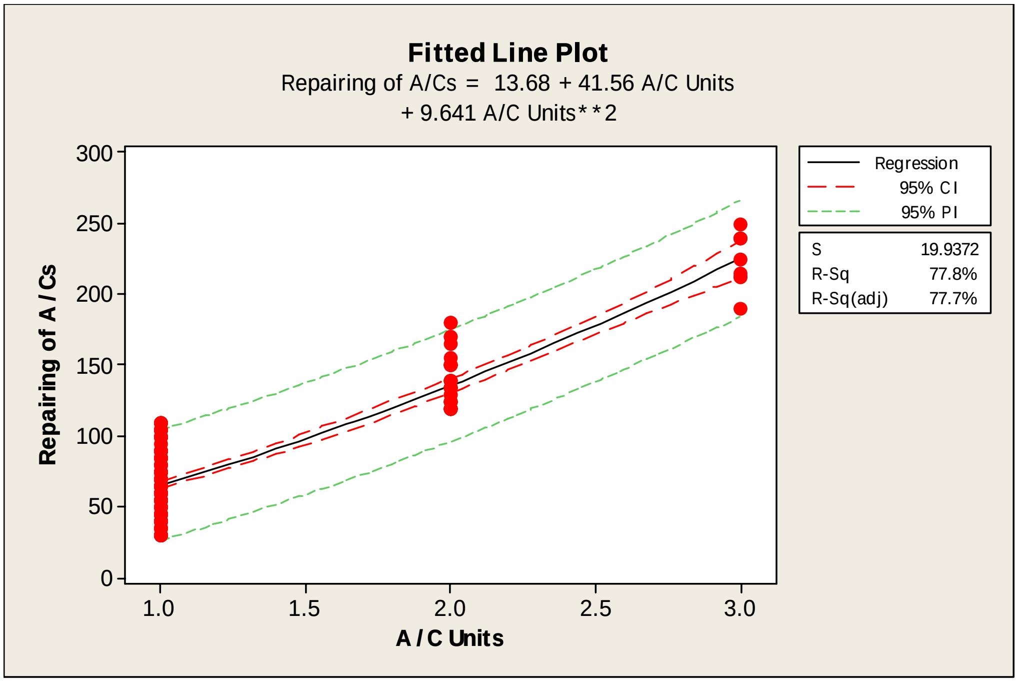

Figure 3: Regression Model for the Repairing of A/Cs Activity

The regression model has a determination coefficient of 77.8%. An analysis of residuals is presented in Figure 4 and Figure 5.

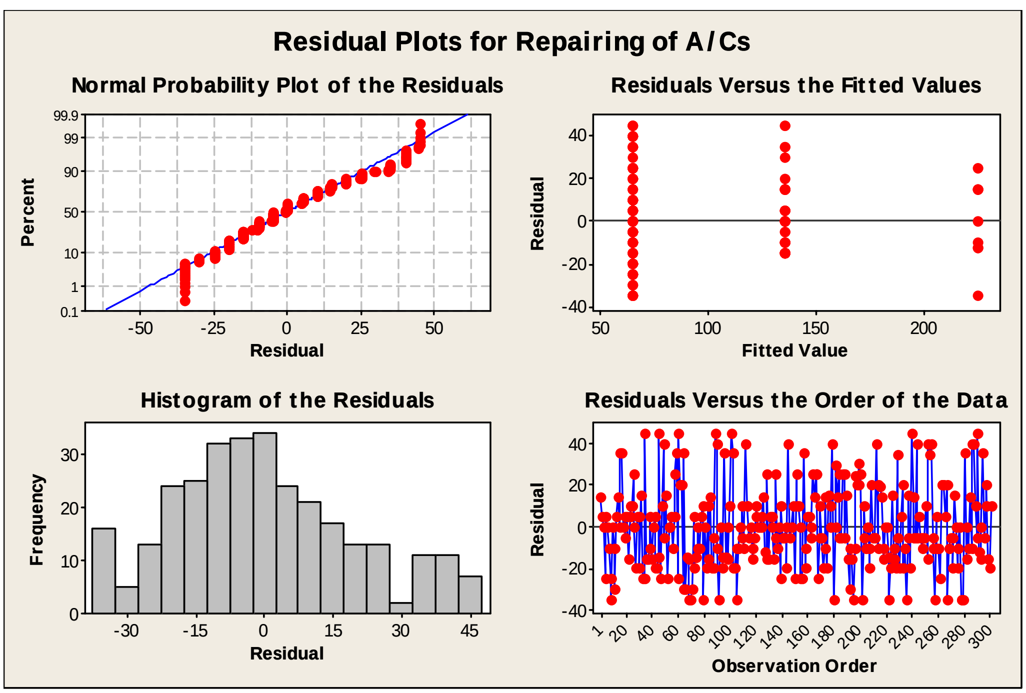

Figure 4: Residual Plots for the Repairing of A/Cs Activity

The analysis for normality in residuals is based on a Normal Probability Plot and a histogram. A Kolmogorov-Smirnov test was also performed to test the assumption of normality in residuals. Results for this test are shown in Figure 5.

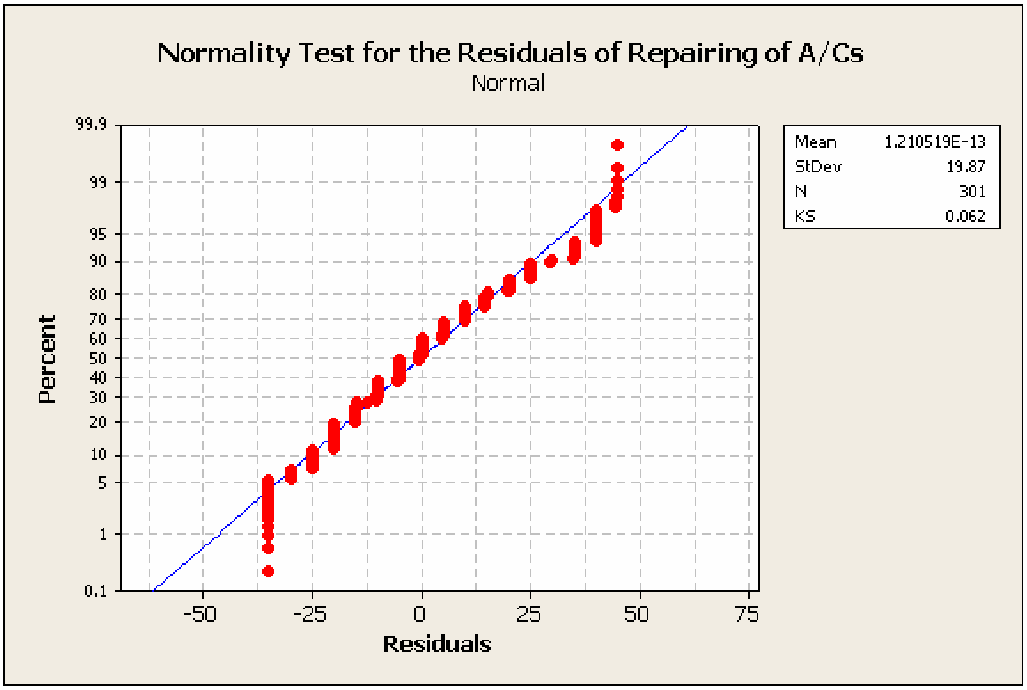

Figure 5: Normality Test for the Residuals of Repairing of A/Cs Activity

The critical value for the Kolmogorov-Smirnov Statistic is compared to the calculated value from the model's residuals. The critical value for a confidence level of 95% and a sample size of n=301 is $1.22/\sqrt{301}$, yielding a value of 0.07032. The calculated value of 0.062 does not exceed the critical value. Therefore, there is no evidence to reject the hypothesis of normality of residuals.

The analysis for constant variance was based on a plot of residuals versus fitted value, a Bartlett's and a Levene's test. The plot of residuals versus fitted values is presented in Figure 4. Results on the Bartlett's and Levene's test are presented in Figure 6.

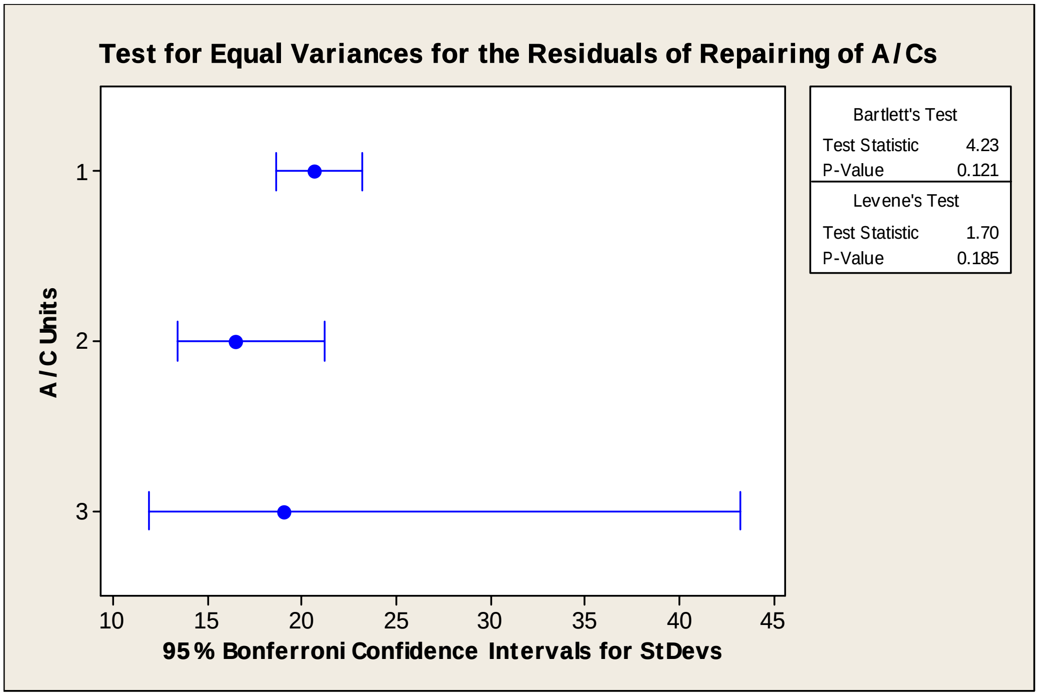

Figure 6: Test for Equal Variances for the Residuals of Repairing of A/Cs Activity

The p-value on the Bartlett's as well as the Levene's test show there is no evidence to reject the hypothesis of equal variance of residuals at all possible values of x.

Based on the previous tests, it can be concluded that the model for the estimation or prediction of the total time needed to the repairing of A/Cs gives appropriate time estimates. The resulting model considering the constant as well as the variable time activities is as follows:

$$y = 17.492 + (13.68 + 41.56\,x + 9.641\,x^2) \qquad \textit{(Equation 4)}$$

A graphical comparison between the Calculated and the Observed Times for the last 100 Work Orders of the Repairing of A/Cs task is presented in Figure 7.

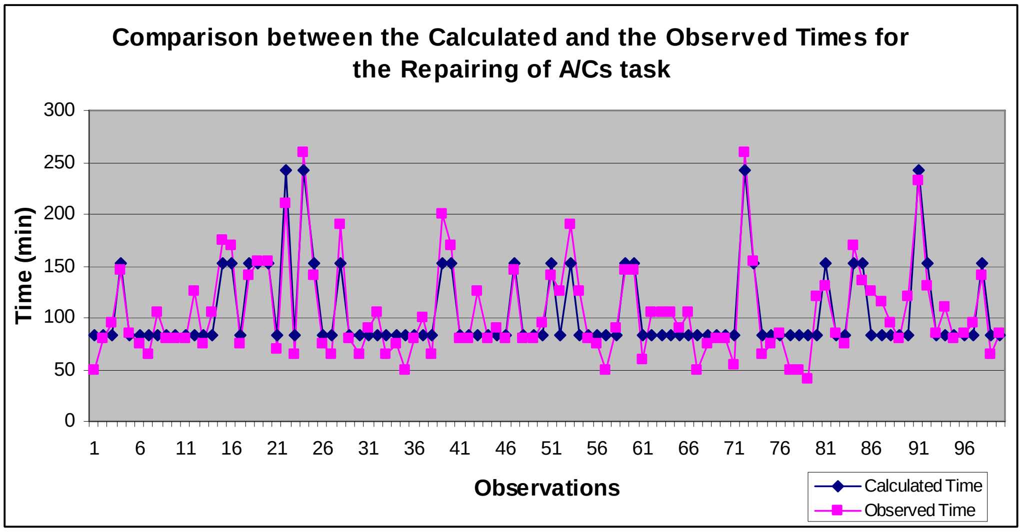

Figure 7: Calculated vs. Observed Time for the Repairing of A/Cs Task

4.1.1.2 Cleaning of A/C Filters

The information gathered from the work orders for the cleaning of A/C Filters shows it involves the following four activities:

- Initial Visit: The employees visit the area to gain information on the amount of A/C filters to be cleaned and the tools or equipment required.
- Cleaning of A/C Filters: Involves the activity of cleaning the A/C filter
- Documentation: Includes the recording of the activities in the order form.
- Revision by Supervisor: Total time elapsed from the completion of the order to the verification and approval by the supervisor.

These activities were classified into productive, avoidable and unavoidable.

Table 3: Classification of the Cleaning of A/C Filters Activities

Activity Description	Classification (Productive, Avoidable, Unavoidable)	Constant or Variable
Initial Visit	A	Not to be considered
Cleaning of A/C Filters	P	V
Documentation	UA	C
Revision by Supervisor	UA	C

The initial visit is classified as an avoidable activity (A) because usually the employees know before hand the number of A/C filters to be cleaned. The documentation and the revision by supervisor are unavoidable activities (UA) that are required for the completion of the task. Cleaning of A/C Filters is the only productive (P) activity because it is the only activity that actually adds value to the task.

The unavoidable activities were classified as constant (C) and the productive activity was classified as variable (V).

To estimate a time for the cleaning of A/C Filters, the weighted average of the times of constant activities (C) was obtained. The original data is given in Table 18. Table 4 summarizes the information of the activities identified in the cleaning of A/C Filters:

Table 4: Summary of Activities for the Cleaning of A/C Filters Task

Activities	Time to Document	Revision by Supervisor
Standard Deviation=	1.316	4.493
Average=	10.370	7.870

Total Average=	18.24

On the other hand, the times of the variable activities were used to develop a regression model. After considering different regression models which included linear, quadratic and cubic models, the best fit was obtained through the following model:

$$y = -19.68 + 77.35\,x - 5.399\,x^2 \qquad \textit{(Equation 5)}$$

Where:
y: The estimated time for the cleaning of A/C Filters activity
x: The amount of A/C filters

An analysis of variance (ANOVA) gave the following results:

```
S = 13.6110   R-Sq = 85.6%   R-Sq(adj) = 85.3%


Analysis of Variance

Source       DF      SS       MS       F      P
Regression    2  115365  57682.3  311.36  0.000
Error       105   19452    185.3
Total       107  134817
```

Figure 8: Analysis of Variance for the Cleaning of A/C Filters Activity

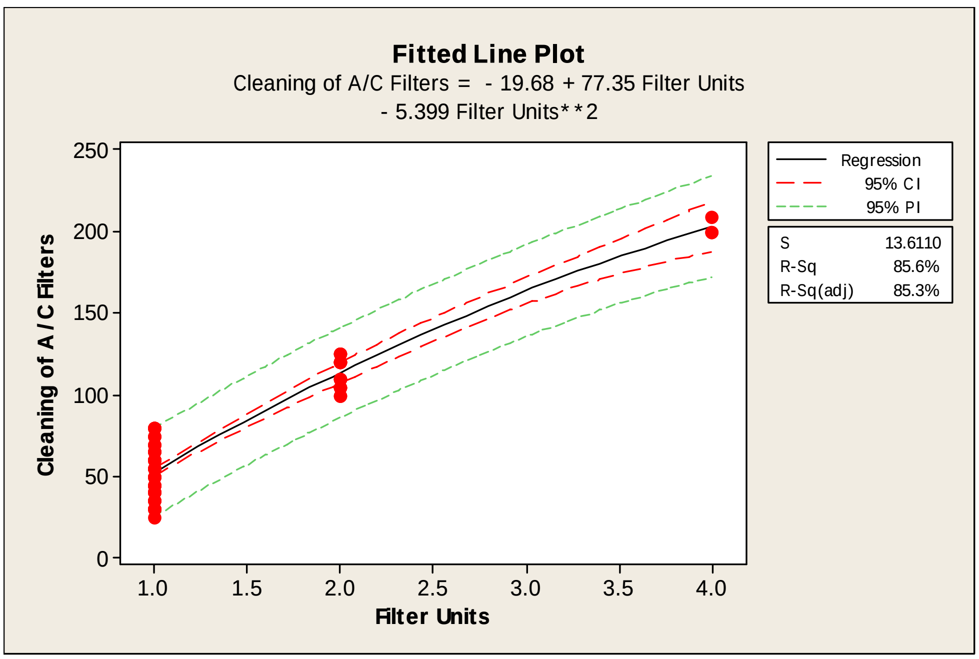

Figure 9: Regression Model for the Cleaning of A/C Filters Activity

The regression model has a determination coefficient of 85.6%. An analysis of residuals is presented in Figure 10 and Figure 11.

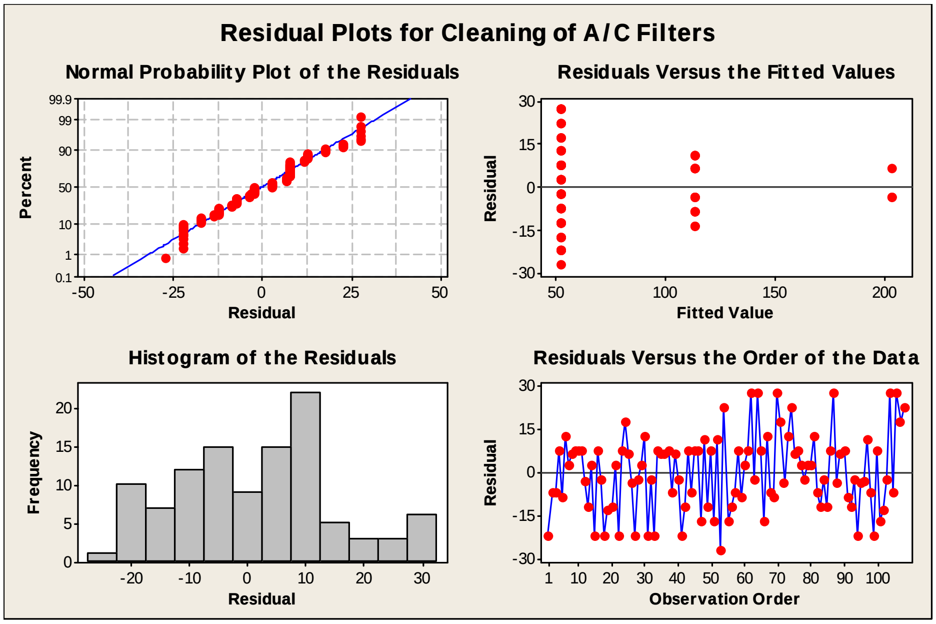

Figure 10: Residual Plots for Cleaning of A/C Filters Activity

The analysis for normality in residuals is based on a Normal Probability Plot and a histogram. A Kolmogorov-Smirnov test was also performed to test the assumption of normality in residuals. Results are shown in Figure 11.

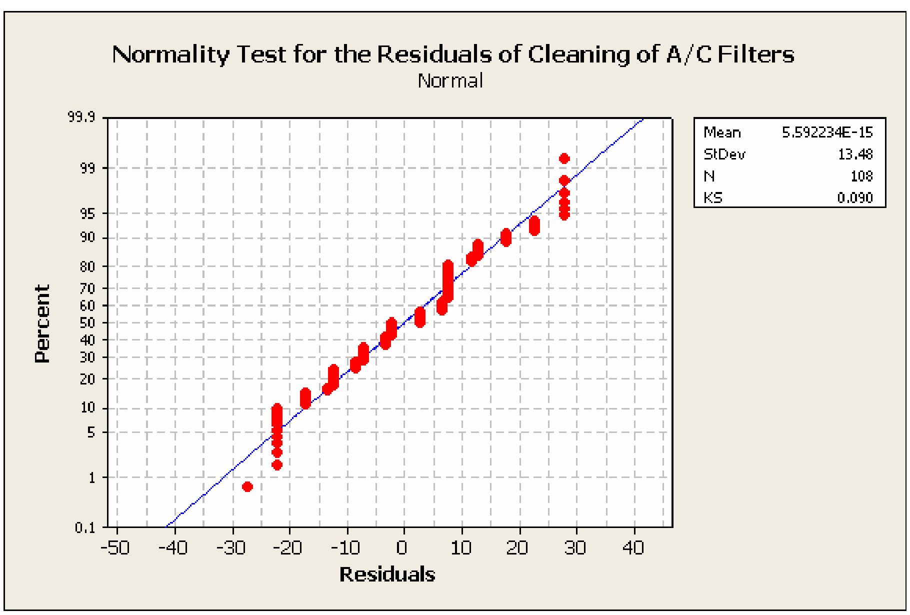

Figure 11: Normality Test for the Residuals of Cleaning of A/C Filters Activity

The critical value for the Kolmogorov-Smirnov Statistic is compared to the calculated value from the model's residuals. The critical value for a confidence level of 95% and a sample size of n=108 is $1.22/\sqrt{108}$, yielding a value of 0.1174. The calculated value of 0.090 does not exceed the critical value. Therefore, there is no evidence to reject the hypothesis of normality of residuals.

The analysis for constant variance was based on a plot of residuals versus fitted values, a Bartlett's and a Levene's test. The plot of residuals versus fitted values is presented in Figure 10. Results on the Bartlett's and Levene's test are presented in Figure 12.

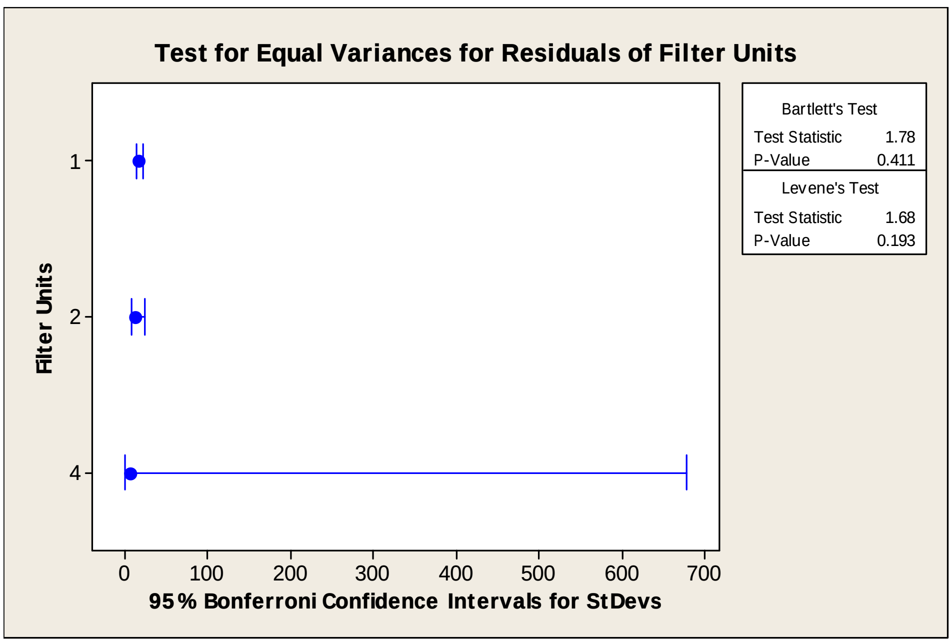

Figure 12: Test for Equal Variances for the Residuals of Cleaning of A/C Filters Activity

The p-value on the Bartlett's as well as the Levene's test show there is no evidence to reject the hypothesis of equal variance of residuals at all possible values of x.

