The Development of Reliability Analysis Toolkit (RAT) For Analyzing Plant Maintenance Data

by

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CERTIFICATION OF APPROVAL

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Approved by,

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(Dr. Hilmi Hussin)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
May 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MUHAMMAD AMIN B ABD KARIM

ABSTRACT

Reliability analysis is an important tool for engineers in assessing the performance of existing operational system of the plant. Major loss can be eliminated and therefore increase the plant profitability. The aim of this study is to develop a toolkit that will assist the engineers in performing the reliability analysis. The main issues found during the research are namely improper methodology used by the engineers and inadequate of time to perform the analysis. In order to solve these issues, a computer based toolkit called as Reliability Analysis Toolkit (RAT) is programmed using the combination of Microsoft Excel, Macro and Visual Basic for the interface. The toolkit (RAT) is developed using two type of analysis which is exploratory and inferential analysis. In exploratory analysis, the plant field maintenance data is processed into graphical charts such as Pareto and trend chart to help the engineer in identifying the critical equipment/systems. In Inferential analysis, the plant field maintenance data is analyzed for independent and identically distributed data (IID) validation whether life data analysis (LDA) may be used or not in the reliability analysis. In this step, Laplace trend test and serial correlation test are used to test the IID assumption. The toolkit will also provides the engineer with the reliability measures for the analysis namely MTBF and failure rate. After the toolkit (RAT) is developed, a case study is conducted to validate the result generated by the toolkit. The results from the toolkit are compared with the result obtain analytically via Excel Spreadsheets. From the demonstrated results, the toolkit shows the ability to analyze the plant field data since the results obtain are exactly similar with analytical results. This study achieved the objective and will expedite the analysis process so that the major plant issues can be addressed timely and appropriately.

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CHAPTER 1

INTRODUCTION

1.1 Background Of Study

Reliability analysis has been applied through the oil and gas industry to serve as a quantified mean to assess plant operation issues and strategic tool for management to increase plant performance. Improvement of plant reliability even in a small scale can significantly contribute to plant profitability (Hussin, 2012). In improving plant operational performance, reliability analysis play a critical role. Reliability analysis identifies, measures and ranks plant weak points with respect to failure, leading to a basis for making better decision to enhance plant reliability (Hussin, 2012).

Quantitative reliability can be defined as 'The probability that an item (component, equipment, or system) will operate without failure for a stated period of time under specified conditions'. (Andrews and Moss, 2002). Reliability is therefore a measure of probability of successful performance of system over a period of time. Reliability assessment initially carried out for systems of components which are assumed to have settled down into steady-sate or useful-life phase as in bathtub curve (Andrews and Moss, 2002). The reliability characteristics of most component families will follow the so-called 'reliability bathtub' curve.

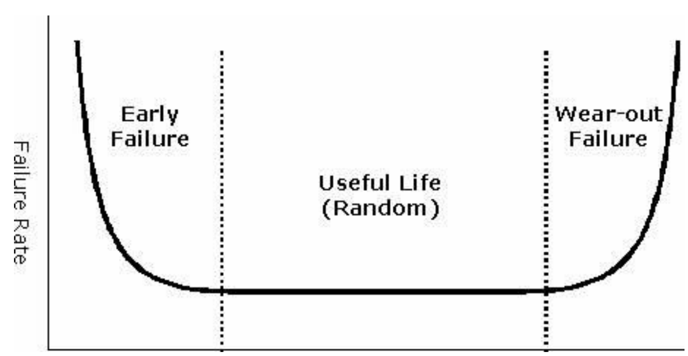

Figure 1 : Bathtub curve

A bathtub curve concept is used to describe a system with many non-repairable components where the failure of each component is statistically identical and independent as well as a repairable system. Bathtub curve can be divided into three phases as shown in Figure 1, where each phase is characterized by different types of distributions. The first phase is early failures, also known as infant mortality and burn-in period. Here, the failure rate is initially higher due to issues such as improper manufacturing, installation and poor materials, but is later gradually decreasing and level off as those problems are identified, solved and reduced and plant personnel's experience increased. In the useful life phase, the failure rate is approximately constant as the failures, assumed mostly stress-related occur at random. This flat-portion of bathtub is also referred as components or systems 'normal operating life' where realistically many components or system spend most of their lifetimes operating (Hussin, 2012). It is vital to understand the concept of bathtub curve since it will be referred in many cases since it reflects the characteristics of the failures in the reliability analysis.

In order to analyze the reliability of oil and gas plant equipment systems, a few measurement will be used. The following are some definitions in reliability measurement in this project according to Dieter and Schmidt (2013).

Table 1 : Common Reliability Measurement

Measurement Term	Definition
Cumulative time to failure, T	When N_0 components are run for a time t without replacing or repairing failed components.
Mean time to failure , MTTF	The sum of the survival time for all the components devided by the number of failures. MTTF is used for parts that are not repaired, like light bulbs, transistors and When a part fails in a non-repairable system, the system fails.
Mean time between failures, MTBF	The mean time between two successive component failures. MTBF is similar to MTTF,but is applied to components or systems that are repaired.

Reliability Analysis is one part of the Reliability, Maintainability and Availability (RAM) studies in analyzing plant performance. RAM plays critical roles such as identifies plant weak points for making effective solutions, assess various alternatives to achieve best option and provides a decision support tool for management to effectively align with organization's objective.

The study employed a few sets of techniques to carry the analysis of plant maintenance data. One of the techniques used in this project is exploratory analysis which consists of qualitative and graphical analysis. The outcomes from this stage of analysis are useful information such as major contributors to failures, highest mode of failures, trend existence and prime causes can be determined (Hussin, 2012). Exploratory analysis as recommended by most researchers,need to be carried out at the beginning of the analysis (Blischke and Murthy, 2000, Andrew and Moss, 2003). The next analysis, that are constructed on two test namely Laplace trend test and serial correlation test (dependency test), on the other hand are consisted of analytical and graphical analysis respectively. Graphical representation such as trend plotting of cumulative number of failures against cumulative time between failures. When the data plotted shows concave up pattern indicates deterioration, concave down pattern indicates improvement and linear plot indicates steady state of performance. Later on, Laplace trend test is utilized as analytical techniques to validate the data of identical data for Homogenous Poisson Process (HPP) versus monotonic trend hypothesis. Lastly, serial correlation test are used to validate the independence hypothesis.

1.2 Problem Statement

Reliability analysis nowdays plays a crutial part in the assessment of oil and gas plant maintenance data as it can determine the performance of the system and can directly affect the cost in term of profitability. Examples of such accidents within the chemical process and oil and gas industries are Flixborough Disaster, Bhopal Disaster, Piper Alpha Disaster, Phillips 66 Disaster, Sodegaura Refinery Disaster, DSM Chemical Plant Explosion, Stockline Plastics Factory Explosion and Texas City Refinery Explosion (Okoh and Haugen, 2013). Investigations of the accidents have uncovered a variety of causes that all related to maintenance. Hence, the management has always tried to implement the best method and approach to perform the corresponding reliability analysis for the best maintenance impact to their plant's systems.

One simple solution for these matters is by simply hiring an outside consultant to perform the analysis. But this method incurred high cost. Plant management can also uses software that available in the market to carry the reliability analysis. One common software used specifically for carrying reliability analysis is Weibull++ (a product of Reliasoft). Unfortunately, the analysis will never be easier in real situation since the data must already be in correct format in order for the software to analyze and produce result. In other words, the reliability analysis software (Weibull++) is designed with the assumption that all the elementary work with the data such as collecting and screening prior to the usage have been done.

Hence, by developing a toolkit that can help the analyst in preparing the data for the use in reliability analysis will significantly expedite the analysis process so that the major plant issues can be addressed timely and appropriately.

1.3 Objective

The objective of this project is to develop a computer based toolkit called as Reliability Analysis Toolkit (RAT) for analyzing the performance of the plant's systems for both exploratory and inferential analysis.

1.4 Scope of Study

The primary research work covers the exploratory and inferential analysis of failure and maintenance field data focusing on repairable items in the plant at operational phase.

CHAPTER 2

LITERATURE REVIEW

2.1 Importance of Reliability Analysis

Reliability analysis plays eminent role in oil and gas industry. Major loss and risk can be prevented with the necessary preventive action taken based on the result of the reliability analysis. British Petroleum recently sustained about USD 23 Billion in Mexico due to equipment failures (Macalister, 2010). Such dreadful tragedy could be avoided if the failures were detected earlier through reliability analysis.

The impact of reliability not only limited to oil and gas industry. Other industry also facing the same result as well. As stated by Orhan *et al.* (2008), based on their study regarding a chemical processing plant, maintenance cost contributed to a major portion of plant operating cost. Maintenance and repairs contributed as high as 17% of the total cost. From the study, even one significant of failure will obviously brings huge amount of losses if the plant performance is in a bad condition due to poor maintenance.

Mishra (2006) stated that the need for reliability was extremely felt because of failure of many military operations in spite of the best effort from the users during the World War II. A study was conducted revealed the following facts:

(i) The electronic equipments/systems used by Navy were operative for only 30% of its total available time because of frequent failures/maintenance problems.

