Development of Maintainability Analysis Toolkit (MAT) for Analysing Plant Maintenance Data of Gas Processing Plant at Operational Phase

by

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CERTIFICATION OF APPROVAL

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Approved by,

____
(Dr. Hilmi bin 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.

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AMIRA NABILLA BINTI NORAHMAD SHAH

ABSTRACT

Maintainability analysis is a part of Reliability, Availability, and Maintainability (RAM) analysis that is used to analyse the plant maintenance data at operational phase in order to ensure the smooth running of a plant operation. Maintainability analysis plays a big role in detecting which subsystems and equipments that contribute the highest downtime and Mean Time to Repair (MTTR) in a system. By recognizing the problems, it helps in preventing any unnecessary maintenance plan to be performed on the less critical equipments and subsystem thus, reducing the plant maintenance cost. The study is conducted due to the lack of software that can perform the maintainability analysis since the maintenance plan is mostly focused on reliability analysis instead of maintainability analysis. The objectives of the study are to develop a framework that can capture maintenance data from the plant and to develop a computer-based toolkit from the developed framework. Maintainability analysis is often abandoned due to the tedious process in extracting the right information needed from the various plant maintenance data. Therefore, a toolkit that can perform the maintainability analysis of the plant maintenance data is needed. The project uses Gas Compression Train (GCT) system maintenance data in the Gas Processing Plant (GPP) as the ground for the analysis to take place. The analysis is done by developing a toolkit by using Visual Basic Application (VBA) of Macros in the Microsoft Excel that aims for a user-friendly interface with a thorough analysis of maintainability. The output is the exploratory analysis that is presented in the form of histogram, pie charts, pareto, and trend charts.

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LIST OF ABBREVIATION

ADT	Administrative Delay Time
AVS	Anti-surge Valve System
CM	Corrective Maintenance
Cost/OH	Maintenance Cost per System/Product Operating Hour
FS	Fuel System
GB	Gearbox
GC	Centrifugal Gas Compressor
GCT	Gas Compression Train
GPP	Gas Processing Plant
GT	Gas Turbine
IID	Independent and Identically Distributed
LDA	Life Distribution Analysis
LDT	Logistic Delay Time
LOS	Lube Oil System
MAT	Maintainability Analysis Toolkit
MDT	Mean Downtime
MMH/OH	Maintenance Man-Hours per System/Operating Hour
MTBF	Mean Time Before Failure
MTBM	Mean Time Between Maintenance
MTBR	Mean Time Before Replacement
MTTR	Mean Time to Repair

NHPP	Non-Homogenous Poisson Process
PdM	Predictive Maintenance
PM	Preventive Maintenance
PRO	Process and Utilities
RAM	Reliability, Availability, and Maintainability
SAP	System and Applications and Products in Data Processing
SERP	Specific Equipment Reliability Plan
SS	Starter System
TAT	Turn Around Time
TCS	Turbine Control System
VB	Microsoft Visual Basic for Windows
VBA	Visual Basic Application
VMS	Vibration Monitoring System

CHAPTER 1

INTRODUCTION

1.1 Project Background

Analysing plant maintenance data is one of the most crucial part in determining the reliability and maintainability of the plant equipments. This is to ensure the smoothness of the plant operation and avoiding any unnecessary additional cost in sustaining the maintainability of the plant.

Maintainability as a part of the Reliability, Availability, and Maintainability (RAM) analysis plays an important role in sustaining the operation of a plant. Maintainability is often related to maintenance where maintainability is one of the characteristics of design, and maintenance is the result of the design. By sustaining a maintainability of plant, it could help in reducing costs of maintenance and increase the availability as well as the reliability of a plant.

The drive of this is study is due to lack of computer-assisted tools and software in analysing the maintainability due to the fact that most existing toolkits and software are focusing more on reliability analysis.

1.2 Problem Statement

The existing process used by the petrochemical plants in analyzing the plant maintenance data is not user friendly and time consuming because the process of extracting data from plant database is too tedious due to various type of data which mostly not in standardized format that it is often not comprehensive. Therefore, to overcome the problem, there is a need to develop a toolkit which can facilitate the maintainability data analysis.

The proposed toolkit will assists engineers to systemically analyze plant data in a more efficient way hence will help them to make a better decision making in improving the performance of the plant.

1.3 Objectives

There are two main objectives of the project.

1. To develop a framework on how to capture and analyze the maintainability data from the plant and the maintenance field data.

2. To develop a computer-based Maintainability Analysis Toolkit (MAT) based on the developed framework. The toolkit will be able to perform:
   - i. Exploratory analysis consisting Pareto, trend chart, pie chart, and histogram.
   - ii. Maintainability measures such as Mean Downtime (MDT).
   - iii. Perform all the analysis mentioned above for both Unplanned Shutdown (USD) and Planned Shutdown (PSD)

1.4 Scope of Study

Scope of study for the development of the toolkit invoves:

1. Plant maintenance data at operational phase
2. Planned Shutdown (PSD)
3. Unplanned Shutdown (USD)
4. Exploratory analysis
5. Maintainability measures – Mean Downtime
6. Microsoft Excel
7. Macros and VBA integration in Microsoft Excel

1.5 Project Relevancy

The project requires knowledge in Reliability, Availability, and Maintainability (RAM) analysis especially in determining the MDT and MTTR of the maintenance plant data. The project also requires the knowledge and skills in using programming function of Macros VBA in Microsoft Excel as most of the project requires the usage of coding and functions to perform the analysis and designing the user interface. Probability and statistic knowledge is necessary in formulating the exploratory analysis in performing the Pareto charts, Laplace test, and also in determining the IID condition.

CHAPTER 2

LITERATURE REVIEW

2.1 Maintainability

Maintainability is one of the most essential parts in ensuring a smoothness operation of a plant aside from reliability. It is a kind of quality characteristic to make equipment maintenance convenient, prompt, and economic (Yang and Yu, 2012).

According to Blanchard and Fabrycky (2006) with a few additions on the definition by Blanchard, Verma and Peterson (1994), maintainability is defined as a characteristic of design and installation which is expressed as the probability that an item will be retained in or restored to a specified condition within a given period of time, when maintenance is performed in accordance with prescribed procedures and resources. (Blanchard, Verma, and Peterson, 1994)

Maintainability needs to be measured in order to analyze the data and it involves a combination of a few factors. There measures of maintainability according to Blanchard, Verma and Peterson (1994) are simplified and is shown in the Fig. 1 which classified the measures into six group. In this project, the measures of MMH/OH and LCC are not taken into account since the project is focusing on the time taken for maintenance and repairing which basically in the combinations of MTBM, MTBR, MDT, and TAT.

Maintenance downtime (MDT) plays an important role is the project since the maintainability is calculated from the downtime which, according to Blanchard and Fybrycky (2006) and Blanchard, Verma, and Peterson (1994) breaks down to three parts:

1. **Active Maintenance Time** which also includes the Corrective Maintenance (CM) and Preventive Maintenance (PM) as its function.

2. **Logistics Delay Time (LDT)** which means the time elapsed while waiting for some required logistics resource (Blanchard and Fabrycky, 2006) like spare parts, a facility, procedure, service, or a particular test.

3. **Administrative Delay Time (ADT)**. It is a downtime as a result of some administrative priority or constraint (Blanchard and Fabrycky, 2006).

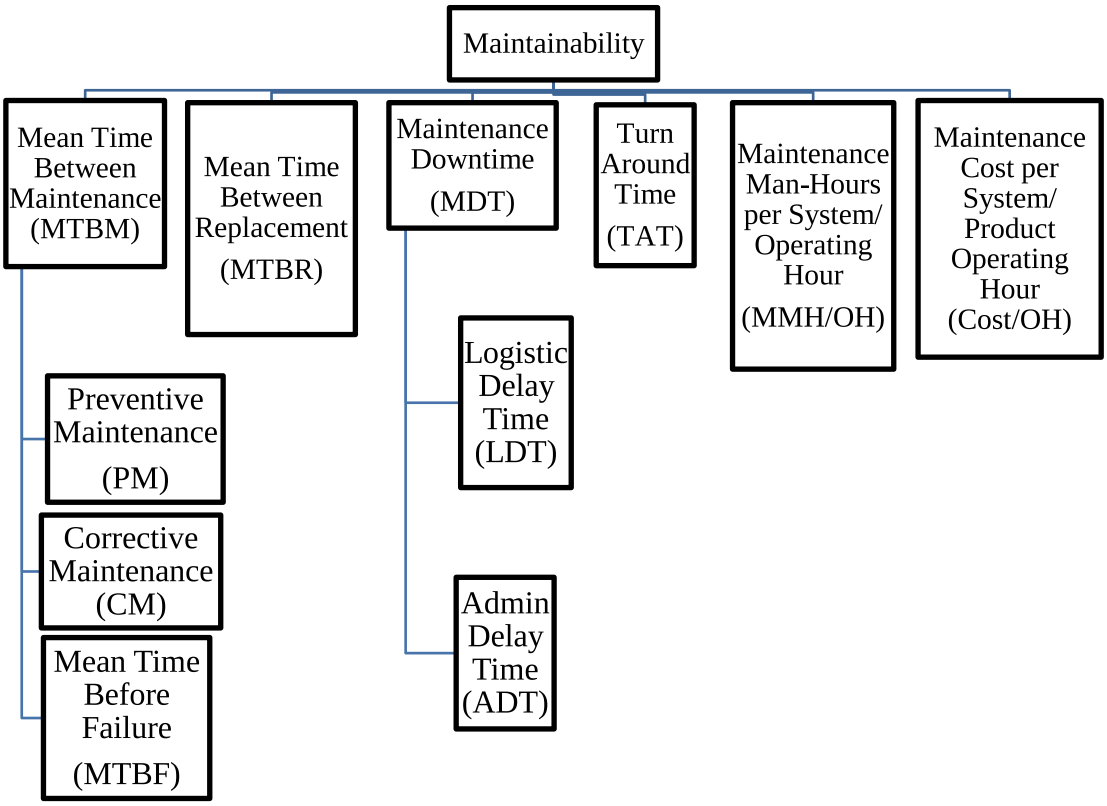

Figure 1. Maintainability Measures

Downtime can also be categorized into two Rausand and Hoyland (2004):

1. Planned vs. Unplanned Downtime
2. Downtime Caused by Failures

Anyhow, to perform a better maintainability analysis involving downtime, one must know the difference between Repair time and Restore time. Repair time is not the same as Restore time as the restore time includes all the time between loss and restoration, time preparing to repair, and starting up after repair. It is not only the time required for repairing purpose (Vesier, 2004). It is also equally important to remember that the importance of maintenance activities is that it directly impacts failure frequency and also failure recovery (Vesier, 2004).

2.2 Maintenance Data Analysis of Operational Plant

Maintainability of plants is currently being monitored and sustained using the plant maintenance plan. The plans are derived from the aforementioned measures of maintainability such as Corrective Maintenance (CM), Preventive Maintenance (PM), and Predictive Maintenance (PdM). Each of the equipments like compressor, pump, turbine, and boiler are using the maintenance plans provided by the vendors or manufacturers.

Anyhow, if there are any failures, damages, or factors that contribute to the downtime of equipment, it is only recorded for monitoring purpose. PETRONAS, as example is using System Applications and Products in Data Processing (SAP) in recording downtimes of equipment in the system. However, the data is not fully utilised to analyse the maintainability of the plant due to many factors such as lack of skilful personnel in handling the software, and also for the fact that the software used for analysing the maintainability can only be accessed and operated by certain people in the company due to its nature that is not user-friendly.

PETRONAS, for instance is developing its reliability plan called as Specific Equipment Reliability Plan (SERP) as a method of improving the reliability of its plant but there are so far no plans has been made for analysing maintainability.

Software like Weibull, Reliasoft, and Maros are already in the current market made available for helping engineers in analysing the plant raw maintenance data to help in improving the Reliability, Availability, and Maintainability (RAM) analysis. Furthermore, the scope of study of these software are more towards reliability engineering rather than maintainability. Even they are interconnected with each other but in there are difference in form of theory and ways of analysing. Weibull, for example is made to perform life data analysis utilizing multiple lifetime distributions (including all forms of the Weibull distribution) that is focused more on reliability engineering.

Based on a study by Azim Houshyar and Bahador Ohahramani (1997), they have suggested a collection of reliability and maintainability data using a processing software. The software should be developed using Visual Basic on Windows that uses data performance of the equipment and generates the statistics on the reliability and maintainability of the machinery or system.

In the proposed software by the authors, the authors suggested that the choice of analysis of the data should offers:

a. Daily reports

   For the purpose of maintainability analysis, the daily reports should display total shift time, machine up-time, down-time, run-time, available time, idle time, tool change time, quality rate, performance efficiency, overall equipment efficiency, mean time between failures, and mean time to repair.

b. Cumulative reports

   The cumulative reports should have display all the aforementioned information for the given time interval

c. Failure reports

   The failure reports should have display the top ten machineries with highest failure rate or machine down-time occurrences and also displays the total number of failure at any given time.

Houshyar and Ohahramani (1997) in their study agreed that the efficient collection and feedback of equipment operation data is critical to a successful reliability and maintainability analysis. The data is critical and can be very helpful in performing any meaningful root cause analysis as it can be use to predict failure rates, trending, and performing root cause analysis of repeating failures.

2.3 Exploratory Analysis

To analyse plant maintenance data in a comprehensive way, exploratory analysis is used. Exploratory analysis is the process of using statistical tools and techniques to investigate data sets in order to gain insight about the data, understand their important characteristics, identify outliers or errors, disclose underlying structure and extract important factors and assist in model formulation (Hussin, 2012). Exploratory analysis includes simple plots like histogram, stem and leaf, box-whiskers, pareto, scattered diagram, and time series (Hussin, 2012). System downtime and lifetime and major factors affecting it can be analysed using the analysis.

According to a study done by Jan H. Kwakkel and Erik Pruyt in 2012, exploratory model and analysis (EMA) can be very useful in helping the users in decision making and determining the model outcomes even where there is uncertainty about models. EMA also can be employed and use successfully in the already well-established techniques such as factorial methods, optimization techniques, and Monte Carlo samplings. EMA is very helpful in identifying the choice of data that influences the model outcomes, it can also helps in determining which policies and plans that would best suit the condition. The study also suggested that since EMA is a computational experiment to analyze complex and uncertain systems, it can also be very useful in exploiting the information to accurately describe a certain behaviour and such can be demonstrated in the trend test chart.

2.4 Visual Basic and Macros

Microsoft Visual Basic for Windows (VB) allows engineers to develop engineering applications that run in the Windows environment (Torres and Anders, 1996). According to Torres and Anders (1996), the software has been used to develop many engineering applications especially in the oil and gas field and some of the applications that have been developed using VB are gas and oil fluid correlations, water pattern analysis, volumetric reserve calculations, simple log analysis, bottom hole pressure analysis, and interpolation software.