Based on the previous tests the model for the estimation or prediction of the total time needed for the cleaning of A/C Filters considering the constant as well as variable activities is as follows:

$$y = 18.24 + (-19.68 + 77.35\,x - 5.399\,x^2) \qquad \textit{(Equation 6)}$$

A graphical comparison between the Calculated and the Observed Times for the last 100 Work Orders of the task of Cleaning of A/C Filters is presented in Figure 13.

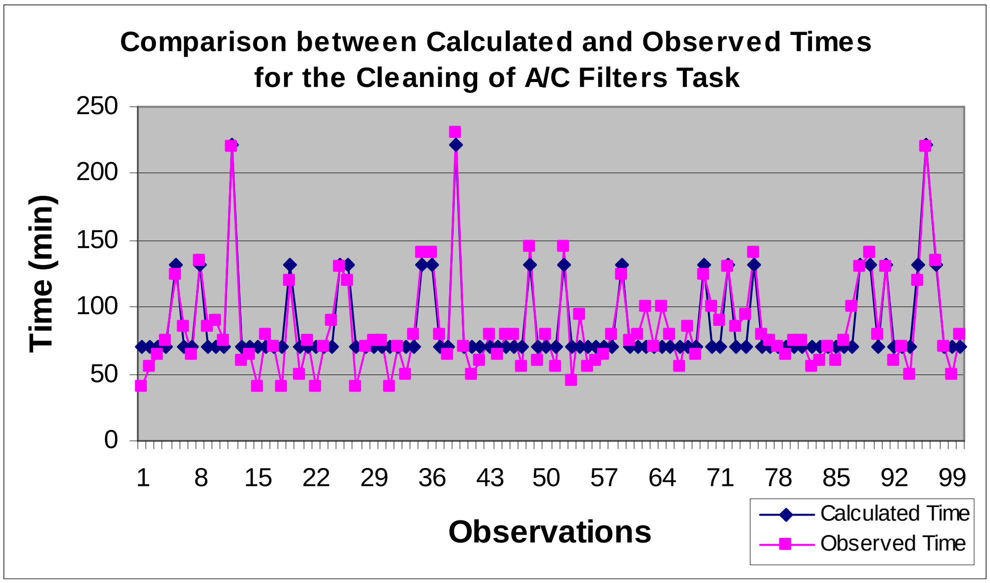

Figure 13: Calculated vs. Observed Time for the Cleaning of A/C Filters Task

4.1.1.3 Repairing of Water Fountains (WF)

Information gathered from the work orders for the Repairing of Water Fountains shows there are four activities involved as follows:

- ❖ Initial Visit: The employees visit the area to gain information about the amount of water fountains to be repaired and the tools or equipment required.
- ❖ Repairing of Water Fountains: Involves the activity of repairing the water fountains
- ❖ Documentation: Includes the recording of the activities in the order form.
- ❖ Revision by Supervisor: Total time elapsed from the completion of the order to the verification and approval by the supervisor.

These activities were classified into productive, avoidable and unavoidable.

Table 5: Classification of the Repairing of WF Activities

Activity Description	**Classification (Productive, Avoidable, Unavoidable)**	**Constant or Variable**
Initial Visit	A	Not to be considered
Repairing of Water Fountains	P	V
Documentation	UA	C
Revision by Supervisor	UA	C

The initial visit is classified as an avoidable activity (A) because usually the employees that will be completing the task know beforehand the number of water fountains to be repaired. The documentation and the revision by supervisor are unavoidable activities (UA) that are required for the completion of the task. Repairing of Water Fountains is the only productive (P) activity because is the only activity that actually adds value to the task.

The unavoidable activities were classified as constant (C) and the productive activity was classified as variable (V).

To estimate the time required for the Repairing of Water Fountains task the weighted average of the times of the constant activities (C) was obtained. The original data is given in Table 19. The following table summarizes the information of the activities identified in the Repairing of Water Fountains task:

Table 6: Summary of Activities for the Repairing of WF Task

Activities	Time to Document	Revision by Supervisor
Standard Deviation=	1.772	4.998
Average=	10.435	6.957

Total Average=	17.392

On the other hand, the times of the variable activities were used to compute a regression model. After considering different regression models which included linear, quadratic and cubic models, the model that best describes the behavior of the given data is:

$$y = 27.71 + 11.60\,x + 18.06\,x^2 \qquad \textit{(Equation 7)}$$

Where:

y: The estimated time for the repairing of Water Fountains activity

x: The amount of water fountains

The Analysis of Variance (ANOVA) yielded the following results:

```
S = 22.4560   R-Sq = 77.8%   R-Sq(adj) = 76.8%


Analysis of Variance

Source      DF       SS       MS      F      P
Regression   2  76175.6  38087.8  75.53  0.000
Error       43  21683.7    504.3
Total       45  97859.2
```

Figure 14: Analysis of Variance for the Repairing of WF Activity

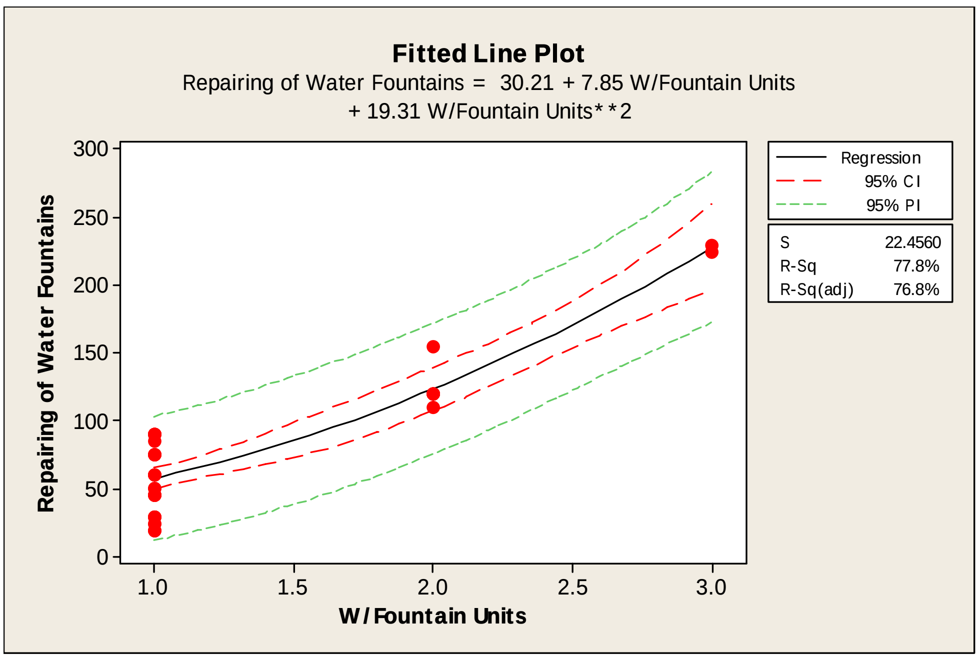

Figure 15: Regression Model for the Repairing of WF Activity

The regression model has a determination coefficient of 77.8 %. An analysis of residuals is presented in Figure 16 and Figure 17.

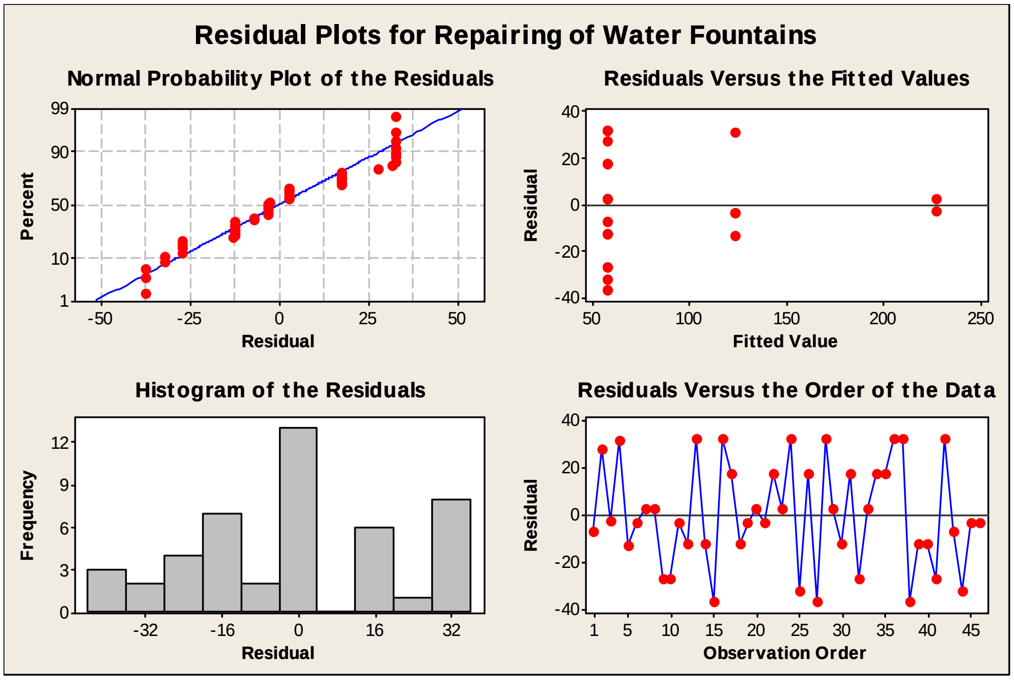

Figure 16: Residual Plots for the Repairing of WF Activity

The analysis for normality in residuals is based on a Normal Probability Plot and a histogram. A Kolmogorov-Smirnov test was also performed to test the assumption of normality in residuals. Results are shown in Figure 17.

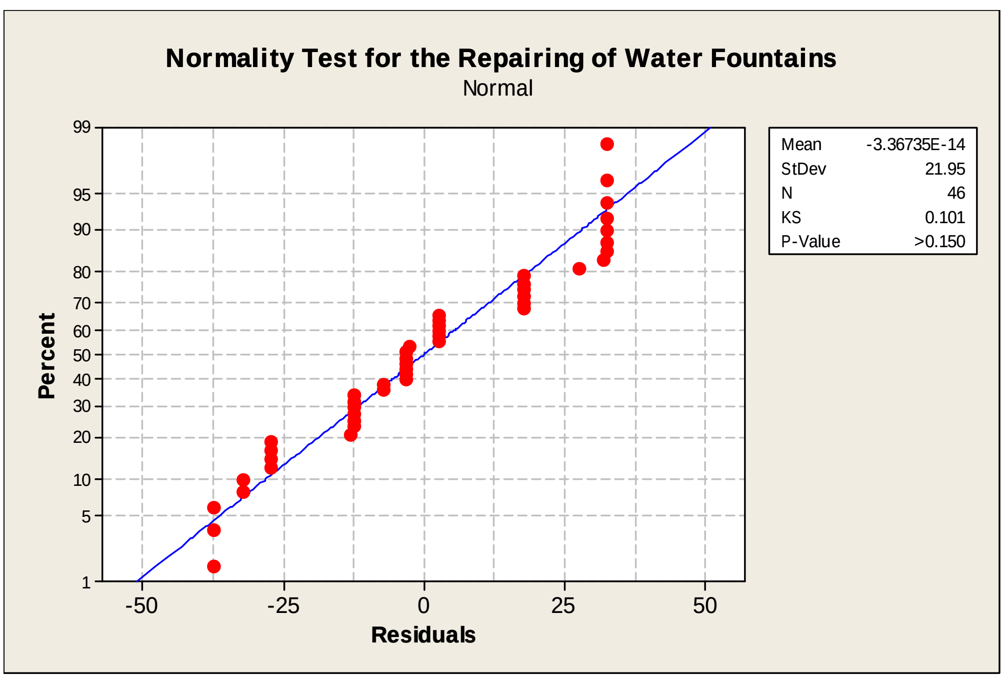

Figure 17: Normality Test for the Residuals of Repairing of WF Activity

The critical value for the Kolmogorov-Smirnov Statistic is compared to the calculated value from the model's residuals. The critical value for a confidence level of 95% and a sample size of n=46 is $1.22/\sqrt{46}$, yielding a value of 0.1799. The calculated value of 0.101 does not exceed the critical value. Therefore, there is no evidence to reject the hypothesis of normality of residuals.

The analysis for constant variance was based on a plot of residuals versus fitted value, a Bartlett's and a Levene's test. The plot of residuals versus fitted values is presented in Figure 16. Results on the Bartlett's and Levene's test are presented in Figure 18.

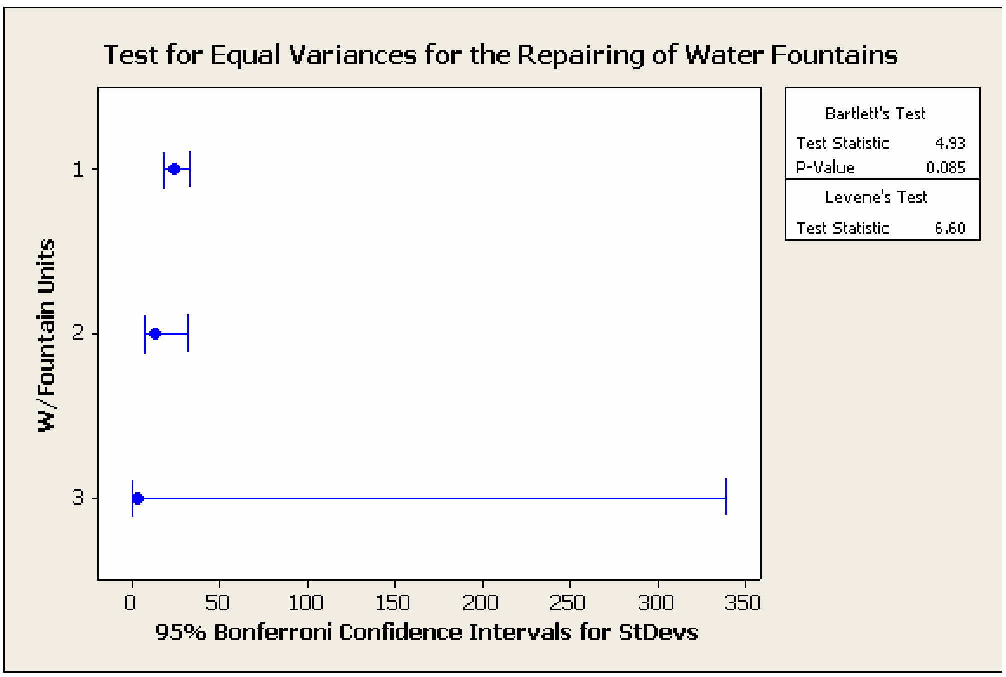

Figure 18: Test for Equal Variances for the Residuals of Repairing of WF Activity

The p-value on the Bartlett's test show there is no evidence to reject the hypothesis of equal variance of residuals at all possible values of x.

Based on the previous tests the model for the estimation or prediction of the total time needed for the Repairing of Water Fountains considering the constant as well as the variable activities is as follows:

$$y = 17.392 + (27.71 + 11.60\,x + 18.06x^2) \qquad \textit{(Equation 8)}$$

A graphical comparison between the Calculated and the Observed Times for the Work Orders of the Repairing of Water Fountains task is presented in Figure 19.

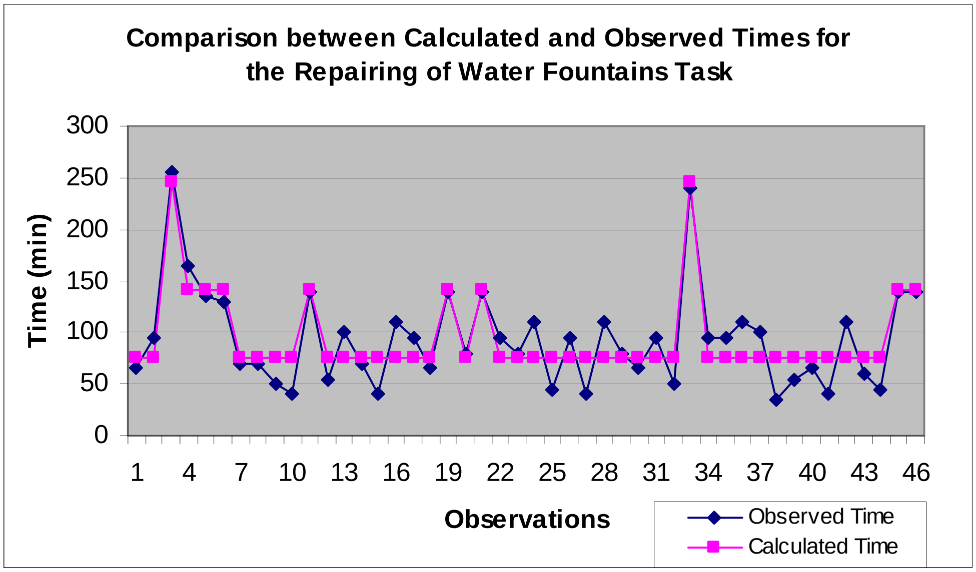

Figure 19: Calculated vs. Observed Time for the Repairing of WF Task

4.1.1.4 Repairing of Extractors

From the information on the work orders for the Repairing of Extractors, this task involves four activities as follows:

- Initial Visit: The employees visit the area to gain information about the amount of extractors to be repaired and the tools or equipment required.
- Repairing of Extractors: Involves the activity of repairing the extractors
- Documentation: Includes the recording of the activities in the order form.
- Revision by Supervisor: Total time elapsed from the completion of the order to the verification and approval by the supervisor.

These activities were classified into productive, avoidable and unavoidable.

Table 7: Classification of the Repairing of Extractors Activities

Activity Description	Classification (Productive, Avoidable, Unavoidable)	Constant or Variable
Initial Visit	A	Not to be considered
Repairing of Extractors	P	V
Documentation	UA	C
Revision by Supervisor	UA	C

The initial visit is classified as an avoidable activity (A) because usually the employees that will be completing the task know beforehand the number of extractors to be repaired. The documentation and the revision by supervisor are unavoidable activities (UA) that are required for the completion of the task. Repairing of Extractors is the only productive (P) activity because is the only activity that actually adds value to the task.

The unavoidable activities were classified as constant (C) and the productive activity was classified as variable (V) (affected by the amount of units maintain).

To compute the estimate time for the Repairing of Extractors task the weighted average of the times of the constant activities (C) was obtained. The original data is given in Table 20. The following table summarizes the information of the activities identified in the Repairing of Extractors task:

Table 8: Summary of Activities for the Repairing of Extractors Task

Activities	Time to Document	Revision by Supervisor
Standard Deviation=	3.638	5.879
Average=	9.118	7.059

Total Average=	16.177

On the other hand, the times of the variable activities were used to develop a regression model. After considering different regression models which included linear, quadratic and cubic models, the model that best describes the behavior of the given data is:

$$y = 7.00 + 61.00\,x - 7.500\,x^2 \qquad \textit{(Equation 9)}$$

Where:

y: The estimated time for the Repairing of Extractors activity

x: The amount of extractors

The Analysis of Variance (ANOVA) yielded the following results:

```
S = 11.3547   R-Sq = 83.6%   R-Sq(adj) = 81.3%


Analysis of Variance

Source      DF       SS       MS      F      P
Regression   2   9206.8  4603.38  35.70  0.000
Error       14   1805.0   128.93
Total       16  11011.8
```

Figure 20: Analysis of Variance for the Repairing of Extractors Activity

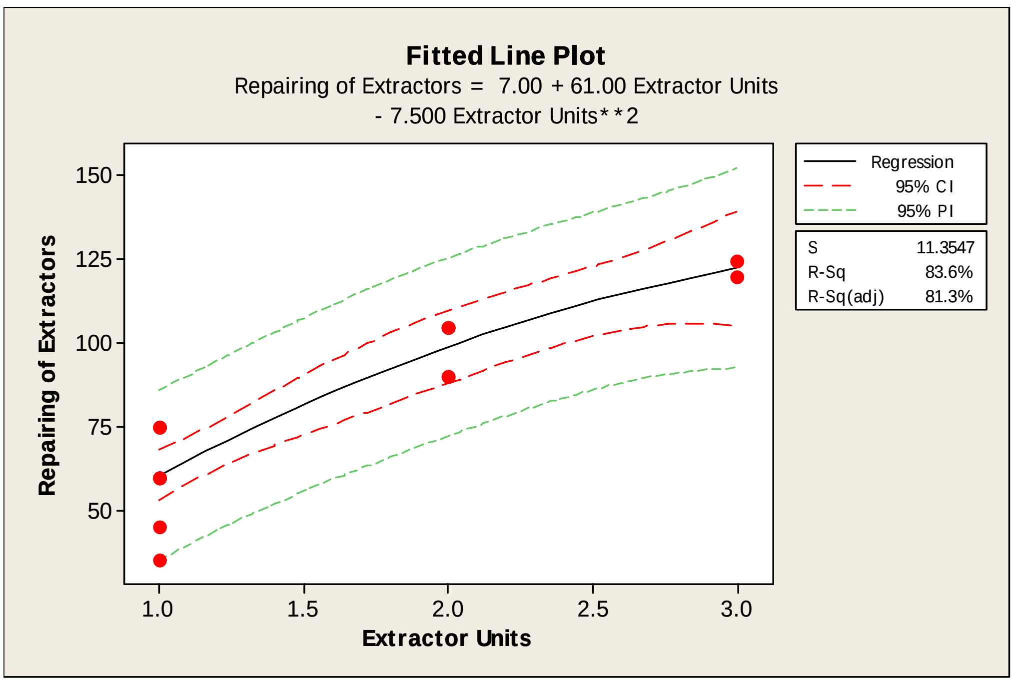

Figure 21: Regression Model for the Repairing Extractors Activity

The regression model has a determination coefficient of 83.6%. An analysis of residuals is presented in Figure 22 and Figure 23.