(ii) Army equipments were either under repair/breakdown or commissioning for almost 60-75% of its total time, which again created problems for a successful mission.

2.3 Reliability analysis approach for plant at operational phase

As proposed by Hussin (2012), the approach will begin with exploratory analysis. Prior to performing analysis, the gathered data are normally subjected to further data manipulating processes. For reliability study, there are will be elementary and reliability analysis. In elementary analysis, simple plots like histogram, stem and leaf, box-whiskers, Pareto, scattered diagram and time series trend can be found useful to get a feel about the data, identifying key variables and possible errors in the data. Descriptive statistics such as mean, median, standard deviation are also used for comparison In the next level of exploratory analysis, more related reliability plots and analysis are conducted. These include rate of occurrence of failures (ROCOF) and trend plot. The main outcomes of the analysis are the identification of key factors affecting system lifetimes and assessment of trend in system's performance such as improving, deteriorating or constant. Knowing these, management can take necessary actions to further improve the system performance.

From the same reference, the next approach will be the inferential analysis. The purpose of this step is to determine the best statistical model to represent the data. Two major portions of works involved namely testing for independent and identical distributed (IID) data and fitting into lifetime distribution. For non-repairable items, the data is assumed IID, and hence can be directly assessed for lifetime distribution analysis (LDA). The data for repairable items, on the other hand, need to be arranged in chronological ordered before they can be tested for IID assumption. Laplace's test has been widely used to test for identically distributed assumption whereas serial correlation test is employed to determine independence condition Laplace's test is also used to determine whether the data can be fitted into HPP distribution. Alternative method is based on a steady state trend of a ROCOF plot. When the data exhibit IID characteristics, they will later be fitted into Mann test for more powerful test on specific distribution.

2.4 Pareto Principle

For phase 1 of the FYP, Pareto techniques is implemented in producing the result which is a part of exploratory analysis. Vilfredo Pareto, an Italian economoist, studied the distribution of wealth in different countries, concluding that a fairly consistent minority about 20% of people controlled the large majority about 80% of the society's wealth.This same distribution has been observed in other areas and has been termed the Pareto Effect.

The Pareto effect even operates in quality improvement : 80% of problems usually stem from 20% of the causes. Pareto Chart is often used to display the Pareto principle in action, arranging data so that the few vital factors that are causing most of the problem reveal themselves. Concentrating improvement effort on these few will have greater impact and be more cost effective than undirected efforts.

2.5 Laplace Trend Test

According to Ionescu and Limnios (1999), the Laplace test statistics, *L* is defined by

$$L = \frac{\frac{\sum_{j=1}^{\hat{n}} T_j}{\hat{n}} - \frac{1}{2}(b+a)}{\sqrt{\frac{1}{12\hat{n}}(b-a)^2}}$$

Where :

a = start of observation time

b = end of observation time

Tj = cumulative time between failure

n =number of failure

The Laplace test, also known as the centroid test, is a measure that compares the centroid of observed arrival times with the mid point of the period of observation. This measure approximates the standardized normal random variable (e.g., z-score). The Laplace test is one method to determine whether discrete events in a process have a trend. A score greater than zero means that there is an upward or increasing trend, and a score less than zero means there is downward or decreasing trend. When the score is greater than (less than) +1.96 (-1.96), we are at least 95% confident that there is a significant trend upward (downward). A score of zero means the trend is a horizontal line.

In determining the reliability of a repairable system, the Laplace test can and should be used to validate the use the constant failure rate (exponential) model. This is critical since the variable of interest in a repairable system is not the lifetime of the system as in classical reliability but the times of successive failures of a single system.

For example, each case of the following is assumed repairable, the observation period is 3800 time units, and event time is time between failure. To use the Laplace test, the inter arrival times below need to be converted to absolute or arrival times (start from the same point). A constant failure rate on a repairable system means the repairs are as "good-as-new." For 1600, 800, 400, and 200, having an increasing failure rate: the Laplace score is +1.00. For 400, 1600, 200, and 800, having a constant failure rate: the Laplace score is 0.0. For 200, 400, 800, and 1600, having a decreasing failure rate: the Laplace score is -1.09.

CHAPTER 3

METHODOLOGY

3.1 Generic Framework Methodology for Reliability Analysis

The approach used in developing RAT for reliability analysis of a system in plant as proposed by Hussin (2012) can be illustrated using six major steps as shown in Figure 3. Based on the reference, reliability analysis focuses on analysis of system failure data and frequency. The study of plant maintenance data will be based on qualitative and quantitative analysis to determine major factors affecting system reliability so that appropriate actions can be recommended.

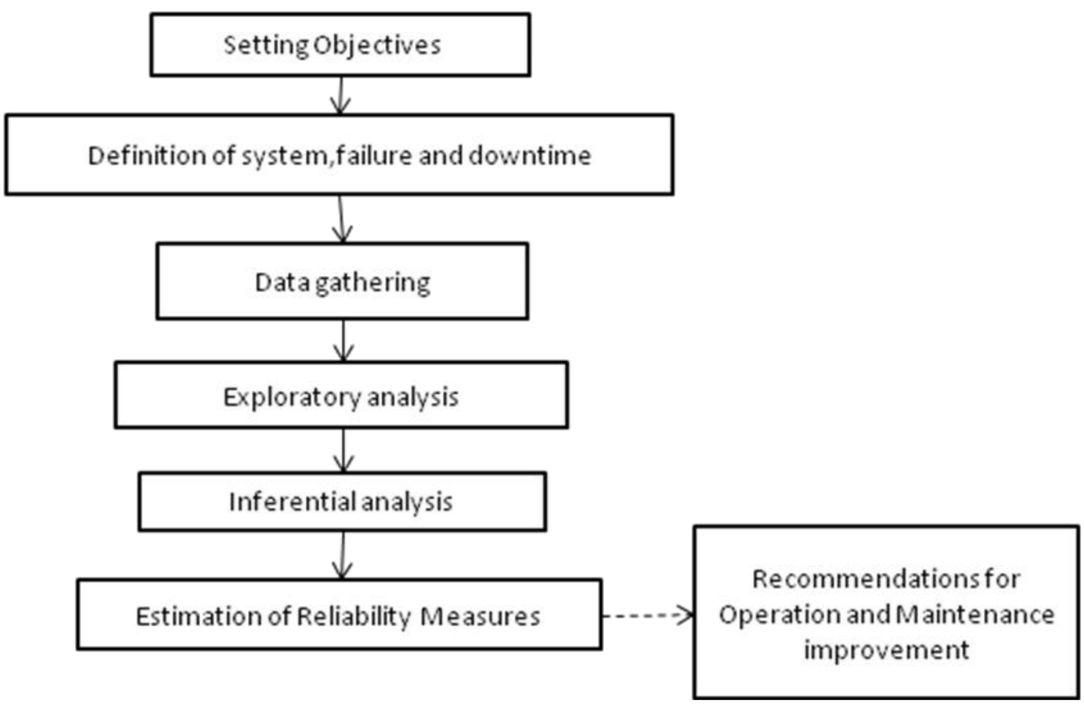

Figure 2 : Generic framework for reliability analysis of a plant system

3.2 Project Methodology for FYP

The project is divided into two phase (phase 1 and phase II) as illustrated in Gantt Charts in Appendix A. Each phase has different objective that is to be accomplished by the end of the study period.

Figure 3 shows the approach employed in completing the project. After the objective is determined, preliminary and literature research are conducted followed with data gathering process. This stage is important to provide initial ideas and concept about the corresponding topic.

The framework development is development process of the 'heart' of the toolkit that consisted of selected analysis tools for analyzing the maintenance of failure data from the field (plant). After the framework is validated, the project proceeds to the next steps into toolkit development process.

The toolkit development is the development process of the software where the failure data is entered and result is automatically generated. This step cover the design process of the toolkit interface such as the input form and database. The final stage of the project is to validate the toolkit using case studies before it is officially completed for usage.