However, those applications are developed using VB stand alone which requires some time for ones to acquire the skills and learn the basic language of programming and coding in the software. For easier and simpler applications, VB has been integrated in the other Microsoft software like Microsoft Excel and Microsoft Word. The simplest method of producing VBA program in Excel is to use the Macro Recorder (Cooke, 2012) as it can perform works that are done in a high-level language.

The usage of Microsoft Excel as the medium of the toolkit is also due to the user familiarity with Excel, Excel's capabilities for data manipulation, charting options in Excel, the ease of building and refreshing Excel-based management briefing books using multiple worksheets and offline queries, and reduced licensing fees by minimizing the number of business intelligence users (Palocsay, et. al 2010). Even it is known that Excel is not a database management system, but it has several built in tools that can help the user to manipulate data and stored them in forms of rows and columns. It also allows users to exploit the data in the forms of charts and performing analysis by inserting formulas and integrating it with Visual Basic for advance usage.

2.5 Gas Compression Train – Case Study

Based on Hussin (2013), Gas Compression Train (GCT) is a parallel gas compression system on an offshore installation that consists of two trains; Train 1 and Train 2. The plant maintenance data for maintainability analysis is provided from the year 2002 until to 2008 that shows the downtime data of gas compression train system (Hussin, 2013). GCT plays a vital role in transferring the gas from all the offshore platforms to the onshore facilities (Hussin, 2012). Due to the high demand of gas, the system has to be ensured its reliability and availability as well as its maintainability for a smooth running of its operation to avoid any losses.

The system comprises of another ten subsystems which is shown in the table below:

Table 1. Subsystem for the Gas Compression Train System (Hilmi et al, 2013)

No	Subsystem	Code
1	Gas Turbine	GT
2	Centrifugal Compressor	GC
3	Starter System	STS
4	Gearbox	GB
5	Fuel System	FS
6	Vibration Monitoring System	VMS
7	Anti-surge Valve System	AVS
8	Lube Oil System	LOS
9	Process and Utilities	PRO
10	Turbine Control System	TCS

Since the data for testing the toolkit comes from the case study, the following assumptions are used in developing the toolkit based on the study by Barabadi et. al (2010) :

1. The system is repairable
2. The system is subjected to repair and maintenance
3. The studied function is assumed to be independent
4. The time to repair excludes all waiting and logistics time

2.6 Repairable system

The assumptions are made to ease the analysis of the data since data from the plant maintenance data consists of various types of maintenance plan. As mentioned in the above section, the system is considered as repairable. Repairable system is defines as the system fails, it can be restored to its functional state (Hussin, 2013). In the case study, the systems are considered as perfect repair model, which means that the system is restored to 'as good as new condition'. This is to ease the analysis by assuming that the system is independent and identically distributed (IID), therefore it could be fitted by a lifetime model (Hussin, 2013).

CHAPTER 3

METHODOLOGY

Methodology is basically a set of proposed procedures that are used to carry out a research. The methodology must be followed religiously in order to ensure that the research is done within time limits. The general methodology that is used for this research is shown in Figure 2 below.

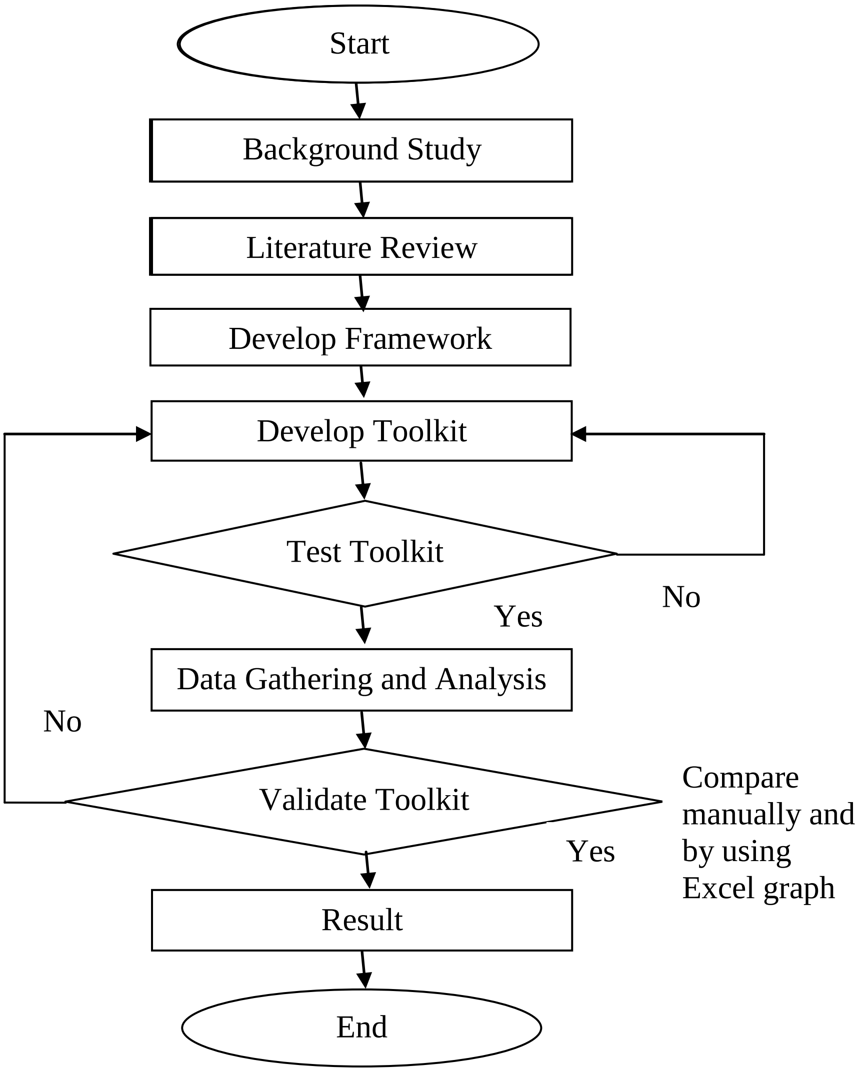

Figure 2. General Methodology Used for the Research

The study starts with literature review to help in understanding the research and continues with the next step of developing a framework. The framework is for providing detailed steps in determining the desired outcomes of the toolkit. The toolkit is focusing more on producing graphs and charts for exploratory analysis and the calculation of MDT for all the subsystems. Figure 3 shows the general framework for developing the maintainability analysis toolkit for this study.

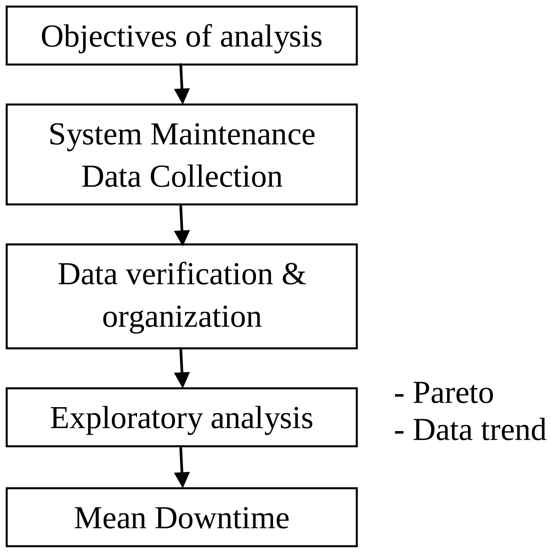

Figure 3. General Framework for Developing the Toolkit

The detailed framework for developing Maintainability Analysis Toolkit (MAT) is illustrated as shown in Figure 4 below.

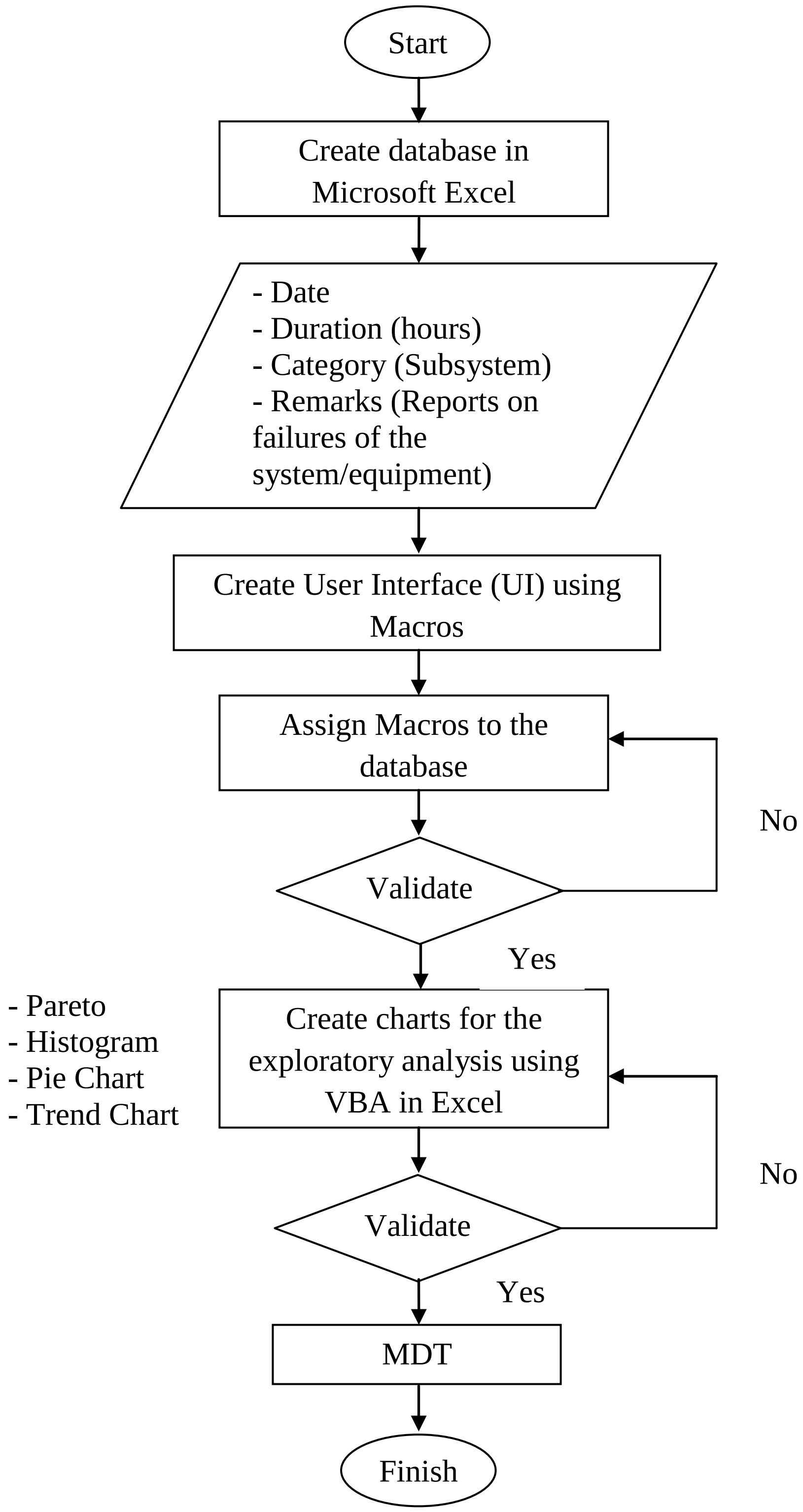

Figure 4. Detailed Framework of Developing MAT

The process flow will be discussed and explained further in Chapter 4, Results and Discussion.

3.1 Tools

Tools that are used for the research as it is mostly used for developing MAT, are:

- Visual Basic Application for Microsoft Excel
- Microsoft Excel
- Macros for Microsoft Excel

3.2 Maintainability Analysis Toolkit

The following shows the flows on how to use the Maintainability Analysis Toolkit (MAT)

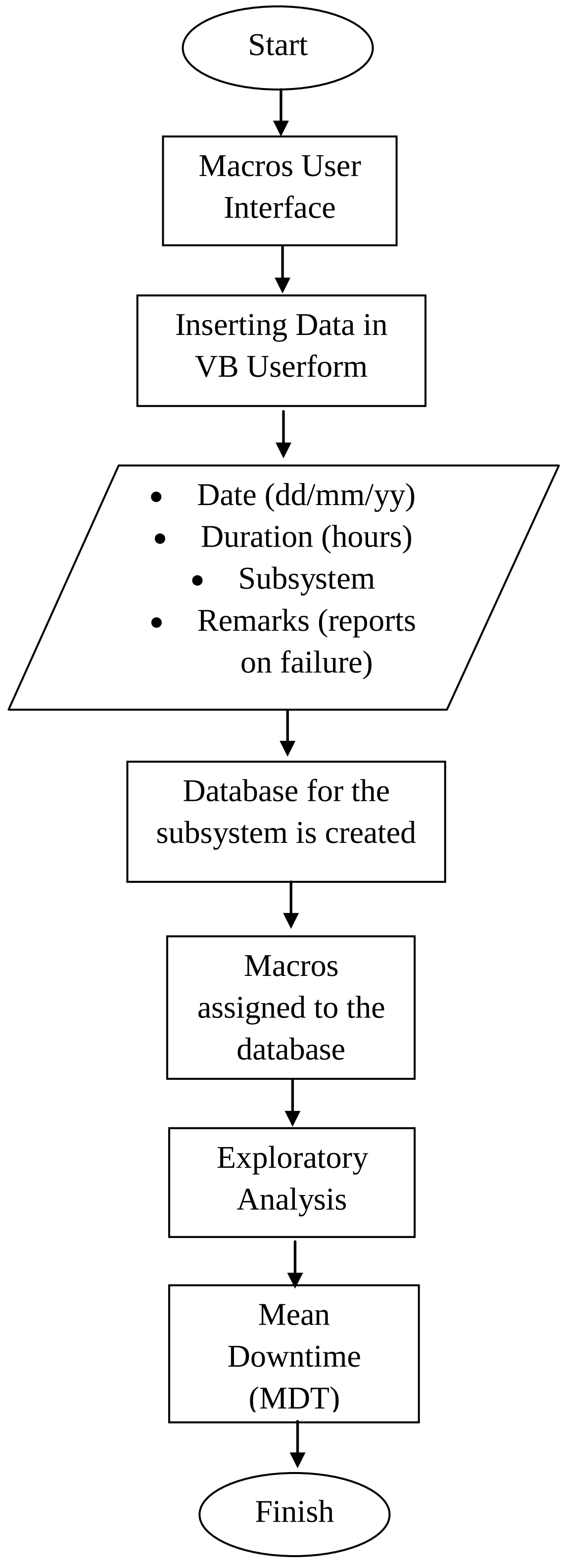

Figure 5. Maintainability Analysis Toolkit (MAT) flowchart

Figure 5 shows the general steps on using MAT. Upon opening the toolkit, user will first see the user interface. After that, the user can insert the maintenance data by clicking the insert data button. The button will show a userform where the users can key in all the data into the database. After the data has been inserted, the database will then be created inside the toolkit. The database created has already been assigned with Macros programming and charts will be generated whenever the user wants, and the MTD for the data is then calculated automatically. The flowchart for methodology on using MAT for both USD and PSD in Figure 5 will be discussed in further details in Chapter 4: Results and Discussion.