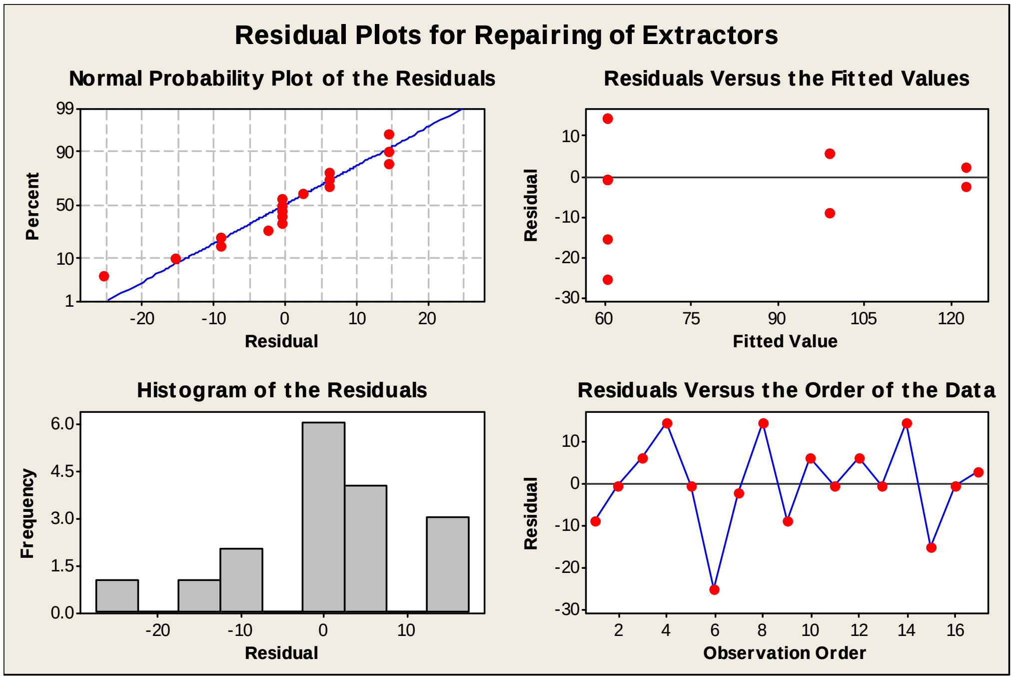

Figure 22: Residual Plots for the Repairing of Extractors Activity

The analysis for normality in residuals is based on a Normal Probability Plot and a histogram. A Kolmogorov-Smirnov test was also performed to test the assumption of normality in residuals. Results are shown in Figure 23

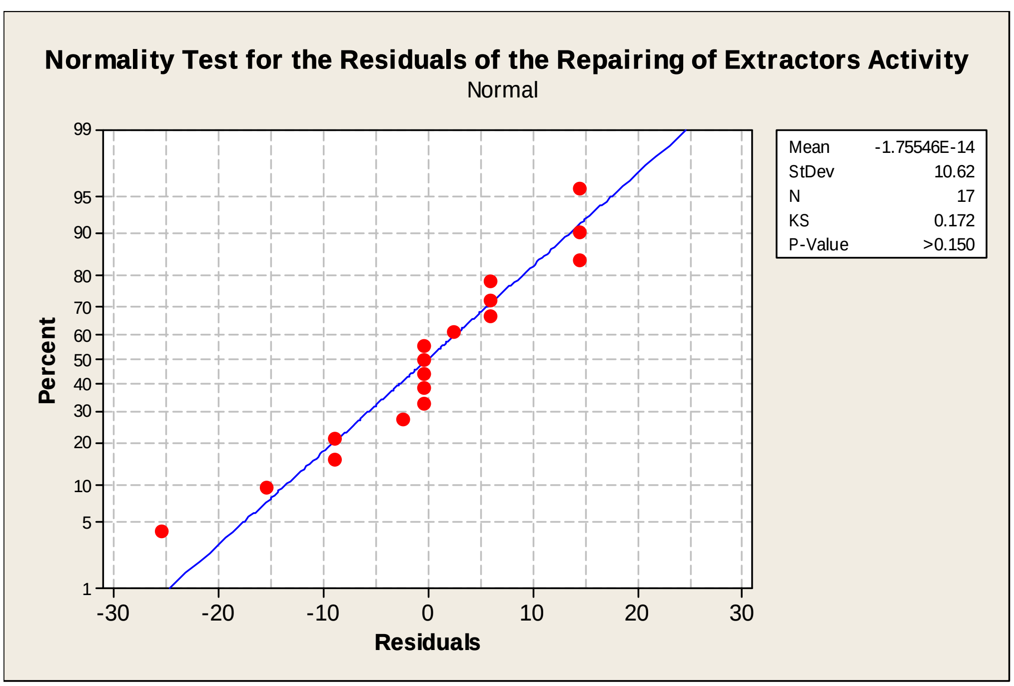

Figure 23: Normality Test for the Residuals of Repairing of Extractors Activity

The critical value for the Kolmogorov-Smirnov Statistic is compared to the calculated value from the model's residuals. The critical value for a confidence level of 95% and a sample size of n=17 is of 0.2863. The calculated value of 0.172 does not exceed the critical value. Therefore, there is no evidence to reject the hypothesis of normality of residuals.

The analysis for constant variance was based on a plot of residuals versus fitted value, an F-test and a Levene's test. The plot of residuals versus fitted values is presented in Figure 22. Results on the F-test and Levene's test are presented in Figure 24.

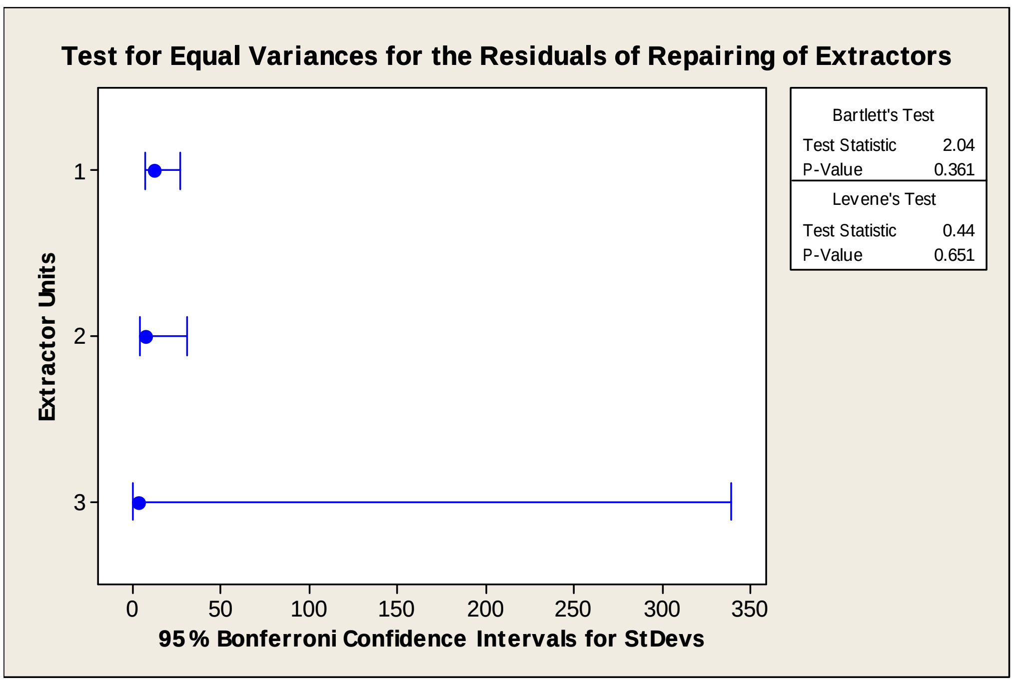

Figure 24: Test for Equal Variances for the Residuals of Repairing Extractors Activity

The p-value on the F-test as well as the Levene's test show there is no evidence to reject the hypothesis of equal variance of residuals at all possible values of x.

Based on the previous tests the model for the estimation or prediction of the total time needed for the Repairing of Extractors considering the constant as well as variable activities is as follows:

$$y = 16.177 + (7.00 + 61.00\ x - 7.500\ x^2) \qquad \textit{(Equation 10)}$$

A graphical comparison between the Calculated and the Observed Times for the Work Orders of the Repairing of Extractors task is presented in Figure 25.

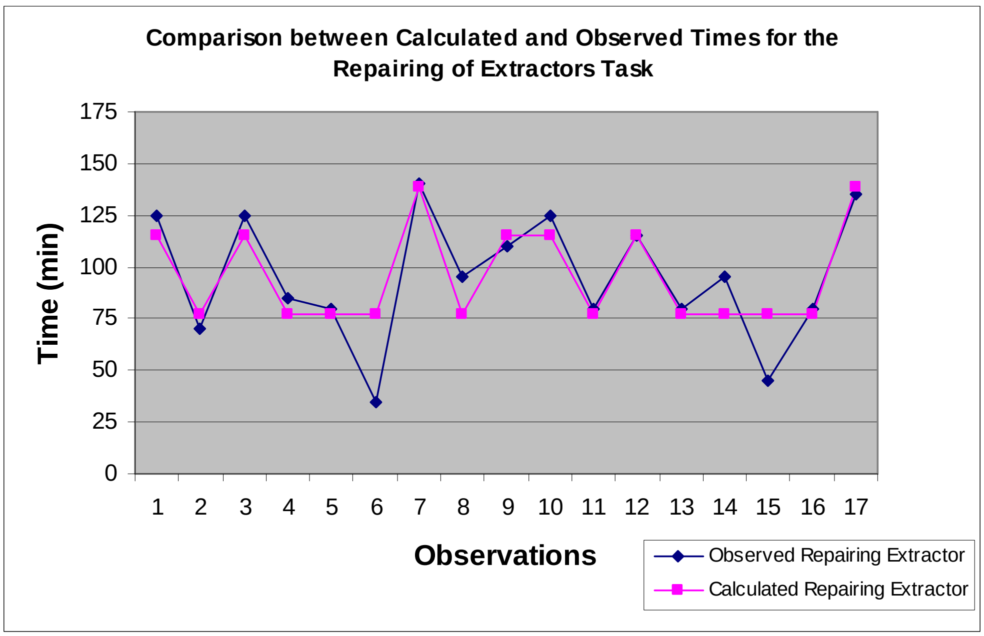

Figure 25: Calculated vs. Observed Time for the Repairing of Extractors Task

4.1.2 Electricity Section

The electricity section is in charge of the maintenance of the electricity flow in the RUM. It also includes the illumination of special activities held at the RUM.

The main tasks held by the electricity section are:

a. Installation of Fluorescent Bulbs
b. Breaker Verification / Activation

4.1.2.1 Installation of Fluorescent Tubes (FT)

From the information gathered by the employees, the work orders for the Installation of Fluorescent Tubes involve five activities as follows:

- Initial Visit: The employees visit the area to gain information about the amount of bulbs to be replaced and the tools or equipment required.
- Materials: Order and pickup at the warehouse of the bulbs and other materials needed.
- Installation of Fluorescent Tubes: Involves the activity of replacement of the tubes
- Documentation: Includes the recording of the activities in the order form.
- Revision by Supervisor: Total time elapsed from the completion of the order to the verification and approval by the supervisor.

These activities were classified into productive, avoidable and unavoidable.

Table 9: Classification of the Installation of FT Activities

Activity Description	Classification (Productive, Avoidable, Unavoidable)	Constant or Variable
Initial Visit	A	Not to be considered
Materials	UA	C
Installation of FT	P	V
Documentation	UA	C
Revision by Supervisor	UA	C

The initial visit is classified as an avoidable activity (A) because usually the employees that will be completing the task know beforehand the number of tubes to be replaced and the type of tube. The pickup of materials, the documentation and the revision by supervisor are unavoidable activities (UA) that are required for the completion of the task. The Installation of Fluorescent Tubes is the only productive (P) activity because is the only activity that actually adds value to the task.

The unavoidable activities were classified as constant (C) and the productive activity was classified as variable (V).

To compute the estimate time for the Installation of Fluorescent Tubes task the weighted average of the times of the constant activities (C) was obtained. The original data is given in Table 21. The following table summarizes the information of the activities identified in the installation of fluorescent tubes task:

Table 10: Summary of Activities for the Installation of FT Task

Activities	Materials	Time to Document	Revision by Supervisor
Standard Deviation=	14.86	6.868	18.41
Average=	20.00	12.377	23.44

Total Average= 55.817

On the other hand, the times of the variable activities were used to compute a regression model. After considering different regression models which included linear, quadratic and cubic models, the model that best describes the behavior of the given data is:

$$y = 48.53 - 9.652x + 0.9626x^2 - 0.02040\,x^3 \qquad \textit{(Equation 11)}$$

Where:

y: The estimated time for the Installation of FT activity

x: The amount of fluorescent tubes

The Analysis of Variance (ANOVA) yielded the following results:

```
S = 10.1583   R-Sq = 83.0%   R-Sq(adj) = 82.1%


Analysis of Variance

Source      DF       SS       MS      F      P
Regression   3  28750.9  9583.62  92.87  0.000
Error       57   5881.9   103.19
Total       60  34632.8
```

Figure 26: Analysis of Variance for the Installation of FT Activity

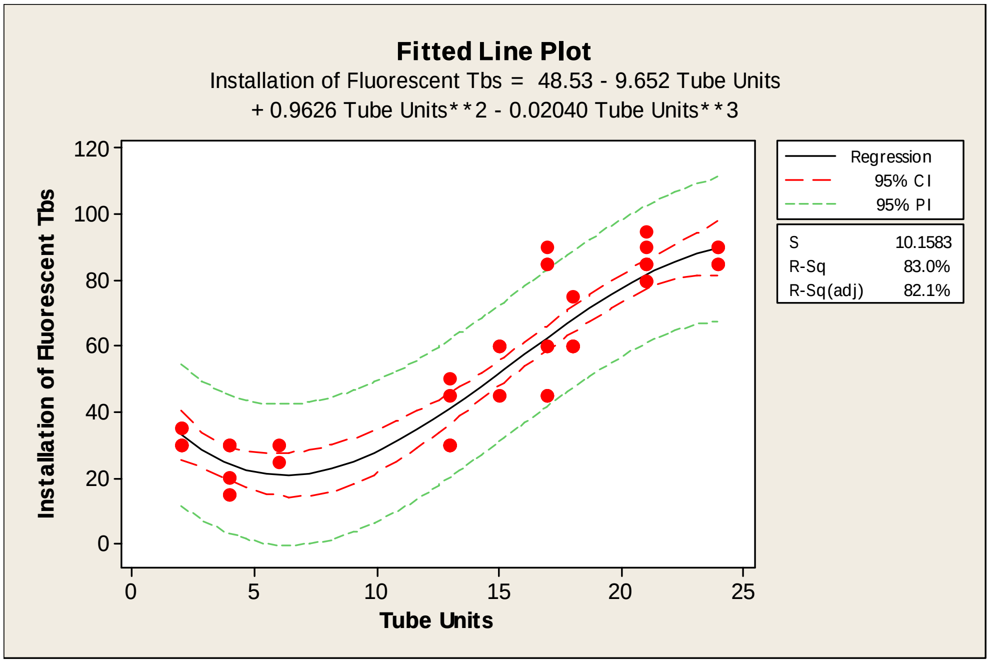

Figure 27: Regression Model for the Installation of FT Activity

The regression model has a determination coefficient of 83.0%. An analysis of residuals is presented in Figure 28 and Figure 29.

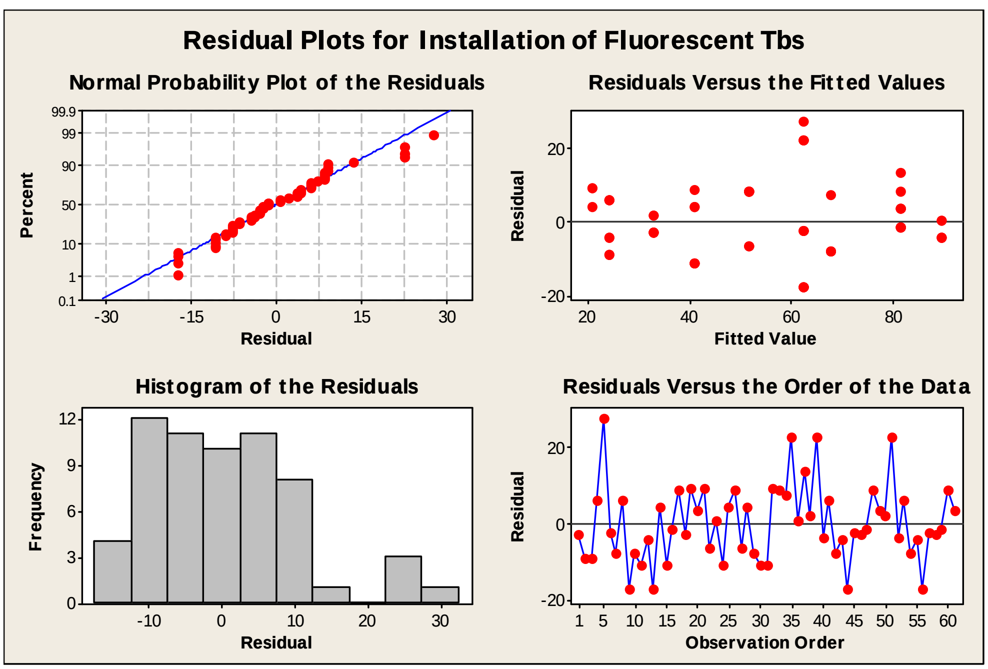

Figure 28: Residual Plots for the Installation of FT Activity

The analysis for normality in residuals is based on a Normal Probability Plot and a histogram. A Kolmogorov-Smirnov test was also performed to test the assumption of normality in residuals. Results are shown in Figure 29.

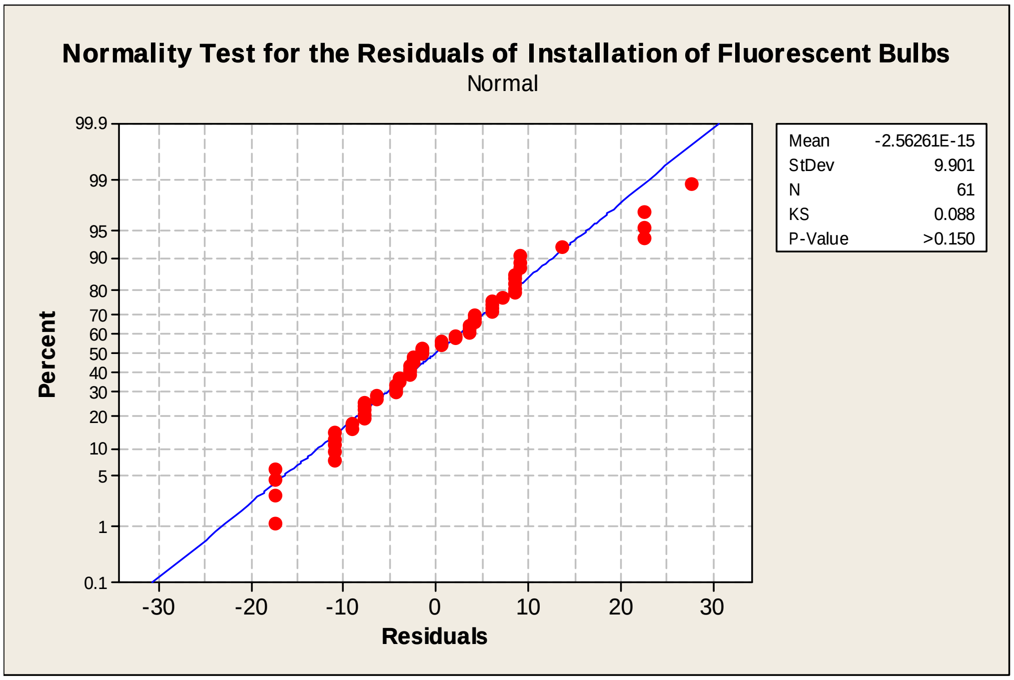

Figure 29: Normality Test for the Residuals of the Installation of FT Activity

The critical value for the Kolmogorov-Smirnov Statistic is compared to the calculated value from the model's residuals. The critical value for a confidence level of 95% and a sample size of n=61 is 0.1562. The calculated value of 0.088 does not exceed the critical value. Therefore, there is no evidence to reject the hypothesis of normality of residuals.

The analysis for constant variance was based on a plot of residuals versus fitted value, a Bartlett's and a Levene's test. The plot of residuals versus fitted values is presented in Figure 28. Results on the Bartlett's and Levene's test are presented in Figure 30.

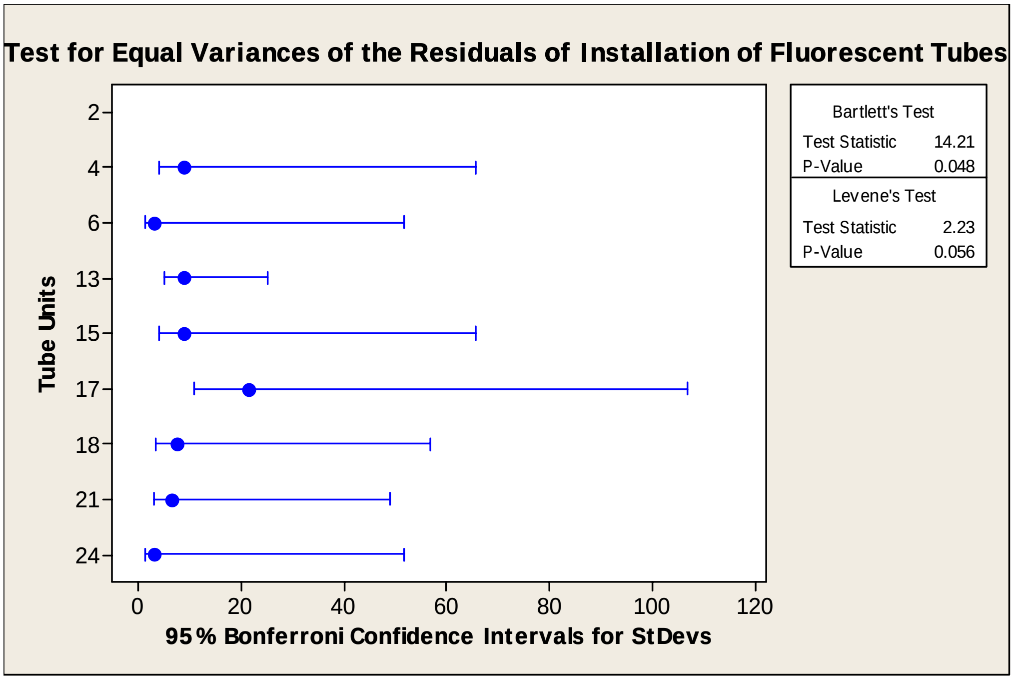

Figure 30: Test for Equal Variances for the Residuals of Installation of FT Activity

Although the p-value on the Bartlett's test shows to be slightly smaller than α of 0.05, the p-value on the Levene's test shows no evidence to reject the hypothesis of equal variance of residuals at all possible values of x. Levene's test is not as sensitive to departures from the normality of residuals.

Based on the previous tests the model for the estimation or prediction of the total time needed for the Installation of FT considering the constant as well as the variable activities is as follows:

$$y = 55.817 + (48.53 - 9.652x + 0.9626x^2 - 0.02040x^3) \qquad \textit{(Equation 12)}$$

A graphical comparison between the Calculated and the Observed Times for the Work Orders of the Installation of FT task is presented in Figure 31.

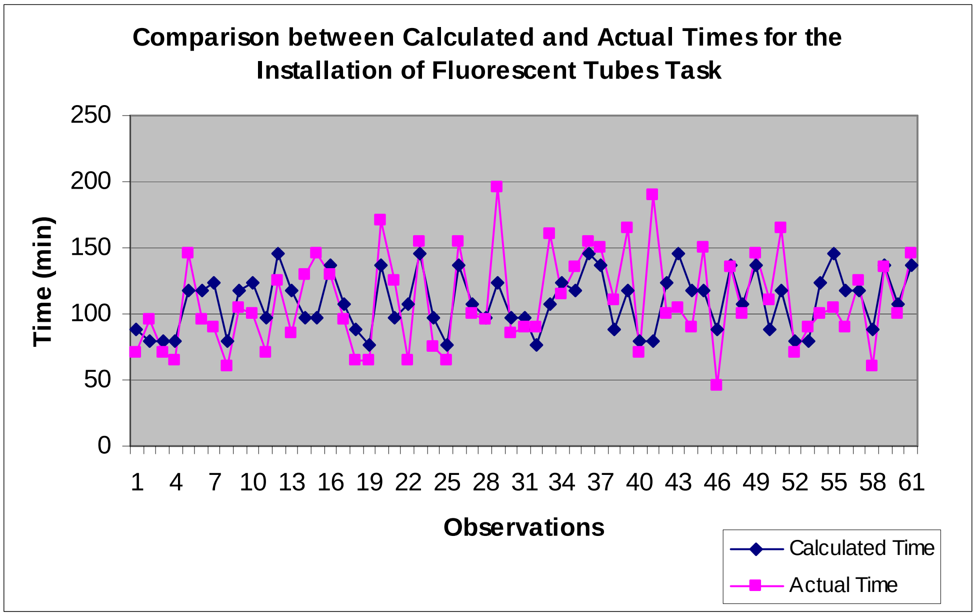

Figure 31: Calculated vs. Observed Time for the Installation of FT Task

4.1.2.2 Breaker Verification / Activation (V/A)

The work orders for the Breaker Verification/Activation involve five activities as follows:

- ❖ Initial Visit: The employees visit the area to gain information about the amount of breakers to be verified and the tools or equipment required.
- ❖ Materials: Order and pickup at the warehouse of the materials needed.
- ❖ Breaker V/A: Involves the activity of verification and activation of breakers
- ❖ Documentation: Includes the recording of the activities in the order form.
- ❖ Revision by Supervisor: Total time elapsed from the completion of the order to the verification and approval by the supervisor.

.

These activities were classified into productive, avoidable and unavoidable.