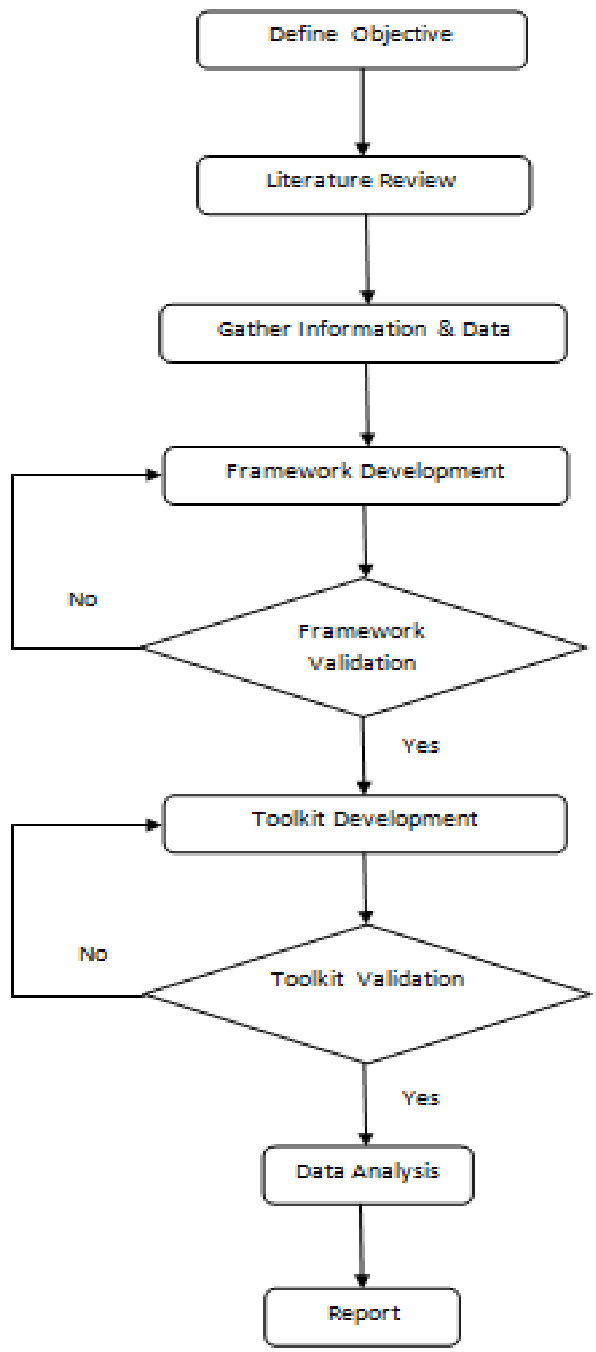

Figure 3 : Flowchart of project methodology

3.3 Framework Methodology for FYP

As mentioned earlier in this report, the framework approach used in the RAT that is based on the proposed generic framework in Figure 3 is using exploratory and inferential analysis.

To elaborate more details about the exploratory and inferential analysis, a flowchart is constructed as shown in Figure 4. Prior to performing analysis, the gathered data are normally subject to further data manipulating processes such as categorization, classification, rearrangement and reordering of data.

From Figure 4, there are two part for inferential analysis namely testing for independent and identically distributed (IID) data and fitting into lifetime distribution. However, it is important to ensure the data exhibit no trend (constant failure). If there is trend existence in the data (not IID), it is not applicable to perform reliability analysis using life data analysis (LDA).

Therefore, to support the hypothesis that the data is IID, two type of test are used in this methodology. The first test involved is Laplace trend test to test for identically distributed assumption (Ascher and Feingold, 1984). The second test is serial correlation test (dependency test) to determine independence condition (Ansell and Phillips, 1994).

Figure 4 : Flowchart of framework for toolkit

3.4 Methodology For Toolkit Development

The following figure 5 shows the processes for developing the toolkit. RAT is designed and build using Microsoft Excel as the main database platform as shown in Figure 6 and Visual Basic as the command language as shown in Figure 7. Macro also used for programming simple task in the toolkit. After designing the interface architecture, the next steps involved is to define the structure and Excel functions that will be used in the toolkit. Some of the Excel functions used are IF, COUNTIF, MAX, AVG, SUM and etc. After the database is established, the toolkit is encoded with Visual Basic and Macro. Some of the coding used in programming the toolkit are shown in APPENDIX B.

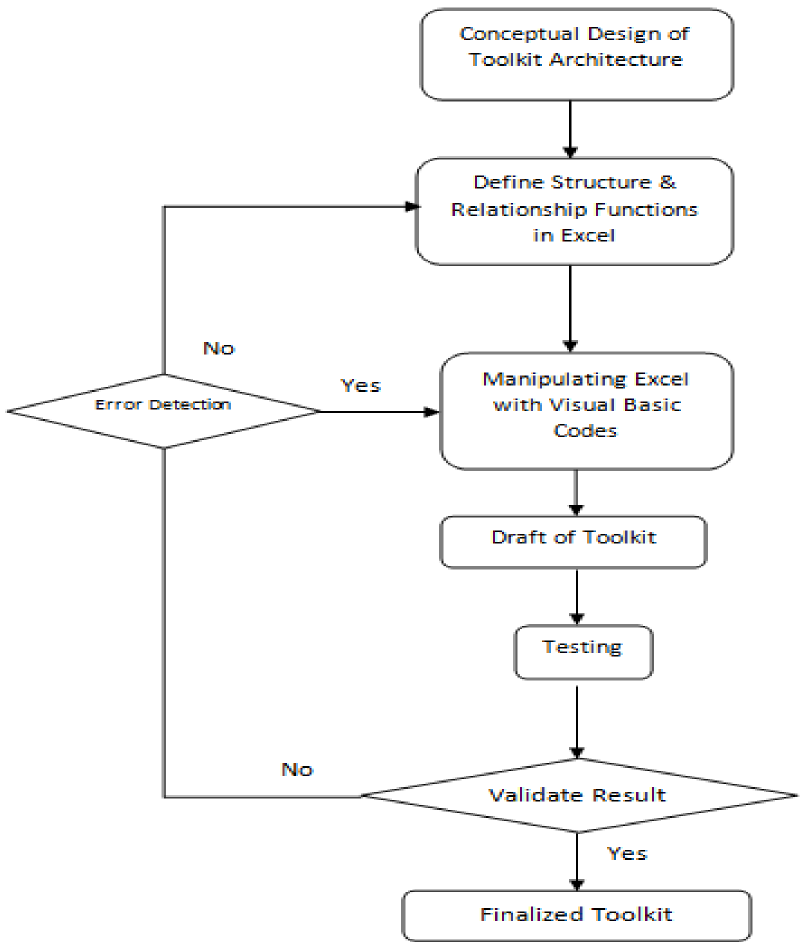

Figure 5 : Flowchart of toolkit development

The advantages of using Visual Basic for programming the toolkit instead of depending on Macro alone is that Visual Basic have the capabilities such as performing higher level of command complexity, processing data in background, featuring multi purpose form and perform conditional looping. On the other hand, Macro can only perform simple command and repetitive shortcuts.

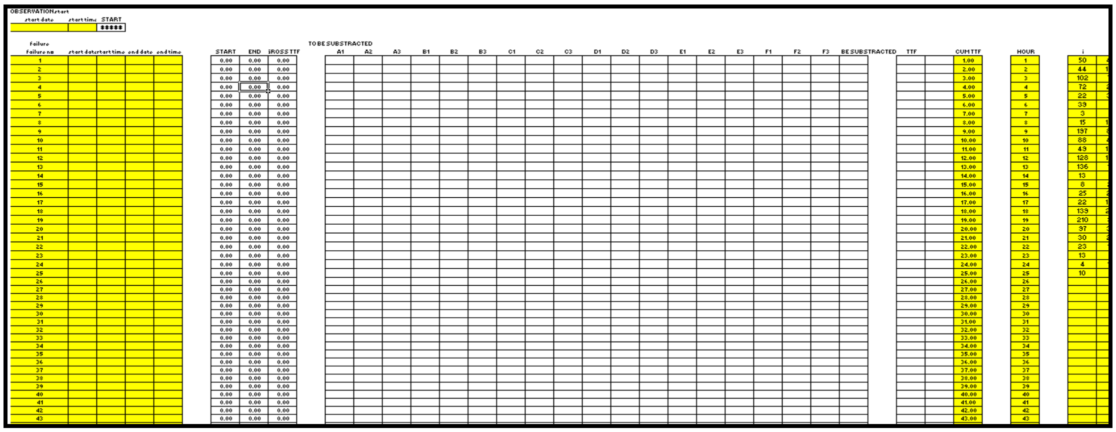

Figure 6 : Building the database platform using Excel

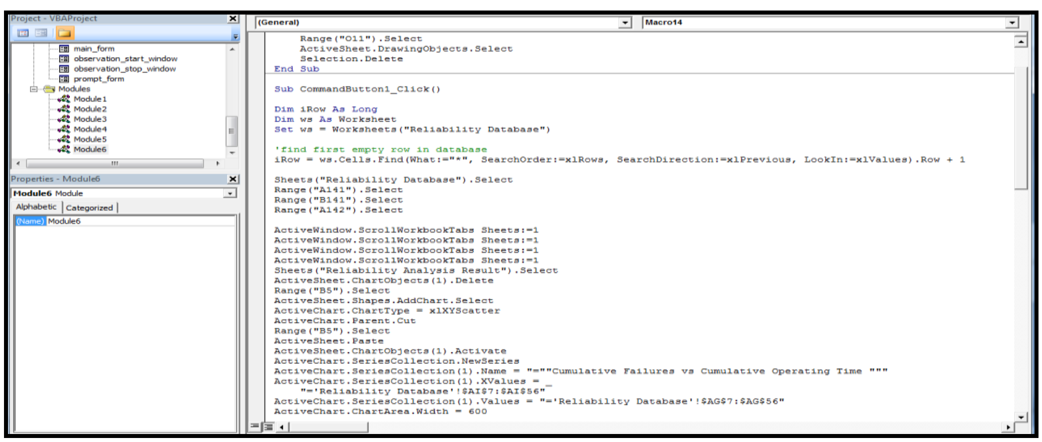

Figure 7 : Encoding for data manipulation using visual basic application embedded in Excel