CHAPTER 4

RESULTS AND DISCUSSION

For the first phase of the project, the author has first developed the toolkit by using Visual Basic Application (VBA) stand alone. The concept is to create a database in VB, and later extracting the data by using the application to be presented in graphical forms as in pie charts, and histogram. But, due to time constraint, the method is changed from using VBA stand alone to using Macros in Microsoft Excel, an integrated VB application is Microsoft software.

The flow process of the development of the toolkit is shown in chapter 3, Methodology in Figure 4. Based on the flow chart, the toolkit is developed by creating database in the Microsoft Excel first. The database is use to store all the inputs received from the user. The database is important because apart from being the platform for data storage, the database also is a platform to do the calculation and perform the function needed in the toolkit.

4.1 MAT for USD

Maintainability Analysis Toolkit (MAT) for analysing the Unplanned Shutdown (USD) is basically developed to analyse the maintenance data for Corrective Maintenance (CM) that has been performed on the GCT subsystems. The CM performed could be due to failures in the subsystems or inspection that has been performed the outside party due to a failure of equipment.

The data used during validating MAT for USD is the actual data from the plant dated from 2002 to 2009. The screenshot of the actual data is inserted in the appendix.

Upon using the toolkit, the user will be brought to the first sheet of the Excel file which is the user interface of the toolkit as shown in Figure 6. In the user interface, the user will see two buttons that can be selected. The button ‘Insert New Data’ is for the user to insert new data for analysis while the button ‘View Database’ will bring the user to the overall database which compressed the database from all the subsystems dated from 2002 to 2020.

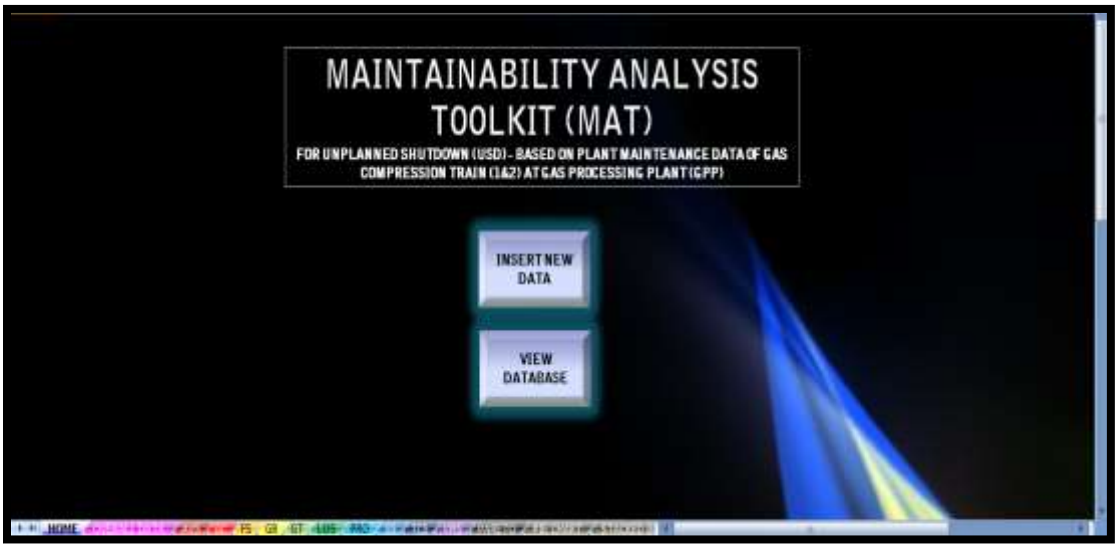

Figure 6. MAT for USD User Interface

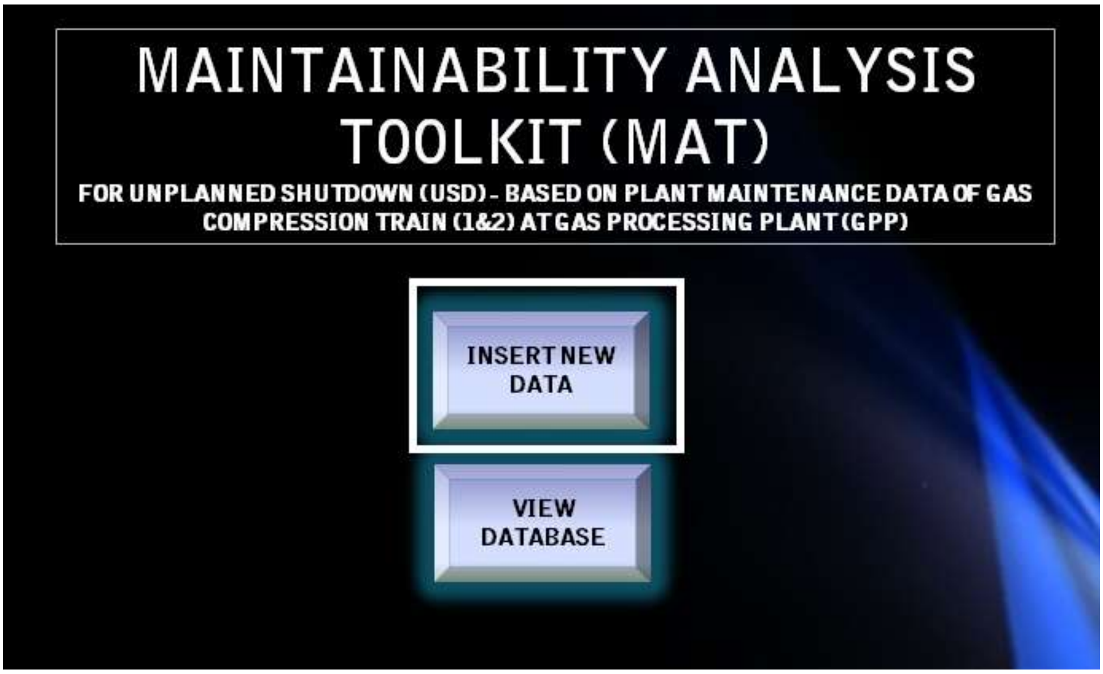

Figure 7. 'Insert New Data' Button

By clicking the 'Insert New Data' button as shown in the Figure 7, the user can insert new data into the database. Upon clicking the button, a userform for the user to key in the data will pop up as shown in Figure 8.

Figure 8. Userform for MAT for USD

The userform requires the user to key in the date, month, and year of the failure into separate boxes. This is to ease the calculation of the cumulative downtime. The months and years boxes are made in the form of dropdown menu to ease the user to key in the data. The toolkit is able to store the data up to the year 2020. In case of modifications, which if the users find that they need to fix the data until certain years, they can do so by fixing the codes and the Excel files. The codes for the VB and Macros for the userform are attached in the Appendices.

The user has to key in the downtime for the failures in the duration box in the userform. The duration has to be in hours. If the duration of the downtime is 1 hour and 30 minutes for example, the user has to convert the duration into hour which is 1.5 hours.

The cause of failure box is for the user to insert any remarks regarding the failure. These remarks will not be stored in the overall database instead it will automatically stored in the subsystem database for the ease of references later. The user can choose which subsystem the data is categorize from the dropdown menu in the ‘Subsystem’ section.

Button ‘Okay’ will automatically insert the data into its respective database and closed the userform. While the button ‘Next’ helps the user to insert multiple data without having to close the userform window. ‘Exit’ button is for the user to exit from the userform. Any data keyed in beforehand will not be saved into the database.

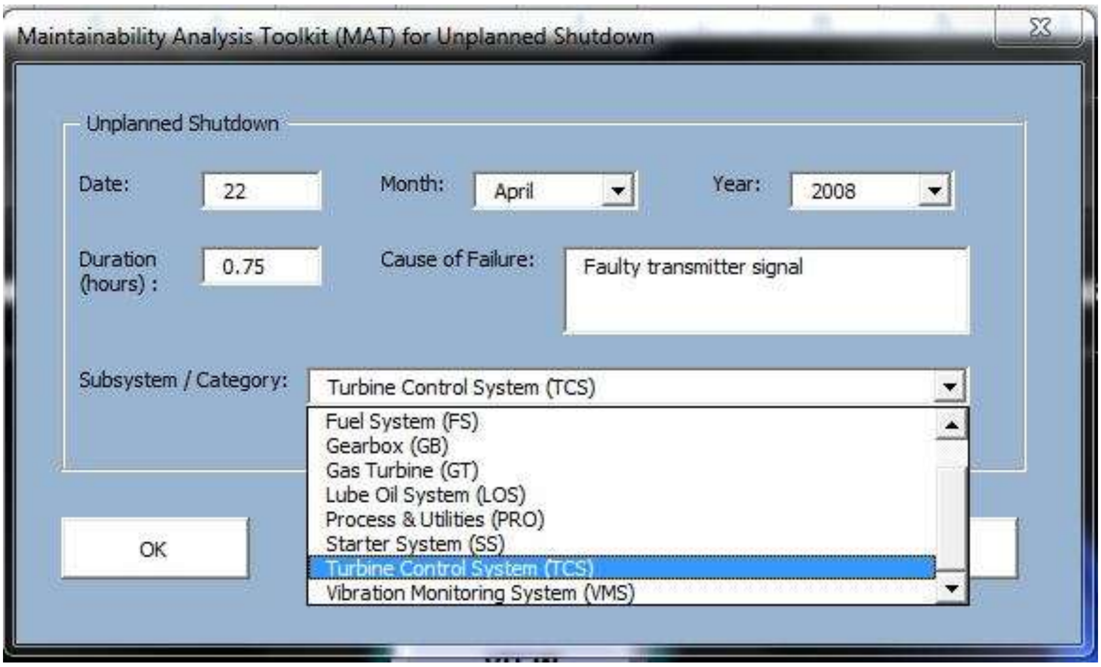

Figure 9. The Full Keyed-in Userform

Figure 9 shows how the userform looks like when it has been keyed in with all the information needed. When the ‘Okay’ button is pressed, the data is saved in the subsystem database.

TURBINE CONTROL SYSTEM (TCS)

Unplanned Shutdown (USD)

Date	Month	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Causes of Failure
16	July				4.5																Tr1 alarm on hard wire trip
19	July							19.5													Tripped due to PLC Communication module
18	April							2													Faulty transmitter signal
22	April							0.75													Faulty transmitter signal

Figure 10. Subsystem Database

Figure 10 showed the updated database for the subsystem for Turbine Control System after the data from Figure 9 is keyed in. The database table consists of the date, month, and year columns as well as the cause of failure column. The duration for every failure is inserted in the years' column. This is to ease the calculation using the coding in Microsoft Excel for calculating the cumulative durations per year.

The database can store up to 50 data per database. This too, can be edited in the Excel files and the Macros coding for further modification.

At the end of the table in the subsystem database is the calculated MDT. MDT is calculated using the equation:

$$Mean\ Downtime, MDT = \frac{Total\ failures\ duration\ (in\ hours)}{Frequency\ of\ the\ failure} \quad \text{(Eq. 1)}$$

The mean downtime is calculated by disregarding the distribution of the failures. It is to get the mean downtime as per failures occurrences.

TOTAL DOWNTIME HOURS	25.75
FREQUENCY	4
MEAN DOWNTIME	6.4375

Figure 11. MDT for TCS Subsystem

Figure 11 shows the calculation of MDT using Equation 1 in the subsystem database for Turbine Control System (TCS) as shown in the Figure 9 and 10.

For the convenience of the user, the MDT for every subsystem is summarized inside a table and is shown in the overall database as shown in Figure 12 while Figure 13 shows the summarized table of the MDT calculated for all subsystem.

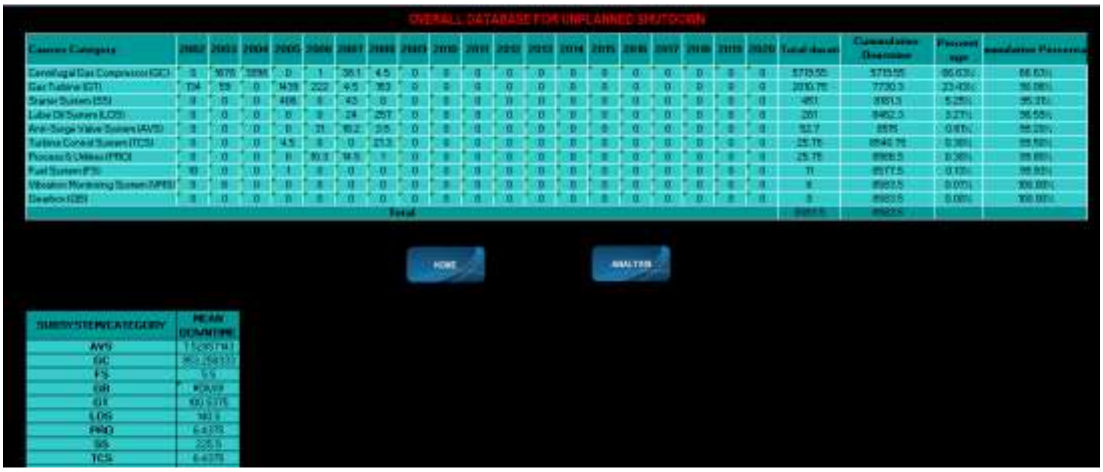

Figure 12. Overall Database of MAT for USD

SUBSYSTEM/CATEGORY	MEAN DOWNTIME
AVS	7.528571429
GC	953.2583333
FS	5.5
GB	#DIV/0!
GT	100.5375
LOS	140.5
PRO	6.4375
SS	225.5
TCS	6.4375
VMS	6

Figure 13. MDT Table for USD

MDT from each subsystem database that has been summarized inside a table is placed in the overall database. This is to ease the user to analyse the MDT without having to go to the end of each page in the subsystem database.

The overall database consists of the ten subsystems (Causes Categories), years (from 2002 until 2020), total duration, cumulative downtime duration, percentage, and cumulative percentage. The duration for each year has been summed up using the formula in the Excel files, which for example in the TCS subsystem, as shown in Figure 10, there are four cases of failures when one happened in 2005 and the other three happened in 2008. The duration for 2005 is taken directly and is inserted in the year 2005 for TCS column and row respectively in the overall database. While for the year 2008, the duration of the failures has to be sum up using the formula in the Microsoft Excel,

=SUM(TCS!I4:I50) (Eq. 2)

'SUM' is the formula used in Microsoft Excel to sum up everything in a column or a row. In this case, the 'SUM' formula is used to sum up the duration of the failures from TCS datasheet (database). 'I4:I50' is the column where the duration for the year 2005 is placed.