Table 11: Classification of the Breaker V/A Activities

Activity Description	Classification (Productive, Avoidable, Unavoidable)	Constant or Variable
Initial Visit	A	Not to be considered
Materials	UA	C
Breaker Verification/Activation	P	V
Documentation	UA	C
Revision by Supervisor	UA	C

The initial visit is classified as an avoidable activity (A) because usually the employees that will be completing the task know beforehand the number of breakers to be maintained. The pickup of materials, the documentation and the revision by supervisor are unavoidable activities (UA) that are required for the completion of the task. The Breaker V/A is the only productive (P) activity because is the only activity that actually adds value to the task.

The unavoidable activities were classified as constant (C) (are not affected by the amount of units in the work order) and the productive activity was classified as variable (V) (affected by the amount of units in the work order).

To compute the estimate time for the Breaker Verification/Activation task the weighted average of the times of the constant activities (C) was obtained. The original data is given in Table 22. The following table summarizes the information of the activities identified in breaker verification/activation task:

Table 12: Summary of Activities for Breaker V/A Task

Activities	Materials	Time to Document	Revision by Supervisor
Standard Deviation=	10.957	2.812	13.270
Average=	7.174	9.783	24.783

Total Average= 41.74

On the other hand, the times of the variable activities were used to compute a regression model. After considering different regression models which included linear, quadratic and cubic models, the model that best describes the behavior of the given data is:

$$y = 0.476 + 48.10\,x \qquad \textit{(Equation 13)}$$

Where:

y: The estimated time for the Breaker Verification/Activation activity

x: The amount of breakers

The Analysis of Variance (ANOVA) yielded the following results:

```
S = 15.3086   R-Sq = 72.0%   R-Sq(adj) = 70.7%


Analysis of Variance

Source      DF       SS       MS      F      P
Regression   1  12672.0  12672.0  54.07  0.000
Error       21   4921.4    234.4
Total       22  17593.5
```

Figure 32: Analysis of Variance for the Breaker V/A Activity

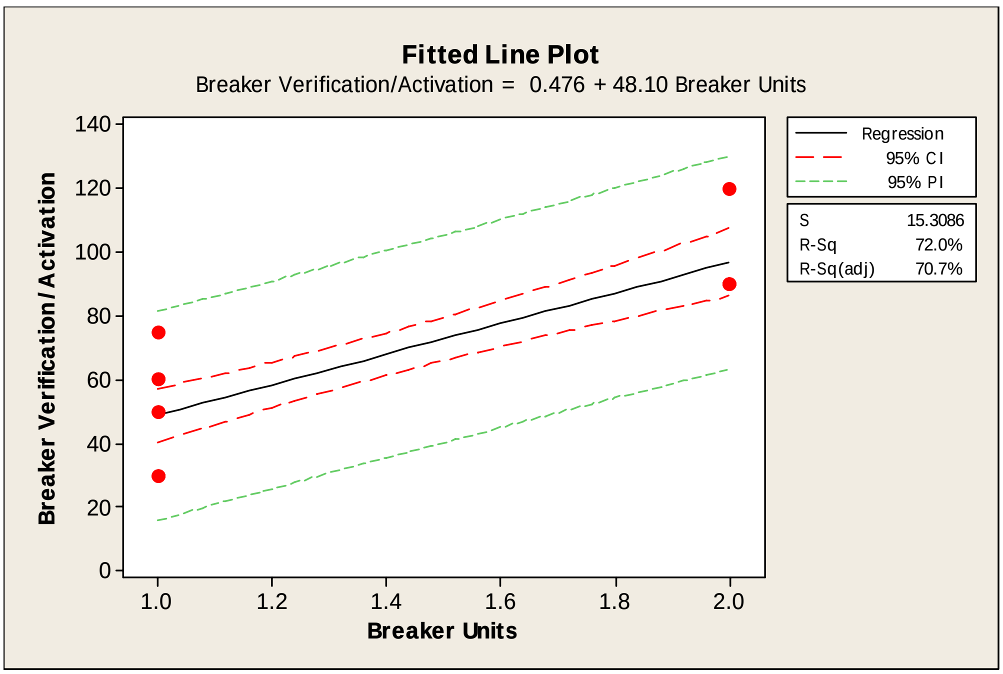

Figure 33: Regression Model for the Breaker V/A Activity

The regression model has a determination coefficient of 72.0%. An analysis of residuals is presented in Figure 34 and Figure 35.

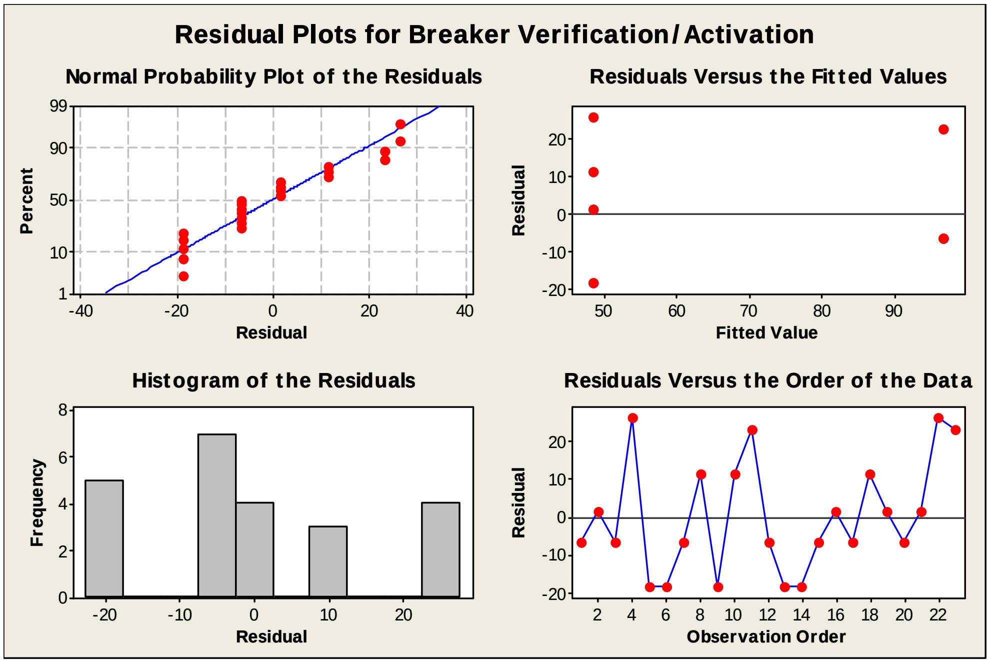

Figure 34: Residual Plots for the Breaker V/A Activity

The analysis for normality in residuals is based on a Normal Probability Plot and a histogram. A Kolmogorov-Smirnov test was also performed to test the assumption of normality in residuals. Results are shown in Figure 35.

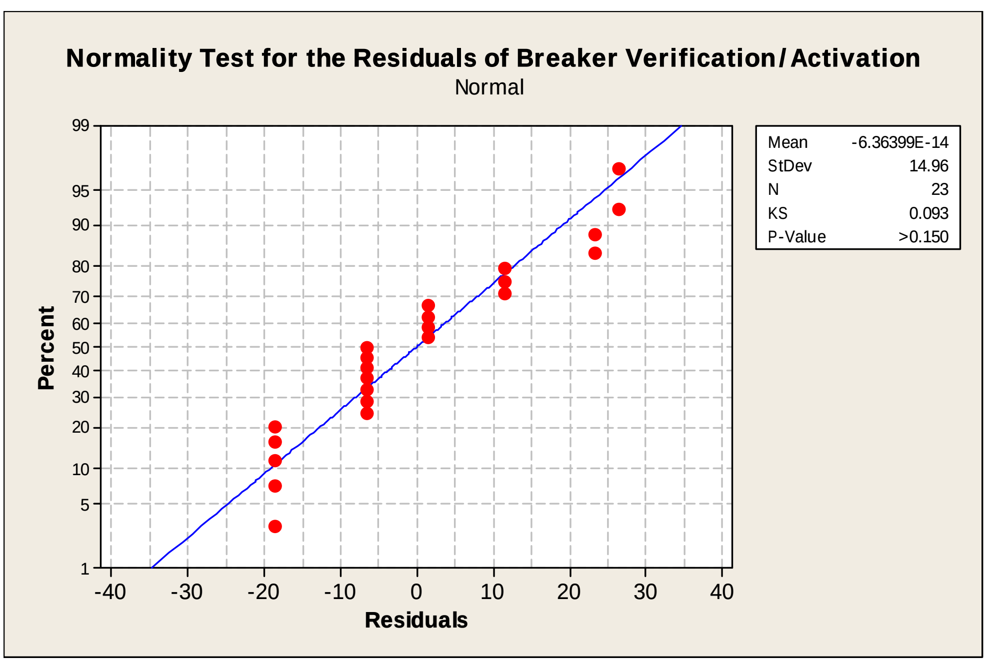

Figure 35: Normality Test of the Residuals of Breaker V/A Activity

The critical value for the Kolmogorov-Smirnov Statistic is compared to the calculated value from the model's residuals. The critical value for a confidence level of 95% and a sample size of n=23 is 0.2475. The calculated value of 0.093 does not exceed the critical value. Therefore, there is no evidence to reject the hypothesis of normality of residuals.

The analysis for constant variance was based on a plot of residuals versus fitted value, an F-test and a Levene's test. The plot of residuals versus fitted values is presented in Figure 34. Results on the F-test and Levene's test are presented in Figure 36.

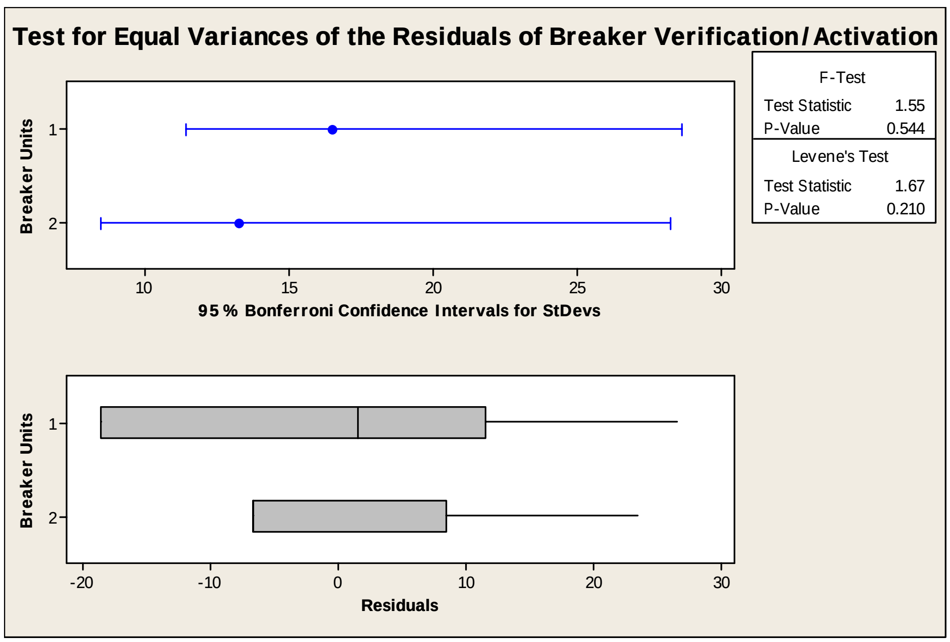

Figure 36: Test for Equal Variances for the Residuals of Breaker V/A Activity

The p-value on the F-test as well as the Levene's test show there is no evidence to reject the hypothesis of equal variance of residuals at all possible values of x.

Based on the previous tests the model for the estimation or prediction of the total time needed for the Breaker Verification/Activation considering the constant as well as the variable activities is as follows:

$$y = 41.74 + (0.476 + 48.10\,x) \qquad \textit{(Equation 14)}$$

A graphical comparison between the Calculated and the Observed Times for the Work Orders of the Breaker V/A task is presented in Figure 37.

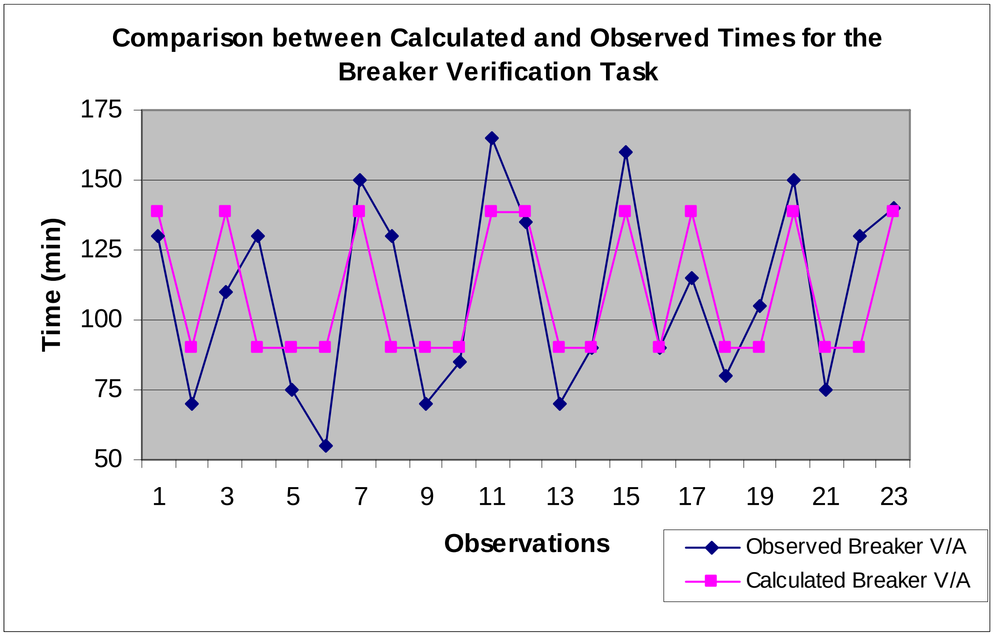

Figure 37: Calculated vs. Observed Breaker V/A Task

4.1.3 Plumbing Section

The plumbing section is in charge of unclogging drains, toilets and sinks in the RUM.

The main tasks held by the plumbing section are:

a. Unclogging of toilets
b. Unclogging of sinks

4.1.3.1 Unclogging of Toilets

Activities performed on the unclogging of toilets task were analyzed from the information gathered by the employees. The work orders for the Unclogging of Toilets involve five activities as follows:

- Initial Visit: The employees visit the area to gain information about the amount of toilets to be unclogged and the tools or equipment required.
- Materials: Order and pickup at the warehouse of the materials needed.
- Unclogging of Toilets: Involves the activity of unclogging the toilets
- Documentation: Includes the recording of the activities in the order form.
- Revision by Supervisor: Total time elapsed from the completion of the order to the verification and approval by the supervisor.

.

These activities were classified into productive, avoidable and unavoidable.

Table 13: Classification of the Unclogging of Toilets Activities

Activity Description	Classification (Productive, Avoidable, Unavoidable)	Constant or Variable
Initial Visit	A	Not to be considered
Materials	UA	C
Unclogging of Toilets	P	V
Documentation	UA	C
Revision by Supervisor	UA	C

The initial visit is classified as an avoidable activity (A) because usually the employees that will be completing the task know beforehand the number of toilets to be maintained. The pickup of materials, the documentation and the revision by supervisor are unavoidable activities (UA) that are required for the completion of the task. The Unclogging of Toilets is the only productive (P) activity because is the only activity that actually adds value to the task.

The unavoidable activities were classified as constant (C) (are not affected by the amount of units in the work order) and the productive activity was classified as variable (V) (affected by the amount of units in the work order).

To compute the estimate time for the Unclogging of Toilets task the weighted average of the times of the constant activities (C) was obtained. The original data is given in Table 23. The following table summarizes the information of the activities identified in the unclogging of toilets task:

Table 14: Summary of Activities for the Unclogging of Toilets Task

Activities	Materials	Time to Document	Revision by Supervisor
Standard Deviation=	9.01	1.364	12.06
Average=	6.98	9.878	29.63

Total Average= 46.488

On the other hand, the times of the variable activities were used to compute a regression model. After considering different regression models which included linear, quadratic and cubic models, the model that best describes the behavior of the given data is:

$$y = 62.79 + 12.74\,x + 13.22\,x^2 \qquad \textit{(Equation 15)}$$

Where:

y: The estimated time for the unclogging of toilets activity

x: The amount of toilets

The Analysis of Variance (ANOVA) yielded the following results:

```
S = 20.7556   R-Sq = 80.9%   R-Sq(adj) = 79.8%


Analysis of Variance

Source      DF       SS       MS      F      P
Regression   2  69117.6  34558.8  80.22  0.000
Error       38  16370.2    430.8
Total       40  85487.8
```

Figure 38: Analysis of Variance for the Unclogging of Toilets Activity

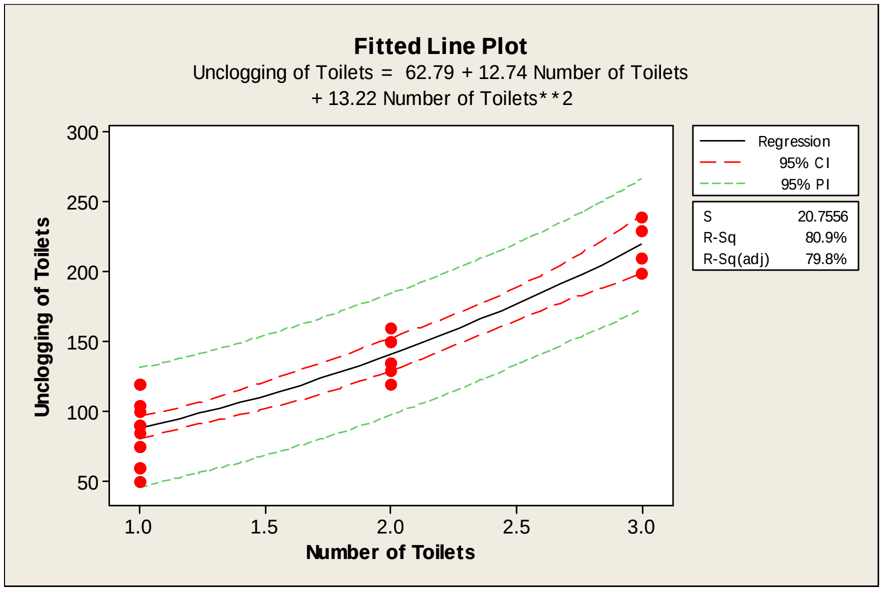

Figure 39: Regression Model for the Unclogging of Toilets Activity

The regression model has a determination coefficient of 80.9%. An analysis of residuals is presented in Figure 40 and Figure 41.

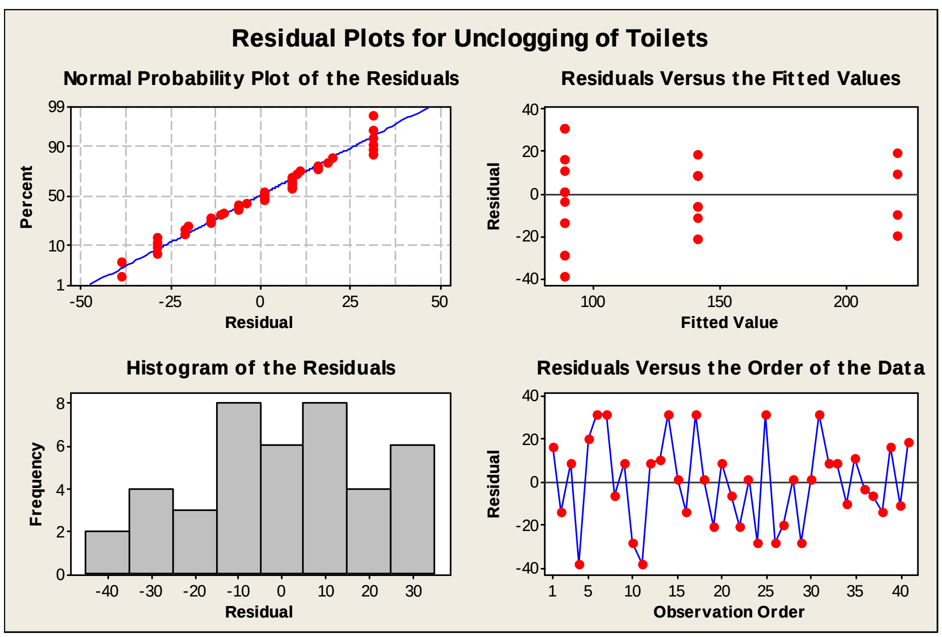

Figure 40: Residual Plots for the Unclogging of Toilets Activity

The analysis for normality in residuals is based on a Normal Probability Plot and a histogram. A Kolmogorov-Smirnov test was also performed to test the assumption of normality in residuals. Results are shown in Figure 41.

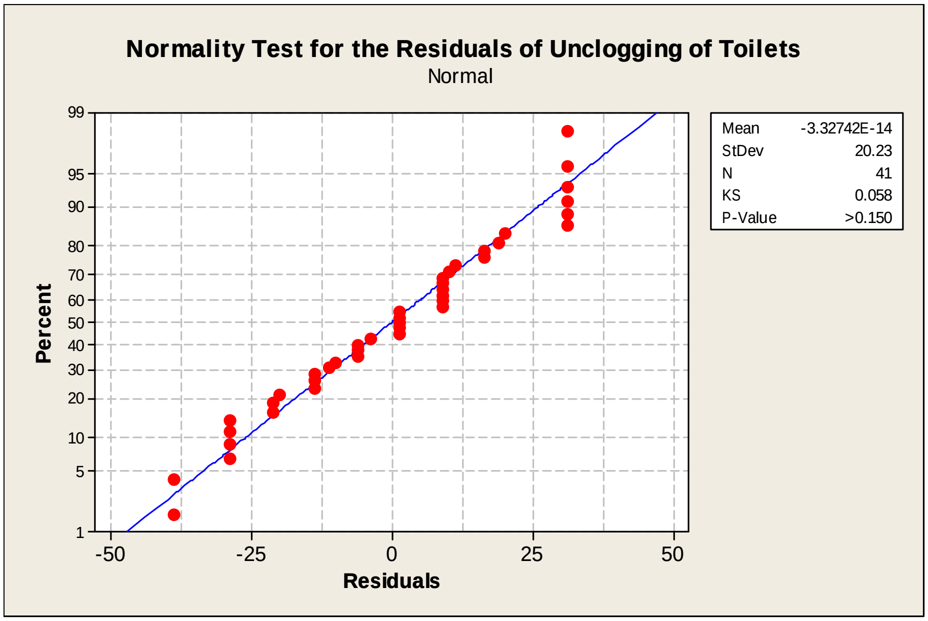

Figure 41: Normality Test of the Residuals of the Unclogging of Toilets Activity

The critical value for the Kolmogorov-Smirnov Statistic is compared to the calculated value from the model's residuals. The critical value for a confidence level of 95% and a sample size of n=41 is 0.1905. The calculated value of 0.058 does not exceed the critical value. Therefore, there is no evidence to reject the hypothesis of normality of residuals.

The analysis for constant variance was based on a plot of residuals versus fitted value, a Bartlett's and a Levene's test. The plot of residuals versus fitted values is presented in Figure 40. Results on the Bartlett's and Levene's test are presented in Figure 42.