CHAPTER 4

RESULT AND DISCUSSION

4.1 Toolkit Interface

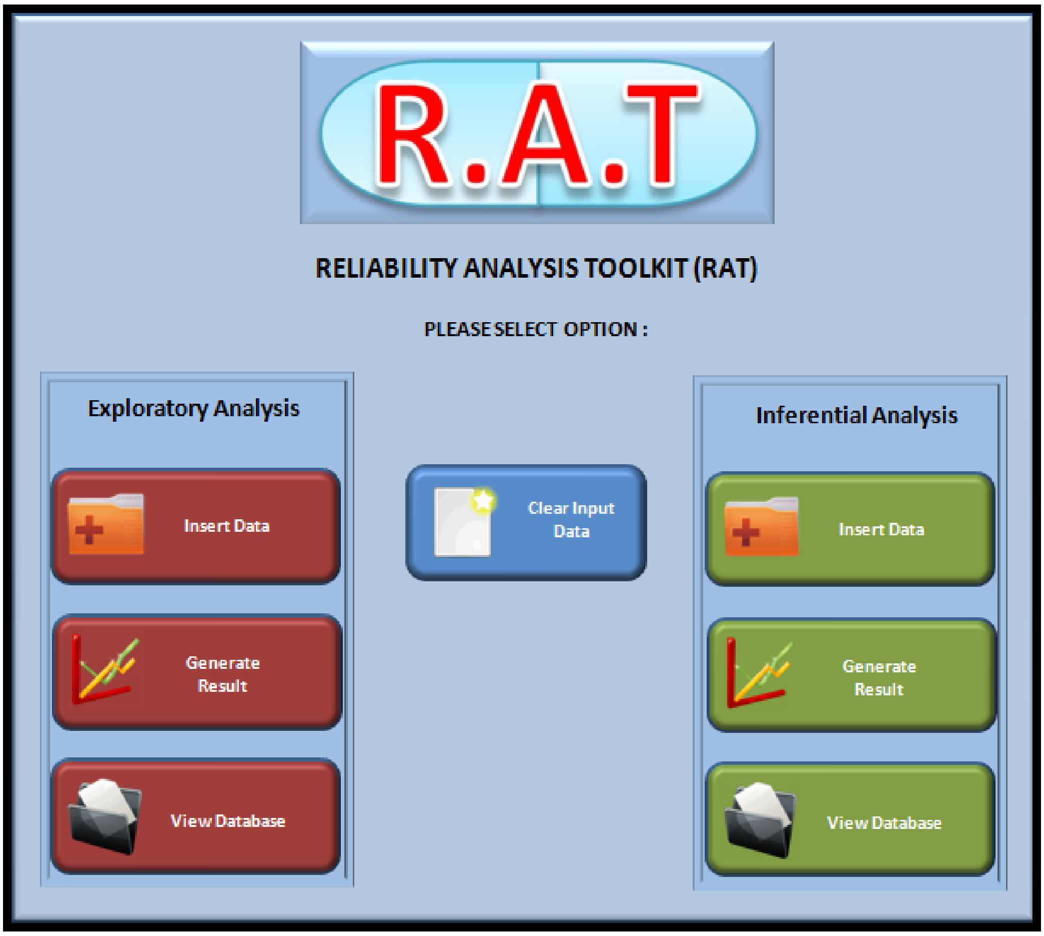

Figure 8 : Main Menu Interface

Figure 8 illustrates the main interface of RAT where the engineer is able to select the option for the analysis. All of the tasks is accomplished by using buttons as shown in Figure 8. Both of the command buttons for exploratory and inferential are programmed in separate features to enable the analyst to obtain the result of either analysis that is in the point of interest.

The plant field maintenance data collected from the computerized management system (CMMS) such as from SAP or Excel spreadsheet are captured using a form window as shown in Figure 9.

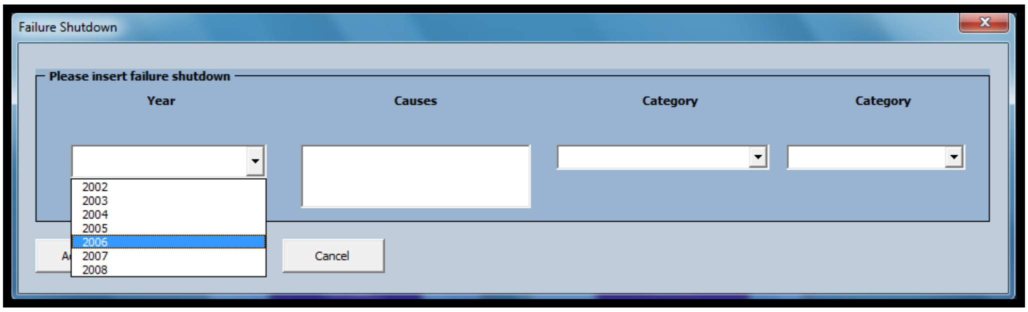

Figure 9 : Form interface to insert data for exploratory analysis

From Figure 9, the user is required to enter the year of the failure shutdown, the causes of the failure shutdown, the subsystem categories and the discipline categories for the toolkit to process for exploratory analysis.

4.2 Exploratory Analysis

Graphical charts used to help the analyst (exploratory analysis) are automatically generated as shown in Figure 10, 11, 12 and 13. From the charts in Figure 10, the analyst can determine the major contributor to overall failures within the specified period of time that the analyst had entered into the toolkit. From this result, the area that contributed to 20% of failures should be addressed for necessary corrective actions in priority since it affects the remaining 80% of failures.

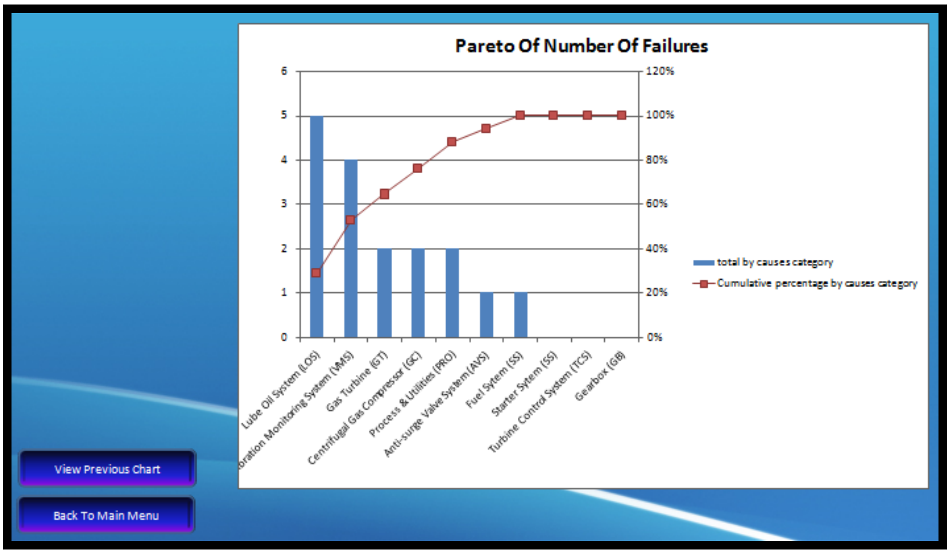

Figure 10 : Generated result for exploratory analysis (Pareto chart of failure according to sub-systems)

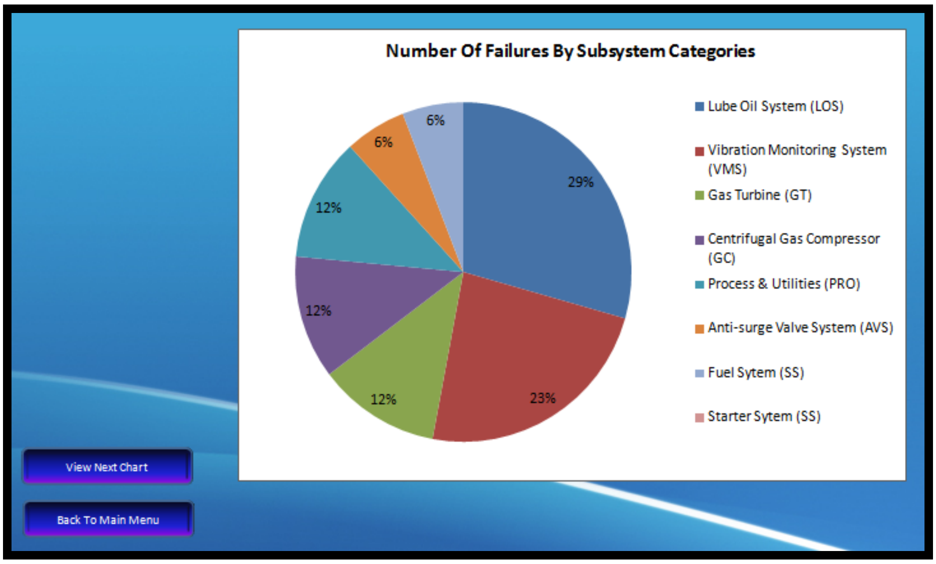

Figure 11 : Generated result for exploratory analysis (failure percentage according to sub-systems)