The list for the formula used in each column for the overall database is provided in the appendix.

The column 'Cumulative Downtime Duration' adjacent to the 'Total Duration' adds up the failures duration from the first subsystem to the tenth subsystem. This is for the later use during the generating the charts in the exploratory analysis. The 'Percentage' column is for calculating the percentage of the downtime duration by using the formula in Equation 3:

$$Percentage = \frac{Total\ downtime\ duration\ in\ a\ subsystem}{Total\ cumulative\ downtime\ duration\ of\ all\ subsystem}$$

(Eq. 3)

Meanwhile, 'Cumulative Percentage' column calculates the cumulative percentage for the whole system using the formula in Equation 4:

$$Cumulative\ Percentage = \frac{Cumulative\ duration\ in\ a\ subsystem}{Total\ cumulative\ downtime\ duration\ of\ all\ subsytem}$$

(Eq. 4)

The cumulative percentage is useful for generating the charts in exploratory analysis that will be explain in the later parts of the report.

For the exploratory analysis, three types of charts will be generated when the user click the button 'Analysis' that is placed below the overall database table as shown in the Figure 12. The 'Home' button that is placed adjacent to the 'Analysis' button will take the user back to the user interface of the program as shown in Figure 6.

The first chart that will be produced by clicking the ‘Analysis’ button is the Pareto Chart. The user will be taken to the datasheet named ‘Pareto’ that could be seen at the datasheet tab at the bottom of the Microsoft Excel files as shown in Figure 14.

Figure 14. 'Pareto' Datasheet Tab at the Bottom of the Toolkit

Macros is applied on ‘Analysis’ button for it to generate the graphs and charts. The coding used for the ‘Analysis’ button is shown in the Figure 15 below:

```
Sub GenerateChart_Click()
```

Figure 15. Macros Coding for 'Analysis' Button

Before generating the charts, the VB coding rearranged the data in the descending order. This is especially for generating the Pareto charts since the data has to be rearranged from highest to lowest number. Instead of doing it manually using the charts option in Microsoft Excel, the data is rearranged using the VB coding as shown in Figure 16 below. The codes are applied to the sheets “Overall Database” and the data is sorted in a descending order as aforementioned in the report.

```
'----Sorting---------------

Range("B3:Y12").Select
ActiveWorkbook.Worksheets("OVERALL DATA").Sort.SortFields.Clear
ActiveWorkbook.Worksheets("OVERALL DATA").Sort.SortFields.Add Key:=Range( _
    "V3:V12"), SortOn:=xlSortOnValues, Order:=xlDescending, DataOption:= _
    xlSortNormal
With ActiveWorkbook.Worksheets("OVERALL DATA").Sort
    .SetRange Range("B2:Y12")
    .Header = xlYes
    .MatchCase = False
    .Orientation = xlTopToBottom
    .SortMethod = xlPinYin
    .Apply
End With
```

Figure 16. VB Codes for Rearranging the Data in the Overall Database

The codes for generating pie charts, stacked bars, and Pareto charts are attached in the Appendix for references.

As aforementioned, after the graphs and charts have been generated, the user will be taken to the Pareto datasheets where the generated Pareto chart is shown as in the Figure 17 below.

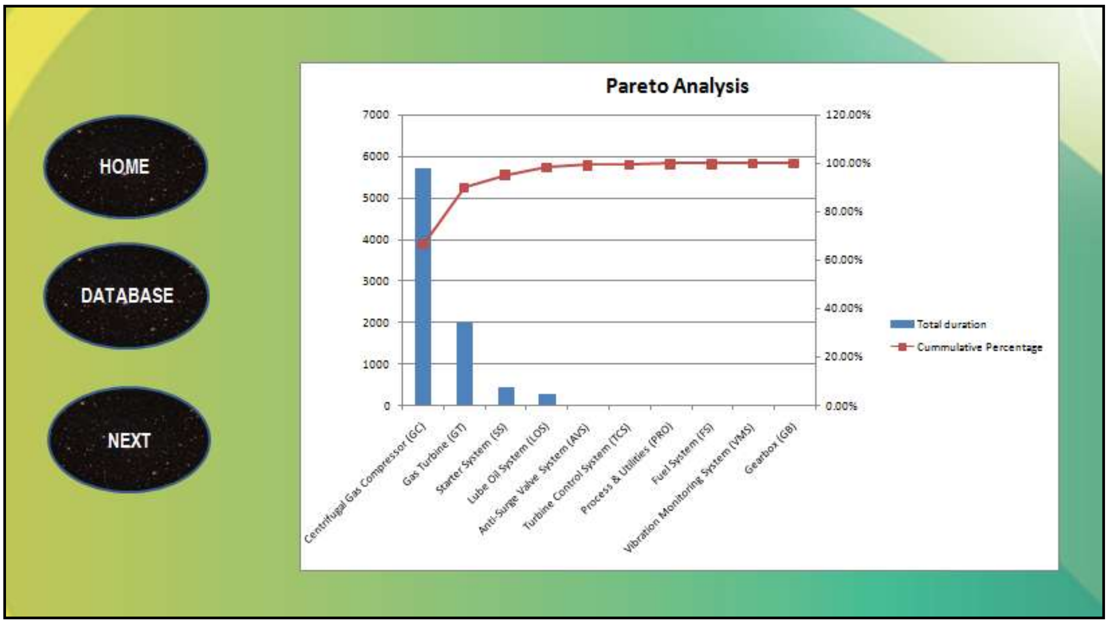

Figure 17. Pareto Chart for USD

The Pareto chart shows the bar chart for every subsystem with the total downtime duration in hours with the trend line for the cumulative percentage. It uses the data in the 'Total Duration' and 'Cumulative Percentage' column in the overall database table. The 'Home', 'Database', and 'Next' button are all have been assigned with Macros coding. The Macros will take the user to the user interface, overall database, and the next page respectively. The 'Next' button will take the user to the datasheets tab that named 'Pie Chart' as shown in the Figure 14. The pie chart generated will look like Figure 18 below.

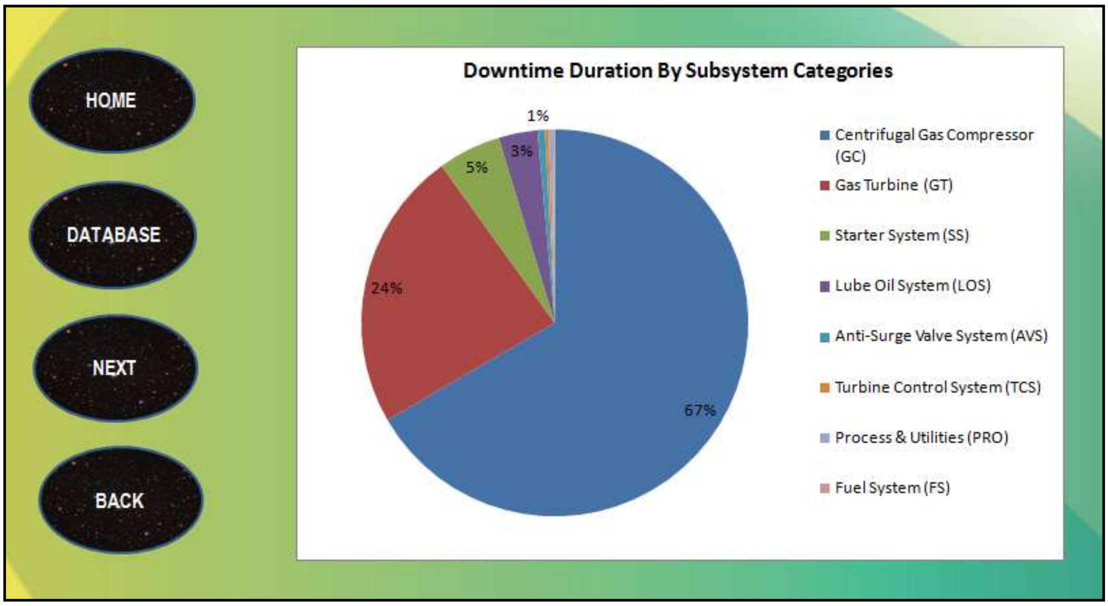

Figure 18. Pie Chart for USD

The 'Home' and 'Database' button has the same function as the ones in the Pareto datasheets while 'Next' and 'Back' button will take the user to the 'Stacked Bars' datasheet and 'Pareto' datasheet respectively. The buttons have been assigned to Macros coding.

The pie chart showed downtime duration by subsystem categories and uses the data from 'Total Duration' in the overall database table. The coding for generating the pie chart is attached in the appendix.

As aforementioned in the report, the 'Next' button takes the user to the 'Stacked Bar' datasheet where the data is arranged in a stacked bar chart as shown in Figure 19 below.

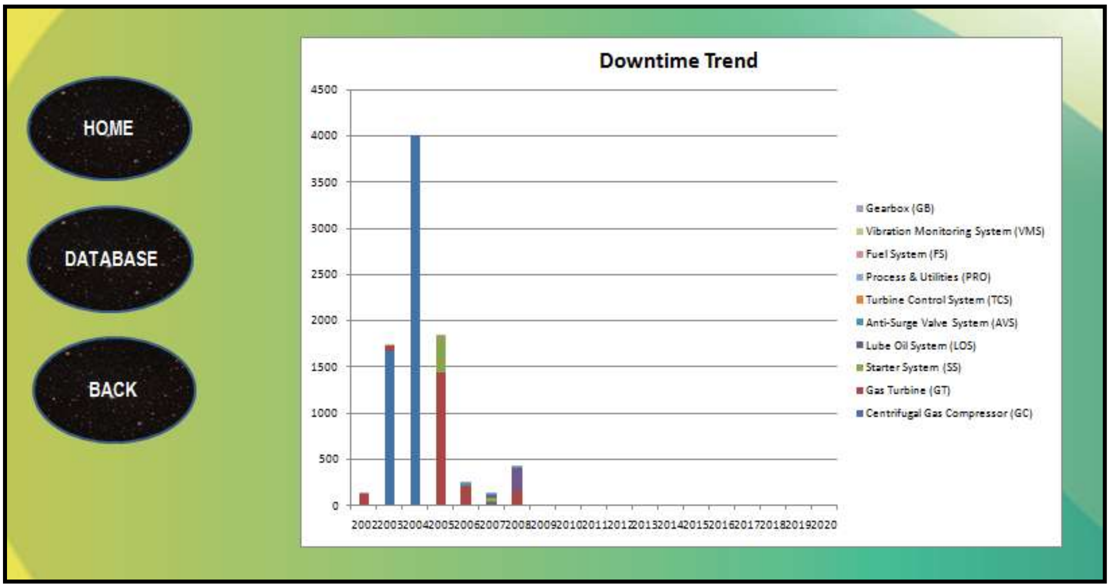

Figure 19. Stacked Bar for USD

The buttons in Figure 19 have been assigned with Macros and performed the same function as aforementioned. ‘Back’ button will take the user to the previous component of exploratory analysis, which is the pie chart.

The chart named as Downtime Trend as it shows the trend of the failures occurrence per year. The data is labelled up to the year 2020. The subsystem categories failure is stacked in a bar for the user to get a clearer picture on which subsystem has been the biggest contributor for the downtime duration as compared to other subsystem in a year. The bar has been labelled with different colour to differentiate the subsystems.

4.2 MAT for PSD

PSD stands for Planned Shutdown which means the MAT is to analyse all the Preventive Maintenance (PM) that has been performed on the subsystem of GCT. There are ten types of PM that has been performed on the GCT which is summarized in Table 2 below.

Table 2. PM Types for PSD

No	Subsystem	Codes
1	4K planned PM (PPM)	4K PPM
2	8K PPM	8K PPM
3	Centrifugal Compressor Bundle Change Out	CCO
4	Combustion Inspection	CI
5	Engine Wash	EW
6	Hot Gas Path Inspection	HGPI
7	Inspection	Inspection
8	Major Inspection	MI
9	Others	Others
10	Turbine Engine Change Out	ECO

MAT for PSD has almost the same features as the one for USD. Except a few changes in the presentation of the userform and added features for individual analysis.

The MAT for PSD user interface is as shown in the Figure 20 below.

Figure 20. User Interface for MAT for PSD

The toolkit has two buttons that allows user to key in new information by clicking the button ‘Insert New Data’ and the ‘View Database’ allows the user to view the overall database from all the subsystem. Figure 21 shows the closed up of the toolkit.