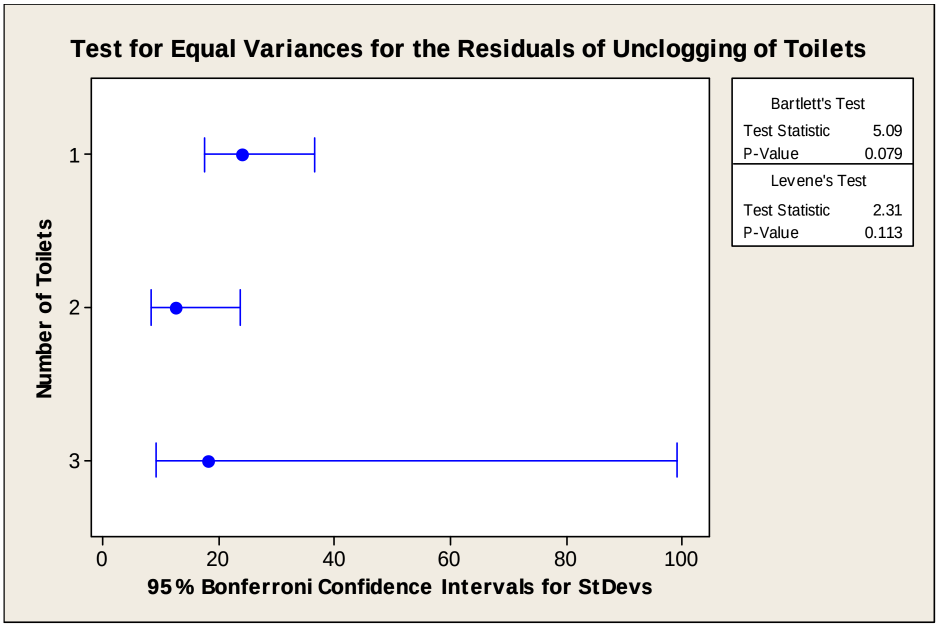

Figure 42: Test for Equal Variances for the Residuals of the Unclogging of Toilets Activity

The p-value on the Bartlett's as well as the Levene's test show there is no evidence to reject the hypothesis of equal variance of residuals at all possible values of x.

Based on the previous tests the model for the estimation or prediction of the total time needed for the unclogging of toilets considering the constant as well as the variable activities is as follows:

$$y = 46.488 + (62.79 + 12.74\, x + 13.22\, x^2) \qquad \textit{(Equation 16)}$$

A graphical comparison between the Calculated and the Observed Times for the Work Orders of the Unclogging of Toilets task is presented in Figure 43.

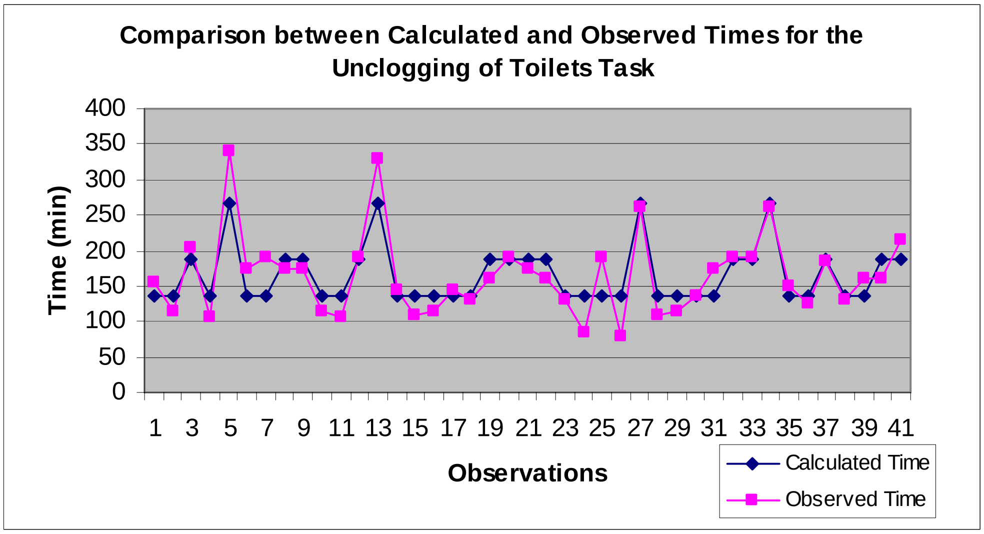

Figure 43: Calculated vs. Observed Time for the Unclogging of Toilets Task

4.1.3.2 Unclogging of Sinks

Activities performed on the unclogging of sinks task were analyzed from the information gathered by the employees. The work orders for the unclogging of sinks involve five activities as follows:

- Initial Visit: The employees visit the area to gain information about the amount of sinks to be unclogged and the tools or equipment required.
- Materials: Order and pickup of the materials needed at the warehouse.
- Unclogging Sinks: Involves the activity of unclogging the sinks
- Documentation: Includes the recording of the activities in the order form.
- Revision by Supervisor: Total time elapsed from the completion of the order to the verification and approval by the supervisor.

.

These activities were classified into productive, avoidable and unavoidable.

Table 15: Classification of the Unclogging of Sinks Activities

Activity Description	Classification (Productive, Avoidable, Unavoidable)	Constant or Variable
Initial Visit	A	Not to be considered
Materials	UA	C
Unclogging Sinks	P	V
Documentation	UA	C
Revision by Supervisor	UA	C

The initial visit is classified as an avoidable activity (A) because usually the employees that will be completing the task know beforehand the number of sinks to be maintained. The pickup of materials, the documentation and the revision by supervisor are unavoidable activities (UA) that are required for the completion of the task. The unclogging of sinks is the only productive (P) activity because is the only activity that actually adds value to the task.

The unavoidable activities were classified as constant (C) (are not affected by the amount of units in the work order) and the productive activity was classified as variable (V) (affected by the amount of units in the work order).

To compute the estimate time for the unclogging of sinks task the weighted average of the times of the constant activities (C) was obtained. The original data is given in Table 24. The following table summarizes the information of the activities identified in the unclogging of sinks task:

Table 16: Summary of Activities for the Unclogging of Sinks Task

Activities	Materials	Time to Document	Revision by Supervisor
Standard Deviation=	10.68	0.737	9.06
Average=	21.41	9.891	28.48

Total Average= 59.781

On the other hand, the times of the variable activities were used to compute a regression model. After considering different regression models which included linear, quadratic and cubic models, the model that best describes the behavior of the given data is:

$$y = 25.95 + 68.38x + 0.158\, x^2 \qquad \textit{(Equation 17)}$$

Where:

y: The estimated time for the unclogging of sinks activity

x: The amount of sinks

The Analysis of Variance (ANOVA) yielded the following results:

```
S = 22.6281   R-Sq = 85.6%   R-Sq(adj) = 84.9%


Analysis of Variance

Source      DF      SS       MS       F      P
Regression   2  130457  65228.3  127.39  0.000
Error       43   22017    512.0
Total       45  152474
```

Figure 44: Analysis of Variance for the Unclogging of Sinks Activity

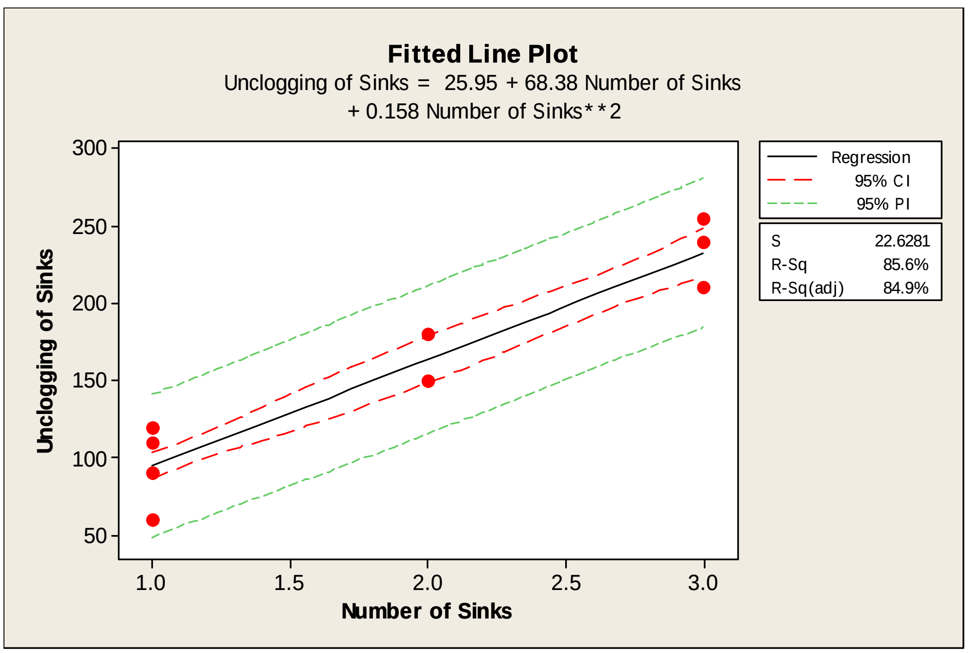

Figure 45: Regression Model for the Unclogging of Sinks Activity

The regression model has a determination coefficient of 85.6%. An analysis of residuals is presented in Figure 46 and Figure 47.

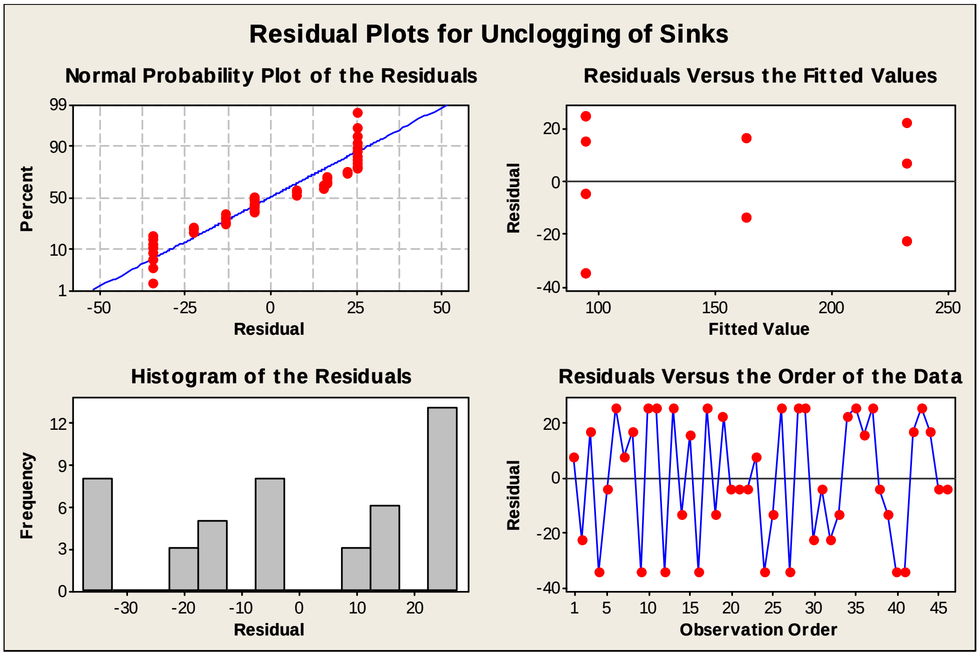

Figure 46: Residual Plots for the Unclogging of Sinks Activity

The analysis for normality in residuals is based on a Normal Probability Plot and a histogram. A Kolmogorov-Smirnov test was also performed to test the assumption of normality in residuals. Results are shown in Figure 47.

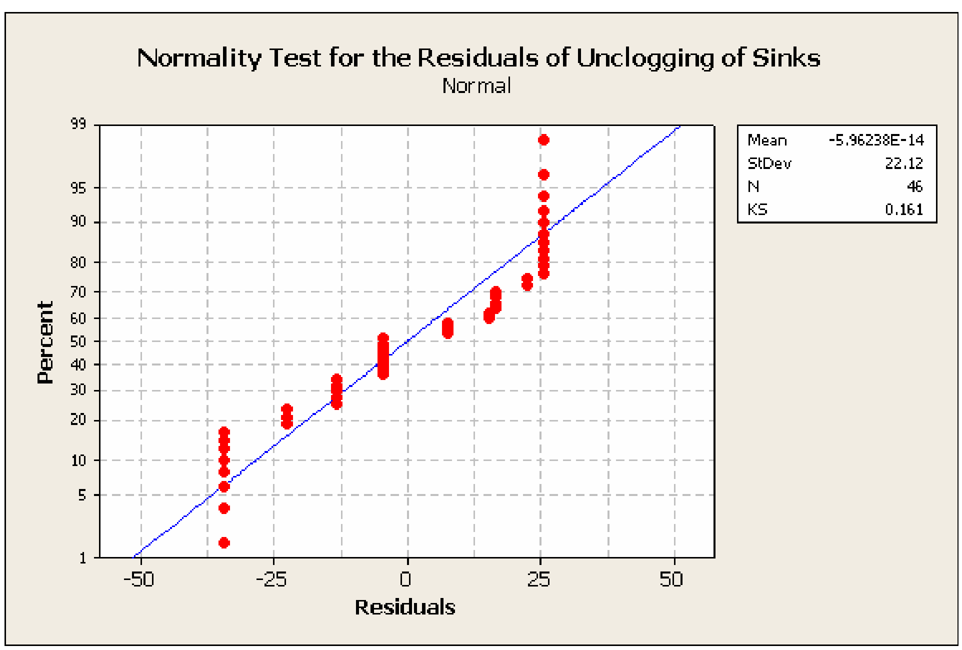

Figure 47: Normality Test of the Residuals of the Unclogging of Sinks Activity

The critical value for the Kolmogorov-Smirnov Statistic is compared to the calculated value from the model's residuals. The critical value for a confidence level of 95% and a sample size of n=46 is 0.1799. The calculated value of 0.161 does not exceed the critical value. Therefore, there is no evidence to reject the hypothesis of normality of residuals.

The analysis for constant variance was based on a plot of residuals versus fitted value, a Bartlett's test and a Levene's test. The plot of residuals versus fitted values is presented in Figure 46. Results on the Bartlett's test and Levene's test are presented in Figure 48.

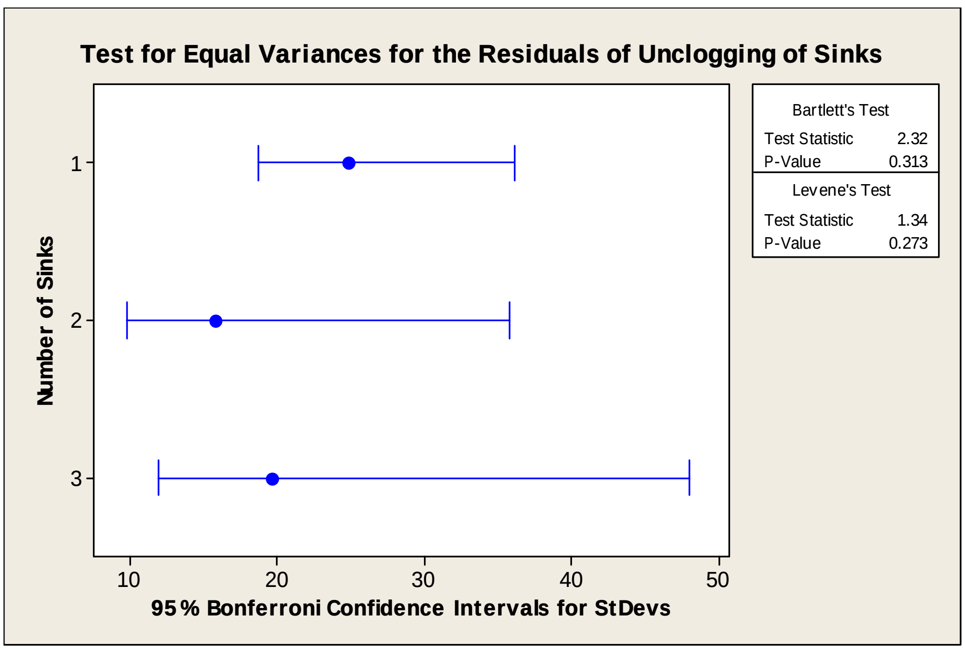

Figure 48: Test for Equal Variances for the Residuals of the Unclogging of Sinks Activity

The p-value on the Bartlett's test as well as the Levene's test show there is no evidence to reject the hypothesis of equal variance of residuals at all possible values of x.

Based on the previous tests the model for the estimation or prediction of the total time needed for the unclogging of sinks considering the constant as well as the variable activities is as follows:

$$y = 59.781 + (25.95 + 68.38x + 0.158\ x^2) \qquad \textit{(Equation 18)}$$

A graphical comparison between the Calculated and the Observed Times for the Work Orders of the Unclogging of Sinks task is presented in Figure 49.

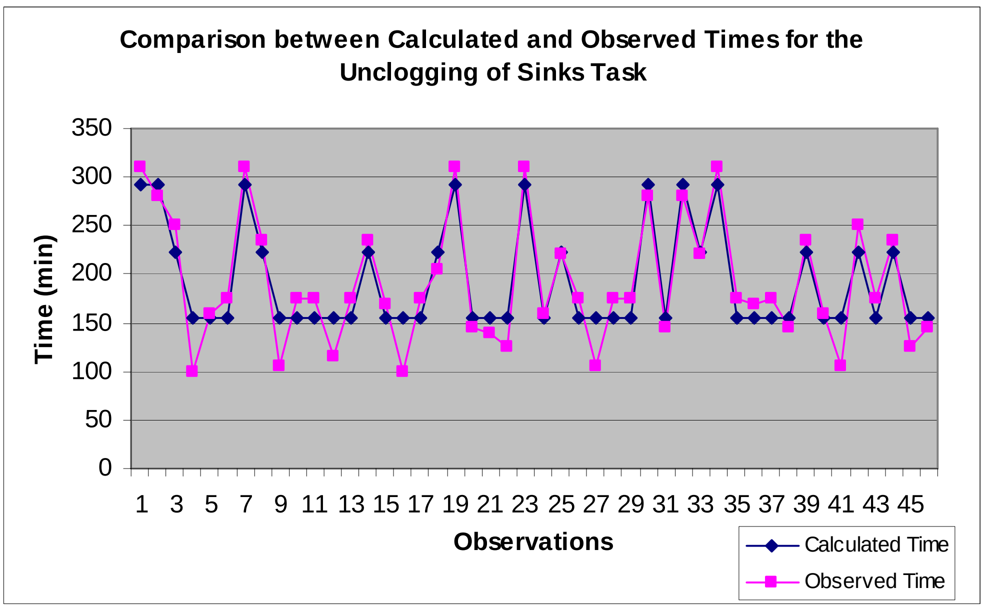

Figure 49: Calculated vs. Observed Time for the Unclogging of Sinks Task

4.2 Database for the time estimates

The database for the tasks' time estimates was designed using Microsoft Access ®. The programming code for this Database is included in Appendix B. The initial menu displays all the FD Sections and the user can select the section of interest by pressing the button with the corresponding name. It also contains an exit button ("Salir") if the user wants to exit the database. Figure 50 shows the components of this form.

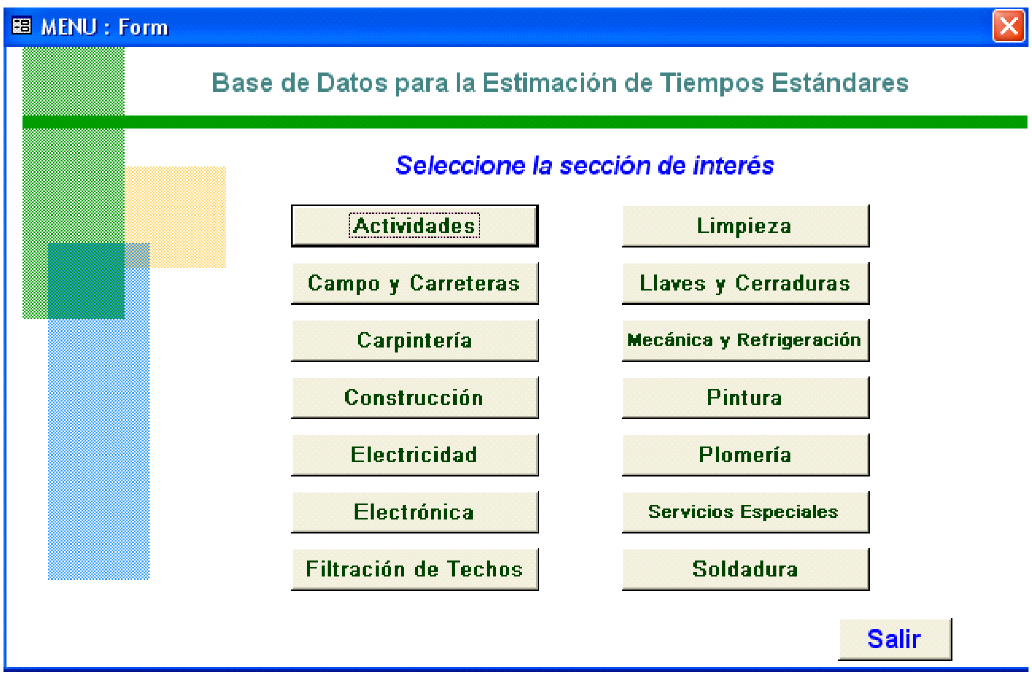

Figure 50: Initial Form of the Time Standards Database

Once the user selects the FD Section of interest another window appears, as shown in Figure 51. The first field of the form is a scroll down menu that contains a list of the tasks related to the selected FD section. The user selects the task of interest from that menu. In the field for quantity ("Cantidad") the user selects the number of units in the work order (Example: the number of A/C to be repaired, etc.).

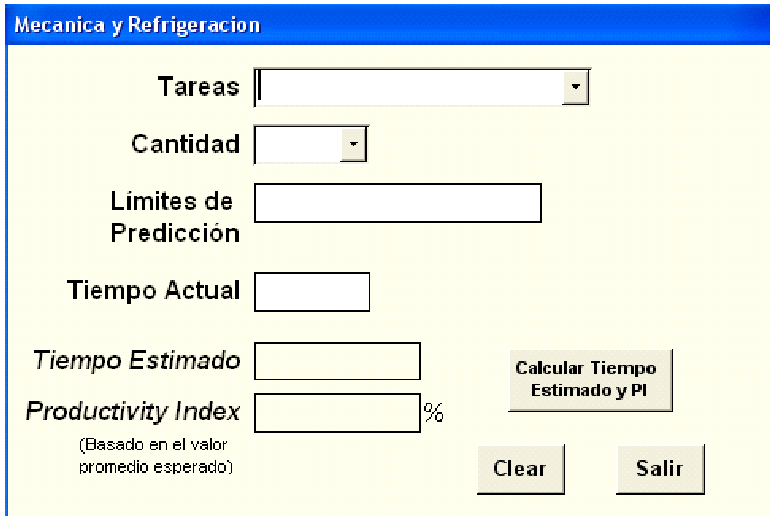

Figure 51: Form for the Selected FD Section

Once the user makes its selection, the prediction limits for the time estimate are displayed. This is shown in Figure 52.

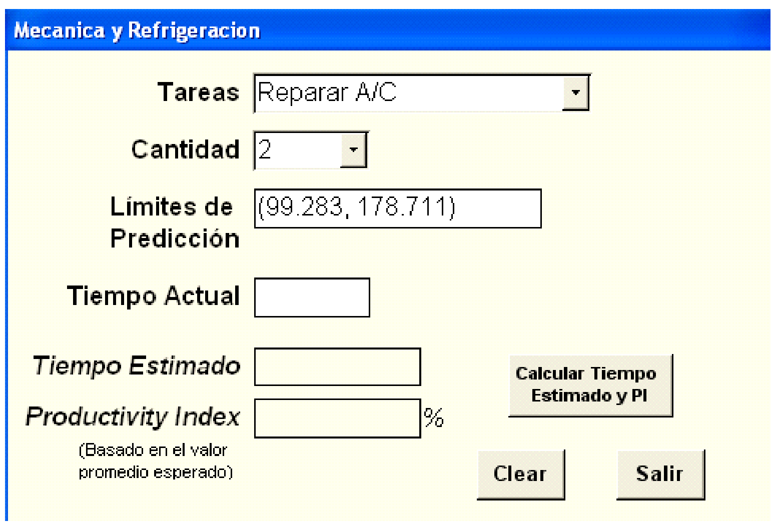

Figure 52: Display of the Prediction Limits

The field for actual time ("Tiempo Actual") is used for the PI calculation. In that case actual time represents the total number of hours spent by employees on the work order. This time is recorded in the work order by the employees.