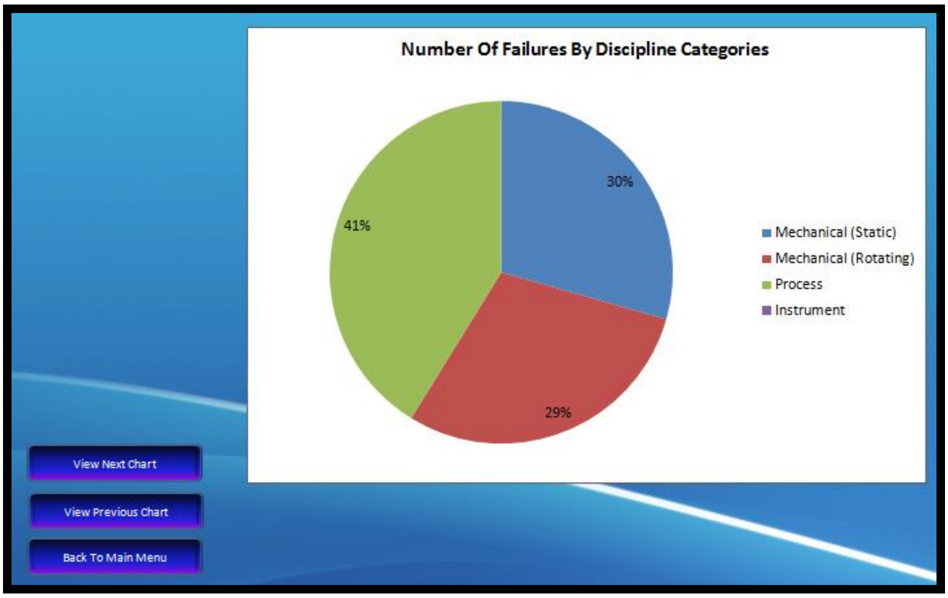

Figure 12 : Generated result for exploratory analysis (failure percentage according to disciplines)

From figures 11 and 12, engineers can address to the management regarding the overall percentage of maintenance cost incurred up to the observation end time by the area.

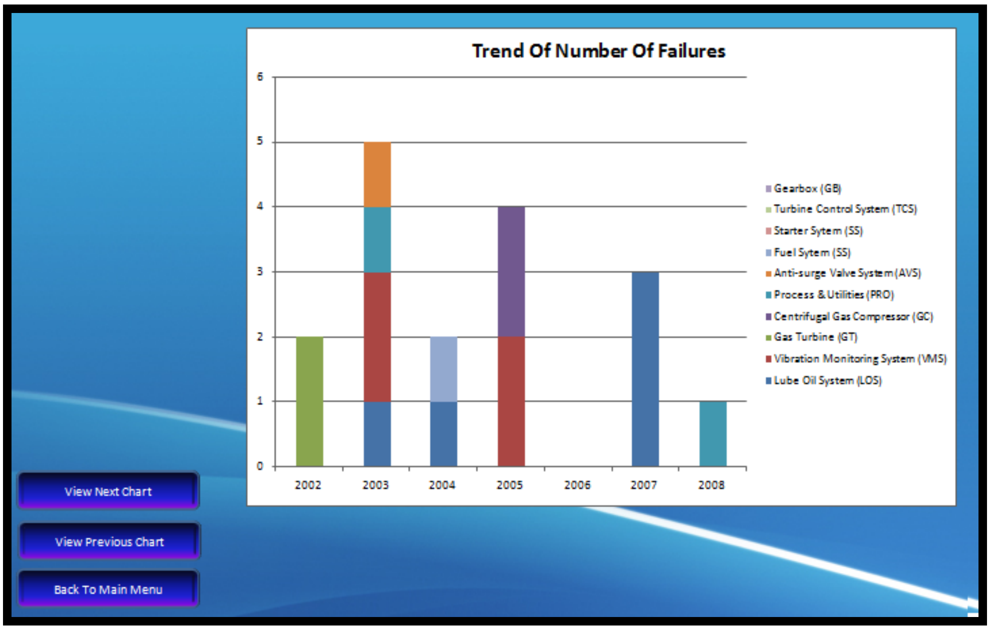

Figure 13 : Generated result for exploratory analysis (failure frequency according to sub-systems)

From the chart displayed in Figure 13, the analyst will be able to see the trend of the failure with respect to time according to the subsystem category. This chart is vital in informing the analyst about the failure that recently occurred and the failure that previously occurred.

4.3 Inferential Analysis

All the data for the inferential analysis is captured using the same method as in exploratory analysis, that is using form windows. Multiple form windows are used for inserting the data since the complexity of analysis exhibit in this stage is higher than the previous exploratory analysis. In addition of that, the usage of multiple form windows also help to prevent the analyst from confusion as a result of overcrowded information to be filled at once. Figure 14,15, 16 and 18 shows the form windows in chronological orders. The prompt window as seen in Figure 17 is used to command the RAT to automatically distinguish between failure or time truncated result.

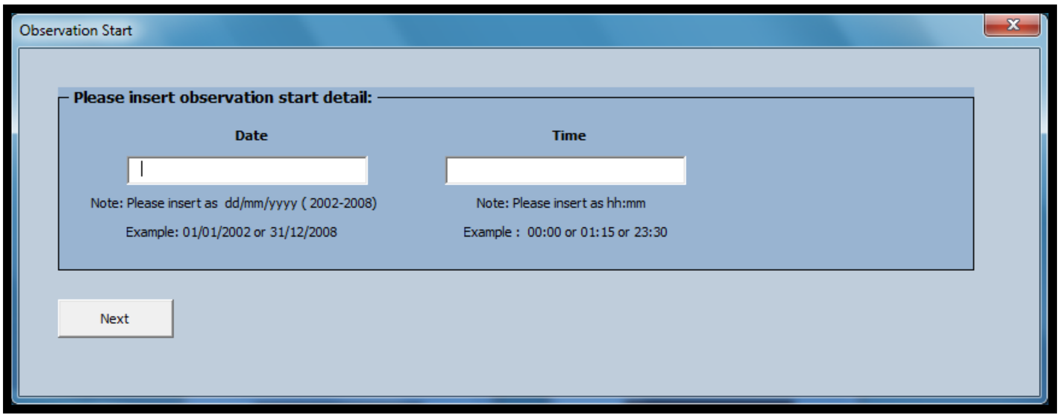

Figure 14 : Form window interface to insert start observation time

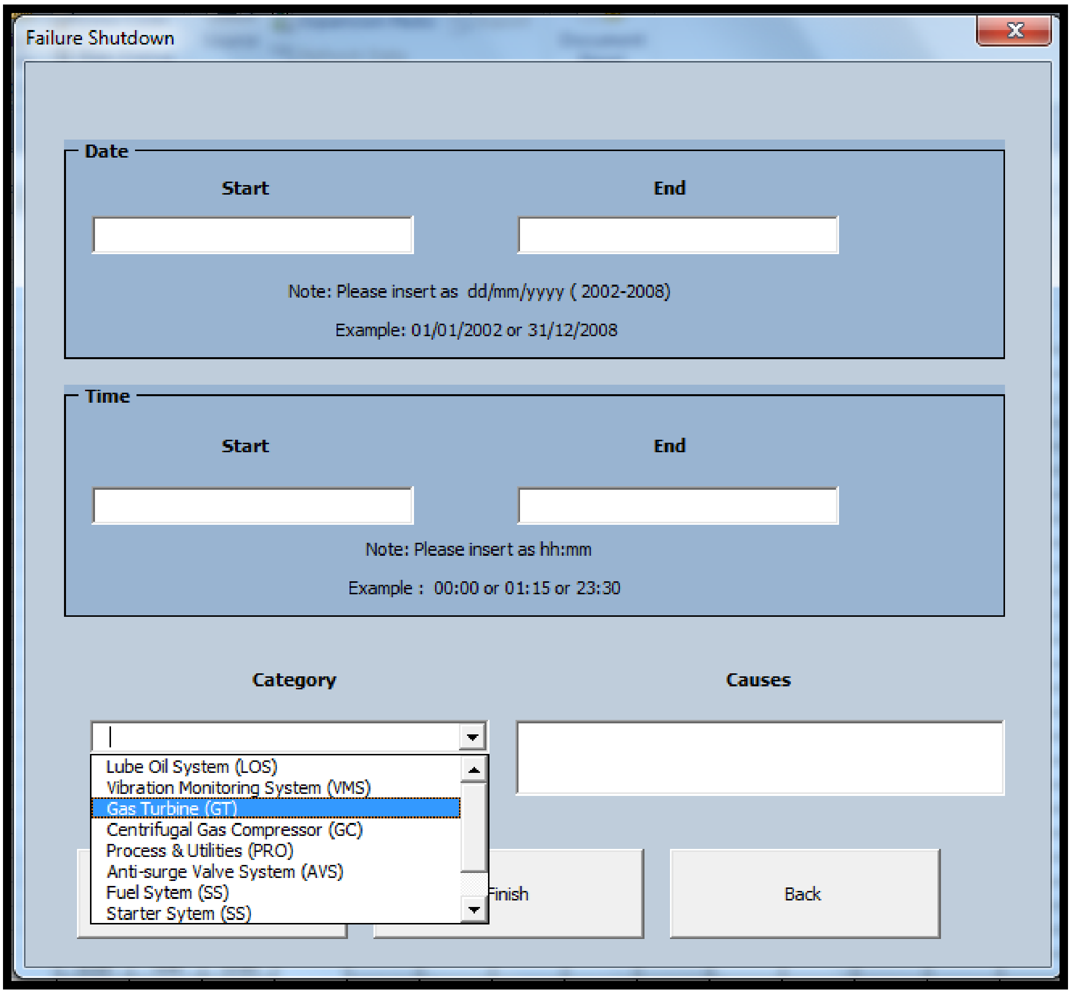

Figure 15 : Form window interface to insert failure shutdown data

Figures 14 and 15, 16 and 18 show the input data that need to be entered for inferential analysis. In order to ease the analyst, the toolkit will automatically substract out the nonfailure shutdown from the overall failure shutdowns to determine the time between failure for the operating time. The analyst will also be able to choose for the end observation method either time or failure truncated as shown in Figure 17. These steps will significantly saves a lot of time for the analyst in screening the data.