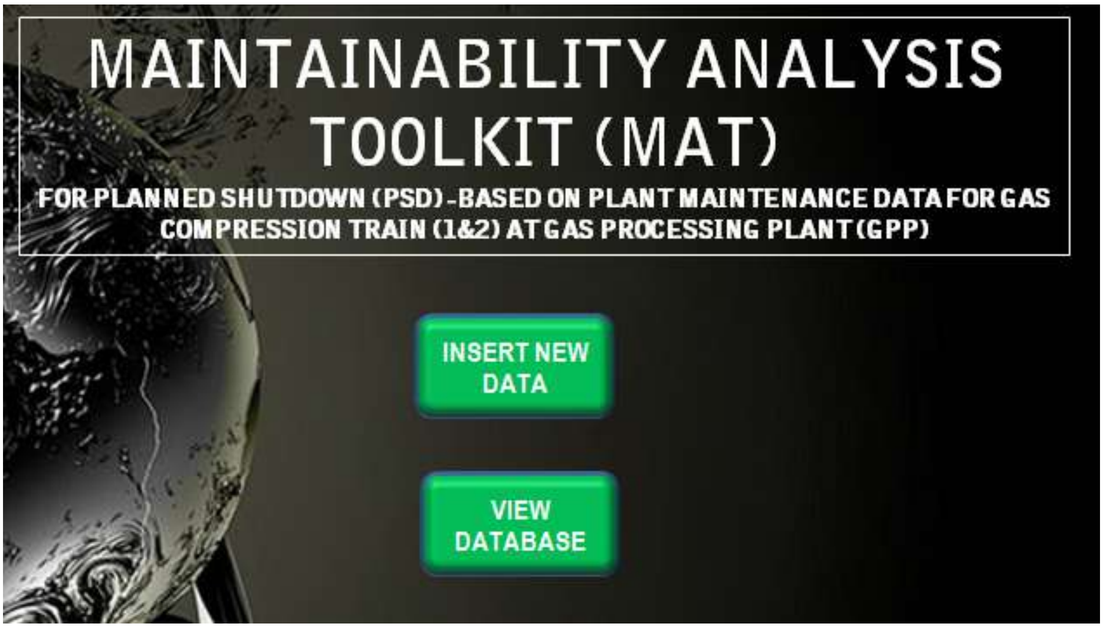

Figure 21. Closer View of the Toolkit

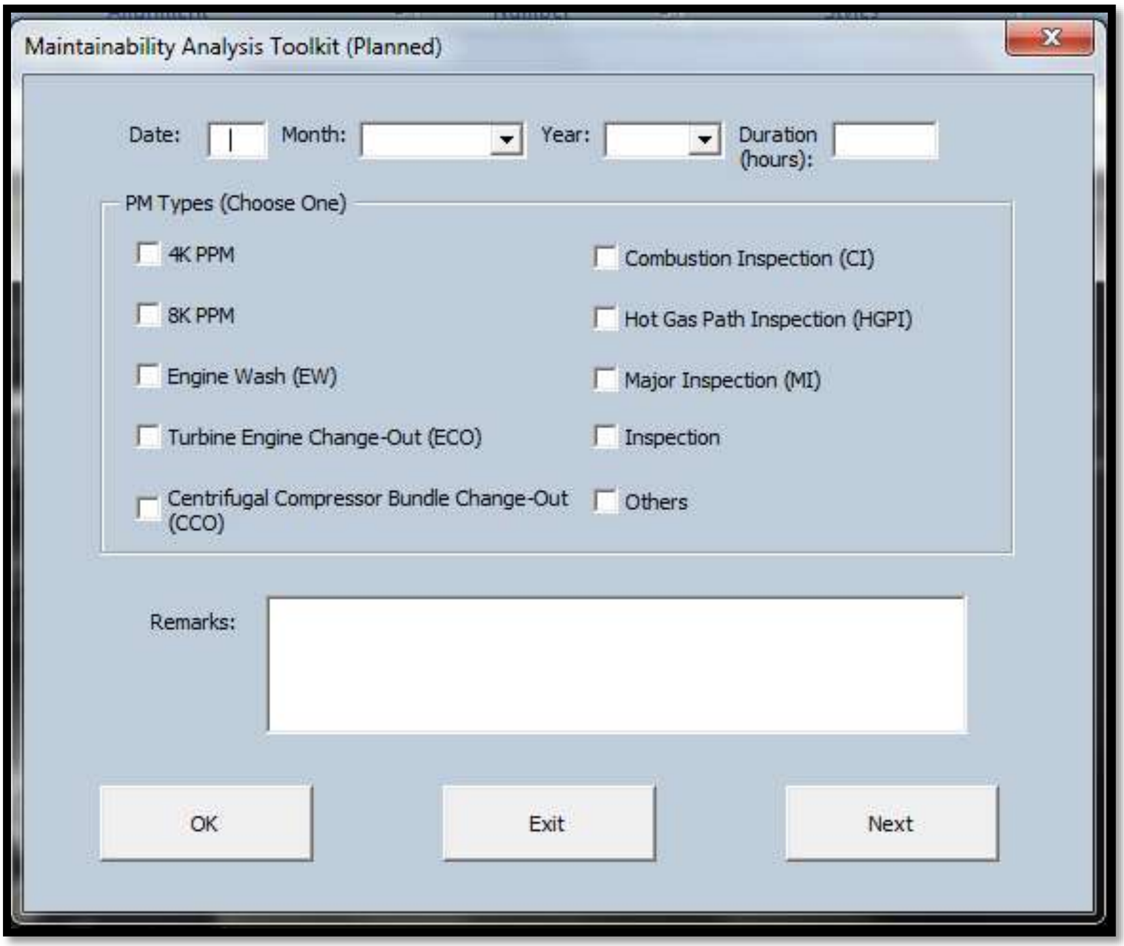

Figure 22. MAT for PSD Userform

By clicking the button 'Insert New Data' in the user interface of the toolkit, a userform like the one as shown in the Figure 22 will show up.

The user needs to key in all the required data into the userform. The date textbox requires the user insert the exact data when the failures happened while the months and the years have been represented in dropdown menu. The PM types are represented in tick boxes where the user can choose and one type of PM that has been performed on the system. Duration textbox is for the user to insert duration of the failures in hours. Remarks textbox requires the user to insert any details of remarks regarding the PM performed.

'OK' button allows the user to save the data inside the database and closed the userform afterwards, while 'Exit' button allows the user to exit the userform without saving the data while ‘Next’ button allows the user to save the data inserted without having to close the userform afterwards.

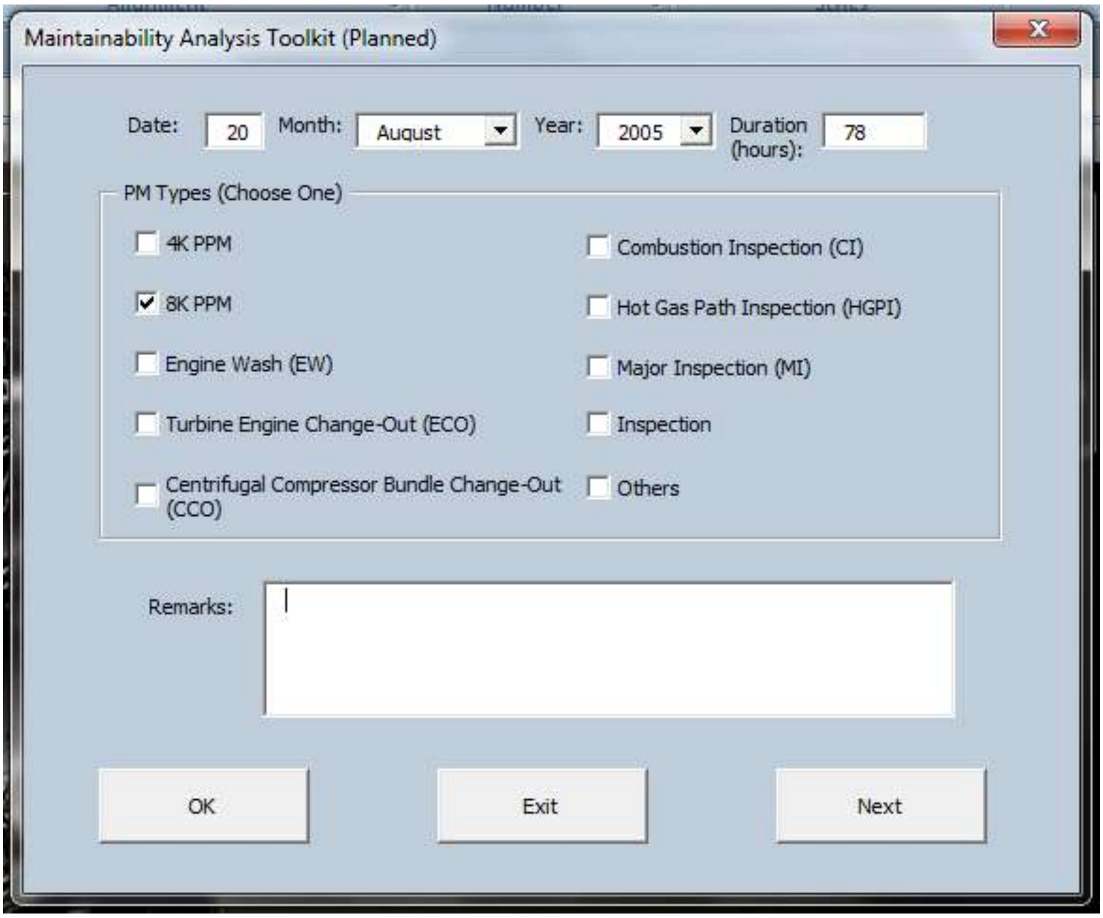

Figure 23. Filled In Userform for PSD

The userform that has been filled in correctly will be looking like the userform shown in the Figure 23 above. The data inserted would directly save in both overall database and the sub-database for each of the PM types. The saving of the data works the same as the ones in MAT for USD. The coding used for making the userform can be viewed in the appendix section.

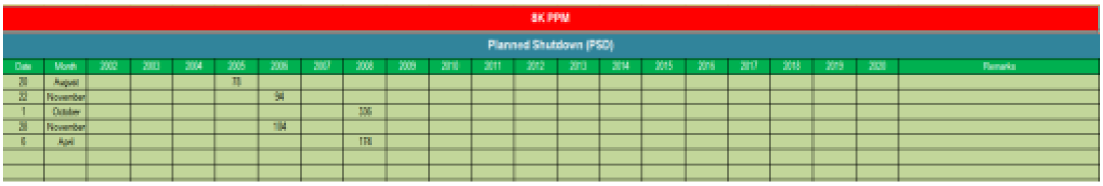

Figure 24. The Sub-system Database for 8K PPM

Figure 24 shows how the data is represented in the sub-database table. The duration of the failures are inserted in the column for each year the failures occurred. This is to ease the sorting in the overall database table for the exploratory analysis purpose.

At the end of the sub-database, MDT is calculated and is represented as shown in the Figure 25 below.

TOTAL DOWNTIME	786
FREQUENCY	5
MEAN DOWNTIME	157.2

Figure 25. MDT Calculated for 8K PPM

The MDT is calculated using the same equation (Equation 1) for calculation of MDT in USD.

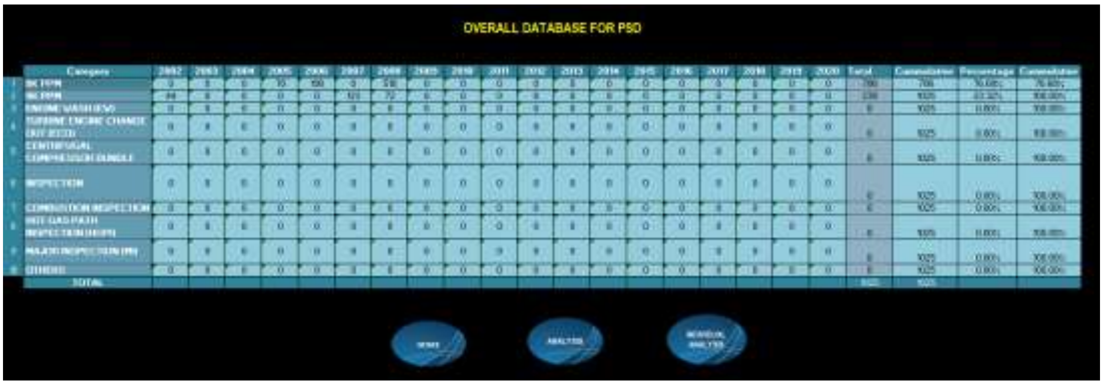

Figure 26. Overall Database for PSD

The database works the same as the ones in the USD with the list of PM Types are represented in a column, and the years are arranged from 2002 to 2020 adjacent to each other in a row as shown in Figure 26. Then ‘Total Duration’ calculates the duration of the failures from 2002 to 2020. ‘Cumulative Duration’ calculates the cumulative duration of the failures using Equation 2. Column ‘Percentage’ and ‘Cumulative Percentage’ also use the same principal as the one for USD.

At the bottom of the overall database datasheet, MDT for all the subsystem is represented in a table.

SUBSYSTEM	MEAN DOWNTIME
4K PPM	59.75
8K PPM	157.2
EW	#DIV/0!
ECO	#DIV/0!
CCO	#DIV/0!
INSPECTION	#DIV/0!
CI	#DIV/0!
HGPI	#DIV/0!
MI	#DIV/0!
OTHERS	#DIV/0!

Figure 27. MDT for All PM Types Represented in a Table

MDT table in Figure 27 shows error in the column because there are no data for other PM types except for 4K PPM and the 8K PPM.

Instead of only two, there are three Macros-assigned buttons in the overall database. The ‘Home’ button takes user to the user interface of MAT while the ‘Analysis’ button allows the user to perform exploratory analysis and the ‘Individual Analysis’ allows the user to produce a stacked bar graph for desired PM types.

When a user clicked ‘Individual Analysis’ button, a userform as shown in Figure 28 below will showed up.

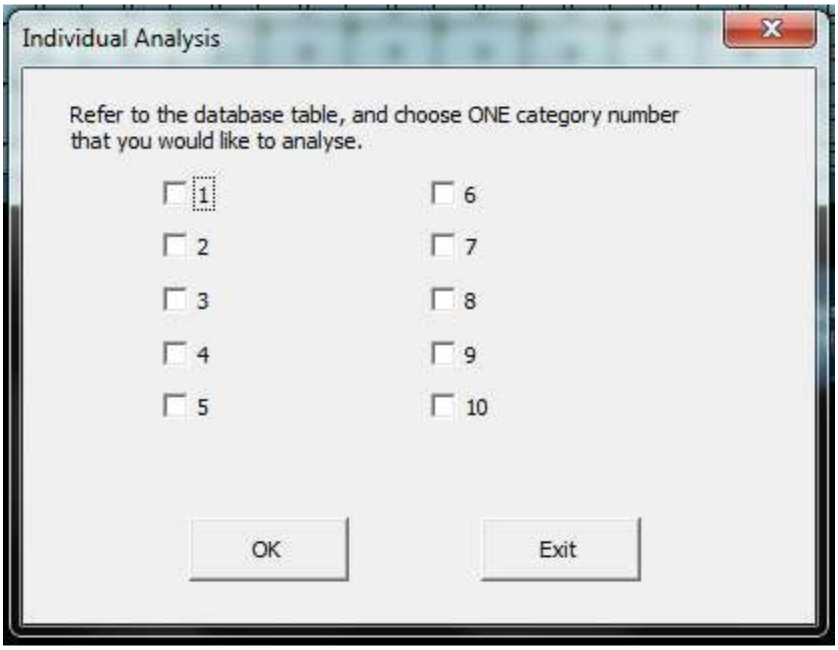

Figure 28. Userform for Individual Analysis

The numbers represent the PM types as shown in Figure 29, and if the user needs to analyse the PM types individually they can tick the desired number in the tick box provided.

	Category	2002	2003
1	8K PPM	0	0
2	4K PPM	44	0
3	ENGINE WASH (EW)	0	0
4	TURBINE ENGINE CHANGE OUT (ECO)	0	0
5	CENTRIFUGAL COMPRESSOR BUNDLE	0	0
6	INSPECTION	0	0
7	COMBUSTION INSPECTION	0	0
8	HOT GAS PATH INSPECTION (HGPI)	0	0
9	MAJOR INSPECTION (MI)	0	0
10	OTHERS	0	0
	TOTAL		

Figure 29. The Number for Each PM Types

The userform uses the numbering system instead of the name of the PM types to perform the individual analysis because the database has been applied with Macros-coding for sorting the data and by using the numbering, the analysis will be consistent to what the user wants.

