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A study on predictive analytics application to ship machinery maintenance

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THESIS

A STUDY ON PREDICTIVE ANALYTICS APPLICATION TO SHIP MACHINERY MAINTENANCE

by

Guan Hock Lee

September 2013

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Engine failures on ships are expensive, and affect operational readiness critically due to long turn-around times for maintenance. Prior to the engine failures, there are signs of engine characteristic changes, for example, exhaust gas temperature (EGT), to indicate that the engine is acting abnormally. This is used as a precursor towards the modeling of failures. There is a threshold limit of 520 degree Celsius for the EGT prior to the need for human intervention. With this knowledge, the use of time series forecasting technique, to predict the crossing over of threshold, is appropriate to model the EGT as a function of its operating running hours and load. This allows maintenance to be scheduled "just in time". When there is a departure of result from the predictive model, Cumulative Sum (CUSUM) Control charts can then be used to monitor the change early before an actual problem arises. This paper discusses and demonstrates the proof of principle for one engine and a particular operating profile of a commercial vessel with the use of predictive analytics. The realization with time series forecasting coupled with CUSUM control chart allows this approach to be extended to other attributes beyond EGT.

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A STUDY ON PREDICTIVE ANALYTICS APPLICATION TO SHIP MACHINERY MAINTENANCE

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Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

Engine failures on ships are expensive, and affect operational readiness critically due to long turn-around times for maintenance. Prior to the engine failures, there are signs of engine characteristic changes, for example, exhaust gas temperature (EGT), to indicate that the engine is acting abnormally. This is used as a precursor towards the modeling of failures. There is a threshold limit of 520 degree Celsius for the EGT prior to the need for human intervention. With this knowledge, the use of time series forecasting technique, to predict the crossing over of threshold, is appropriate to model the EGT as a function of its operating running hours and load. This allows maintenance to be scheduled “just in time”. When there is a departure of result from the predictive model, Cumulative Sum (CUSUM) Control charts can then be used to monitor the change early before an actual problem arises. This paper discusses and demonstrates the proof of principle for one engine and a particular operating profile of a commercial vessel with the use of predictive analytics. The realization with time series forecasting coupled with CUSUM control chart allows this approach to be extended to other attributes beyond EGT.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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LIST OF ACRONYMS AND ABBREVIATIONS

ABS	American Bureau of Shipping
ACMS	Alarm Control and Monitoring System
ARL	Average Run Length
CBM	Condition Based Maintenance
CPP	Controllable Pitch Propeller
CUSUM	Cumulative Sum
DI	Decision Interval
DoD	Department of Defense
ECR	Engine Control Room
EGT	Exhaust Gas Temperature
FAT	Factory Acceptance Test
GAO	Government Accountability Office
HFO	Heavy Fuel Oil
IO	Input/output
ME	Main Engine
MMI	Man-Machine Interface
MS	Microsoft
MSE	Mean Square Error
NPS	Naval Postgraduate School
PO	Port Office
ROPAX	Roll-On-Roll-Off Passenger Ship
RPM	Revolution per Minute
SaaS	Software as a Service
TCO	Total Cost of Ownership
VBA	Visual BASIC for Application
WH	Wheelhouse

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EXECUTIVE SUMMARY

This thesis demonstrates the application of predictive analytics to ship machinery maintenance to aid in the reduction of operational downtime and increase the overall effectiveness of a ship maintenance program. It also covers predictive analytics tools available in the market for machinery maintenance and how they can benefit the users to improve operational availability and system effectiveness.

Condition-based maintenance is a means of applying predictive analytics methods to manufacturing facilities in a planned maintenance policy where prevention is better than cure. The main difference between scheduled maintenance and condition-based maintenance is that the former is scheduled in time whereby the latter mostly has dynamic or on-request intervals.

A failure is a condition (or state) characterized by the inability of a material, structure or system to fulfill its intended purpose (task or mission), resulting in its retirement from usable service (Pau 1981). For this thesis, the failures mentioned will be associated with the functional failures of the system and studied by observing the abnormal behavior of the system towards failure limit.

The study of the above was based on the utilization of data obtained from an Alarm Control and Monitoring System (ACMS) installed onboard a commercial vessel. The database used for this research was provided by Singapore Technologies Marine Ltd and collected through ACMS installed onboard a Roll-On-Roll-Off Passenger (ROPAX) Ship. The period of data collection is 12/19/2010 to 3/18/2011. This set of data enabled discovery of trends and patterns for the prediction on the functional failure behavior of a shipboard main engine. With the analysis of the findings, a precursor, symptom or set of symptoms, can then indicate the need for a maintenance activity to take place before any critical failures occur.

The focus of the study was on one of the main engine attributes–main engine exhaust gas temperature. High exhaust gas temperature reflects potential problems at the combustion chamber which may or may not cause an overall failure to the Main Engine.

However, unusually high exhaust gas temperature poises a potential problem to the overall Main Engine operation and is worthy of study. The study aims to establish that the use of such methodology is achievable and implementable for the main engine system. After the verification on the usability of such methodology, it could then be extended to other system attributes in future.

Two techniques of statistical analysis, mainly time series models and cumulative sum control charts, are discussed in this thesis. A time series is a set of observations on a quantitative variable collected over time (Ragsdale 2012). CUSUM Control Charts are employed to detect a process that has deviated from a specified mean. Visual BASIC for Application (VBA) of Microsoft (MS) Office Excel was used as the statistical tool employed for the two techniques of statistical analysis.

Both time series forecasting as well as CUSUM control charts are shown to be capable of detecting anomalies. Time series models are used for the predicting or forecasting of the future behavior of variables applied for offline analysis while CUSUM is better applied for real-time online use. The application of both methodologies, facilitates “just in time” maintenance, thereby reducing operational downtime and improves the overall effectiveness of a ship maintenance program.

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The author would like to express his most sincere gratitude to Professor David Olwell, his thesis supervisor, for guidance, coaching and patience while working on this thesis throughout the year. His encouragement and advice have helped the author overcome many challenges along the way for the successful completion of this thesis on time. His expertise on the topic of preventive maintenance provided insights into this area of study and allowed the author to build on the methodology for predictive analytics application to ship machinery maintenance.

The author would like to thank Professor Fotis Papoulis, the second reader for this thesis, for his advice on the selection of engine parameters for this study. His expertise in the field of propulsion systems allowed the author to have a deeper understanding of the propulsion systems and the coupling between the sub-systems.

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I. INTRODUCTION

Operational readiness is a key issue for military forces, especially in a time of decreasing resources. Improving system operational availability offers a way to provide a constant level of force structure while fielding fewer systems. One way to improve operational availability is to provide preventive maintenance "just in time" to avoid both the cost and 'down time' of corrective maintenance and unnecessary preventive maintenance. This thesis explores the use of a predictive analytics approach to study the failures of a commercial main engine (ME) and then suggests how the approach could be broadened to naval ships.

In today's environment, resources must be well maintained and ready for use whenever called upon. This can be achieved by performing less total corrective (unscheduled) and preventive (scheduled) maintenance as well as by reducing the total administrative and logistical downtime spent waiting for parts, maintenance personnel, or transportation during a given period. It is a difficult task to identify a preventive maintenance period accurately. Overall operational availability of resources can be improved with the implementation of preventive maintenance, since maintenance is considered a core component in ensuring that the machinery is functioning efficiently.

According to the United States Department of Defense (DoD) Operation and Maintenance Overview budget estimate report, the FY2013 budget estimates $33,758.3 million for Navy operating forces as compared to the FY2012 enacted $31,021.5 million. Ship operations account for approximately $1.5 billion. Out of that, $762 million was for long-term planned maintenance (U.S. Government Accountability Office 2013). More recently, maintenance of surface ships was deferred as a result of the mandatory budget cuts (U.S. Naval Institute News 2013). The United States Navy was reported to have expended millions of dollars on maintenance actions that are carried out in phased periods (United States Department of Defense 2012).

Software and hardware may be used to evaluate component health and the condition of a system based on operational usage. In turn, this information can provide insights on when to schedule maintenance periods, based on statistical and engineering analyses that predict functional failures of machineries. The determination of a precursor for maintenance leads to a better, if not equivalent, operational availability at a reduced cost, because maintenance is done only when needed.

This thesis studied how the application of predictive analytics to ship machinery maintenance can aid in the reduction of operational downtime and increase the overall effectiveness of ship maintenance program.

This approach was based on the use of data obtained from an Alarm Control and Monitoring System (ACMS) installed onboard a commercial vessel. This set of data enabled discovery of trends and patterns for the prediction of the functional failure behavior of a shipboard main engine. With the analysis of the findings, a precursor, symptom or set of symptoms can indicate the need for a maintenance activity to take place before any critical failures occur.