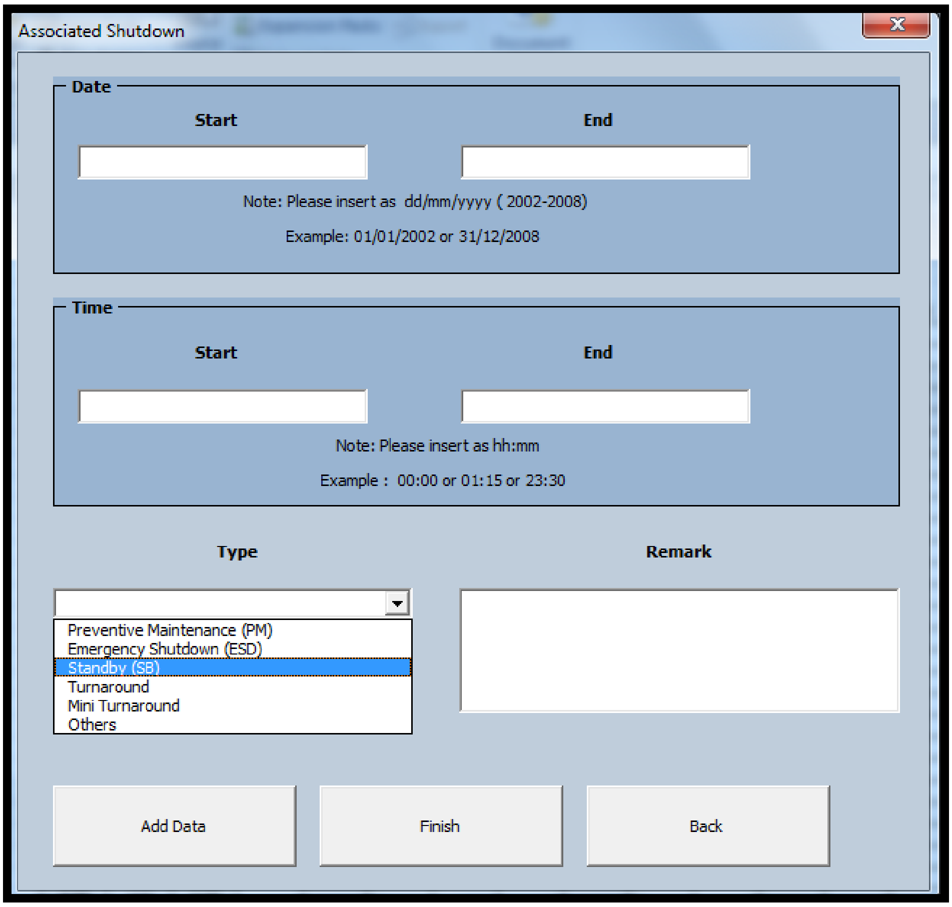

Figure 16 : Form window interface to insert associated shutdown data

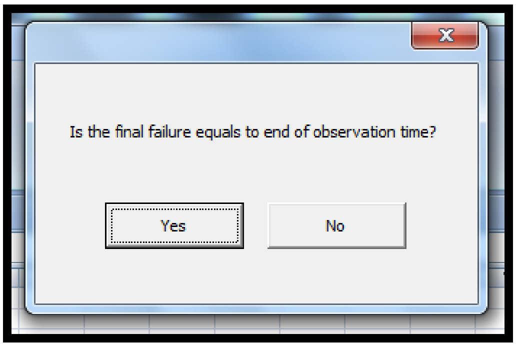

Figure 17 : Prompt window interface to determine either failure truncated or time truncated

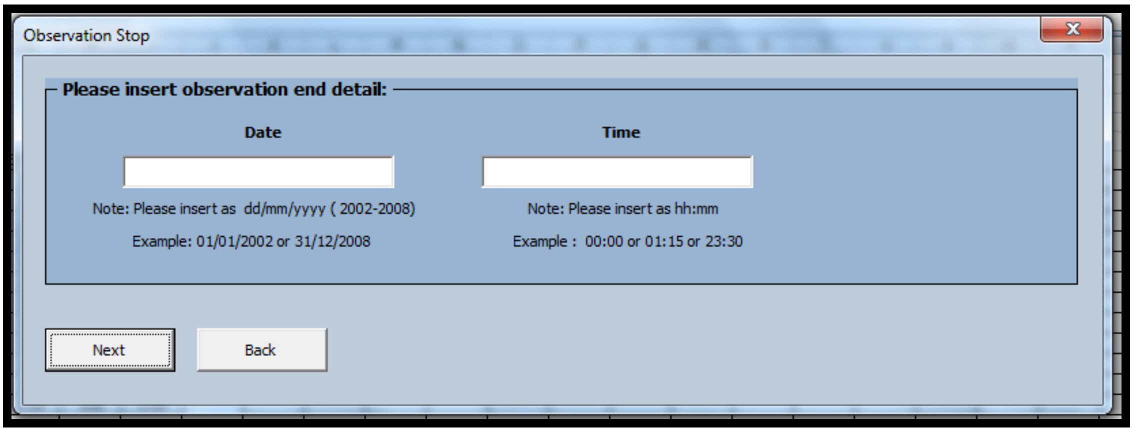

Figure 18 : Form window interface to insert end of observation time

For inferential analysis, the inserted data is automatically plotted for graphical analysis as shown in Figure 19. This plot helps the analyst to obtain a rough understanding about the trend in the data such as a concave up shows increasing in failure rate, concave down signifies decreasing failure rate and linear plot shows constant failure rate before proceeding with detecting the trend later using statistical tool (Laplace Trend Test) equipped in the toolkit.