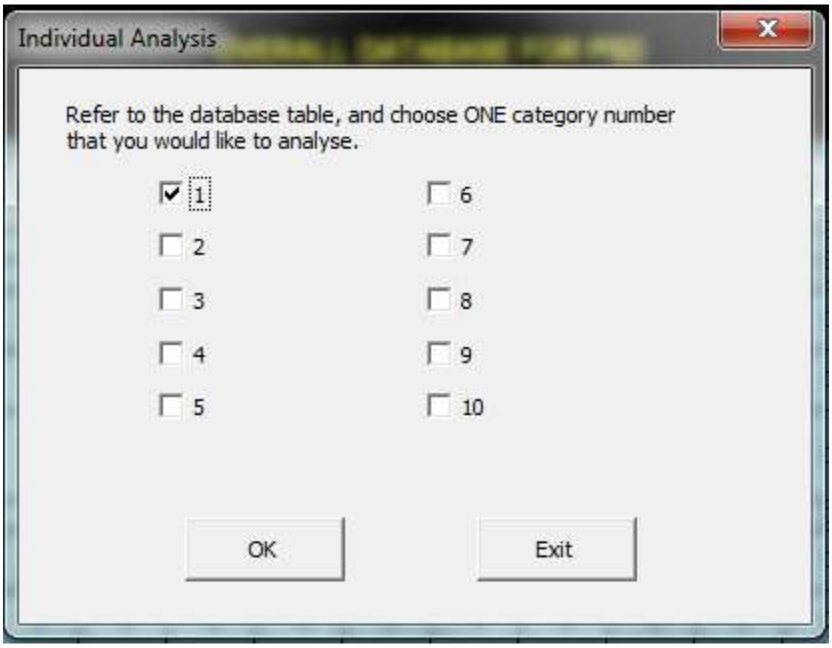

Figure 30. Example of Individual Analysis Userform

In Figure 30, the example given that the user chooses the first PM types which referring to Figure 29 shows that the PM types is the 8K PPM. Therefore, a bar chart showing the analysis will pop up in the datasheet named ‘INDIVIDUAL’.

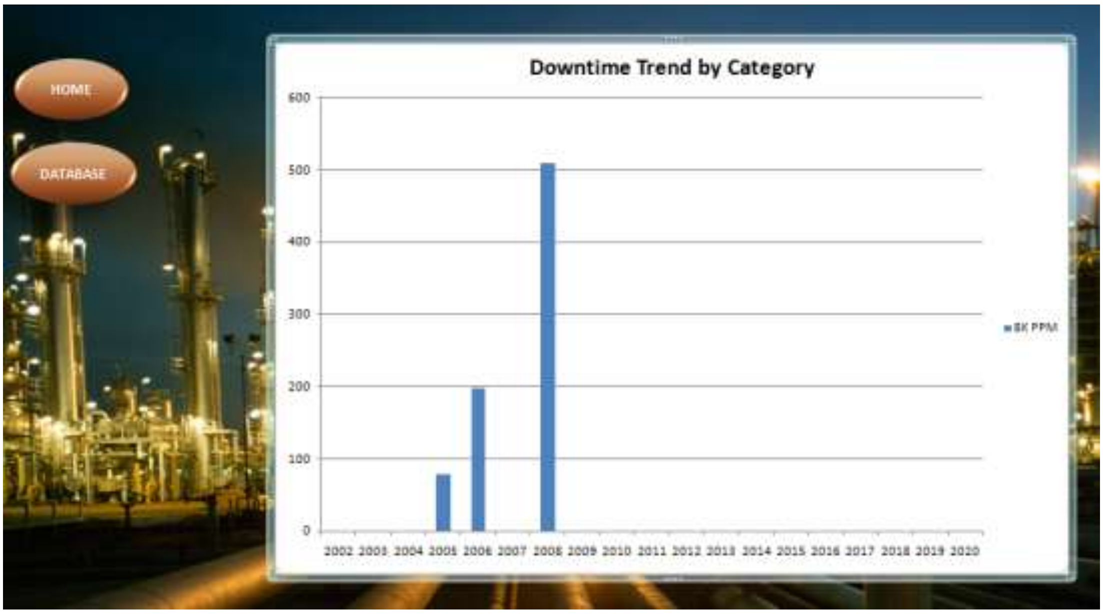

Figure 31. The Individual Analysis for 8K PPM

Figure 31 shows the individual analysis for PM Types 8K PPM. The individual analysis is using exploratory analysis by using bar chart and showed the downtime hours in term of years. The button that is placed near the individual analysis chart is the ‘Home’ and ‘Database’ buttons which when clicked, will take the user back to the user interface and the user database respectively.

The analysis produced by MAT for PSD is the same as the exploratory analysis produced by MAT for USD. The exploratory analysis of MAT for PSD is shown in the Figure 32, 33, and 34 for the Pareto chart, pie chart, and the stacked bar analysis respectively.

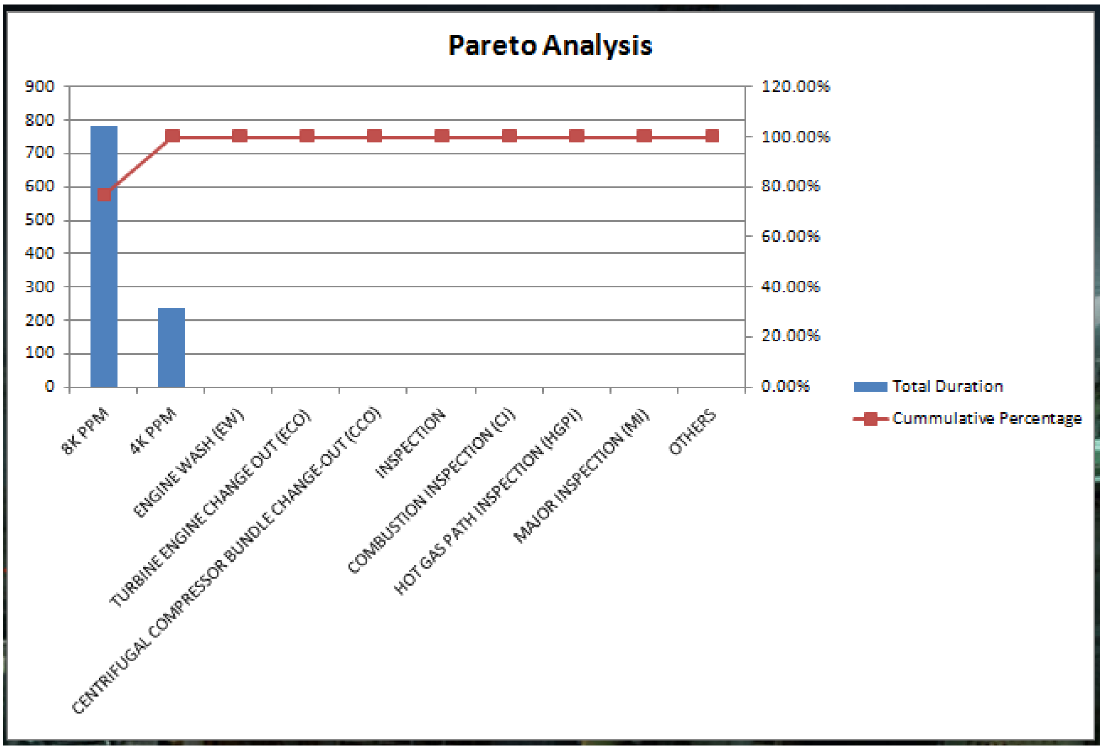

Figure 32. Pareto Chart for MAT for PSD

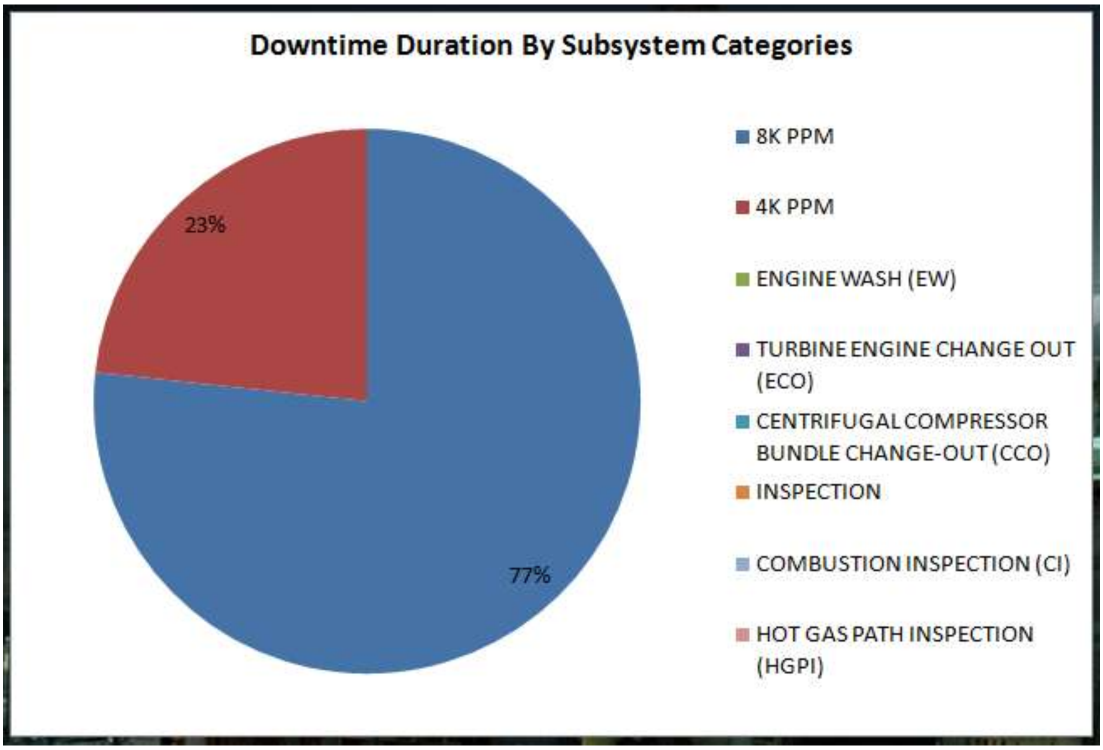

Figure 33. Pie Chart of MAT for PSD

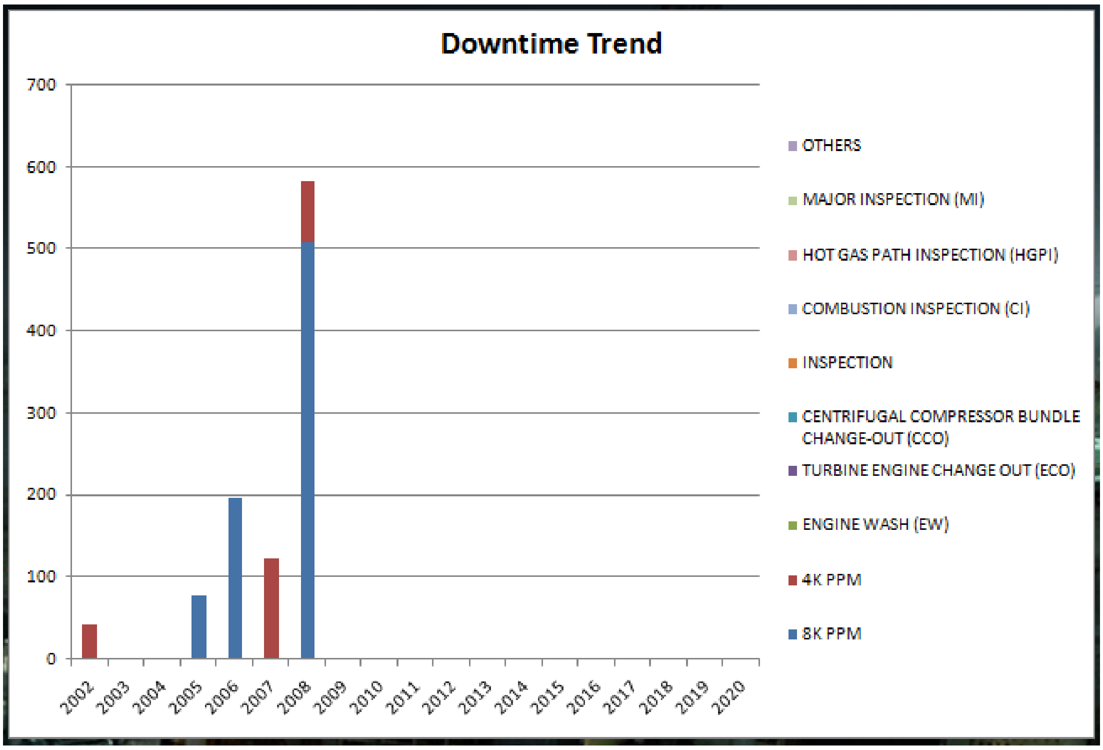

Figure 34. Stacked Bar Produced by MAT for PSD

The exploratory analysis produced by MAT for PSD used the same principle as the one used for MAT for USD. The charts are placed on the datasheets with the names of the charts as explained in the MAT for USD section. This is to avoid confusion for the user when using the toolkit for it uses the same working principle and almost the same interface.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The primary objective of the project is to develop a toolkit that can analyse plant maintenance data and perform maintainability analysis on the data. The objectives are then divided into other sub-objectives in order to ensure that the maintainability analysis is done stage by stage. The project has achieved its sub-objectives which are to perform exploratory analysis for the plant maintenance data. The toolkit developed using the Macros VBA in Excel has given the desired output such as catching and storing the data into the database and also presenting the data in the form of graphs and charts. Literature review has been done to increase understanding in the field especially those regarding the usage of Macros VBA in Excel since it requires a lot of understanding in programming and coding language. The understanding in maintainability analysis also is required especially in conducting the project in the second phase when the data needs to be split up according to its maintenance plan, whether it is planned, unplanned, preventive, or corrective maintenance.

The toolkit has been developed to perform on two different sets of data which are Planned Shutdown (PSD) and Unplanned Shutdown (USD). The exploratory analysis has been performed on the data for both toolkits and has given out the desired outputs. The exploratory analysis by the toolkit has proven to help the users in detecting the most critical subsystem by using the plant maintenance data from the case study.

5.2 Recommendation

5.2.1 User-friendly

The project can be further developed in the future by improving the toolkit from using VBA in Microsoft Excel into using fully Visual Basic stand alone program. It could help in developing a more high-end user interface with more user-friendly features such as adapting the toolkit according to the subsystem of the plants. As for the current toolkit is done according to the case study, the process of adapting and transferring the toolkit to another system could be a bit tedious even it is possible to do so.

5.2.2 Full Integration

The toolkit can be further developed to fully integrate the analysis both the reliability and maintainability. This could be done by using VB stand alone, or VBA in Microsoft Excel. By integrating both maintainability and reliability analysis, users perform the analysis in the same toolkit instead having to perform the analysis in two different toolkits.

5.2.3 Inferential analysis

In the future, the toolkit can be further develops to perform the inferential analysis on the plant maintenance data. The data does not have to be proven whether it is IDD before inserting the data into the existing software like Weibull to perform the inferential analysis. In the future, the exploratory and inferential analysis can be done in one toolkit with lower cost.