Once the user selects the activity, the number of units in the work order and enters the actual time, he proceeds to press the calculate button ("Calcular Tiempo Estimado y PI"). The estimated time and the PI will be displayed in the corresponding boxes as shown in Figure 53. The window also has a clear button to reset to blank the values of the fields and an exit button ("Salir") to close the window.

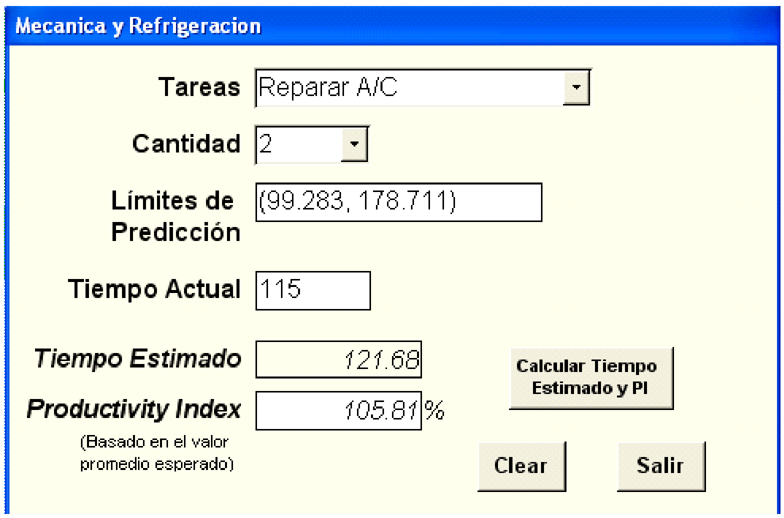

Figure 53: Example of a Time Estimate Calculation for the Repairing A/C Task

The advantages from this database are that supervisors of each section can:

- ❖ Calculate in advance the estimated time to perform a task.
- ❖ Assign their employees to the work orders in a more effective way.
- ❖ Compare the actual time vs. the estimated time to get a better understanding of work order efficiency through the Productivity Index (PI).

Work orders with low efficiency can be analyzed to identify areas of opportunity for improvements. Low efficiency could be due to shortages in tools, equipment or materials, incomplete or wrong information, among others.

4.3 Improvements to the Work Orders (WO) Database

The FD management requested to have complete and accurate reports on the status of the work orders by date and section. The following changes were made to fulfill their request.

The forms, queries and reports used for requesting work order reports were already partially designed. Changes were made on all of them since error messages were received when users were trying to access reports as shown in Figure 54.

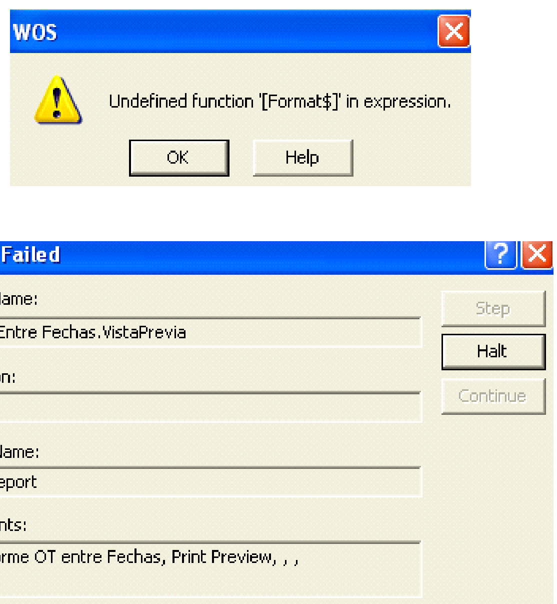

Figure 54: Error Messages Displayed When Users Tried to Access Reports

Some of the changes were made to allow retrieval of reports by section or for the entire department, for a given time period. Also, the report generated did not include the time period of the work orders listed. This was added as requested by the users.

The work order system as currently designed requires a confirmation from the supervisor upon order completion. This confirmation sends the order to the data administrator for order closure. The capability of sending back the order to the supervisor, when errors were found or information was missing was not designed into the system. This capability was added as requested by the data administrator.

Upon order closure by the data administrator detailed information related to the order could not be accessed. A command button was designed to allow the Department Manager to access information on closed orders. The window is shown in Figure 55. This button opens a window asking for a username and a password for security of data integrity. The window is shown in Figure 56.

Figure 55: Principal Menu Form for the WO Database

Once the user presses the access button, a form is displayed as follows:

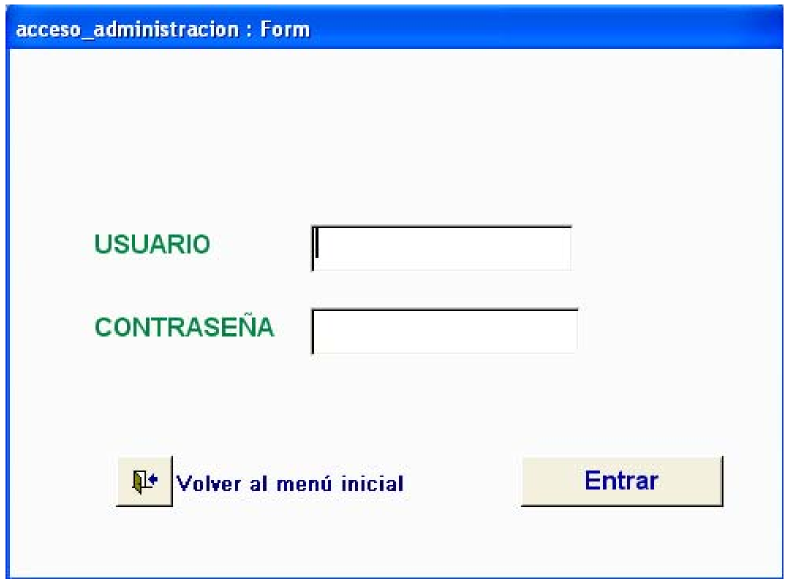

Figure 56: Initial Form for the Management Personnel

If there is an error in either one of the submitted information, the form returns an error message. An error message is also displayed when any of the required fields were left blank. Examples of these error messages are provided in Figure 57, Figure 58 and Figure 59. The message displayed when the access is granted is given in Figure 60. The programming code for the management form is included in Appendix C.

Figure 57: Error Message Displayed When the Password is Missing

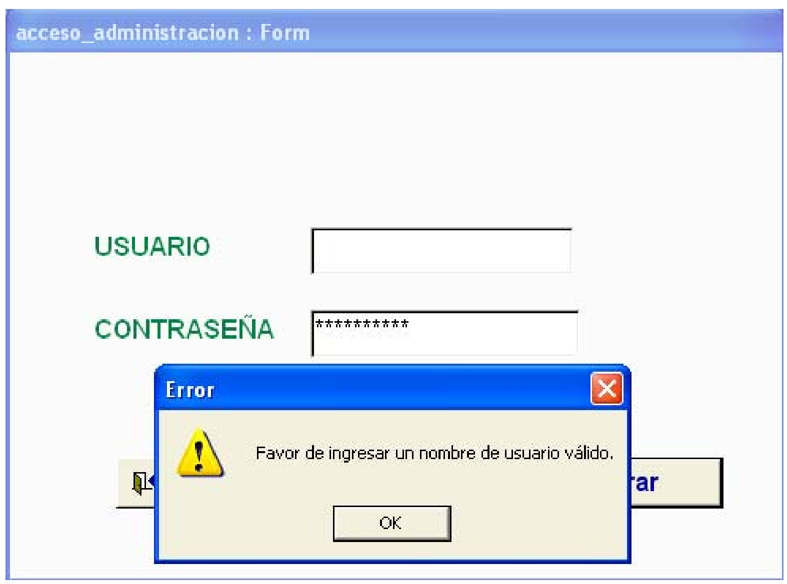

Figure 58: Error Message Displayed When the Username is Missing

Figure 59: Error Message Displayed When the Username or Password is Incorrect

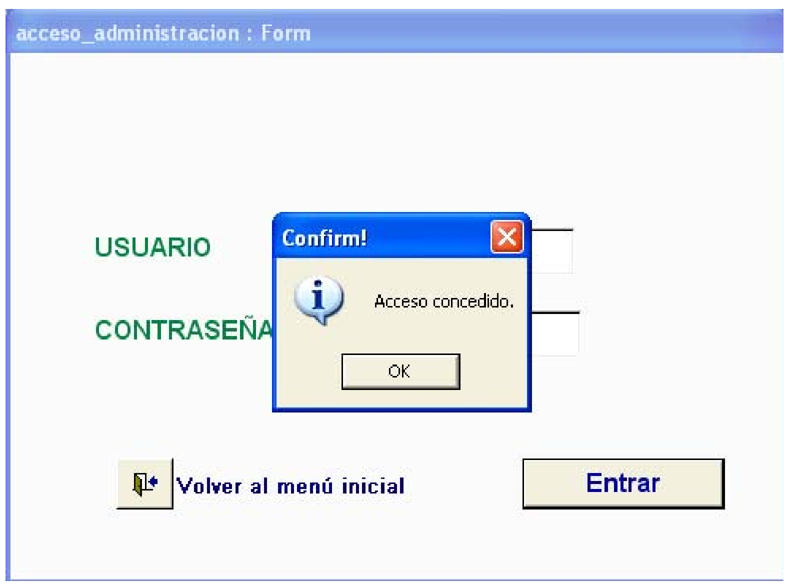

Figure 60: Message Displayed When Access is Granted

Once the Department Manager submits the username and password and has access, the system opens the window shown in Figure 61.

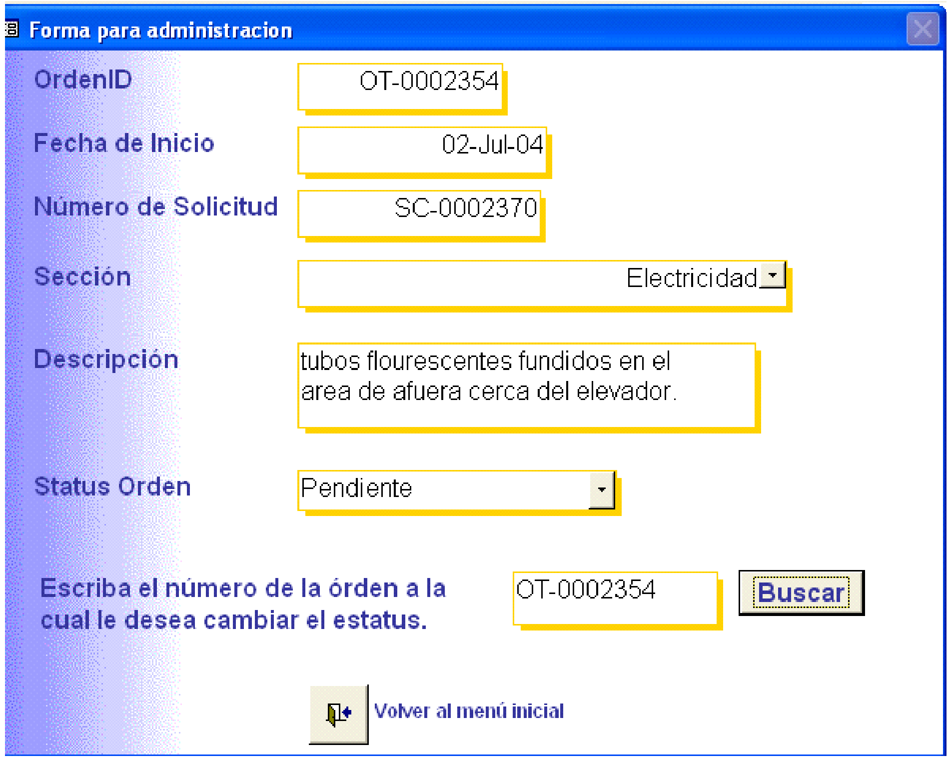

Figure 61: Example of a Work Order Search

In this form the user enters the work order number and then presses the search button ("Buscar"). It displays the basic work order information: the date it was generated, the section to which the work order belongs, the description of the required maintenance and the status of the work order. The user can return to the previous form any time by pressing the return-to-the-previous-menu button ("Volver al menú inicial").

Changes required on closed orders can be performed by changing the work order status from closed to pending. This makes the order available to the data administrator for changes if needed.

Another small change made to the WO database was the addition and deletion of buildings in the buildings list as requested by the secretaries.

4.4 Opportunities for improvement at the FD

A survey was developed and administered to employees to gather information on mayor obstacles in performing their tasks. Appendix D includes an example of the survey.

The survey was administered to a total of 35 out of 54 employees; 13 from refrigeration, 13 from plumbing and 9 from electricity. The subjects of interest were the availability and adequacy of materials, tools, vehicles and training. Other aspects considered were the awaiting time for materials, tools and vehicles.

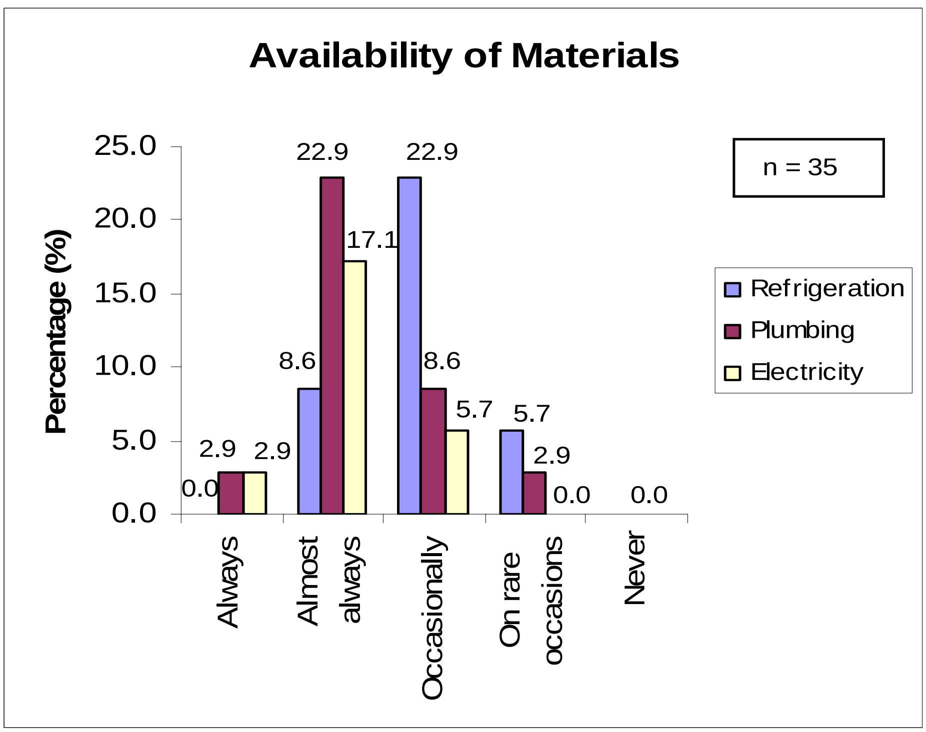

Figure 62: Availability of Materials

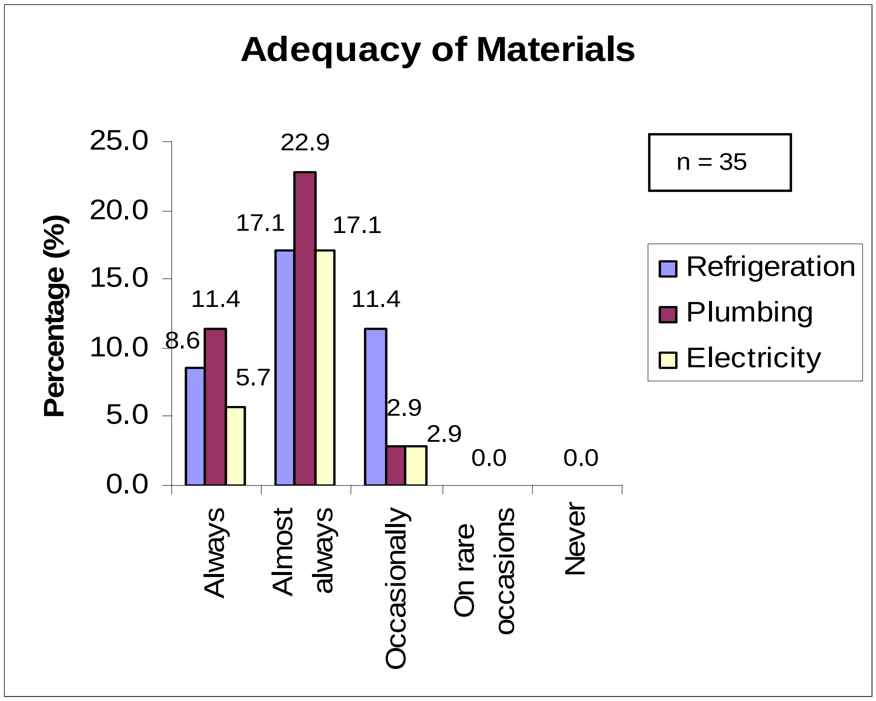

Figure 63: Adequacy of Materials

Figure 62 and Figure 63 show that the materials are available and adequate for the electricity (20% and 22.85% respectively) and plumbing (25.72% and 34.29% respectively) sections. Materials availability and adequacy do not seem to represent a major obstacle to process productivity. However, the refrigeration section has an opportunity for improvement in terms of materials availability. Also, the adequacy of materials has to be looked closer to determine if there are any materials available in the market more adequate and cost effective for the operations.

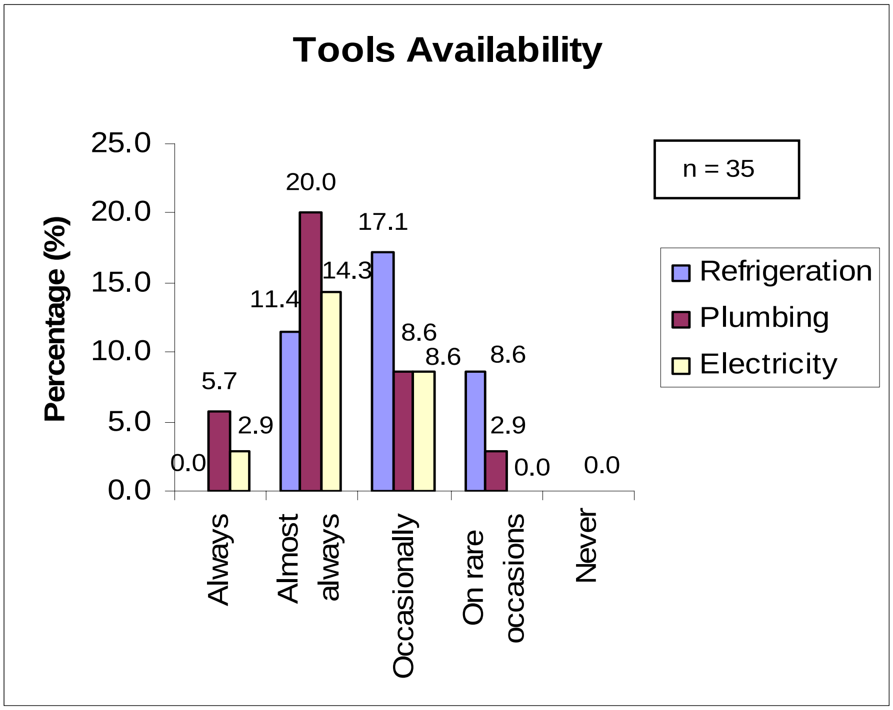

Figure 64: Tools Availability

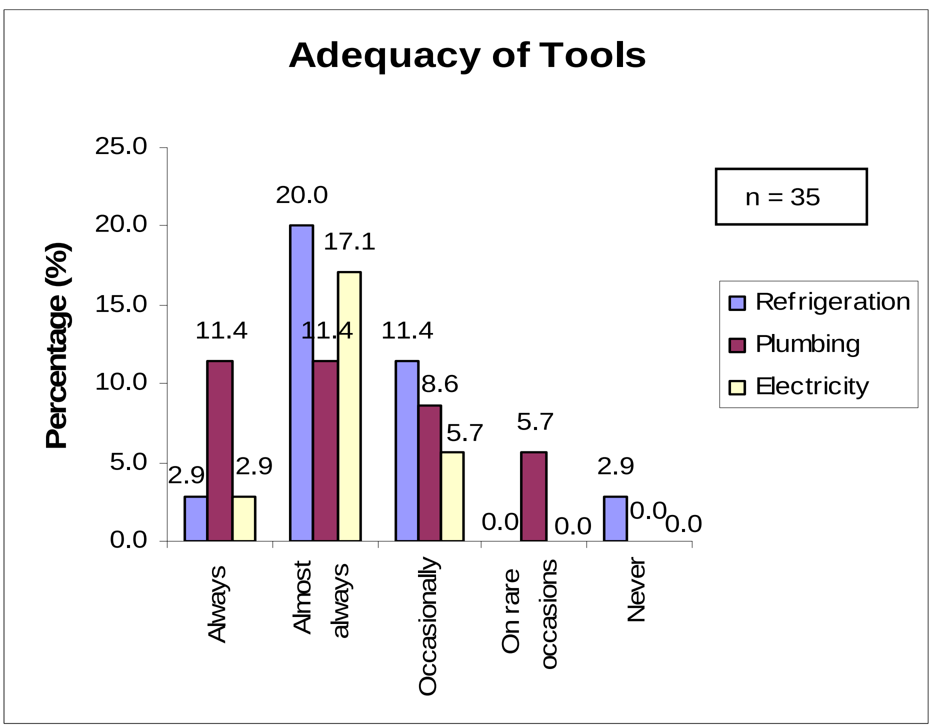

Figure 65: Adequacy of Tools

Tools are another important factor on process efficiency. Figure 64 and Figure 65 show that the tools are available 17.15% and adequate 20% of the times for the electricity section. This does not seem to be the case for the plumbing and refrigeration sections. From conversations held with some employees and from the comments included in the survey, the tools suffer from extreme wear and tear since these tools are used on a daily basis. This is especially true for the refrigeration and plumbing sections, where they recently had large decommissions of tools.

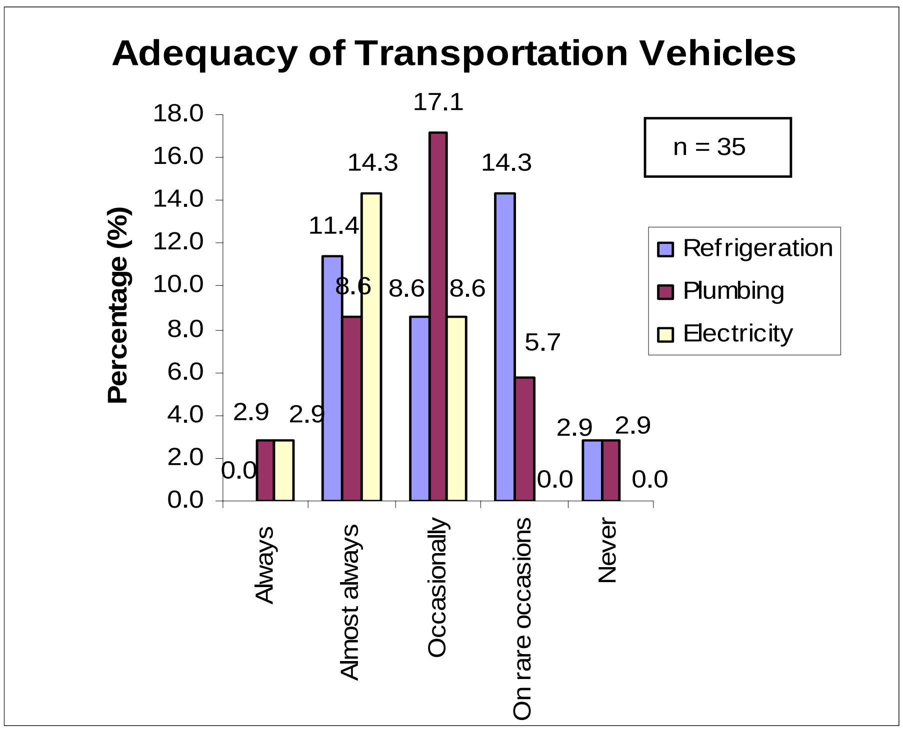

Figure 66: Adequacy of Transportation Vehicles

Figure 66 show that the adequacy of transportation vehicles is an area for improvement. Some employees reported that it is necessary to have a closed trunk in the vehicles because they carry materials and tools. They said that the vehicle can not be left unattended. Therefore one employee is assigned to guarding tools and materials until they start the job.