A. CONDITION-BASED MAINTENANCE

Maintenance is the process of restoring an item to the state whereby it can perform its required functions. Even a layperson understands that machines fail after a period of usage and that a certain level of maintenance is required in order to keep the machine running. However, not many appreciate the philosophy and strategy of maintenance. Most also know that maintenance can generally be broken down into scheduled (Preventive) and unscheduled (Corrective) maintenance (Blanchard and Fabrycky 2001). Trained mechanics then make more sophisticated assessments, as shown in Figure 1, demonstrating different approaches employed to prevent failures or to repair the system (Williams, Davis, and Drake 1994). Condition-based maintenance (CBM) is an area that is often unexploited due to its high initial cost in implementation and the failure by people to recognize the potential benefits of performing proactive maintenance.

CBM is a means of applying predictive analytics methods to manufacturing facilities in a planned maintenance policy where prevention is better than cure. The main difference between scheduled maintenance and CBM is that scheduled maintenance is scheduled in time whereby CBM mostly has dynamic or on-request intervals.

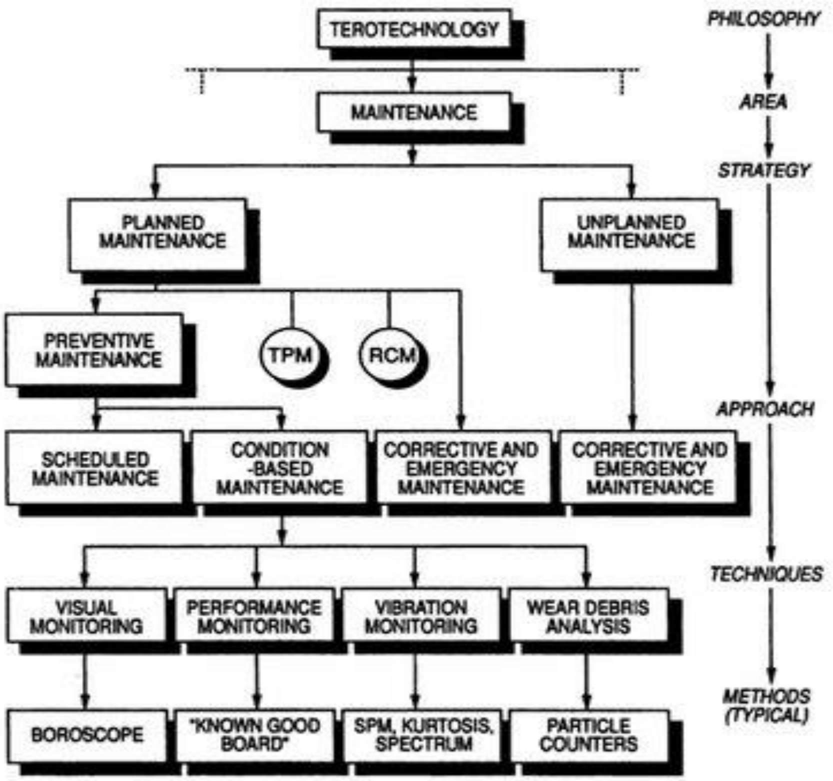


Figure 1. Relationship of CBM to various forms of maintenance (From Williams, Davis and Drake 1994).

The CBM system involves a number of subsystems and capabilities such as sensing and data acquisition, signal processing, condition and health estimation, prognostics and decision assistance. In order to gain access to the system and have visual monitoring and data information, a Man-Machine Interface (MMI) such as an Alarm Control and Monitoring System (ACMS) can be utilized. Typically, a CBM system consists of the integration of various hardware and software, which results in the high initial implementation cost.

CBM makes use of the information collected on equipment through monitoring systems such as an ACMS and compares this online data to the machinery's conditions with predefined operating thresholds. Data that falls outside of this threshold generates a maintenance alert to the operator that signifies a probable problem or area of concern.

B. ALARM CONTROL AND MONITORING SYSTEM

An ACMS integrates the control and monitoring of the various shipboard systems into a centralized system and serves to provide real-time data, alarm monitoring, and control of the ship's platform systems. It is a proven solution to a ship's automation needs, and it has become a trend for commercial ship owners to adopt this system. The trend for the adoption of automation reduces workload and dependence on engine crews. It also allows data to be extracted from ACMS for analysis. ACMS allows information to be visible through the human-machine interface screen pages, also known as mimics, at prominent or important locations like the Wheelhouse (WH), Engine Control Room (ECR), and Port Office (PO). These data are processed and displayed via the monitor through different mimic pages. The information can be displayed in the forms of pictorial, text, trends and graphs to facilitate easy comprehension by the operators. An example of the mimic is as shown in Figure 2 where the system overview is shown.

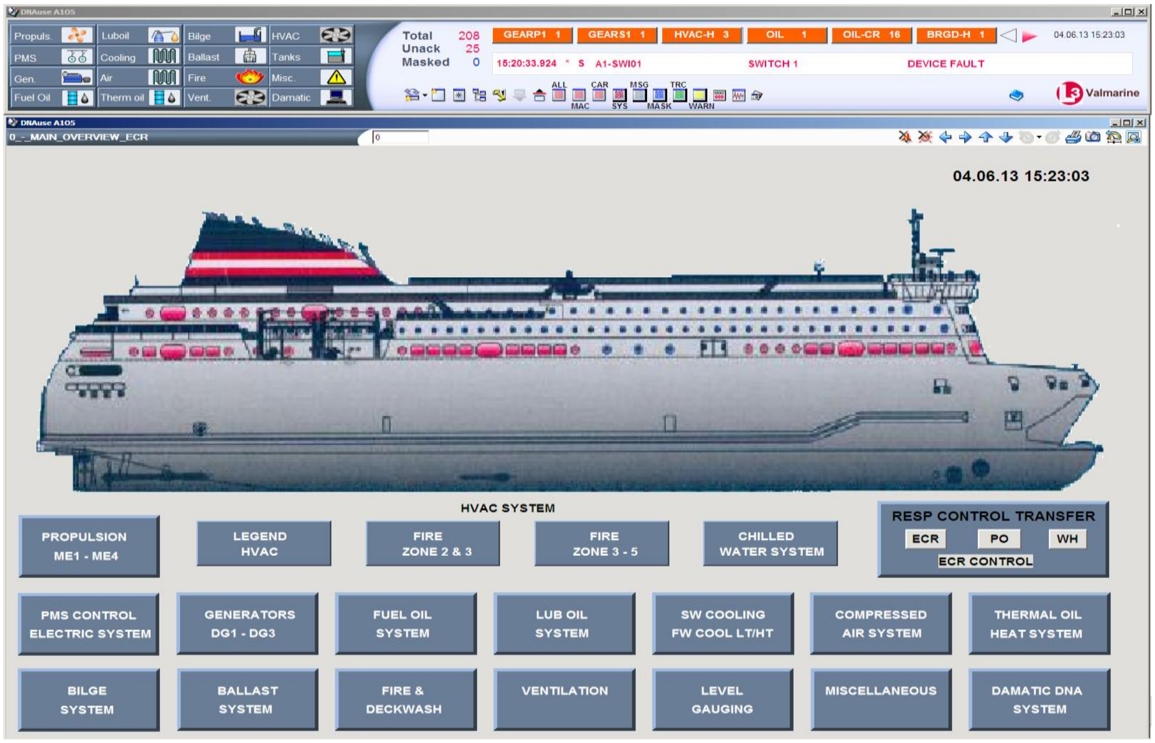


Figure 2. ACMS of Roll-On-Roll-Off Passenger Ship Design Mimic (From Singapore Technologies Marine Limited 2010).

Ship’s data derived from the ACMS can be used as an extension for predictive analytics for maintenance of ship machinery. The data can be compared to a predefined machinery operating threshold and an alert triggered when the data falls outside of the acceptable area. CBM can be integrated into ACMS, or it can perform as a subsystem on its own by reading the required data from ACMS.

C. PROBLEM DEFINITION

While the thesis suggests that the application of predictive analytics on ship machinery maintenance can aid in the reduction of operational downtime and increase the overall effectiveness of the ship maintenance program, the initial research shows that there is more that the system needs to achieve. This section will define the problem by identifying the gaps that need to be filled by the system, as well as the scope, limitations and constraints of the project.

1. Problem Identification

With the understanding from background and initial research, information pertaining to the use of predictive analytics is not conclusive. This includes the use of an appropriate precursor to model and signify machine failures. The selection of an appropriate precursor is still not concise for a variety of reasons, such as proprietary concerns, the lack of in-depth information and publication on the methodology for achieving it, as well as poor utilization of available information that can be used for analysis. With this understanding, three gaps are identified, and they are as follows:

a. Lack of use of existing data

With the current technology, many ships do have information-gathering capabilities such as ACMS, but these data are seldom extracted for analysis to contribute towards preventive maintenance because there is an overwhelming amount of information available. There is underutilization of the data available.

b. Lack of expertise to analyze data

There is a lack of expertise to accurately extract the relevant data from the vast amount of information available, sort them and analyze them for signs of failure. Correlation of the various parameters that leads to failures is not well understood by operators, so there is no means to predict machine failures.

c. Lack of support for initial high-cost investment

Typically, companies are concerned about the high initial cost of implementing a CBM system. They believe that it is not justifiable for the costs involved. They also fail to recognize the high maintenance cost incurred throughout the system life cycle. This idea that regularly scheduled maintenance and corrective maintenance is cheaper is the traditional approach. Reluctance to invest in the CBM system can also be attributed to poorly communicated or skewed figures and forecasts during the initial conceptual phase of a project, projecting minimal costs in the competition for contracts.