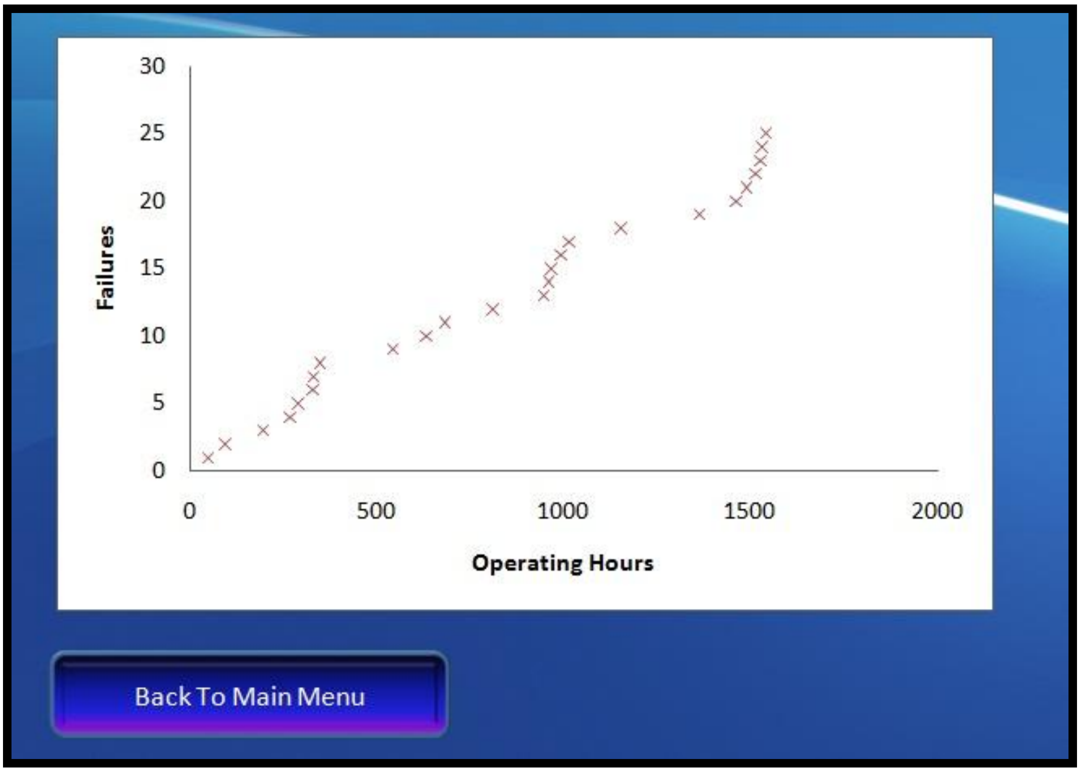

Figure 19 : Cumulative failure vs cumulative operating hours

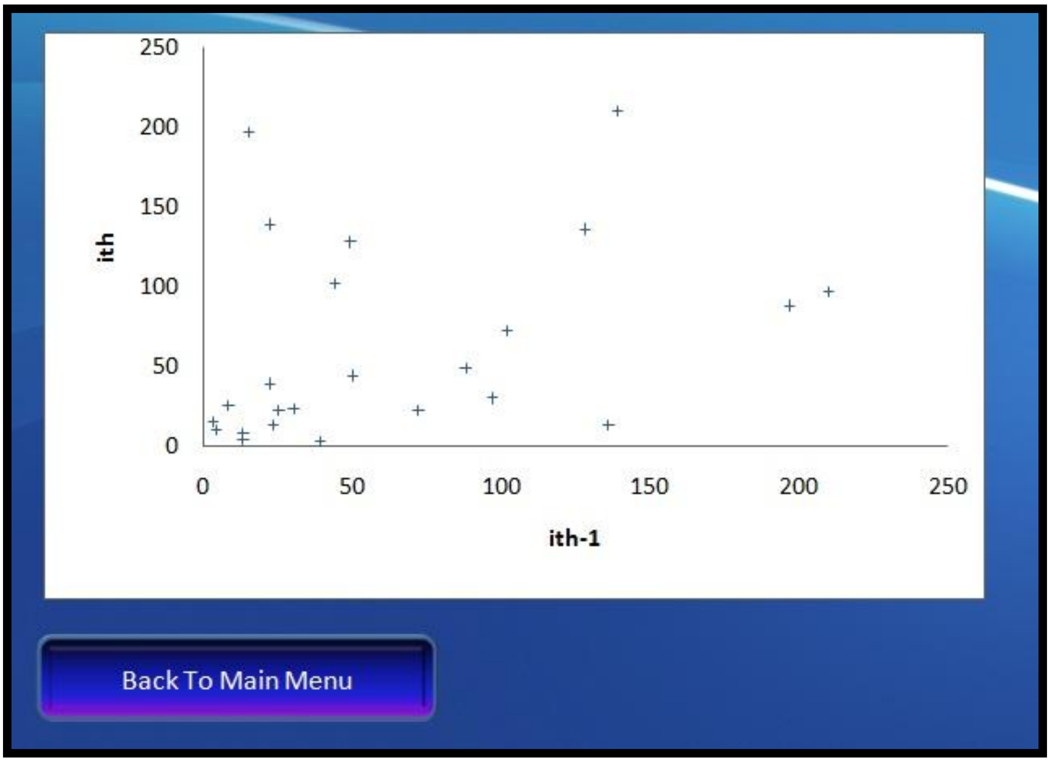

Figure 20 : Dependency Test

The next plot generated in inferential analysis is dependency plot or independent test as shown in Figure 20. The plot helps the analyst to graphically check whether the data is related to each other or not. If the data is scattered, the assumption for independent is validated.

The analysis ends with the result summary as shown in Figure 21. The toolkit will automatically generates the results that are the identical test, independent test as well as reliability measures for the analyzed system that are mean time between failure (MTBF) and failure rate (λ). If the L value calculated by the tookit is within the range of -1.96 and 1.96, the data follows no trend by 95% of confidence. Otherwise, the data follows a trend and LDA method is not applicable for the reliability analysis.

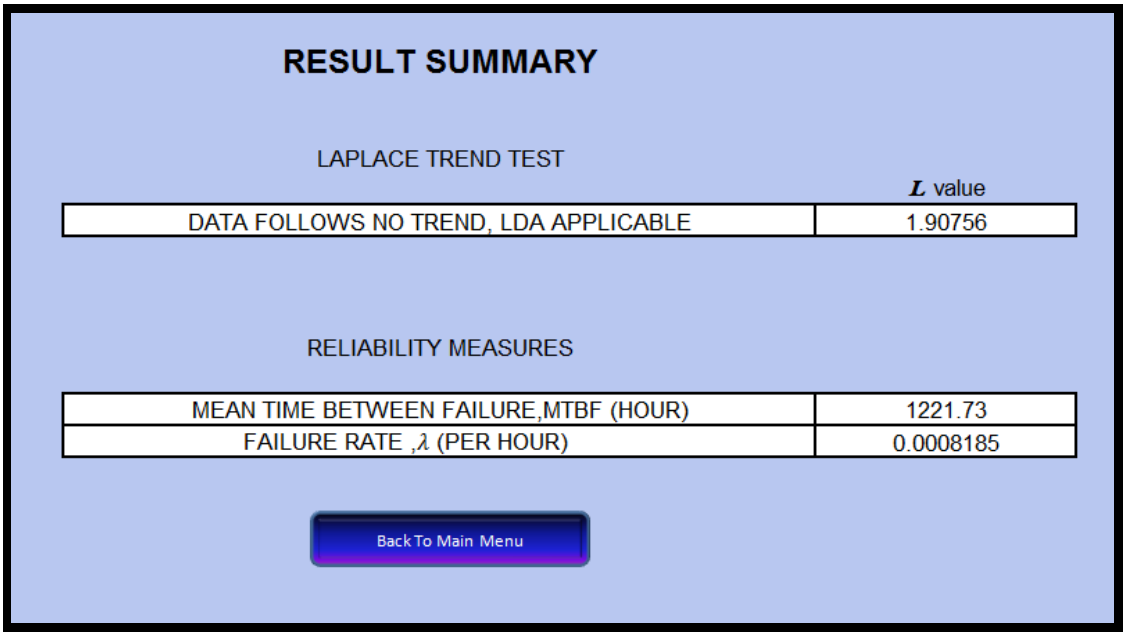

Figure 21 : Result Summary for Analysis

4.2 Toolkit Validation Case Study

In order to validate the toolkit, a case study is conducted. For this case study an analysis is carried on a gas compression train that used to transport the crude oil from offshore platform to the onshore terminal. The plant is categorized into 10 areas or subsystem for the purpose of data analysis which are Gas Turbine (GT), Centrifugal Gas Compressor (GC), Starter System (STS), Gearbox (GB), Fuel System (FS), Vibration Monitoring System (VMS), Anti-surge Valve System (AVS),Lube Oil System (LOS), Process and Utilities (PRO), Turbine Control System (TCS).

For the validation process, the result of the toolkit is compared with the analytical result. Analytical results are obtained using calculation and plotting via Excel Spreadsheet.

The toolkit managed to produces the exact result for all the result. Examples of the compared results are as seen in Figures 22, 23, 24 and 25 respectively.