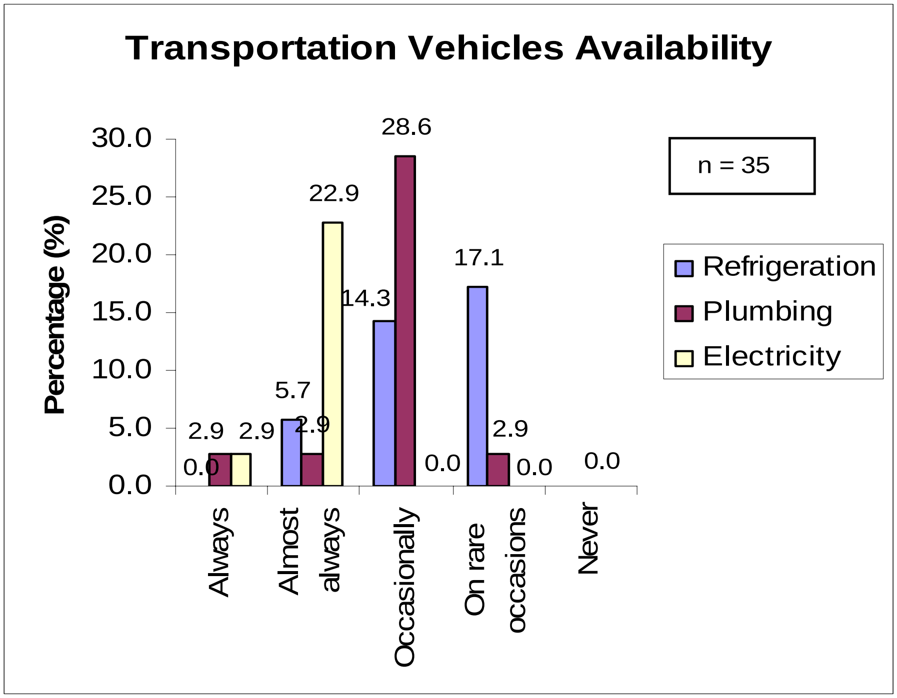

Figure 67: Transportation Vehicles Availability

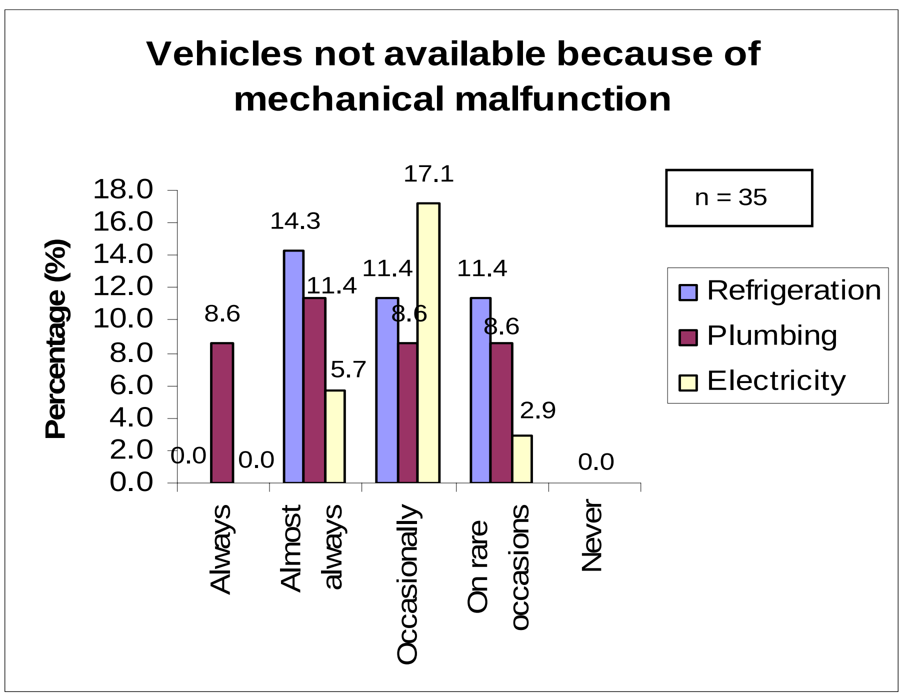

Figure 68: Vehicles not Available Because of Mechanical Malfunction

When asked about vehicles availability only a 37.15% assured these were available always or almost always. It was learn by the researcher that although mechanical malfunctions are frequent as shown in Figure 68, the biggest obstacle is the lack of vehicle permits. Obtaining a permit can take a long time because of the bureaucracy process at the University. This leaves some vehicles in good conditions unavailable for work.

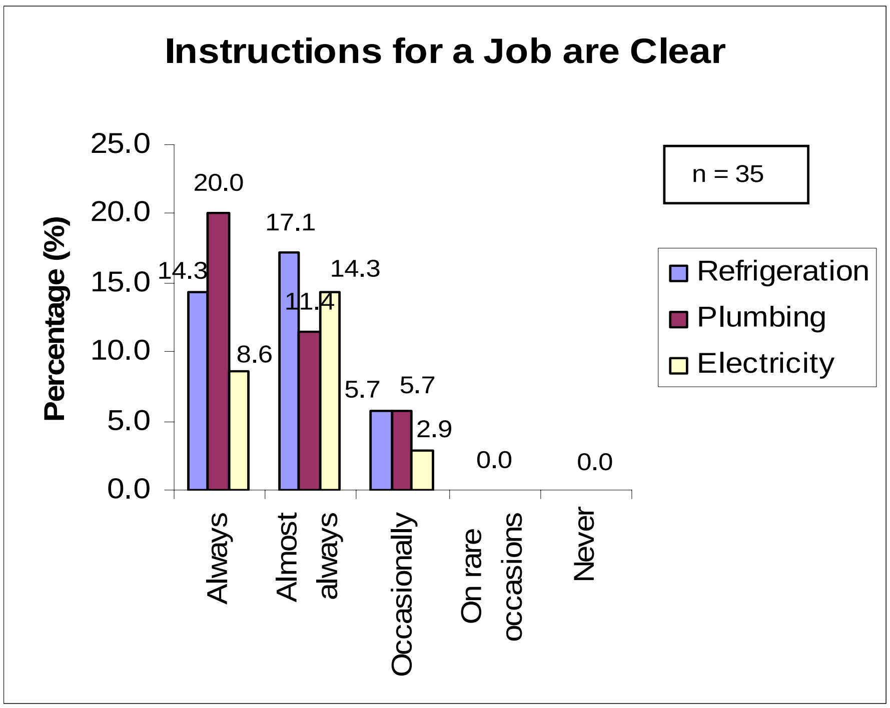

Figure 69: Instructions for a Job are Clear

Figure 69 shows employees have a clear understanding of the requirements of the jobs and this does not represent an obstacle in process productivity.

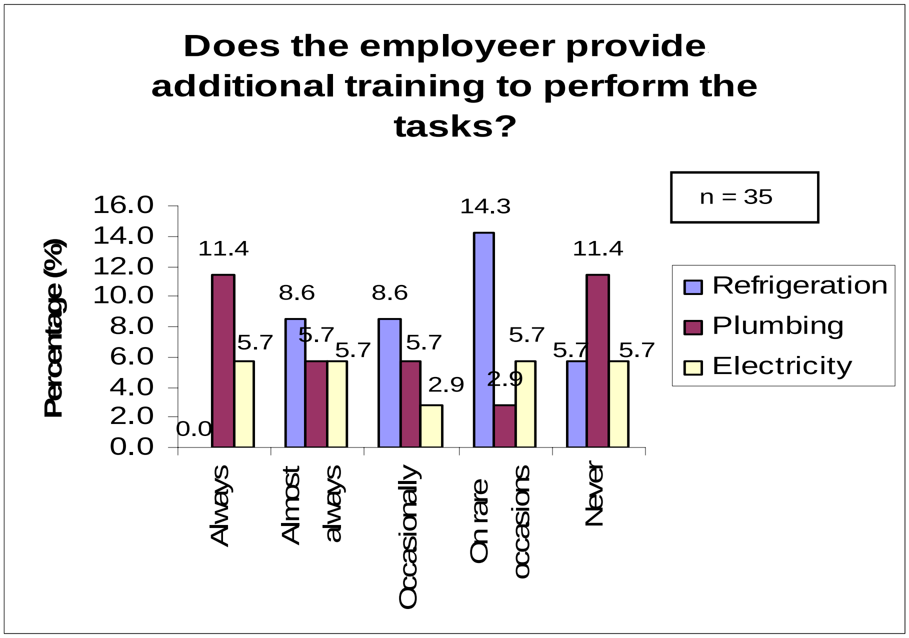

Figure 70: Additional Training Provided

When asked if the employer provides on-going training only a 37.13% assured always or almost always. It was learned the employer provides the opportunity of paid tuition at the university to all employees. However, only few take advantage of this opportunity. This is the reason why Figure 70 shows inconsistent answers

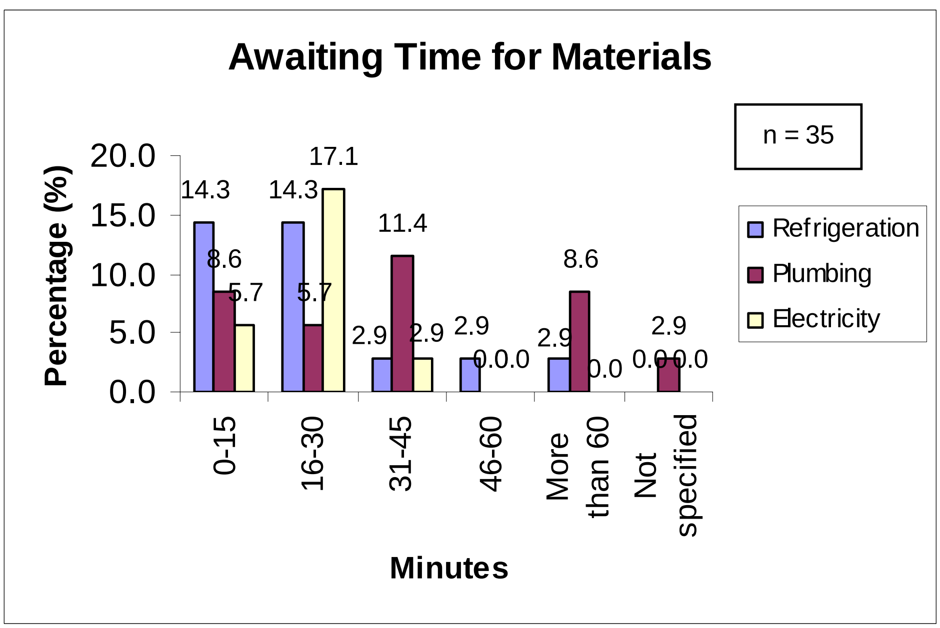

Figure 71: Awaiting Time for Materials

Figure 71 shows the average awaiting time for materials reported in the survey. Employees said the dispatch of materials is fast as long as the warehouse has the required materials. Some of these materials are ordered only when requested to have low inventory costs.

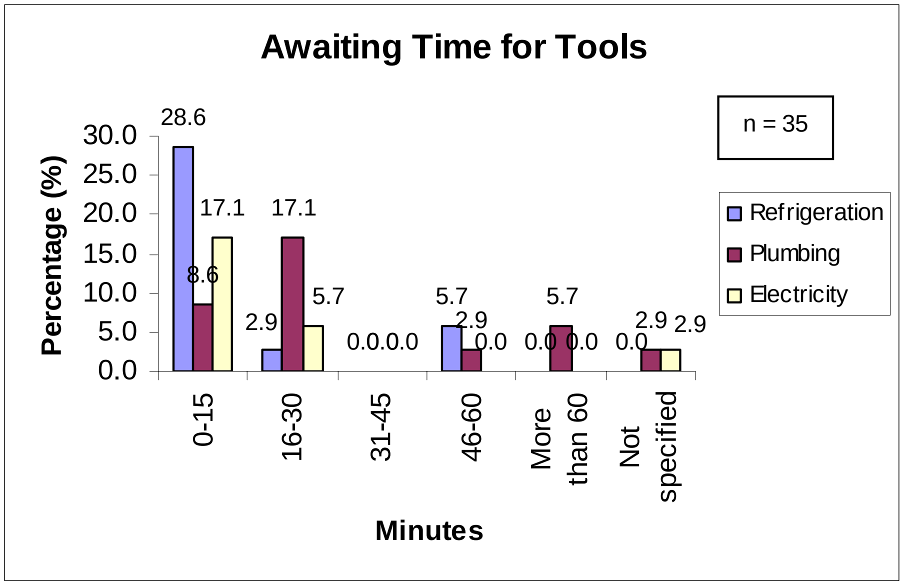

Figure 72: Awaiting Time for Tools

Figure 72 shows the average awaiting time for tools reported in the survey. As established earlier, the lack of sufficient tools is also evident in this question at the plumbing (25.71%) and refrigeration (31.43%) sections.

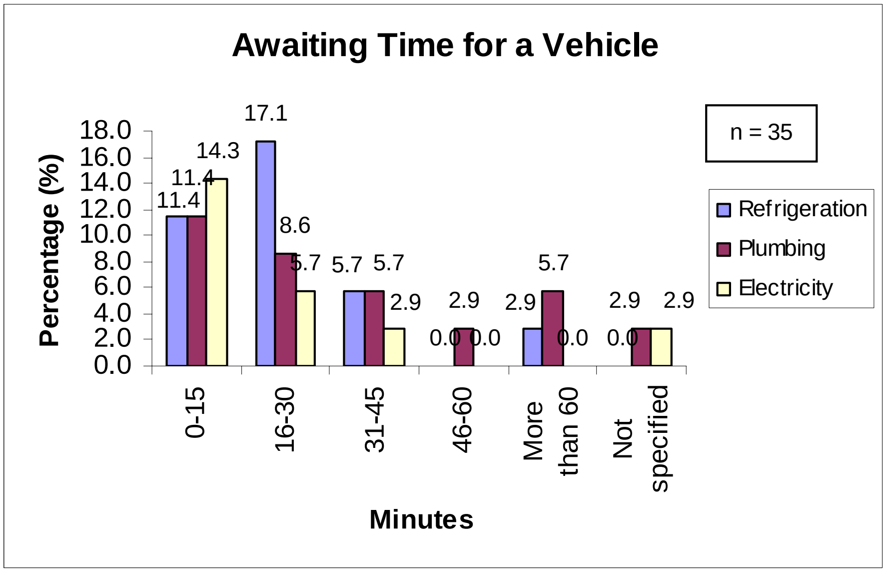

Figure 73: Awaiting Time for a Vehicle

Figure 73 shows the average awaiting time for a vehicle reported in the survey. It is shown that there are not sufficient vehicles to satisfy all jobs requirements on a timely manner.

Conclusions

The research provided models for the estimation of durations of the maintenance tasks performed by the selected sections of the FD. Even tough the statistical analysis supported the hypothesis of normality and equal variance of residuals, there is concern on the robustness of the test due to the small amount of data on some of the cases.

The designed database for the time estimation provides a good tool to the supervisors as well as the management of the FD in terms of prediction of work order duration. Also, with this database the actual time can be compared to the estimated time yielding a Productivity Index (PI). By using this database, supervisors can assign their employees to the work orders in a more effective manner.

The reporting system of the current WO database was improved. Reports were redesigned and new options were provided to the users in terms of range of date’s selection. Requests by management to provide a form for accessing and changing the status of closed work orders was included in the WO Database.

In terms of opportunities for improvement at the FD, it is very important to address the problem of insufficiency of adequate tools. Also, a minor change at all vehicles to add a cover for the trunk can relief the stress of losing materials or tools and leaves all employees available for other productive activities. The University must improve the maintenance provided to their vehicles as well as improve the process of getting vehicles permits. If it is allowed by the budget, it would be very useful to buy more vehicles.

Recommendations

The recommendations offered after the completion of the research are as follows:

- *Add more data for the development of estimation models*: This in order to improve the robustness of the statistical tests and the reliability of the models.
- *Need of a Database Administrator*: The Facilities Department needs a person capable of designing new reports as well as performing required changes to the user forms, tables and/or queries to both the WO Database and the Time Estimates Database.
- *Time Estimates Database updates*: It is recommended to update this database when new observations are available.
- *Add to the Time Estimates Database the FD sections not included in this research work:* Only the Refrigeration, Electricity and Plumbing sections are currently included in the Time Estimates Database.
- *Further analysis of work order data:* This to determine if the number of employees assigned to the work order is a significant factor on order completion lead time.
- *Addition of control charts for model monitoring and validation.*
- *Add to the Time Estimates database a module for "Weekly or Monthly Capacity Requirements Planning"*.

Bibliography

[1] Alreck, Pamela L; Settle, Robert B. "The Survey Research Handbook; Guidelines and Strategies for Conducting a Survey". 2nd Edition. McGraw-Hill Publishing. 1995.

[2] Asian Productivity Organization. "Productivity Measurement in the Service Sector", P 1-8

[3] Barnes, Ralph M. "Motion and Time Study Design and Measurement of Work". 7th edition. John Wiley and Sons. P 361-389.

[4] Caudron, Chari. "The Changing Union Agenda". Personnel Journal. March. 1995.

[5] Chan, A. "Modeling building durations in Hong Kong". Construction Management and Economics. Vol 17. P.186-196. 1999.

[6] Chan, D., Kumaraswamy M., Modeling and predicting construction durations in Hong Kong public housing. Construction Management and Economics. Vol 17. P.351-362. 1999.

[7] Chatterjee, Samprit; Hadi, Ali S.; Price, Bertram. "Regression Analysis by Example". 3rd Edition. John Wiley and Sons, Inc. 2000.

[8] Cohen,Y."Accelerating the generation of work measurement standards through automatic speech recognition: a laboratory study". International Journal of production Research 1998, vol. 36, no. 10, 2701-2715

[9] Daffin, Chris; Reed, Geoff; Vaze, Prabhat. "Labour Productivity for the Non-Production Industries". Economic Trends No. 579 February, 2002. P 41-56

[10] Devore, Jay L. “Probability and Statistics for Engineering and the Sciences”. 4th Edition. Wadsworth Publishing Company. 1995.

[11] Garcia Diaz, Martha L. “A Methodology to Facilitate Continuous Improvement in the Services Provided by the Facilities Department at UPRM”. Thesis M.S. July, 2004

[12] Gro¨nroos, Christian; Ojasalo, Katri. “Service Productivity towards a Conceptualization of the Transformation of Inputs into Economic Results in Services”, Journal of Business Research 57 (2004) P 414– 423.

[13] Hahn, Gerald J; Meeker, William Q. “Statistical Intervals; A guide for Practitioners”. John Wiley and Sons, Inc.

[14] Inman, R; Mehra, Satish. "Potential Union Conflict in JIT Implementation?". Production and inventory management Journal, 4th Quarter, 1989.

[15] Krisťák, Jozef. "Work analysis and time measurement in advanced manufacturing systems". IPA Slovakia.

[16] Montgomery, Douglas C. “Design and Analysis of Experiments”. 5th Edition. John Wiley and Sons, Inc.

[17] Montgomery, Douglas C. “Introduction to Linear Regression Analysis”. 3rd Edition. John Wiley and Sons, Inc. 2001.

[18] Niebel, B."Methods, Standards and work Design". 10th Edition. Mc Graw-Hill. 1993. Boston. USA.

[19] Nordhaus, William D. “Alternative Methods for Measuring Productivity Growth”. November, 2000. P 1-13.

[20] Pagell, Mark; Handfield, Robert. "The Impact of Unions on Operations Strategy" Production and Operations Management. Vol 9, No. 2, Summer 2000

[21] Patten, Mildred L. “Questionnaire Research; A Practical Guide”. 2nd Edition. Pyrczak Publishing. 2001.

[22] Randolph Thomas, H.; Zavrski, Ivica. “Construction Baseline Productivity: Theory and Practice”, Journal of Construction Engineering and Management. September/October. P.295-303. 1999

[23] Sherwood, Mark K. “Difficulties in the measurement of service outputs”. Monthly Labor Review. March 1994. P 11-19

[24] Thomas, H. Randolph; Zavrski, Ivica. “Construction Baseline Productivity”. Journal of Construction Engineering and Management. September/October 1999. P 295-303

[25] Triplett, Jack; Bosworth, Barry P. “Productivity Measurement Issues in Services Industries: “Baumol’s Desease” has Been Cured”. Federal Reserve Bank of New York, Economic Policy Review. P 23-33.

[26] U.S. Department of Labor, Bureau of Labor Statistics. “BLS Handbook of Methods”, Chapters 10-12, April 1997.

[27] U.S. Department of Labor, Bureau of Labor Statistics. “Data sources and methods for measuring multifactor productivity in the utility services industries (SIC 49)”, P 1-31.

[28] Walpole, Ronald E; Myers, Raymond H. “Probability and Statistics for Engineers and Scientists”. 3rd Edition. Macmillan Publishing.

[29] Wu, Jack A; Wu, Nesa L. “Productivity Management of Indirect Labour through Variable Work Measurement and Control”. International Journal of Operations and Production Management, Vol. 11 No. 8. P 48-58, 1991.