These gaps formed the basis for the problem statement addressed by this project. It can be summarized as follows:

Apply predictive analytics to study and analyze ship machinery failures for a precursor to ship maintenance indicator that leads to reduced operational downtime and increased of the overall effectiveness of ship maintenance program.

This study was intended to expand and deepen knowledge of predictive analytics related to ship maintenance through the conduct of more extensive and thorough research methodology. Current capabilities of predictive analytics are widely marketed. The challenge remains to address the issue on the know-how needed and to support a general application of the methodology across all machinery maintenance.

2. Scope

The main scope of this thesis covers the study of predictive analytics tools available in the market for machinery maintenance and how predictive analytics can benefit the users of such applications in operational availability and system effectiveness. Other issues include:

- Examination of the existing technology for predictive analytics application;
- Examination of the related functions that have been researched or are in the process of being researched;
- Examination of the system architecture/concepts being employed in the systems being used;
- Investigation of the risk associated with such integration;
- Analysis of the data extracted that are relevant to the predictive analytics analysis;
- Obtaining a predictive analytics model for the ship engine machinery maintenance; and
- Investigation of the model to encapsulate enough parameters for sound analysis.

3. Limitations

There are several limitations to this thesis. These limitations are identified in the following sections.

a. Collecting enough engine data for analysis

The engine data is collected from an operational commercial vessel. The storage capacity of the ACMS is limited in size and therefore limits the amount of data that can be extracted from the system for analysis. There will be occasions when the older data are overwritten by the more current ones. An estimate of three-months' worth of data is available for analysis at any point during data extraction.

b. Analyzing enough engine parameters to construct a conclusive predictive model

There are many engine attributes as well as other systems' attributes that will influence and affect the accuracy of the predictive model. The complexity of the model for this thesis study is inevitably constrained by the time allocated to this study. As such, the model may not encompass all the attributes that may constitute a complete model.

c. *Schedule considerations hamper analysis of a working predictive model*

Schedule ultimately limited the amount of time available for the exploration and analysis of the predictive model. This limitation may lead to a less comprehensive analysis of the predictive model.

4. Constraints

a. *To use existing commercial ship engine data*

This constraint means that the model is more inclined to the particular class of vessel from which the data are being extracted. It may not be identical to or completely appropriate for use on other classes of vessels and adjustments may have to be made.

b. *To use available software resources for modeling*

The available software inevitably shapes the presentation of the result depending on the software functions available.

D. PREVIOUS WORK

Brian P. Murphy, in his 2000 thesis (Murphy, 2000), mentioned the use of Condition Based Maintenance concepts in which the software diagnostics tools in the multi-level machinery health assessment could provide machinery monitoring and prediction of components' remaining time until a problem occurred. It was highlighted that this situation awareness of the systems allows the reduction of crew workload associated with maintenance and operation by virtue of the "just in time" maintenance concept and eliminates the need for roving watch standers taking handwritten readings of the machinery status. There were no further details mentioned with respect to the methodology and success of such a program.

John E. Harding, in his 1994 thesis (Harding, 1994), studied the use of Pseudo Wigner-Ville Distribution and wavelets analysis as two methods for condition monitoring of non-stationary and transient shipboard machinery for the detection of fault locations and their severity level. The motivation for his research paper was to increase the operational capability of naval vessels by establishing some indicator of the health of the equipment and allows “just in time” maintenance to be performed. His results show a complete representation of the harmonic nature of the compressor component and that a change in the mechanical condition of the machine could be established by conducting Pseudo Wigner-Ville Distribution analysis. The disadvantage of the methodology is that a complete analysis is time consuming, and it is only applicable to moving components.

In their 1990 research and development report for David Taylor Research Center, Christopher P. Nemarich, Wayne W. Boblitt, and David W. Harrell (Nemarich et al. 1990) mentioned the development of a demonstration model of a CBM monitoring system for propulsion and auxiliary systems. The expected benefits of CBM are improved maintenance procedures and scheduling, increased machinery operational readiness, and reduced logistics support cost. They make use of sensors and monitoring systems to gather the data and information for prognostics capability. Prognosis projects future health based on current and past conditions. It makes use of a probabilistic model of the high pressure air compressor to provide predictions of future machine health. Probabilities are assigned to these predictions to give the operators an indication of the degree of confidence with which the prediction is made. No further details were mentioned on the degree of success for such a methodology, and there are future plans mentioned to look into this area of research.

Jose A. Orosa, Angel M. Costa and Rafael Santos from the University of A Coruña (Orosa et al. 2011), Spain mentioned the use of Visual Basic for Application for predictive maintenance methodology in their 2011 research. A control chart is being used to study the exhaust gas temperature in the engine. The control chart is one of the most important and commonly used among the statistical Quality Control methods for monitoring process stability and variability. It is a graphical display of a process parameter plotted against time, with a center line and two control limits (Jennings and Drake 1997). The exhaust gas temperature sample failure in the main engine is sampled and, consequently, the p-charts were selected. The p-chart monitors the percent of samples having the condition, relative to either a fixed or varying sample size, when each sample can either have this condition or not. Any points outside the control limits can imply a shift in the process and indicates a potential problem.

E. AREA OF RESEARCH AND APPROACH

Predictive analytics have a number of traits that make them a more attractive approach as compared to the conventional method of the maintenance concept. Predictive analytics can be used to determine events and outcomes before they occur. They can provide simulation of a process to determine the risks, as well as facilitate "what if" scenarios to determine the optimum course of action. Firstly, they are capable of providing valuable information that can lead to a smarter decision. Secondly, they have the ability to detect patterns to initiate action. Finally, with the capability to aggregate and correlate information, they allow suspicious trends to be captured before loss occurs. These features allow improved collaboration and better control for a better Total Cost of Ownership (TCO) of a vessel.

Predictive analytics are not without their disadvantages. First, they, like all models in the market, remain to be tested and verified for inherent inaccuracy. This inaccuracy may be due to an error in model specification. A model is only as good as it is defined, and it may include factors that are not significant predictors or factors that may be significant but unobserved. Another consideration is the inherent error term of the model. An error term represents the portion of the model that is unexplained. This error term can be substantial, even in well specified models, and can result in variation between predictions and actual outcomes.

Second, the initial high cost involved in the implementation of predictive analytics techniques discourages investment. The high costs are associated with the hardware and software necessary to facilitate predictive modeling.

Finally, even with the information available, the predictive model is dependent on how clean and accurate the acquired data is. If there are too many legacy systems with poor record keeping, the data may be unfit for use.

Predictive analytics appear to have the potential to be the upcoming trend for machinery maintenance to be used as a tool for the next generation. With the increased use of sensors and data monitoring systems onboard vessels, vast amounts of information are waiting to be collected, utilized and analyzed to provide better prediction of machinery failures. The cost effectiveness of such a technique to tap on the existing infrastructure, determining "just in time" maintenance would theoretically and logically be attractive. Therefore, this paper aims to justify the application of predictive analytics on ship machinery maintenance.

F. STATISTICAL TOOLS

The statistical tool selected for this thesis is Visual BASIC for Application (VBA) of Microsoft (MS) Office Excel. Microsoft owns the VBA, whose code is compiled (Microsoft 2010; Excel 2010; Jelen and Syrstad 2008; and Roman 2002) in an intermediate language called the p-code; the latter code is stored by the hosting application (Access, Excel, Word) as a separate stream in structured storage files independent from the document streams.

The intermediate code is then executed by a virtual machine. Therefore, the obtained software resource can only operate in a Windows 98 or above operating system. Calculus operations and graphics required for the results can be carried out in MS Excel.

The executable program, anygeth, obtained from CUSUM website of the School of Statistics, University of Minnesota (www.stat.umn.edu) is used for the calculation of CUSUM reference value and the decision intervals.

G. ORGANIZATION OF STUDY

This thesis first introduces the readers to the concepts of CBM and the available tools to support it, such as ACMS. A summary of previous work is provided, along with the author's area of research and the possible tools used to achieve the objectives of this research.

Chapter II provides an overview of predictive analytics such that sufficient knowledge of the history, purpose, and methodology can be explained and serves as a basis for the rest of the chapters.

Chapter III describes the database and procedures that are used to choose the data for use, and presents the steps of the methodology that leads to the results of this research.

Chapter IV discusses the results and outputs of the models that were trained in supporting the goal of this research.