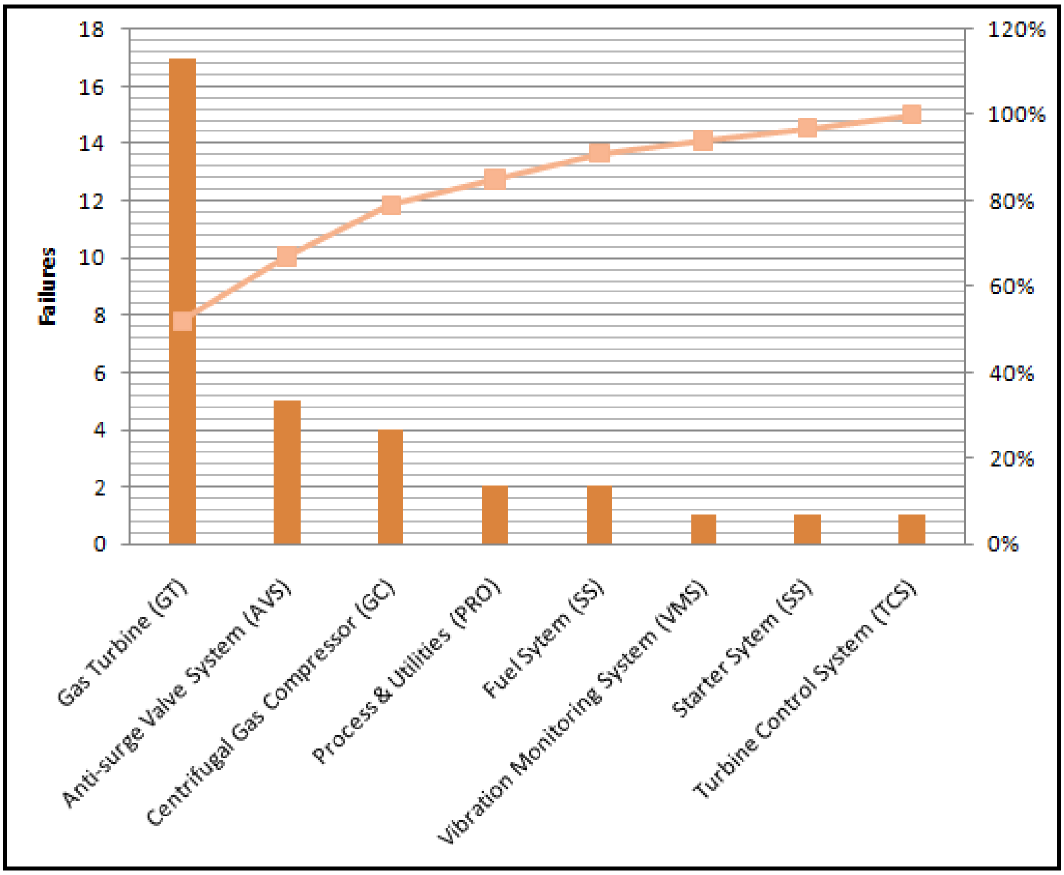

Figure 22 : Analytical Result for Pareto of Failures

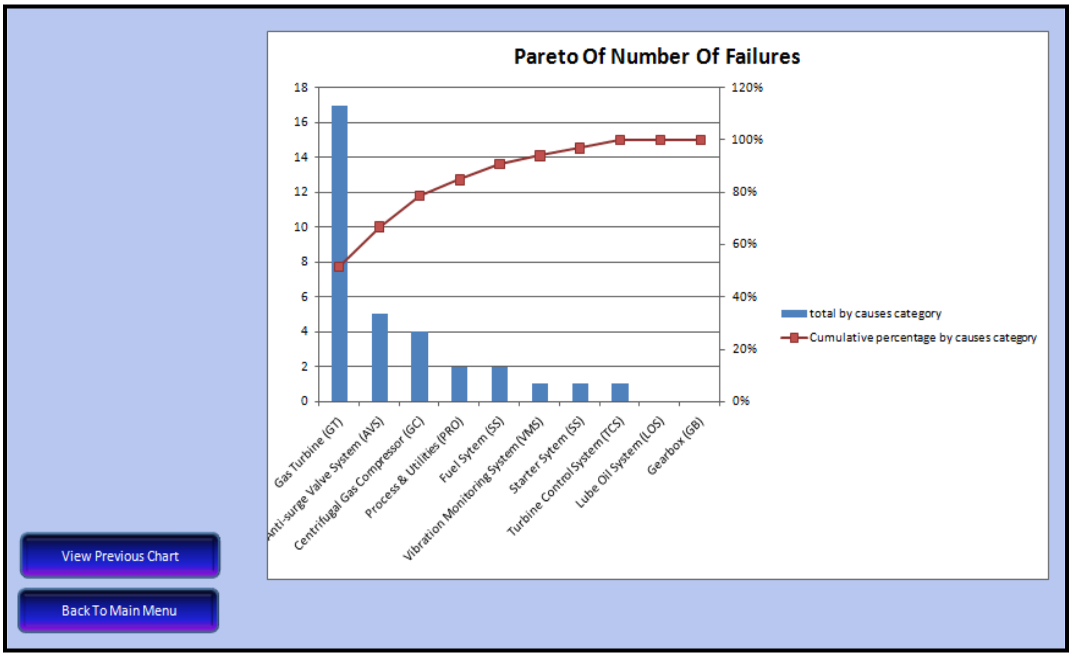

Figure 23 : Toolkit Result for Pareto of Failures

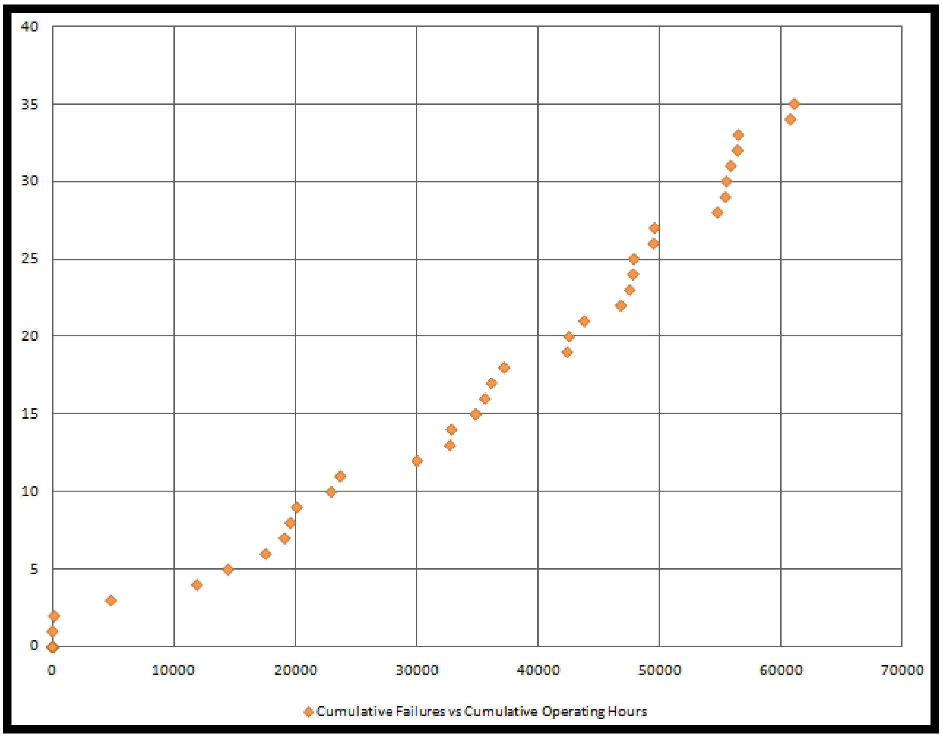

Figure 24 : Analytical Result for Cumulative Failure Plot

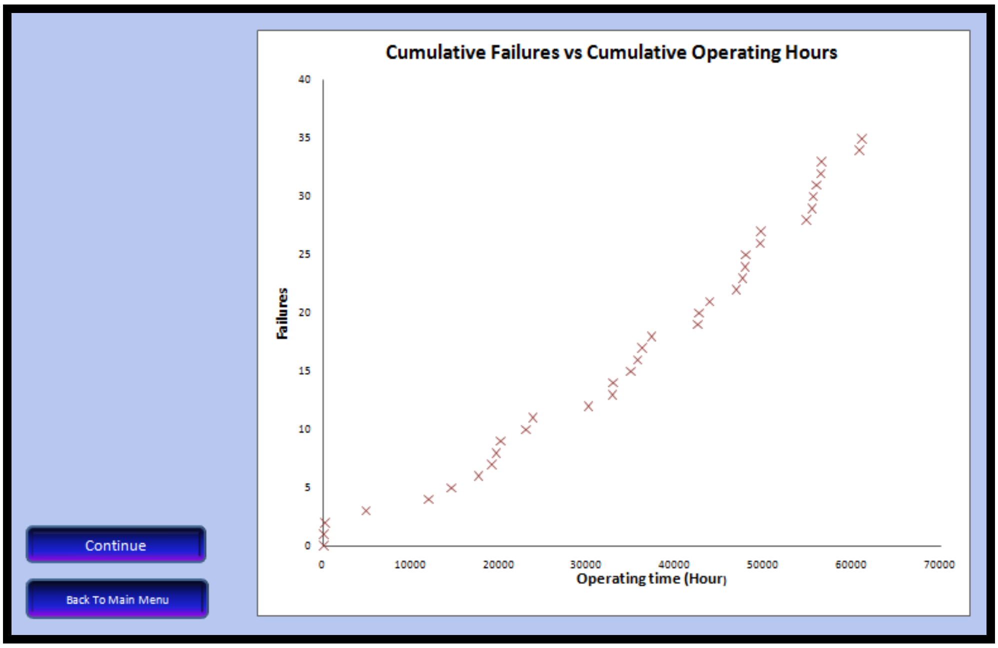

Figure 25 : Toolkit Result for Cumulative Failure Plot

Table 2 : Comparison Between Toolkit And Analytical For Various Values

Comparison	Toolkit	Analytical
L Value	1.9075	1.9075
Mean Time Between Failure,MTBF (Hour)	1221.73	1221.73
Failure Rate ,λ (Per Hour)	0.0008185	0.0008185

For inferential analysis, the value of the Laplace calculated by the toolkit is compared with analytical result as shown in Table 2. The result shows no significance in differences. Similarly with the reliability measures (failure rate and MTBF) generated from the toolkit shows insignificance differences.

CHAPTER 5

CONCLUSIONS & RECOMMENDATIONS

The objective of the project to develop Reliability Analysis Toolkit (RAT) has been achieved. As demonstrated, the toolkit can analyze the plant field data for both exploratory and inferential analysis. In exploratory, graphical chart such as Pareto and trend chart are plotted to highlight critical area/system that need to be addressed by engineers. The result of the inferential analysis will assist engineer in determining whether the data is IID or not. Finally, the reliability measures such as MTBF and failure rate will be generated for the reliability analysis.

As for recommendations for future development, the size of the database may be increased and the toolkit may be improvised to perform various tests specifically in conducting the reliability analysis such as Mann test (Renewal Process). In addition of that, the toolkit may also be equipped with maintainability and availability analysis functions. User interface may also be upgraded to enable the user to easily customize the option features in the window forms accordingly with the plant's specifications.

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APPENDICES