Appendix

A. Work Orders Original Data

Table 17: The Repairing of A/Cs Task Times with its Corresponding Activities

Repairing of A/Cs	A/C Units	Initial Visit	Time to Document	Revision by supervisor
150	2	30	10	0
70	1	30	10	10
65	1	30	10	10
40	1	10	10	0
140	2	20	10	0
65	1	15	15	10
125	2	35	10	0
40	1	30	10	0
30	1	20	10	0
65	1	30	5	10
55	1	30	10	0
35	1	30	25	0
70	1	15	15	0
150	2	20	15	10
65	1	15	10	0
100	1	35	15	0
100	1	30	0	10
65	1	30	15	0
140	2	10	10	0
60	1	15	10	0
70	1	15	10	0
120	2	10	10	10
140	2	10	15	10
75	1	30	10	10
75	1	10	10	0
90	1	15	10	0
65	1	15	10	0
45	1	15	10	0
70	1	15	15	0
70	1	30	15	10
45	1	15	10	0
80	1	15	10	0
40	1	25	10	0
40	1	30	10	0
110	1	15	10	0
120	2	35	10	10
120	2	10	10	0
55	1	20	10	0

The Repairing of A/Cs Task Times with its Corresponding Activities (cont.)				
70	1	15	10	10
120	2	10	10	0
65	1	30	10	10
70	1	15	10	0
45	1	10	10	10
45	1	30	10	0
50	1	30	10	0
110	1	15	10	10
40	1	15	10	0
75	1	25	5	0
105	1	15	10	10
60	1	15	10	10
80	1	10	10	10
40	1	30	10	0
65	1	35	10	0
135	2	30	10	0
140	2	10	10	10
55	1	15	10	10
140	2	10	10	0
90	1	15	10	10
100	1	15	10	10
40	1	10	10	10
110	1	15	10	10
85	1	10	10	0
85	1	15	10	0
35	1	10	10	10
100	1	15	10	0
35	1	20	10	0
50	1	15	10	20
120	2	15	10	10
30	1	10	10	0
30	1	20	10	10
35	1	15	10	0
70	1	25	10	0
45	1	30	10	20
50	1	30	10	0
55	1	30	10	10
65	1	15	10	20
55	1	10	10	0
70	1	35	10	0
75	1	20	10	10
30	1	20	10	0
135	2	15	10	10
45	1	10	10	0
75	1	10	10	0
120	2	15	10	10
150	2	15	10	0
45	1	15	10	20

The Repairing of A/Cs Task Times with its Corresponding Activities (cont.)				
45	1	15	10	0
60	1	15	10	15
180	2	30	10	0
105	1	20	10	10
55	1	15	10	0
30	1	15	10	20
135	2	15	10	0
50	1	15	10	10
45	1	15	10	10
100	1	20	10	0
50	1	15	10	15
65	1	15	10	0
120	2	10	10	20
75	1	15	10	0
110	1	20	10	0
100	1	10	10	10
45	1	30	10	0
45	1	30	10	10
125	2	15	10	0
30	1	10	10	15
55	1	20	10	20
65	1	15	10	0
130	2	15	10	0
75	1	15	10	0
215	3	20	10	0
105	1	35	10	15
75	1	30	10	0
75	1	20	10	0
60	1	15	10	0
65	1	10	10	0
55	1	15	10	10
120	2	15	10	10
60	1	15	10	10
70	1	30	10	0
75	1	25	10	10
65	1	30	10	0
65	1	20	10	0
70	1	35	10	10
135	2	30	10	10
150	2	15	10	0
213	3	30	10	10
120	2	30	10	10
90	1	20	10	10
120	2	15	10	10
70	1	30	10	0
135	2	30	10	10
70	1	30	10	10
120	2	30	10	10

The Repairing of A/Cs Task Times with its Corresponding Activities (cont.)				
130	2	30	10	10
90	1	15	10	10
55	1	30	10	10
65	1	20	10	20
40	1	20	10	10
75	1	20	10	10
60	1	20	10	10
60	1	30	10	10
65	1	15	10	10
45	1	10	10	0
105	1	15	10	10
60	1	15	10	10
65	1	20	10	10
65	1	10	10	10
75	1	30	10	10
40	1	15	10	10
90	1	30	10	10
75	1	15	10	10
75	1	15	10	10
65	1	15	10	10
40	1	20	10	10
40	1	30	10	10
100	1	30	10	10
45	1	15	10	10
55	1	10	10	10
70	1	15	10	10
70	1	15	10	10
60	1	10	10	10
65	1	15	10	10
90	1	30	10	10
150	2	20	10	10
90	1	20	10	10
90	1	20	10	10
40	1	30	10	10
60	1	25	10	10
75	1	30	10	10
60	1	30	10	10
45	1	30	10	10
55	1	10	10	10
150	2	10	10	10
45	1	20	10	10
240	3	15	10	10
75	1	30	10	10
225	3	20	10	10
105	1	30	10	10
30	1	15	10	10
65	1	15	10	10
165	2	15	10	10

The Repairing of A/Cs Task Times with its Corresponding Activities (cont.)				
150	2	15	10	10
90	1	30	10	10
60	1	15	10	10
60	1	15	10	10
90	1	35	10	10
90	1	30	10	10
60	1	30	10	0
80	1	25	10	10
120	2	20	10	10
35	1	25	10	10
55	1	10	0	0
120	2	10	10	10
30	1	25	10	10
55	1	20	10	10
250	3	15	10	10
85	1	30	10	10
85	1	15	10	10
95	1	30	10	10
90	1	15	10	10
30	1	10	10	10
60	1	15	10	10
75	1	30	10	10
125	2	15	10	10
65	1	15	10	10
55	1	30	10	10
45	1	25	10	10
85	1	20	10	10
60	1	35	10	10
60	1	15	10	10
60	1	15	10	10
105	1	25	10	10
55	1	20	10	10
85	1	20	10	10
155	2	10	10	10
150	2	10	10	10
55	1	30	10	10
120	2	15	10	10
135	2	15	10	10
135	2	25	10	10
50	1	15	10	10
190	3	15	10	10
45	1	10	10	10
240	3	20	10	10
120	2	10	10	10
55	1	20	10	10
45	1	20	10	10
170	2	20	10	10
60	1	20	10	10

The Repairing of A/Cs Task Times with its Corresponding Activities (cont.)				
45	1	15	10	10
70	1	10	10	10
85	1	10	10	10
45	1	15	10	10
55	1	10	10	10
30	1	20	10	10
60	1	20	10	10
80	1	15	10	10
45	1	15	10	10
180	2	10	10	10
150	2	20	10	10
60	1	15	10	10
60	1	15	10	10
105	1	10	10	10
60	1	20	10	10
70	1	10	10	10
60	1	20	10	10
125	2	10	10	10
60	1	20	10	10
60	1	10	10	10
75	1	15	10	10
120	2	10	10	10
105	1	15	10	10
170	2	15	10	10
105	1	20	10	10
60	1	25	10	10
55	1	15	10	10
30	1	15	10	10
70	1	15	10	10
125	2	20	10	10
125	2	10	10	10
40	1	10	10	10
85	1	15	10	10
85	1	20	10	10
85	1	15	10	10
70	1	10	10	10
85	1	15	10	10
30	1	15	10	10
55	1	10	10	10
60	1	30	10	10
60	1	10	10	10
45	1	15	10	0
240	3	15	10	10
135	2	30	10	10
45	1	15	10	10
55	1	35	10	10
65	1	20	10	10
30	1	20	10	10

The Repairing of A/Cs Task Times with its Corresponding Activities (cont.)				
30	1	20	10	10
30	1	30	10	0
100	1	25	10	10
120	2	10	10	0
65	1	20	10	10
55	1	15	10	10
150	2	20	10	10
125	2	35	10	0
105	1	20	10	10
105	1	15	10	0
75	1	30	10	10
60	1	20	10	10
110	1	15	10	0
213	3	20	10	10
120	2	30	10	0
65	1	10	10	10
100	1	10	10	0
60	1	25	10	10
75	1	15	10	0
85	1	20	10	0
120	2	30	10	10
45	1	15	10	10
75	1	35	10	0

Table 18: The Cleaning of A/C Filters Task Times with its Corresponding Activities

Cleaning of A/C Filters	Filter Units	Initial Visit	Time to Document	Revision by supervisor
30	1	25	10	0
45	1	30	10	0
45	1	15	10	10
60	1	10	15	0
105	2	15	10	10
65	1	20	10	10
55	1	15	10	0
120	2	20	15	0
60	1	25	15	10
60	1	20	15	15
60	1	15	15	0
200	4	15	10	10
40	1	15	10	10
55	1	5	10	0
30	1	5	10	0
60	1	20	10	10
50	1	25	10	10
30	1	20	10	0
100	2	10	10	10
40	1	10	10	0
55	1	20	10	10
30	1	10	10	0
60	1	5	10	0
70	1	5	10	10
120	2	20	10	0
110	2	5	10	0
30	1	10	10	0
50	1	5	10	10
55	1	15	10	10
65	1	25	10	0
30	1	5	10	0
50	1	5	10	10
30	1	10	10	10
60	1	10	10	10
120	2	15	10	10
120	2	25	10	10
60	1	10	10	10
45	1	10	10	10
210	4	15	10	10
50	1	10	10	10
30	1	10	10	10
40	1	10	10	10
60	1	15	10	10
45	1	10	10	10
60	1	25	10	10

The Cleaning of A/C Filters Task Times with its Corresponding Activities (cont.)				
60	1	15	10	10
35	1	20	10	10
125	2	20	10	10
40	1	15	10	10
60	1	20	10	10
35	1	15	10	10
125	2	25	10	10
25	1	5	10	10
75	1	30	10	10
35	1	20	10	10
40	1	20	10	10
45	1	30	10	10
60	1	20	10	10
105	2	15	10	10
55	1	10	10	10
60	1	15	10	10
80	1	10	10	10
50	1	10	10	10
80	1	10	10	10
60	1	15	10	10
35	1	15	10	10
65	1	20	10	10
45	1	20	10	10
105	2	10	10	10
80	1	10	10	10
70	1	10	10	10
110	2	10	10	10
65	1	10	10	10
75	1	20	10	10
120	2	10	10	10
60	1	15	10	10
55	1	15	10	10
50	1	10	10	10
55	1	25	10	0
55	1	10	10	10
65	1	20	10	0
45	1	5	10	0
40	1	10	10	10
50	1	10	10	10
40	1	25	10	10
60	1	5	10	5
80	1	15	10	10
110	2	15	10	10
120	2	20	10	10
60	1	15	10	10
105	2	15	10	15
40	1	15	10	10
50	1	10	10	10

The Cleaning of A/C Filters Task Times with its Corresponding Activities (cont.)				
30	1	10	10	10
110	2	5	10	0
200	4	15	10	10
125	2	15	10	0
45	1	15	10	15
30	1	15	10	10
60	1	10	10	10
35	1	10	10	10
100	2	20	15	15
50	1	5	10	0
80	1	25	15	0
45	1	15	15	15
80	1	10	10	10
70	1	10	10	0
75	1	15	10	10

Table 19: The Repairing of Water Fountains Task Times with its Corresponding Activities

Repairing of WF	WF Units	Initial Visit	Document	Revision by supervisor
50	1	20	15	0
85	1	30	10	0
225	3	15	20	10
155	2	20	10	0
110	2	10	10	15
120	2	30	10	0
60	1	35	10	0
60	1	20	10	0
30	1	10	10	10
30	1	15	10	0
120	2	30	10	10
45	1	10	10	0
90	1	20	10	0
45	1	20	10	15
20	1	10	10	10
90	1	30	10	10
75	1	20	10	10
45	1	20	10	10
120	2	15	10	10
60	1	20	10	10
120	2	20	10	10
75	1	20	10	10
60	1	15	10	10
90	1	20	10	10
25	1	20	10	10
75	1	15	10	10
20	1	15	10	10
90	1	20	10	10
60	1	20	10	10
45	1	15	10	10
75	1	15	10	10
30	1	20	10	10
230	3	20	10	0
75	1	20	10	10
75	1	30	10	10
90	1	30	10	10
90	1	20	10	0
20	1	20	15	0
45	1	10	10	0
45	1	15	10	10
30	1	30	10	0
90	1	20	10	10
50	1	20	10	0
25	1	10	10	10
120	2	20	10	10
120	2	20	10	10

Table 20: The Repairing of Extractors Tasks Times with its Corresponding Activities

Repairing of Extractors	Extractor Units	Initial Visit	Time to Document	Revision by supervisor
90	2	5	15	20
60	1	25	10	0
105	2	15	10	10
75	1	15	10	0
60	1	5	10	10
35	1	10	0	0
120	3	25	10	10
75	1	15	10	10
90	2	10	10	10
105	2	15	10	10
60	1	10	10	10
105	2	15	10	0
60	1	5	10	10
75	1	10	10	10
45	1	10	0	0
60	1	15	10	10
125	3	25	10	0

Table 21: The Installation of FT Task Times with its Corresponding Activities

Installation of Fluorescent Tubes	Tube Units	Initial Visit	Materials	Time to Document	Revision by Supervisor
30	2	15	5	15	20
15	4	10	15	5	60
15	4	15	15	15	25
30	4	5	15	5	15
90	17	15	15	10	30
60	17	15	15	10	10
60	18	15	5	10	15
30	4	15	5	5	20
45	17	15	15	30	15
60	18	10	10	15	15
30	13	15	15	10	15
85	24	30	10	10	20
45	17	15	15	15	10
45	13	15	15	10	60
30	13	15	15	10	90
80	21	10	20	15	15
60	15	15	10	5	20
30	2	15	15	15	5
30	6	15	15	10	10
85	21	15	15	10	60
50	13	30	15	30	30
45	15	5	10	5	5
90	24	15	15	20	30
30	13	15	15	10	20
25	6	0	5	5	30
90	21	30	30	15	20
45	15	15	30	10	15
45	13	15	5	30	15
60	18	20	15	20	100
30	13	20	10	15	30
30	13	15	15	20	25
30	6	30	30	10	20
60	15	30	30	10	60
75	18	15	15	10	15
85	17	15	30	5	15
90	24	15	30	15	20
95	21	15	30	5	20
35	2	30	30	30	15
85	17	60	45	15	20
20	4	30	30	5	15
30	4	15	105	10	45
60	18	15	15	10	15
85	24	5	10	5	5
45	17	15	15	10	20
60	17	60	45	15	30

The Installation of FT Task Times with its Corresponding Activities (cont.)					
30	2	5	5	5	5
80	21	15	15	20	20
60	15	15	15	10	15
85	21	30	30	10	20
35	2	30	30	30	15
85	17	30	45	15	20
20	4	30	30	5	15
30	4	15	30	10	20
60	18	15	15	10	15
85	24	5	10	5	5
45	17	15	15	10	20
60	17	60	20	15	30
30	2	20	15	5	10
80	21	15	15	20	20
60	15	15	15	10	15
85	21	30	30	10	20

Table 22: The Breaker V/A Task Times with its Corresponding Activities

Breaker Verification / Activation	Breaker Units	Initial Visit	Materials	Time to Document	Revision by Supervisor
90	2	0	0	10	30
50	1	0	0	5	15
90	2	45	0	10	10
75	1	30	15	10	30
30	1	15	0	15	30
30	1	30	0	5	20
90	2	15	30	10	20
60	1	60	0	10	60
30	1	30	15	5	20
60	1	60	0	10	15
120	2	30	0	15	30
90	2	30	0	15	30
30	1	15	0	10	30
30	1	15	30	10	20
90	2	60	0	10	60
50	1	30	15	5	20
90	2	60	0	10	15
60	1	45	0	10	10
50	1	30	15	10	30
90	2	15	30	10	20
50	1	60	0	10	15
75	1	30	15	10	30
120	2	45	0	10	10

Table 23: The Unclogging of Toilets Task Times with its Corresponding Activities

Unclogging of Toilets	Number of Toilets	Initial Visit	Materials	Time to Document	Revision by Supervisor
105	1	30	15	5	30
75	1	15	0	10	30
150	2	15	15	10	30
50	1	15	15	10	30
240	3	30	30	10	60
120	1	15	15	10	30
120	1	0	0	10	60
135	2	60	0	10	30
150	2	0	0	10	15
60	1	15	15	10	30
50	1	15	15	10	30
150	2	10	0	10	30
230	3	30	30	10	60
120	1	15	0	10	15
90	1	0	0	10	10
75	1	15	0	10	30
120	1	15	0	10	15
90	1	0	0	10	30
120	2	60	0	10	30
150	2	0	0	10	30
135	2	0	0	10	30
120	2	0	0	10	30
90	1	0	0	10	30
60	1	0	0	10	15
120	1	0	0	10	60
60	1	0	0	10	10
200	3	20	20	10	30
90	1	0	0	10	10
60	1	15	15	10	30
90	1	0	0	15	30
120	1	15	15	10	30
150	2	30	0	10	30
150	2	30	0	10	30
210	3	20	15	10	25
100	1	20	15	5	30
85	1	15	0	10	30
135	2	40	10	10	30
75	1	15	15	10	30
105	1	15	15	10	30
130	2	15	0	10	20
160	2	20	15	10	30

Table 24: The Unclogging of Sinks Task Times with its Corresponding Activities

Unclogging of Sinks	Number of Sinks	Initial Visit	Materials	Time to Document	Revision by Supervisor
240	3	30	30	10	30
210	3	30	30	10	30
180	2	30	30	10	30
60	1	15	15	10	15
90	1	30	30	10	30
120	1	15	15	10	30
240	3	30	30	10	30
180	2	15	15	10	30
60	1	15	15	10	20
120	1	15	15	10	30
120	1	15	15	10	30
60	1	30	15	10	30
120	1	15	15	10	30
150	2	15	15	10	60
110	1	20	20	10	30
60	1	15	15	10	15
120	1	15	15	10	30
150	2	15	15	10	30
255	3	30	15	10	30
90	1	30	30	10	15
90	1	30	15	5	30
90	1	15	15	10	10
240	3	30	30	10	30
60	1	30	60	10	30
150	2	30	30	10	30
120	1	15	15	10	30
60	1	30	15	10	20
120	1	15	15	10	30
120	1	15	15	10	30
210	3	60	30	10	30
90	1	15	15	10	30
210	3	30	30	10	30
150	2	30	30	10	30
255	3	30	15	10	30
120	1	15	15	10	30
110	1	20	20	10	30
120	1	15	15	10	30
90	1	15	15	10	30
150	2	15	15	10	60
60	1	30	60	10	30
60	1	30	15	10	20
180	2	30	30	10	30
120	1	15	15	10	30
180	2	15	15	10	30
90	1	15	15	10	10
90	1	30	30	10	15

B. Programming Code for the Time Estimates Database

```
Option Compare Database
Dim qty As Integer
Dim savedCaption As String



Private Sub cmbQTY_Change()
   On Error Resume Next
   tID = Me.cmbTarea.Value
   If tID = "" Then Exit Sub

   qty = Me.cmbQTY.Value
   If qty < 0 Then Exit Sub


   Dim sql As String
   sql = "SELECT Intervalos_de_Prediccion.* FROM Intervalos_de_Prediccion WHERE
TareaID =" & tID & " and cantidad= " & qty & ";"

   Dim rs As adodb.Recordset

   Me.RecordSource = sql
   Me.Requery

   'Set rs = Me.Recordset
   Dim s As String

   s = "(" & Me.Recordset.Fields("PLIM1") & ", " & Me.Recordset.Fields("PLIM2") & ")"
   Me.txtBounds.SetFocus
   Me.txtBounds.Text = s
   'MsgBox s



End Sub
Public Sub computePI()
   Dim rs As adodb.Recordset

   tID = Me.cmbTarea.Value
   If tID = "" Then
      MsgBox "Por favor seleccione una tarea."
      Exit Sub
   End If
```

```
    If qty < 0 Then
        MsgBox "Por favor seleccione una cantidad."
        Exit Sub
    End If

    sql = "SELECT * FROM Tareas WHERE ID =" & tID & ";"
    txtTActual.SetFocus
    If txtTActual.Text = "" Then
        MsgBox "Por favor entre el tiempo actual."
        Exit Sub
    End If
    tActual = txtTActual.Text
    Me.RecordSource = sql
    Me.Requery

    Dim constante As Double, f1 As Double, f2 As Double, f3 As Double

    constante = Me.Recordset.Fields("constante")
    f1 = Me.Recordset.Fields("Formula1")
    f2 = Me.Recordset.Fields("Formula2")
    f3 = Me.Recordset.Fields("Formula3")

    Tiempo = constante + (qty * f1) + (qty * qty * f2) + (qty * qty * qty * f3)
    txtTiempo.Text = Tiempo
    txtPI.SetFocus
    txtPI.Text = (Tiempo / Val(tActual)) * 100

End Sub



Public Sub showSeccion(secID As String)
    On Error Resume Next
    Me.cmbTarea.RowSource = "SELECT Tareas.Tarea, Tareas.ID, Tareas.Seccion FROM
Tareas WHERE ((Tareas.Seccion=" & secID & "));"
    Me.cmbTarea.Requery

    Dim rs As adodb.Recordset, sql As String
    sql = "SELECT seccion FROM secciones WHERE ID =" & secID & ";"
    Me.RecordSource = sql
    Me.Requery
    savedCaption = Me.Form.Caption
    Me.Form.Caption = Me.Recordset.Fields("seccion")

    Me.cmbTarea.SetFocus

End Sub
```

```
Private Sub cmbTarea_Change()
   On Error Resume Next
   tID = Me.cmbTarea.Value
   If tID = "" Then Exit Sub
   Dim sql As String
   sql = "SELECT Intervalos_de_Prediccion.cantidad FROM Intervalos_de_Prediccion
WHERE Intervalos_de_Prediccion.TareaID =" + tID + ";"
   'MsgBox sql

   cmbQTY.RowSource = sql
   cmbQTY.Requery

End Sub



Private Sub cmdPI_Click()
   computePI
End Sub



Private Sub Form_Activate()
   If Me.Tag <> "" Then
      showSeccion Me.Tag
      Beep
   End If
End Sub



Private Sub Form_Close()
   Me.Form.Caption = "frmCalTiempos"
End Sub


Private Sub Form_Open(Cancel As Integer)
End Sub


Private Sub Reset_form_Click()
Me.txtTActual.SetFocus
txtTActual.Text = ""
txtPI.SetFocus
txtPI.Text = ""
txtBounds.SetFocus
txtBounds.Text = ""
```

```
txtTiempo.SetFocus
txtTiempo.Text = ""
qty = 0
End Sub

Private Sub Salir_electric_Click()
On Error GoTo Err_Salir_electric_Click

    DoCmd.Close

Exit_Salir_electric_Click:
    Exit Sub

Err_Salir_electric_Click:
    MsgBox Err.Description
    Resume Exit_Salir_electric_Click

End Sub



Private Sub Command19_Click()
On Error GoTo Err_Command19_Click

    Screen.PreviousControl.SetFocus
    DoCmd.FindNext

Exit_Command19_Click:
    Exit Sub

Err_Command19_Click:
    MsgBox Err.Description
    Resume Exit_Command19_Click

End Sub
```

C. Programming Code for the Management Form

```
Private Sub Command5_Click()

Dim GetData As ADODB.Recordset
Set GetData = New ADODB.Recordset

If IsNull(Me.Txtusername) Then
MsgBox "Favor de ingresar un nombre de usuario válido.", vbExclamation, "Error"
Me.Txtusername.SetFocus
Exit Sub
ElseIf IsNull(Me.txtpassword) Then
MsgBox "Favor de ingresar una contraseña válida.", vbExclamation, "Error"
Me.txtpassword.SetFocus
Exit Sub
End If
GetData.Open "SELECT * FROM usuarios_administracion WHERE(UserName = '" &
Me.Txtusername & "' AND Password = '" & Me.txtpassword & "')", _
CurrentProject.Connection, adOpenKeyset, adLockOptimistic
If GetData.EOF Or GetData.BOF Then
MsgBox "Nombre de usuario o contraseña inválida. Trate de nuevo.", vbExclamation,
"Error"
Me.Txtusername.SetFocus
Exit Sub
End If
MsgBox "Acceso concedido.", vbInformation, "Confirm!"

Dim stDocName As String
DoCmd.Close
stDocName = "Forma_para_administracion"

DoCmd.OpenForm stDocName

Exit Sub
End Sub

Private Sub cerrar_forma_accesoadm_Click()
On Error GoTo Err_cerrar_forma_accesoadm_Click

Dim stDocName As String
stDocName = "MENU"

    DoCmd.Close
    DoCmd.OpenForm stDocName
```

```
Exit_cerrar_forma_accesoadm_Click:
    Exit Sub

Err_cerrar_forma_accesoadm_Click:
    MsgBox Err.Description
    Resume Exit_cerrar_forma_accesoadm_Click

End Sub
```

D. Questionnaire

Cuestionario para determinar áreas de oportunidad en el Departamento de Facilidades del RUM
==

Instrucciones: Favor de leer cada línea y seleccionar la frecuencia en que ocurre (siempre, casi siempre, a veces, rara vez, nunca). Si tiene algún comentario o sugerencia puede incluirlo en los espacios provistos.

	Siempre	Casi siempre	A veces	Rara vez	Nunca
Los materiales están disponibles					
Los materiales son adecuados					
Las herramientas están disponibles					
Las herramientas son adecuadas					
Los vehículos de transporte utilizados son los adecuados					
Vehículos no disponibles por desperfectos mecánicos					
Vehículo disponible cuando se necesita					
Las instrucciones para hacer un trabajo están claras					
¿Provee el patrono adiestramiento adicional para realizar las tareas?					

Instrucciones: Favor de marcar en los cuadros provistos el tiempo aproximado de espera para cada aseveración.

	0-15 min.	16-30 min.	31-45 min.	45-60 min.	Más de 60 min.
Tiempo de espera por materiales una vez estos son solicitados					
Tiempo de espera por herramientas una vez estas son solicitadas					
Tiempo de espera por vehículo de transporte una vez este es solicitado					

¿Que otra sugerencia puede proveer para mejorar la productividad en su área de trabajo?

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¡Muchas gracias por su sincera aportación!