Finally, Chapter V summarizes the conclusions drawn from this research and provides recommendations for future research opportunities associated with the predictive analytics technique.

II. PREDICTIVE ANALYTICS OVERVIEW

Predictive analytics is essentially an area of statistical analysis that requires the extraction of information from data and using the information to predict future trends and behavior patterns (Nyce 2007). Techniques commonly used in predictive analytics are drawn from a variety of fields such as statistics, modeling, machine learning, and data mining (Eckerson 2007).

One important distinction of predictive analytics from other business intelligence tools is that it goes beyond visualizing data and human assumptions; instead it combines data, theory, and mathematics to make forecasts about the future using current and historical facts (Grant 2011).

A. HISTORY

Predictive analytics was discovered only a decade ago, and it is the amalgamation of four various fields: mathematical techniques, data storage capacity, data processing power, and data creation. The mathematical techniques have existed and improved since the founding of the Econometric Society in 1930. The data storage capacity has been around since 1977 with Oracle's commercialization of the relational database. The processing power has existed since IBM commercialized business computing with the IBM 360. Software as a Service (SaaS) and social media provided the final requirement, data creation (Grant 2011).

Predictive analytics is employed in a variety of industries, which includes financial services, telecommunications, and healthcare. One of the most well-known applications is the FICO score, a credit scoring which is widely used in the financial services (Fair Isaac Corporation 2009).

B. DEFINITIONS OF THE MAIN COMPONENTS OF THE READINESS CONCEPT

A failure is a condition (or state) characterized by the inability of a material, structure, or system to fulfill its intended purpose (task or mission), resulting in its retirement from usable service (Pau 1981). For this thesis, the failures mentioned will be associated with the functional failures of the system and studied by observing the abnormality behavior of the system in relation to the failure limit.

Degradation is an event that impairs or deteriorates the system’s ability to perform its specified tasks or mission. This includes improper controls and the effects of the environment (Pau 1981).

Failure detection is the act of identifying the presence of an unspecified failure mode in a system, resulting in an unexpected malfunction (Pau 1981). The failure detection is done through the ACMS for the main engine system under study.

Failure diagnosis is the process of identifying a failure mode (or condition) from an evaluation of its signs and symptoms (such as performance monitoring measurements) (Pau 1981). Failure prognosis is the art or act of forecasting a future condition based on present signs and symptoms observed.

Readiness is the ability of the system to carry out a specified task or mission at a specified performance level, without catastrophic failure or interruption, when activated at any given time (Pau 1981).

C. PREDICTIVE ANALYTICS TECHNIQUES

The study of predictive analytics encompasses a variety of techniques ranging from statistics, modeling, machine learning, and data mining that analyzes past and current data to make predictions about future events. Two techniques of statistical analysis, mainly time series models and cumulative sum control chart, will be discussed in this thesis.

1. Time series models

A time series is a set of observations on a quantitative variable collected over time (Ragsdale 2012). Time series models are used for the predicting or forecasting of the future behavior of variables. In many engineering situations, it is nearly impossible to forecast time series data using a causal regression model since we do not know which causal independent variables are influencing a particular time series variable. This makes it difficult to build a regression model. Even if we do have some insight as to which causal variables are affecting a time series, the best regression function estimated from these data might not accurately reflect so. Finally, even with a well-fit regression function to data, there is a possibility that we may have to forecast the values of the independent variable to estimate the future values of the dependent (time series) variable. Forecasting the causal independent variables might be more difficult than forecasting the original time series variable.

The possibility of discovering systematic variation in the past behavior of the time series variable allows the construction of a model of this behavior to help in forecasting the future behavior. For instance, a fluctuation reflected in data could help to make estimates about the future, or trends found (whether they are upward or downward), in the time series, might be expected to continue in the future. Techniques that analyze the past behavior of a time series variable to predict the future are sometimes referred to as extrapolation models (Ragsdale 2012). The general form of the model is

$$Y_{t+1} = f\,(Y_{t,} Y_{t-1,} Y_{t-2,} \ldots) \tag{1.1}$$

where, Y_{t+1} represents the predicted value for the time series variable in the time period, *t+1*, Y_t represents the actual value of the time series variable in time period *t*, $Y_{t-1,}$ represents the actual value of the time series variable in period *t-1*, and so on. The purpose of an extrapolation model is to identify a function *f()* for Equation 1.1 that produces accurate forecasts of future values of the time series variable.

There are three techniques that are appropriate for stationary time series where there is no significant upward or downward trend in data over a period of time. They are: moving average, weighted moving average, and exponential smoothing. This is useful in this study as the data are presumably stationary unless there is a probable failure that might cause this deviation from the trend. Only moving average will be explained in this paper.

The predicted value of the time series in period *t+1* (denoted byY_{t+1}) for the moving average technique is simply the average of the *k* previous observations in the series; that is:

$$Y_{t+1} = \frac{Y_t + Y_{t-1} + \ldots + Y_{t-k+1}}{k} \qquad (1.2)$$

The value k in Equation 1.2 determines how many previous observations will be included in the moving average. This technique tends to average out the highs and lows observed and recorded in the original data. The larger the value of k, the smoother the moving average prediction will be.

We can then study the Mean Square Error (MSE) to look at the accuracy of the prediction. The MSE is defined as

$$MSE = \frac{1}{n} \sum_i \left(Y_i - Y_i \right)^2 \qquad (1.3)$$

where Y_i represents the actual value for the i^{th} observation in the time series, and Y_i is the forecasted or predicted value for this observation. These quantities measure the differences between the actual values in the time series and the predicted values.

2. Cumulative Sum (CUSUM) Control Chart[1]

CUSUM control charts are used when it is imperative to detect a process that has wandered away from a specified process mean. Although Shewhart $\overline{X}$ -charts can detect if a process is moving beyond a two or three sigma shift, they are not effective at spotting a smaller shift in the mean (Crosier 1988). The idea of CUSUM charting was recognized as intuitively attractive for detecting smaller but persistent shift (Hawkins and Olwell 1998).

The basis for the CUSUM chart for a normal mean is that while the process is in control, the reading X_n are statistically independent and follow a normal distribution with known μ and known standard deviation σ. This reminds us of the importance of checking for the lack of correlation. The assumption that the reading follows a normal distribution is important because knowing the distribution of the data is essential to figure

[1] The concept & methodology explained in this paper Chapter II, Section C.2 (from pages 16 to 24) is referenced from *Cumulative Sum Charts and Charting for Quality Improvement* by Douglas M. Hawkins & David H. Olwell. The contents are either paraphrased or reproduced in part to retain the concept put forth by the mentioned authors.

out the chart's false alarm rate and how sensitive it is to actual shift. The last assumptions that the exact values of the parameters μ and σ are known is seldom the case in reality. However, it can be approximated by measuring the process over a long period while it is under a state of statistical control. These estimates can be used as true parameter values. It should be noted that the data sets must be large enough to obtain a reasonably close estimate of these parameters to be close enough to the true values for practical application.

The CUSUM, C_n, can be defined in two ways. Equation 1.4 defines it in the original scale of the problem, and Equation 1.5 defines the standardized version with the reading having zero mean and unit standard deviation.

$$C_n = \sum_{j=1}^{n} \left(X_j - \mu \right) \tag{1.4}$$

$$U_j = \left(X_j - \mu \right) / \sigma$$

$$S_n = \sum_{j=1}^{n} u_j \tag{1.5}$$

In Equation 1.5, CUSUM S_n is scaled by a factor of σ, the standard deviation of the reading. Therefore, the CUSUMs of C_n and S_n are identical except for the units of the vertical axis. The vertical axis of the S_n CUSUM will be measured in multiples of the standard deviation σ of the data whereas the vertical axis of the C_n CUSUM will be measured in the same units as *X*.

Statistically, CUSUM C_n is the sum of independent normal $C_n \sim N\left(0, \sigma^2\right)$ quantities. Its distribution is

$$C_n \sim N\left(0, n\sigma^2\right) \tag{1.6}$$

The standard deviation of C_n increases with *n* and is proportional to the square root of *n*. As n increases, C_n is likely to be increasingly far from zero. This has a direct implication on the mechanics of plotting a C_n CUSUM. Even if the process is in control, it may not be able to be captured on a single printed page or within the screen of the computer.

The recursive form of the C_n equation can be written as

$$\begin{aligned} C_0 &= 0 \\ C_n &= C_{n-1} + \left(X_n - \mu\right) \end{aligned} \tag{1.7}$$

The recursive form aids in easy computation of the CUSUM. Each point of the CUSUM is the previous point plus the offset of the latest point from μ.