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APPENDIX A

Key Milestone and Gantt Chart for FYP I

Table 3. Milestone for FYP I

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of Project Topic								MID SEM BREAK							
2	Literature Review															
3	Submission of Extended Proposal															
4	Developing the Toolkit															
5	Proposal Defense															
6	Toolkit Testing and Improvement															
7	Submission of Interim Draft Report															
8	Submission of Interim Report															

Key Milestone and Gantt Chart for FYP II

Table 4. Milestone for FYP II

No	**Detail/Week**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**MID SEM BREAK**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1	Data Collection, Extraction, and Further Improvement of MAT																
2	Submission of Progress Report									○							
3	Completion of Toolkit Development (Results)																
4	Pre-EDX												○				
5	Submission of Draft Report													○			
6	Submission of Dissertation (soft bound)														○		
7	Submission of Technical Paper														○		
8	Oral Presentation															○	
9	Submission of Project Dissertation (Hard Bound)																○

Legends:

Project Activity

○ Key Milestone

APPENDIX C

Table 5. Coding Name for MAT for USD

Control	Name in VBA	Caption
Userform	UnplannedMATUserform	Maintainability Analysis Toolkit (Unplanned)
Textbox	UnplannedDateTextBox	N/A
Combobox	UnplannedMonthComboBox	N/A
Combobox	UnplannedYearComboBox	N/A
Combobox	UnplannedCategoryComboBox	N/A
Textbox	UnplannedDurationTextBox	N/A
Textbox	UnplannedCauseTextBox	N/A
Command Button	OKButton	OK
Command Button	CancelButton	Cancel
Command Button	ClearButton	Clear Form

Table 6. Coding Names for MAT for PSD

Control	Name in VBA	Caption
Userform	PlannedMATUserForm	Maintainability Analysis Toolkit (Planned)
Textbox	PlannedDateTextBox	N/A
Combobox	PlannedMonthComboBox	N/A
Combobox	PlannedYearComboBox	N/A
TextBox	PlannedDurationTextBox	N/A
Checkbox	FourPPMCheckBox1	4K PPM
	EightPPMCheckBox2	8K PPM
	EngineWashCheckBox3	Engine Wash (EW)
	TurbineEngineCheckBox4	Turbine Engine Change Out (ECO)
	CentCompCheckBox5	Centrifugal Compressor Bundle Change-Out (CCO)
	InspectionCheckBox6	Inspection
	OthersCheckBox7	Others
	MajorInspectionCheckBox8	Major Inspection (MI)
	CombInspectionCheckBox9	Combustion Inspection (CI)
	HotGasInspectionCheckBox10	Hot Gas Path Inspection (HGPI)
Textbox	PlannedRemarksTextBox	N/A
Combobox	PlannedCategoryComboBox	N/A
Command Button	OKButton	OK
Command Button	CancelButton	Exit
Command Button	ClearButton	Next

APPENDIX D

Coding for MAT for USD Userform

```
Private Sub UserForm_Initialize()

'Empty UnplannedDateTextBox
UnplannedDateTextBox.Value = ""

'Empty UnplannedDurationTextBox
UnplannedDurationTextBox.Value = ""

'Empty UnplannedCauseFailureTextBox
UnplannedCauseFailureTextBox.Value = ""

'Empty UnplannedMonthComboBox
UnplannedMonthComboBox.Clear

'Fill UnplannedMonthComboBox
With UnplannedMonthComboBox
   .AddItem "January"
   .AddItem "February"
   .AddItem "March"
   .AddItem "April"
   .AddItem "May"
   .AddItem "June"
   .AddItem "July"
   .AddItem "August"
   .AddItem "September"
   .AddItem "October"
   .AddItem "November"
   .AddItem "December"

End With
```

```
'Empty UnplannedYearComboBox
UnplannedYearComboBox.Clear

'Fill UnplannedYearComboBox
With UnplannedYearComboBox
   .AddItem "2002"
   .AddItem "2003"
   .AddItem "2004"
   .AddItem "2005"
   .AddItem "2006"
   .AddItem "2007"
   .AddItem "2008"
   .AddItem "2009"
End With

'Empty UnplannedCategoryComboBox
UnplannedCategoryComboBox.Clear

'Fill UnplannedCategoryComboBox
With UnplannedCategoryComboBox
   .AddItem "Anti-Surge Valve System (AVS)"
   .AddItem "Centrifugal Gas Compressor (GC)"
   .AddItem "Fuel System (FS)"
   .AddItem "Gearbox (GB)"
   .AddItem "Gas Turbine (GT)"
   .AddItem "Lube Oil System (LOS)"
   .AddItem "Process & Utilities (PRO)"
   .AddItem "Starter System (SS)"
   .AddItem "Turbine Control System (TCS)"
   .AddItem "Vibration Monitoring System (VMS)"
End With


End Sub
```

```
Sub CommandButton1_Click()

UnplannedMATUserForm.Show

End Sub
```

```
Sub GenerateChart_Click()

'----Sorting---------------

Range("B3:Y12").Select
ActiveWorkbook.Worksheets("OVERALL
DATA").Sort.SortFields.Clear
ActiveWorkbook.Worksheets("OVERALL
DATA").Sort.SortFields.Add Key:=Range( _
    "V3:V12"), SortOn:=xlSortOnValues,
Order:=xlDescending, DataOption:= _
    xlSortNormal
With ActiveWorkbook.Worksheets("OVERALL DATA").Sort
    .SetRange Range("B2:Y12")
    .Header = xlYes
    .MatchCase = False
    .Orientation = xlTopToBottom
    .SortMethod = xlPinYin
    .Apply
End With
```

```
'----Create Pie Chart 1----
Dim wsItem As Worksheet
Dim chtObj As ChartObject
For Each wsItem In ThisWorkbook.Worksheets
    For Each chtObj In wsItem.ChartObjects
        chtObj.Delete
    Next
Next
Range("B3:B12,V3:V12").Select
ActiveSheet.Shapes.AddChart.Select
ActiveChart.SetSourceData Source:=Range( _
    "'OVERALL DATA'!$B$3:$B$12,'OVERALL
DATA'!$V$3:$V$12")
ActiveChart.ChartType = xlPie

ActiveChart.Legend.Font.Size = 14
ActiveChart.SeriesCollection(1).HasDataLabels = True
ActiveChart.SeriesCollection(1).DataLabels.Font.Size =
14
ActiveChart.ChartArea.Width = 600
ActiveChart.ChartArea.Height = 400
'ActiveChart.ChartStyle = 42
ActiveChart.Legend.Font.Size = 14
'ActiveChart.SeriesCollection(1).HasDataLabels = True
'ActiveChart.SeriesCollection(1).DataLabels.Font.Size
= 14
'ActiveChart.ApplyDataLabels
xlDataLabelsShowLabelAndPercent
ActiveSheet.ChartObjects(1).Activate
ActiveSheet.ChartObjects(1).Cut
Sheets("PIE CHART").Select

'LOCATION OF CHART WHERE IT IS PASTED

Application.Goto Worksheets("PIE CHART").Range("I5"),
True
ActiveSheet.Paste

With Worksheets("PIE CHART").ChartObjects(1).Chart
    .HasTitle = True
    .ChartTitle.Text = "Downtime Duration By Subsystem
Categories"
End With
```

```
'coding for hiding the labels in the pie charts

For x = 1 To
ActiveChart.SeriesCollection(1).Points.Count
If
ActiveChart.SeriesCollection(1).Points(x).DataLabel.Tex
t = "0%" Then
ActiveChart.SeriesCollection(1).Points(x).DataLabel.Del
ete
End If
Next x
```

```
'----Create Stacked Column Chart----

ActiveSheet.Shapes.AddChart.Select
ActiveChart.ChartType = xlColumnStacked
ActiveChart.SetSourceData Source:=Range( _
    "'OVERALL DATA'!$B$3:$B$12")

ActiveChart.SeriesCollection(1).Select
Selection.Delete

ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(1).Name = Range( _
    "'OVERALL DATA'!$B$3")
ActiveChart.SeriesCollection(1).Values = Range( _
    "'OVERALL DATA'!$C$3:$U$3")
ActiveChart.SeriesCollection(1).XValues =
Worksheets("OVERALL DATA").Range("C2:U2")

ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(2).Name = Range( _
    "'OVERALL DATA'!$B$4")
ActiveChart.SeriesCollection(2).Values = Range( _
    "'OVERALL DATA'!$C$4:$U$4")

ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(3).Name = Range( _
    "'OVERALL DATA'!$B$5")
ActiveChart.SeriesCollection(3).Values = Range( _
    "'OVERALL DATA'!$C$5:$U$5")

ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(4).Name = Range( _
    "'OVERALL DATA'!$B$6")
ActiveChart.SeriesCollection(4).Values = Range( _
    "'OVERALL DATA'!$C$6:$U$6")

ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(5).Name = Range( _
    "'OVERALL DATA'!$B$7")
ActiveChart.SeriesCollection(5).Values = Range( _
    "'OVERALL DATA'!$C$7:$U$7")
```

```
ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(6).Name = Range( _
    "'OVERALL DATA'!$B$8")
ActiveChart.SeriesCollection(6).Values = Range( _
    "'OVERALL DATA'!$C$8:$U$8")

ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(7).Name = Range( _
    "'OVERALL DATA'!$B$9")
ActiveChart.SeriesCollection(7).Values = Range( _
    "'OVERALL DATA'!$C$9:$U$9")

ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(8).Name = Range( _
    "'OVERALL DATA'!$B$10")
ActiveChart.SeriesCollection(8).Values = Range( _
    "'OVERALL DATA'!$C$10:$U$10")

ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(9).Name = Range( _
    "'OVERALL DATA'!$B$11")
ActiveChart.SeriesCollection(9).Values = Range( _
    "'OVERALL DATA'!$C$11:$U$11")

ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(10).Name = Range( _
    "'OVERALL DATA'!$B$12")
ActiveChart.SeriesCollection(10).Values = Range( _
    "'OVERALL DATA'!$C$12:$U$12")

ActiveChart.ChartArea.Width = 600
ActiveChart.ChartArea.Height = 400
'ActiveChart.ChartStyle = 42
'ActiveChart.Legend.Font.Size = 14
ActiveSheet.ChartObjects(2).Activate
ActiveSheet.ChartObjects(2).Cut
Sheets("STACKED BAR").Select
```

```
ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(6).Name = Range( _
    "'OVERALL DATA'!$B$8")
ActiveChart.SeriesCollection(6).Values = Range( _
    "'OVERALL DATA'!$C$8:$U$8")

ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(7).Name = Range( _
    "'OVERALL DATA'!$B$9")
ActiveChart.SeriesCollection(7).Values = Range( _
    "'OVERALL DATA'!$C$9:$U$9")

ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(8).Name = Range( _
    "'OVERALL DATA'!$B$10")
ActiveChart.SeriesCollection(8).Values = Range( _
    "'OVERALL DATA'!$C$10:$U$10")

ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(9).Name = Range( _
    "'OVERALL DATA'!$B$11")
ActiveChart.SeriesCollection(9).Values = Range( _
    "'OVERALL DATA'!$C$11:$U$11")

ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(10).Name = Range( _
    "'OVERALL DATA'!$B$12")
ActiveChart.SeriesCollection(10).Values = Range( _
    "'OVERALL DATA'!$C$12:$U$12")

ActiveChart.ChartArea.Width = 600
ActiveChart.ChartArea.Height = 400
'ActiveChart.ChartStyle = 42
'ActiveChart.Legend.Font.Size = 14
ActiveSheet.ChartObjects(2).Activate
ActiveSheet.ChartObjects(2).Cut
Sheets("STACKED BAR").Select
```

```
'LOCATION OF CHART WHERE IT IS PASTED

Application.Goto Worksheets("STACKED BAR").Range("I5"),
True
ActiveSheet.Paste



With Worksheets("STACKED BAR").ChartObjects(1).Chart
    .HasTitle = True
    .ChartTitle.Text = "Downtime Trend"
End With
```

```
'----Create Pareto Chart----

Range("B2:B12,V2:V12,Y2:Y12").Select
ActiveSheet.Shapes.AddChart.Select
ActiveChart.SetSourceData Source:=Range( _
    "'OVERALL DATA'!$B$3:$B$12,'OVERALL
DATA'!$V$3:$V$12,'OVERALL DATA'!$Y$3:$Y$12")
ActiveChart.ChartType = xlColumnClustered

ActiveChart.SeriesCollection(1).Name = Range( _
    "'OVERALL DATA'!$V$2")
ActiveChart.SeriesCollection(1).Values = Range( _
    "'OVERALL DATA'!$V$3:$V$12")

ActiveChart.SeriesCollection(2).Name = Range( _
    "'OVERALL DATA'!$Y$2")
ActiveChart.SeriesCollection(2).Values = Range( _
    "'OVERALL DATA'!$Y$3:$Y$12")

ActiveChart.ChartArea.Width = 600
ActiveChart.ChartArea.Height = 400
'ActiveChart.ChartStyle = 42
'ActiveChart.Legend.Font.Size = 14
ActiveSheet.ChartObjects(2).Activate
ActiveSheet.ChartObjects(2).Cut
Sheets("PARETO").Select


'LOCATION OF CHART WHERE IT IS PASTED

Application.Goto Worksheets("PARETO").Range("I5"), True
ActiveSheet.Paste

ActiveChart.SeriesCollection(2).AxisGroup = 2
ActiveChart.SeriesCollection(2).ChartType =
xlLineMarkers

With Worksheets("PARETO").ChartObjects(1).Chart
    .HasTitle = True
    .ChartTitle.Text = "Pareto Analysis"
End With
```

```
Sheets("PARETO").Select



Application.Goto Worksheets("PIE CHART").Range("A1"),
True
Application.Goto Worksheets("STACKED BAR").Range("A1"),
True
Application.Goto Worksheets("PARETO").Range("A1"), True


Application.Goto Worksheets("PARETO").Range("A1"), True



End Sub
```

```
Sub EditVewDatabase_Click()

Sheets("OVERALL DATA").Select

    Sheets("OVERALL DATA").Select
Application.Goto Worksheets("OVERALL DATA").Range("A1"),
True
End Sub
Sub overDbBack_Click()
Sheets("HOME").Select
End Sub
Sub overChartBack_Click()
Sheets("OVERALL DATA").Select
End Sub
Sub NextOval1_Click()
Sheets("PIE CHART").Select
End Sub
Sub NextOval2_Click()
Sheets("STACKED BAR").Select
End Sub
Sub BackOval1_Click()
Sheets("PARETO").Select
End Sub
Sub AddData_Click()
UnplannedMATUserForm.Show
End Sub
```