The standardized recursive form of the C_n equation can be written as

$$\begin{aligned} S_0 &= 0 \\ S_n &= S_{n-1} + U_n \end{aligned} \tag{1.8}$$

The out-of-control distribution of the CUSUM describes a means to diagnose shifts in mean. This serves as a pre-warning that there is an anomalies observed in the process and the possibility of a failure. It triggers the need for further diagnosis or maintenance actions. Suppose that at some instant *m* the distribution of X_n changes from $N\left(\mu,\sigma^2\right)$ to $N\left(\mu+\delta,\sigma^2\right)$. This means that from instant *m* onwards the mean of X_n undergoes a persistent shift of size δ. At any subsequent instant, *n*, CUSUM can be written as

$$\begin{aligned} C_n &= \sum_{i=1}^{n}\left(X_i - \mu\right) \\ &= \sum_{i=1}^{m}\left(X_i - \mu\right) + \sum_{i=m+1}^{n}\left(X_i - \mu\right) \end{aligned} \tag{1.9}$$

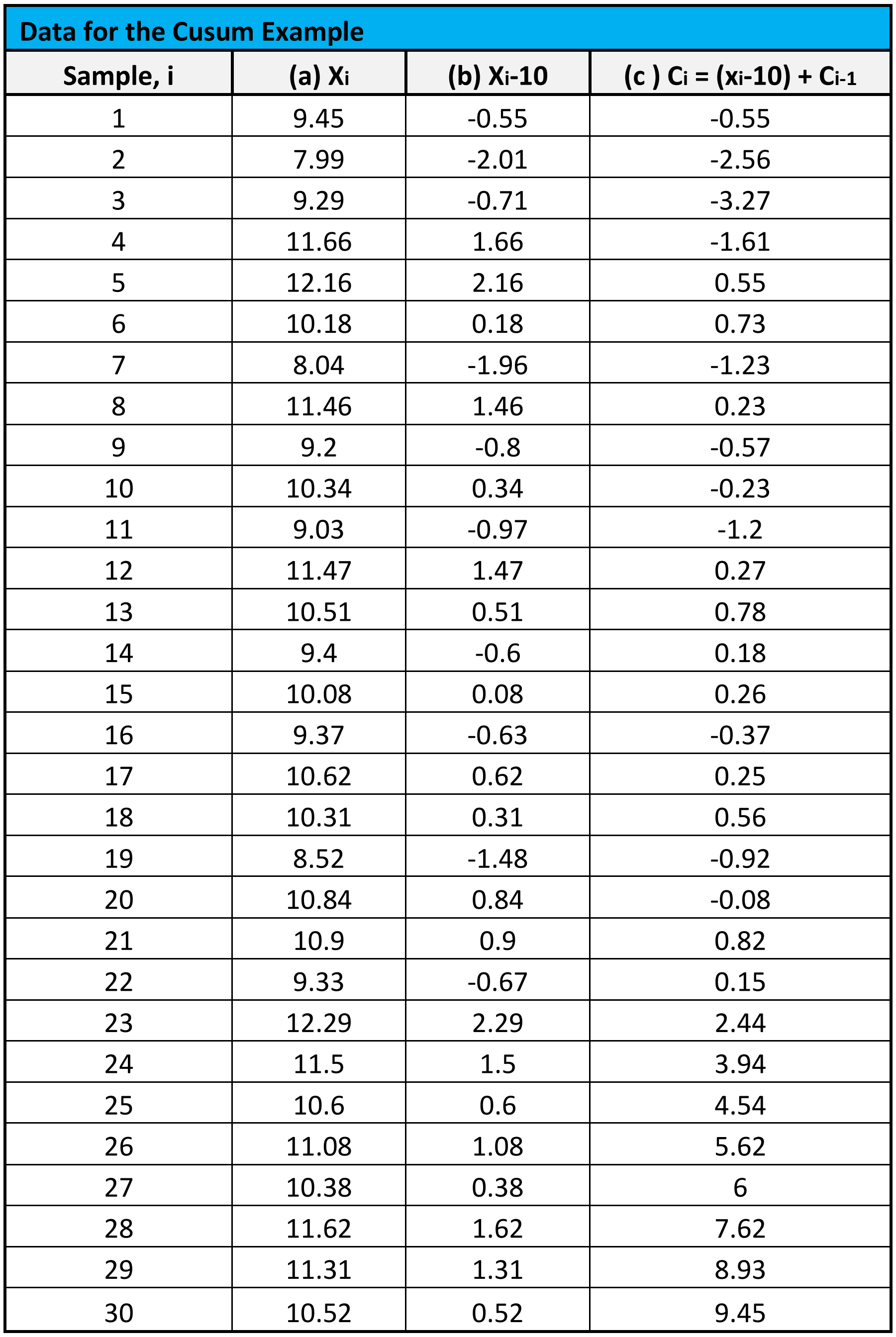
As the second term of the summation is distributed as $N\left(\delta,\sigma^2\right)$, it will have a distribution of

$$\sum_{i=m+1}^{n}\left(X_i - \mu\right) \sim N\left[\left(n-m\right)\delta,\left(n-m\right)\sigma^2\right] \tag{1.10}$$

This means that the average value of CUSUM at time $n > m$ is $(n\text{-}m)\delta$. It also means that starting from the point (m, C_m), the CUSUM on average will trace a path centered on a line of slope δ. This serves as the basis for using CUSUM to detect shifts in mean. While the process remains in control and the reading X_n follows the in-control $N\left(\mu,\sigma^2\right)$ distribution, the CUSUM follows a distribution centered on the horizontal axis. If the mean undergoes a step change, then the CUSUM develops a linear drift, and its distribution will center instead on a line where slope δ equals the shift in mean. The diagnosis of the CUSUM therefore consists of distinguishing the no-drift in-control behavior from the linear drift behavior following a mean shift. What it means here is that the CUSUM defined in Equation 1.9 is a random walk with mean 0. If the mean shifts upward to some value *n* > *m*, an upward or positive drift will develop in CUSUM. Conversely, if the mean shifts downward to some value *n* < *m*, then a downward or negative drift will develop in CUSUM.

An example on the plot of CUSUM is shown in Figure 3. The process mean remains at target value of 10 and Equation 1.9 is used for the calculation. The equation that follows is a manipulation of Equation 1.9 and it describes how the calculations are done in tabular form, with the data and steps shown in Table 1.

$$\begin{aligned} C_i &= \sum_{j=1}^{i}\left(x_j - 10\right) \\ &= \left(x_i - 10\right) + \sum_{j=1}^{i-1}\left(x_j - 10\right) \\ &= \left(x_i - 10\right) + C_{i-1} \end{aligned}$$



Data for the Cusum Example

Sample, i	(a) X_i	(b) X_i-10	(c) $C_i = (x_i-10) + C_{i-1}$
1	9.45	-0.55	-0.55
2	7.99	-2.01	-2.56
3	9.29	-0.71	-3.27
4	11.66	1.66	-1.61
5	12.16	2.16	0.55
6	10.18	0.18	0.73
7	8.04	-1.96	-1.23
8	11.46	1.46	0.23
9	9.2	-0.8	-0.57
10	10.34	0.34	-0.23
11	9.03	-0.97	-1.2
12	11.47	1.47	0.27
13	10.51	0.51	0.78
14	9.4	-0.6	0.18
15	10.08	0.08	0.26
16	9.37	-0.63	-0.37
17	10.62	0.62	0.25
18	10.31	0.31	0.56
19	8.52	-1.48	-0.92
20	10.84	0.84	-0.08
21	10.9	0.9	0.82
22	9.33	-0.67	0.15
23	12.29	2.29	2.44
24	11.5	1.5	3.94
25	10.6	0.6	4.54
26	11.08	1.08	5.62
27	10.38	0.38	6
28	11.62	1.62	7.62
29	11.31	1.31	8.93
30	10.52	0.52	9.45

Table 1. Data for the CUSUM Example (From Montgomery 2009).

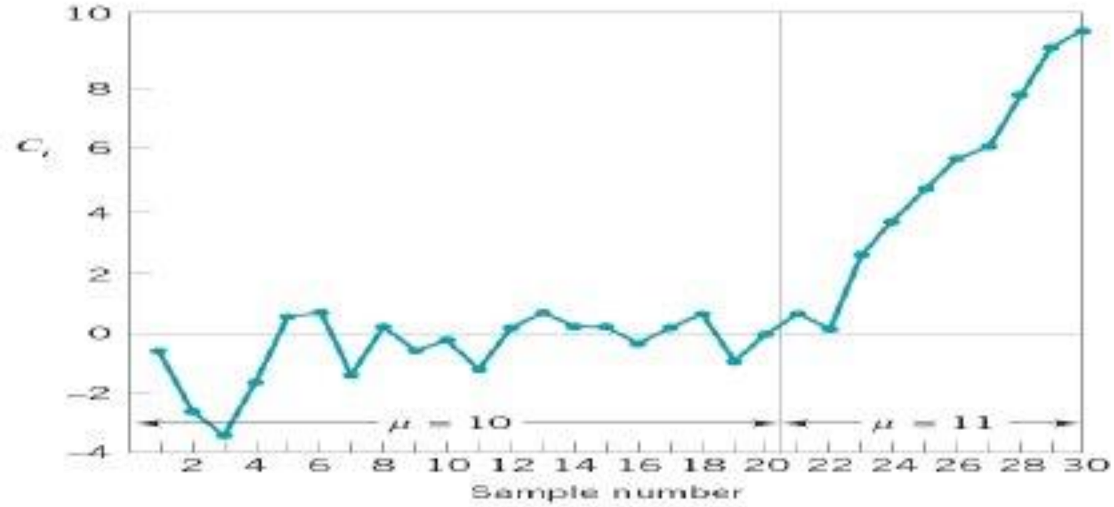


Figure 3. Plot of the CUSUM from column (c) of Table 1 (From Montgomery 2009).

The formal tool used historically for the determination of shift in mean is the V-mask (Hawkins & Olwell 1998). However, we will discuss the "decision interval," or DI form, of the CUSUM in this paper. The DI form is the algebraically equivalent form of the CUSUM, and it provides ease in the determination of the "real" shifts visually. It is equivalent to setting up the v-mask from the CUSUM C_n (or S_n) and diagnosing it using a V-mask of a particular slope k and particular leg height h. Monitoring X_n for an upward shift in mean is done by setting up the sequence

$$C_0^+ = 0$$
$$C_n^+ = \max\left(0, C_{n-1}^+ + X_n - \mu - k\right)$$

signaling an upward shift in mean if

$$C_n^+ > h$$

If there is a signal, the estimate of m, the time of occurrence of the shift, is given in the C_n CUSUM as that previous value farthest below the v-mask; in the DI form, it is the most recent observation for which $C_m^+ = 0$.

The DI CUSUM C_n^+ tests for upward mean shifts. For a downward shift in mean, the following sequence was set up.

$$C_0^- = 0$$
$$C_n^- = \min\left(0, C_{n-1}^- + X_n - \mu + k\right)$$

with a signal if

$$C_n^- < -h$$

When there is an indication of a downward shift in mean, the last point *m* for which $C_m^- = 0$ as the estimate of the instant preceding the change in mean.

The CUSUM slope estimator is given by

$$\overset{\wedge}{\delta} = \frac{C_n - C_m}{n - m} \tag{1.11}$$

The DI form of the CUSUM can be used to estimate the magnitude of the shift in mean. The segment of the DI CUSUM leading to the signal starts with some case *m* for which $C_m = 0$ and then is positive up to the point at which it crosses the decision interval *h*. The equation $C_n^+ = C_m^+ + \sum_{i=m+1}^{n} \left(X_i - \mu - k\right)$ shows the form in the described segment.

Following the shift in mean from μ to $\mu + \delta$, the summand has a normal distribution with mean $\delta - k$. δ can then be estimated by adding *k* to the slope of the DI CUSUM from point *m* to point *n*, giving the estimate

$$\delta = k + \frac{C_n^+ - C_m^+}{n - m} \tag{1.12}$$

which reduces to $k + \dfrac{C_n^+}{n - m}$ since $C_m^+ = 0$.

Similarly, if the downward DI CUSUM signals a shift, then the magnitude of the shift can be estimated by

$$\delta = -k + \frac{C_n^-}{n - m} \tag{1.13}$$

Note that C_n^+ and C_n^- are both necessarily positive and negative, respectively; it is therefore impossible for the estimate of δ to lie between –*k* and *k*. This also shows that the estimate of the shift produced by CUSUM is biased away from zero.

Similarly, the standardized V-mask-type CUSUM Sn has decision interval equivalents S_n^+ and S_n^- defined by the recursive equations

$$S_0^+ = 0 \tag{1.14}$$

$$S_0^- = 0 \tag{1.15}$$

$$S_n^+ = \max(0, S_{n-1}^+ + U_n - k) \tag{1.16}$$

$$S_n^- = \min(0, S_{n-1}^- + U_n + k) \tag{1.17}$$

The upward CUSUM chart starts out at its initial state S_0^+. After that, it may stay on the axis or move into positive values. Each set of positive values will end in one of these two ways: either the CUSUM returns to zero, or it crosses the decision interval. When the chart crosses the decision interval, this indicates a shift may have happened and requires attention to diagnose the shift. The CUSUM will generally then be restarted. The whole sequence going from the starting point to the CUSUM crossing the decision interval is called a run. The number of observations from the starting point up to the point at which the decision interval is crossed is called the run length.

When the CUSUM gives a signal although there is no shift occurring, it is known as a Type 1 error, analogous to the classical hypothesis testing. These false alarms are undesirable as they caused the unnecessary expenditure of time and effort in search of nonexistent problems. As such, the runs between inevitable false alarms would be preferred to be as long as possible.

An error in control charting is analogous to a Type II error in classical hypothesis testing. This is a chart remaining within its decision interval even though a probable problem has surfaced. If there has been a shift big enough to have practical implications, it would be desired to be detected as soon as possible.

The run is a random variable, having a mean, a variance, and a distribution. Its mean is called the average run length or ARL. The ARL is an imperfect but useful summary number of the general tendency towards long or short runs. It is less than perfect since the run length distribution turns out to be highly variable. A high in-control ARL does not rule out the possibility of a very short run before the CUSUM gives a false alarm, and a low out-of-control ARL for the CUSUM is no guarantee that there would not be a long run before the CUSUM detected an actual shift. Despite these imperfections, the ARL is an easily interpreted, well-defined measure for which good algorithms are available. It is the standard measure of performance of the CUSUM. Chapter IV Section C will describe further on the *h*, *k* and ARL relationship and how it is calculated from the software program, anygeth.

III. DATA DESCRIPTION AND METHODOLOGY

A. SOURCES OF FAILURES

Failure is the inability of a component, machine, or process to function properly (Scutti and McBrine 2002). Failures can occur in individual parts, the whole machine, or the entire process itself. The analysis of failure has always been a critical process in determining the root causes of the problems in engineering. Even so, this logical process can sometimes be complex. To analyze the failure, many different technical disciplines can be engaged and employed, coupled with a variety of observation, inspection, and laboratory techniques. It is imperative to analyze and pinpoint where exactly the failure lies in order to be able to rectify it effectively.

There are three main categories of failures, and they are described as follows:

- Functionality: The simplest form of a failure is a system or component that operates but does not perform its intended function.
- Service life: This is the next level of failure whereby the system or component performs its function but is rendered unreliable or unsafe.
- Inoperability: This is the most severe form of failure whereby a system or component is totally inoperable.

The most common reasons for failures include the following:

- Service or operation conditions (use and misuse);
- Improper maintenance (intentional or unintentional);
- Improper testing or inspection;
- Assembly error;
- Fabrication/manufacturing errors; or
- Design errors (stress, materials selection, and assumed material condition or properties).

A typical system block diagram of a main engine is as shown in Figure 4.