APPENDIX E

Codes for MAT for PSD Userforms, and Exploratory Analysis (charts and graphs)

```
Private Sub UserForm_Initialize()

'Empty PlannedDateTextBox
PlannedDateTextBox.Value = ""

'Empty PlannedMonthComboBox
PlannedMonthComboBox.Clear

'Fill PlannedMonthComboBox
With PlannedMonthComboBox
    .AddItem "January"
    .AddItem "February"
    .AddItem "March"
    .AddItem "April"
    .AddItem "May"
    .AddItem "June"
    .AddItem "July"
    .AddItem "August"
    .AddItem "September"
    .AddItem "October"
    .AddItem "November"
    .AddItem "December"
End With

'Empty PlannedYearComboBox
PlannedYearComboBox.Clear
```

```
'Fill PlannedYearComboBox
With PlannedYearComboBox
   .AddItem "2002"
   .AddItem "2003"
   .AddItem "2004"
   .AddItem "2005"
   .AddItem "2006"
   .AddItem "2007"
   .AddItem "2008"
   .AddItem "2009"
   .AddItem "2010"
   .AddItem "2011"
   .AddItem "2012"
   .AddItem "2013"
   .AddItem "2014"
   .AddItem "2015"
   .AddItem "2016"
   .AddItem "2017"
   .AddItem "2018"
   .AddItem "2019"
   .AddItem "2020"
End With

'Uncheck PMTypesCheckBoxes
Me.FourPPMCheckBox1.Value = False
Me.EightPPMCheckBox2.Value = False
Me.EngineWashCheckBox3.Value = False
Me.TurbineEngineCheckBox4.Value = False
Me.CentCompCheckBox5.Value = False
Me.InspectionCheckBox6.Value = False
Me.OthersCheckBox7.Value = False
Me.MajorInspectionCheckBox8.Value = False
Me.CombInspectionCheckBox9.Value = False
Me.HotGasInspectionCheckBox10.Value = False

'Empty PlannedRemarksTextBox
PlannedRemarksTextBox.Value = ""

End Sub
```

```
Sheets("INDIVIDUAL").Select

'LOCATION OF CHART WHERE IT IS PASTED

Application.Goto Worksheets("INDIVIDUAL").Range("I5"),
True
ActiveSheet.Paste



With Worksheets("INDIVIDUAL").ChartObjects(1).Chart
    .HasTitle = True
    .ChartTitle.Text = "Downtime Trend by Category"
End With




End Sub
Private Sub EngineCheckBox3_Click()

End Sub

Private Sub UserForm_Initialize()

'Uncheck PMTypesCheckBoxes
Me.FourCheckBox1.Value = False
Me.EightCheckBox2.Value = False
Me.EngineCheckBox3.Value = False
Me.TurbineCheckBox4.Value = False
Me.CompCheckBox5.Value = False
Me.InspectCheckBox6.Value = False
Me.CombInsCheckBox7.Value = False
Me.HotGasInsCheckBox8.Value = False
Me.MajorInsCheckBox9.Value = False
Me.OthersInsCheckBox10.Value = False

End Sub
```

```
Sub GenerateChart_Click()

'----Sorting---------------

Range("B4:Y13").Select
ActiveWorkbook.Worksheets("OVERALL
DATABASE").Sort.SortFields.Clear
ActiveWorkbook.Worksheets("OVERALL
DATABASE").Sort.SortFields.Add Key:=Range( _
    "V4:V13"), SortOn:=xlSortOnValues,
Order:=xlDescending, DataOption:= _
    xlSortNormal
With ActiveWorkbook.Worksheets("OVERALL DATABASE").Sort
    .SetRange Range("B3:Y13")
    .Header = xlYes
    .MatchCase = False
    .Orientation = xlTopToBottom
    .SortMethod = xlPinYin
    .Apply
End With
```

```
'----Create Pie Chart 1----

Dim wsItem As Worksheet
Dim chtObj As ChartObject

For Each wsItem In ThisWorkbook.Worksheets
    For Each chtObj In wsItem.ChartObjects
        chtObj.Delete
    Next
Next

Range("B4:B13,V4:V13").Select
ActiveSheet.Shapes.AddChart.Select
ActiveChart.SetSourceData Source:=Range( _
    "'OVERALL DATABASE'!$B$4:$B$13,'OVERALL
DATABASE'!$V$4:$V$13")
ActiveChart.ChartType = xlPie

ActiveChart.Legend.Font.Size = 14
ActiveChart.SeriesCollection(1).HasDataLabels = True
ActiveChart.SeriesCollection(1).DataLabels.Font.Size =
14
ActiveChart.ChartArea.Width = 600
ActiveChart.ChartArea.Height = 400
'ActiveChart.ChartStyle = 42
ActiveChart.Legend.Font.Size = 14
'ActiveChart.SeriesCollection(1).HasDataLabels = True
'ActiveChart.SeriesCollection(1).DataLabels.Font.Size =
14
'ActiveChart.ApplyDataLabels
xlDataLabelsShowLabelAndPercent
ActiveSheet.ChartObjects(1).Activate
ActiveSheet.ChartObjects(1).Cut
Sheets("PIE CHART").Select
```

```
'LOCATION OF CHART WHERE IT IS PASTED

Application.Goto Worksheets("PIE CHART").Range("I5"), True
ActiveSheet.Paste


With Worksheets("PIE CHART").ChartObjects(1).Chart
    .HasTitle = True
    .ChartTitle.Text = "Downtime Duration By Subsystem
Categories"
End With

ActiveChart.ApplyLayout (6)
```

```
'codes for hiding the labels in the pie chart

For x = 1 To ActiveChart.SeriesCollection(1).Points.Count
If
ActiveChart.SeriesCollection(1).Points(x).DataLabel.Text =
"0%" Then
ActiveChart.SeriesCollection(1).Points(x).DataLabel.Delete
End If
Next x
```

```
'----Create Stacked Column Chart----

ActiveSheet.Shapes.AddChart.Select
ActiveChart.ChartType = xlColumnStacked
ActiveChart.SetSourceData Source:=Range( _
    "'OVERALL DATABASE'!$B$4:$B$13")

ActiveChart.SeriesCollection(1).Select
Selection.Delete

ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(1).Name = Range( _
    "'OVERALL DATABASE'!$B$4")
ActiveChart.SeriesCollection(1).Values = Range( _
    "'OVERALL DATABASE'!$C$4:$U$4")
ActiveChart.SeriesCollection(1).XValues =
Worksheets("OVERALL DATABASE").Range("C3:U3")

ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(2).Name = Range( _
    "'OVERALL DATABASE'!$B$5")
ActiveChart.SeriesCollection(2).Values = Range( _
    "'OVERALL DATABASE'!$C$5:$U$5")

ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(3).Name = Range( _
    "'OVERALL DATABASE'!$B$6")
ActiveChart.SeriesCollection(3).Values = Range( _
    "'OVERALL DATABASE'!$C$6:$U$6")

ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(4).Name = Range( _
    "'OVERALL DATABASE'!$B$7")
ActiveChart.SeriesCollection(4).Values = Range( _
    "'OVERALL DATABASE'!$C$7:$U$7")

ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(5).Name = Range( _
    "'OVERALL DATABASE'!$B$8")
ActiveChart.SeriesCollection(5).Values = Range( _
    "'OVERALL DATABASE'!$C$8:$U$8")
```

```
ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(6).Name = Range( _
    "'OVERALL DATABASE'!$B$9")
ActiveChart.SeriesCollection(6).Values = Range( _
    "'OVERALL DATABASE'!$C$9:$U$9")

ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(7).Name = Range( _
    "'OVERALL DATABASE'!$B$10")
ActiveChart.SeriesCollection(7).Values = Range( _
    "'OVERALL DATABASE'!$C$10:$U$10")

ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(8).Name = Range( _
    "'OVERALL DATABASE'!$B$11")
ActiveChart.SeriesCollection(8).Values = Range( _
    "'OVERALL DATABASE'!$C$11:$U$11")

ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(9).Name = Range( _
    "'OVERALL DATABASE'!$B$12")
ActiveChart.SeriesCollection(9).Values = Range( _
    "'OVERALL DATABASE'!$C$12:$U$12")

ActiveChart.SeriesCollection.NewSeries
ActiveChart.SeriesCollection(10).Name = Range( _
    "'OVERALL DATABASE'!$B$13")
ActiveChart.SeriesCollection(10).Values = Range( _
    "'OVERALL DATABASE'!$C$13:$U$13")

ActiveChart.ChartArea.Width = 600
ActiveChart.ChartArea.Height = 400
'ActiveChart.ChartStyle = 42
'ActiveChart.Legend.Font.Size = 14
ActiveSheet.ChartObjects(2).Activate
ActiveSheet.ChartObjects(2).Cut
Sheets("STACKED BAR").Select
```

```
'LOCATION OF CHART WHERE IT IS PASTED

Application.Goto Worksheets("STACKED BAR").Range("I5"),
True
ActiveSheet.Paste



With Worksheets("STACKED BAR").ChartObjects(1).Chart
    .HasTitle = True
    .ChartTitle.Text = "Downtime Trend"
End With
```

```
'----Create Pareto Chart----

Range("B3:B13,V3:V13,Y3:Y13").Select
ActiveSheet.Shapes.AddChart.Select
ActiveChart.SetSourceData Source:=Range( _
    "'OVERALL DATABASE'!$B$4:$B$13,'OVERALL
DATABASE'!$V$4:$V$13,'OVERALL DATABASE'!$Y$4:$Y$13")
ActiveChart.ChartType = xlColumnClustered

ActiveChart.SeriesCollection(1).Name = Range( _
    "'OVERALL DATABASE'!$V$3")
ActiveChart.SeriesCollection(1).Values = Range( _
    "'OVERALL DATABASE'!$V$4:$V$13")

ActiveChart.SeriesCollection(2).Name = Range( _
    "'OVERALL DATABASE'!$Y$3")
ActiveChart.SeriesCollection(2).Values = Range( _
    "'OVERALL DATABASE'!$Y$4:$Y$13")

ActiveChart.ChartArea.Width = 600
ActiveChart.ChartArea.Height = 400
'ActiveChart.ChartStyle = 42
'ActiveChart.Legend.Font.Size = 14
ActiveSheet.ChartObjects(2).Activate
ActiveSheet.ChartObjects(2).Cut
Sheets("PARETO").Select
```

```
'LOCATION OF CHART WHERE IT IS PASTED

Application.Goto Worksheets("PARETO").Range("I5"), True
ActiveSheet.Paste

ActiveChart.SeriesCollection(2).AxisGroup = 2
ActiveChart.SeriesCollection(2).ChartType =
xlLineMarkers

With Worksheets("PARETO").ChartObjects(1).Chart
     .HasTitle = True
     .ChartTitle.Text = "Pareto Analysis"
End With




'--------






Sheets("PARETO").Select





Application.Goto Worksheets("PIE CHART").Range("A1"),
True
Application.Goto Worksheets("STACKED BAR").Range("A1"),
True
Application.Goto Worksheets("PARETO").Range("A1"), True


Application.Goto Worksheets("PARETO").Range("A1"), True



End Sub
```

```
Sub EditVewDatabase_Click()

Sheets("OVERALL DATABASE").Select


    Sheets("OVERALL DATABASE").Select
Application.Goto Worksheets("OVERALL
DATABASE").Range("A1"), True
End Sub
Sub HomeDbBack_Click()
Sheets("HOME").Select
End Sub
Sub DBChartBack_Click()
Sheets("OVERALL DATABASE").Select
End Sub
Sub NextPieOval1_Click()
Sheets("PIE CHART").Select
End Sub
Sub NextBarOval2_Click()
Sheets("STACKED BAR").Select
End Sub
Sub BackParetoOval1_Click()
Sheets("PARETO").Select
End Sub
Sub AddData_Click()
AnalysisUserForm.Show
End Sub
```

APPENDIX F

Snapshot of Raw Plant Maintenance Data

Time			shutdown				
Date	Oper (days)	/w fail/pm (days	type	downtime (hrs)	cause of downtime/failure	Rectification work done	Subsystem
27/4/02	-2		USD	16	Not available	No report	
17/5/02	15	15	USD	72	Borescope inspection by rolls royce?	No report	1
17/6/02	21	6	USD	62.25	Borescope inspection by rolls royce?	No report	1
1/10/02	124	103	PSD	44	4K PPM		
9/1/03	216	92	USD	6	compressor high vibration	Recalibrate the vibration sensor	6
18/5/03	337	121	PSD	226.5 (STDBY)			
20/11/03	511	174	USD	59	start up problem (after engine wash)	No report	1
14/4/04	618	107	USD	10	Not available	No report	
21/8/04	747	129	USD	6	Not available	No report	
2/1/05	812	65	USD	9.5	Not Available	No report	
27/1/05	832	20	USD	4	Not Available	No report	
28/2/05	854	22	USD	42	Hydraulic starter hose burst	Replace hydraulic starter hose	1
16/7/05	972	118	USD	4.5	Tr1 alarm on hard wire trip	Reset the control panel	10
20/8/05	1003	31	PSD	78	8K PPM		
23/8/05	1004	1	USD	26	Start failure due to low scavenge pressure	Bleed valve control valve actuator stem or plunger was sticky. Service the control actuator stem.	1
1/6/06	1267	263	USD	0.5	fuel control sd low	No report	1
22/9/06	1380	113	USD	8	Tr1 LSC failure	Replaced the faulty load sharing controller card	7
27/9/06	1385	5	USD	23	Anti surge valve controller failure	Replaced the faulty anti surge controller card	7
22/11/06	1440	55	PSD	94	8K PPM		
26/12/06	1469	29	USD	144	engine replacement due to eroded HPT nozzle	Replace the engine with newly overhauled engine	1
19/2/07	1500	31	USD	38.05	high vibration on the comp DE	Perform trim balancing	2
14/3/07	1523	23	USD	24	Low lube oil level	Topup lube oil	8
26/4/07	1566	43	USD	13	faulty power card for CCC controller	Replaced the faulty power module card	7
8/7/07	1639	73	PSD	67.5	4K PPM		
1/12/07	1783	144	USD	1.5	PCD sensing line tubing broken	Replaced the broken tubing	1
7/12/07	1789	6	USD	43	auxiliary pump seized and coupling parted. troubleshoot lube oil pump & detergent wash	Isolated the unit and activated the backup pump	3
29/1/08	1840	51	PSD	68.5	8K PPM		
1/2/08	1841	1	USD	37	Start failed on yard valve sequence (2nd stg recycle) After PM	Recalibrate the discharge, suction and loading valves.	1
7/6/08	1967	126	USD	4	shutdown due to low discharge pressure	Recalibrate the discharge pressure transmitter	2
7/7/08	1997	30	USD	0.5	Train 1 trip due to 2nd stage anti-surge (FIC-2520)	Recheck the anti surge controller	7
19/7/08	2009	12	USD	18.5	tripped due to PLC Communication Failure	Checked the PLC Communication module	10
22/7/08	2012	3	USD	0.5	tripped to idle due to discharge temp high	Inspected the gas cooler	1
1/10/08	2079	67	PSD	336	compressor bundle changeout+8kppm		
15/10/08	2080	1	USD	115	flexi hose issue	Replace the flexible hose	1
21/10/08	2083	3	USD	257	lube oil contaminated	Replace the lube oil	8
endtime	2142						

Subsystem:

1 - Gas Turbine
2 - Gas compressor
3 - Starter system
4 - Gearbox
5 - Fuel system
6 - Vibration monitoring system
7 - Antisurge valve system
8 - Lube oil system
9 - Process
10 - Turbine control system