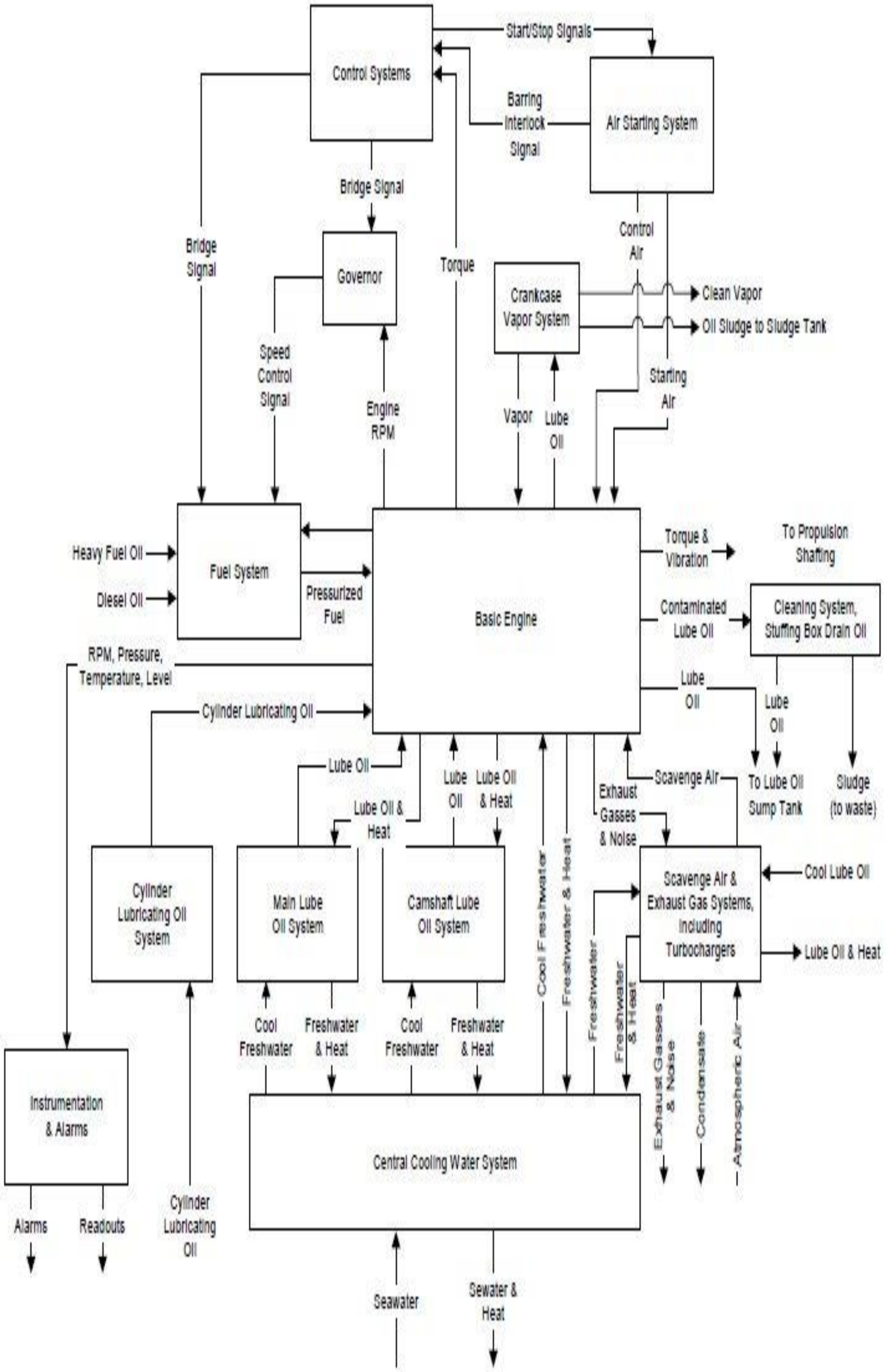


Figure 4. System block diagram of typical main engine (From American Bureau of Shipping 2003).

As seen from the system block diagram above, there are many interfaces and interactions between systems, subsystems, and components required for proper operation of a main engine. In this paper, the focus will be exploring the use of predictive analytics using the CUSUM and time series methodology presented in Chapter II. The focus of the study will be on one of the main engine attributes—main engine exhaust gas temperature (EGT). High EGT reflects potential problems at the combustion chamber, which may or may not cause an overall failure to Main Engine (ME). However, this attribute poised a potential problem to the overall ME operation and is worthy of study. The study aims to establish that the use of such a methodology is achievable and implementable for a main engine system. After the verification of the usability of such a methodology, it could then be extended to the whole system in future.

The high temperature of diesel exhaust gas is due to the fact that it is a product of combustion ignition. Despite this, the temperature for diesel exhaust gas still needs to be controlled within a reasonable range. This is to avoid thermal stressing of other components. There are many reasons for the temperature of diesel exhaust gas to go uncharacteristically high in marine diesel engines. Most cases can be attributed to a fuel system fault which can lead to either a scavenge fire and/or destructive fuel valve. The occurrence of high EGT may also trigger a series of events—seizure of the exhaust valve, a burnt turbocharger at the side turbine as well as engine slowdown, a feature of the safety device associated with the main engine.

The operation of the exhaust valve is described below to provide an overview of the causes that lead to the temperature rise of exhaust gas. The use of a hydraulically operated exhaust valve is common nowadays where the spring action is provided by a pneumatic arrangement instead of a mechanical spring. An overview of the action is as shown in Figure 5.

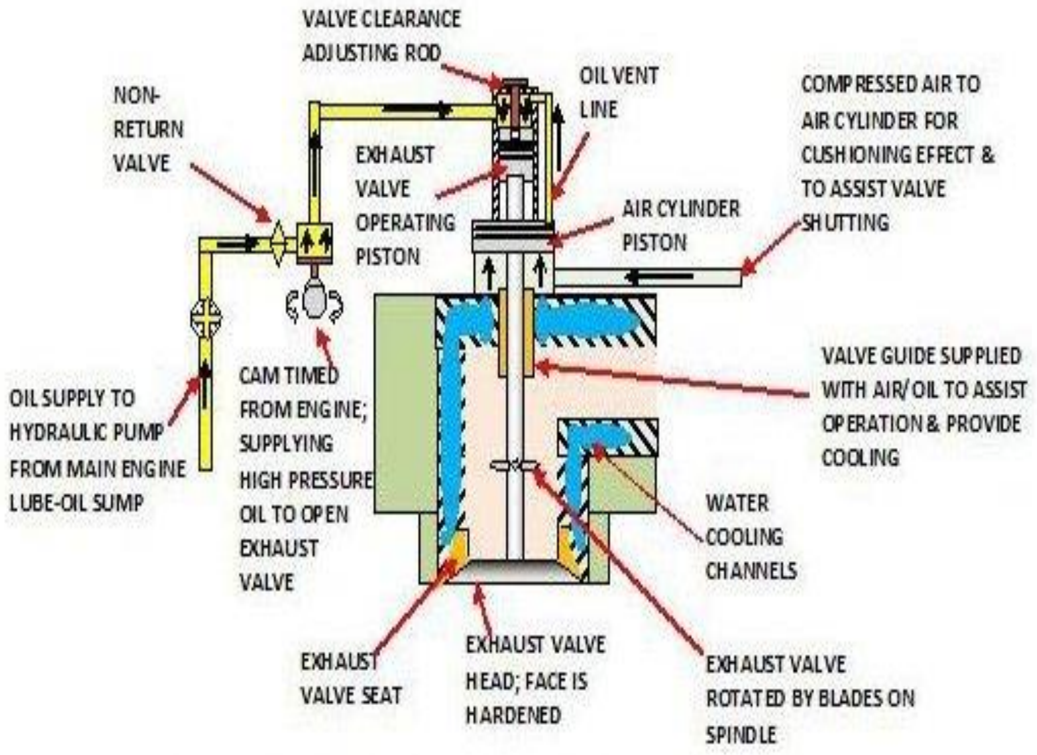

VALVE CLEARANCE ADJUSTING ROD
OIL VENT LINE
COMPRESSED AIR TO AIR CYLINDER FOR CUSHIONING EFFECT & TO ASSIST VALVE SHUTTING
NON-RETURN VALVE
EXHAUST VALVE OPERATING PISTON
AIR CYLINDER PISTON
VALVE GUIDE SUPPLIED WITH AIR/OIL TO ASSIST OPERATION & PROVIDE COOLING
OIL SUPPLY TO HYDRAULIC PUMP FROM MAIN ENGINE LUBE-OIL SUMP
CAM TIMED FROM ENGINE; SUPPLYING HIGH PRESSURE OIL TO OPEN EXHAUST VALVE
WATER COOLING CHANNELS
EXHAUST VALVE SEAT
EXHAUST VALVE HEAD; FACE IS HARDENED
EXHAUST VALVE ROTATED BY BLADES ON SPINDLE

Figure 5. Section through typical exhaust valve used on modern two-stroke marine diesel engines (From Scott 2011).

Both the hydraulic action of oil and pneumatic pressure are used for the operation. In order to open the valve, oil from the lube oil system of the engine is used. The oil is supplied by a hydraulic pump to a cam on a periodic basis to eject exhaust gases into the valve, which is followed by combustion.

The exhaust gas not only assists in valve closure, it also provides a spring-cushioning effect. It is mixed with a minute quantity of lube oil that is used for keeping the valve guide cool with the use of a bleed-off from this air supply as well as for lubrication purposes.

The exhaust valve is enclosed in a water cooled cage with fresh water being circulated through channels cast or machined within the cage. Uniform wear and tear to the valve head and seat occurs with every rotation of the valve. Valve rotation is achievable with the use of blades welded onto the lower end of the valve spindle. Each time the exhaust gas exits from the chamber, the valve is rotated by a small amount.

Cast iron is frequently chosen as the material used for the manufacture of the exhaust valve cage and the valve guides. Cast iron is chosen as these two parts require a malleable, self-lubricating material due to the continuous action between the guide and the valve spindle. The valve is renewable and is made from a hard wearing material such as molybdenum steel, while the spindle itself is made out of Nimonic, a superalloy comprised of nickel, chromium, titanium, and aluminum. In order to make the valve sturdy to prevent wear and tear at a fast rate, the seating face of the valve is specially treated to increase its toughness properties.

The rise of the exhaust gas temperature outside the standard range has a great impact on the life cycle of the exhaust valve and also on the deterioration of the piston rings and the cylinder liner. It is therefore vital to be aware of the various symptoms and causes for an exhaust gas temperature rise to ensure that the temperature stays within the safety zone. Some of the common causes for the rise of EGT are listed in Table 2.

No.	Causes	Descriptions
1	Increase in Engine Load	Resistance can be increased to a fairly large extent through the fouling and deformation of the ship’s hull, which leads to an increased load.
		Damage to propeller blades due to drifting wood or going aground can subject the engine to an increased load.
2	Fuel Valve/Supply	Poor maintenance or inferior heavy fuel oil (HFO) supply can cause the nozzle hole of the fuel injection valve to be enlarged. This then leads to a rise in exhaust gas temperature.
3	Exhaust Valve Passing	Badly damaged or worn valve head or seat causes blow-by of exhaust gasses on combustion.
4	Fouling of Exhaust Gas Passageways	Combustion products build up on the turbocharger nozzle and the surface of turbine blades resulting in the clogging of the exhaust gas passage, thereby reducing turbocharger efficiency.
		Clogging also increases back-pressure in the passageways to the turbocharger, hence restricting the efficient removal of the gases.
5	Fouling of Scavenge Air Passageways	Oil mist on suction casing and the diffuser of the turbocharger will result in the fouling of the air-side.
		Combustion products clog up cylinder liner scavenge port.
6	Leakage of the Scavenge Air	Scavenge air supply leakage can occur between the turbo-blowers and scavenge tableau, hence decreasing air supply pressure to ports.
7	Scavenge Fire	A build-up of lube-oil can be ignited by a spark from a blow-by of piston rings and cause a fire to occur in the scavenging chamber.
8	Insufficient/Unsatisfactory HFO Treatment	Extensive treatment of HFO through filtration, heat exchangers, and centrifuging to remove water and particles must be done on a regular basis.
9	Insufficient Air Supply to Blower	Clogged blower compressor suction filters.
		Insufficient air supply to blower.

10	Exhaust Valve Timing Problem	This can be caused by timing gear slipping off hydraulic/pneumatic supply to operating components.
		Unburned oil will seep into the exhaust pipe if the exhaust valve opens too early.
11	Leakage in Exhaust valves	A leaking exhaust valve can lead to a decrease in oil & oxygen mixture inside the cylinder. This will eventually result in a reduction of the mass of air and after combustion that occurs in the exhaust pipes.
12	Injection timing is not properly set	A too little fuel injection advanced angle will delay the injections of fuel oil inside of the cylinders. This will cause the rest of the oil to burn inside of the exhaust pipe.
13	Fuel injector failure	Secondary injection may result from a failure in fuel injector, and will result in the after burning of a diesel engine. It results in the reduction of power generated by one cylinder whereas the rest of the cylinders have a high load.
14	Bad oil atomization	A bad atomizer will result in the inefficient burning of fuel oil gas, which will lead to after-burning once it goes into the exhaust pipe.
15	Bad Installation of fuel oil atomizer	Gaskets of atomizer are not installed correctly. A thick gasket would most likely results in an inappropriate position of fuel spray nozzle.
16	Compression pressure inappropriate	Gaskets between cylinders and cylinder liners are too thick, resulting in a reduction in compression pressure due to increased cylinder volume. The delay of ignition will result in the post burning.
		Excessive wear of cylinder ring would most likely cause a reduction in compression pressure because the gas will enter into the crank case. After burning happens when unburned oil goes into the exhaust pipe.
17	Turbocharger faults	Bearing of turbocharger damaged leading to a reduction in rotation speed. The amount of air entering into the combustion chamber will be less than normal thus resulting in the unburned fuel oil going into the exhaust pipe. There are many causes of a high pressure drop inside of the turbocharger such as a dirty air filter, carbon deposits on the surfaces of nozzle ring and waste gas impeller.

18	Charged air cooler failure	If the pipes for fresh water have fouling inside of the charged air cooler, it may result in the insufficient heat exchange. This will cause charged air to warm up. As a result of that, the exhaust gas will also have a higher temperature. Clogged air channel inside of the charged air cooler will cause the amount of air charged into the cylinders to decrease. Insufficient burning is the main reason for high EGT. Turbocharger and charged air cooler are two parts of diesel engines that are most likely to result in a high EGT. High EGT would happen if the charged air cooler is clogged and may even make the whole ship stop running.
19	Controllable pitch propeller ship with shaft generator or offshore drilling unit circumstances	It is quite normal for this to happen in a controllable pitch propeller ship when the diesel engine is either in idle load or low load conditions. The total amount of exhaust gas is too low to drive the turbocharger efficiently. Charged air is not sufficient for the oil mist waiting to burn. These will cause the exhaust gas to have an excessively high temperature. When the engine load reaches its normal level, it will draw in much more fresh air thus the black smoke and high EGT will be eliminated.

Table 2. Common causes for an exhaust gas temperature rise (After Scott 2011).

In this paper, we are focusing on the use of prognostics to determine the probable occurrence of failure. After predicting the possibility of the occurrence of failures, there is still a need to undertake the diagnostic part to determine the root cause of the failure and rectify it. Table 3 shows a list of the possible causes of exhaust gas temperature issues as well as some recommended troubleshooting suggestions.

Error/System	Causes	Troubleshooting
Accumulator unit		
Alarm exhaust temperature deviation, failure of the cylinder, fuel leakage on the magnet	Cylinder switched off by the volume limiting valve.	Stop the engine and release rail pressure. Start the engine again. If the cylinder stops again, the following components must be checked and damaged components are to be replaced: 1) Injection nozzle (for failure), 2) Injection nozzle holder (for failure), 3) High pressure pipe (for fault or leaks), 4) 3/2 way valve (for fault or leaks).
	Wire breakage, failure of the electrical connection on the magnet, the plug connection, or the connection clamp.	Check cable connection, plug housing and connection clamp.
Fuel Injection Valves		
Exhaust gas temperature deviation	Failure of the injection nozzle, injection nozzle faulty, injection needle sticking, injection nozzle holes are blocked, injection nozzle needle seat is damaged, high pressure connection between nozzle and holder is damaged.	Replace parts in question.
	Nozzle opening pressure has fallen below.	Adjust the nozzle opening pressure accordingly.
Non-return valve (resetting non-return valve in valve group)		
Exhaust gas temperature deviation	Failure of the non-return valve.	Replace non-return valve.
	Seat of pressure limiting valve is damaged.	
	Pressure of the non-return valve has fallen (was set to 100 bar in the new condition, wear threshold is at approx. 60 bar).	

Disturbances during Operation		
Exhaust gas temperatures increased on all cylinders	Increased charging air temperature due to ineffective air cooler.	Clean air cooler.
	Fouling of air and gas passages.	Clean air and gas passages.
	Insufficient cleaning of fuel oil or changed combustion characteristics.	Check separator and fuel filters.
	Poor fuel quality.	Change fuel.
Exhaust gas temperatures increased on one cylinders	Fuel valve or valve nozzle defective.	Overhaul fuel valve.
	Leaky exhaust valves.	Check the valve clearance or change the cylinder head. Pressure test the cylinder by means of special tool.
	Damaged fuel pump cam/roller.	Replace camshaft section and roller.
Exhaust gas temperatures decreases on all cylinders	Decreased charging air temperature.	Check the thermostatic valve in the cooling water system.
Exhaust gas temperatures decreases on one cylinders	Fuel pump plunger is sticking or leaking.	Change fuel pump plunger/barrel assembly.
Exhaust gas temperature (level control deviation or mean value change)		
Common-Rail system	Rail pressure too low.	Check the deviation between the set and actual values of rail pressure, rectify fault if necessary.
Fuel System	Fuel pressure in front of high pressure pumps too low, feed pump faulty.	Check regulating valve on feed pump and adjust if necessary (>10 bar).
Engine	Engine or individual cylinders severely overloaded.	Check Magnetic Valve Control and exhaust temperature.
Charge air system	Charged air temperature too high, charged air pressure too low.	Check differential pressure charged air cooler. Check and clean charged air cooler and turbocharger.
Injection valves	Injection valves faulty.	Repair or replace injection valves.
Cylinder head	Cylinder head - Inlet duct contaminated.	Check inlet valves. Clean turbocharger.

Inlet and exhaust valves	Inlet or exhaust valves sticking, valve springs broken, valves leaking.	Remove cause. Replace valve spring.
Control and monitoring system	Indicating device or connection line faulty. Temperature sensor faulty. Cabling/Connections defective/faulty.	Investigate cause and remove. Replace affected components. Replace temperature sensor. Investigate cause and remove. Replace affected components.
Turbocharger	Turbocharger contaminated or faulty.	Repair or clean turbocharger.

Table 3. Common exhaust gas temperature errors and troubleshooting guide (After MAN Diesel 2009).

B. DATA COLLECTION

The database used for this research was provided by Singapore Technologies Marine, Ltd. and collected through ACMS installed onboard a Roll-On-Roll-Off Passenger (ROPAX) Ship. The period of data collection ran from December 19, 2010 to March 18, 2011. The data was extracted from the ACMS server under the trending folder. As the data is numerous and big in size, it was reorganized according to various sea-going events. This makes sense because the main engine is not in operation at harbor, and data obtained from this point will translate to useless data for the analysis. Currently, this re-organization is done manually due to a lack of means to classify the data.

C. SELECTION OF VARIABLES

The engines under study have the designation 10L 32/44CR from MAN Diesel as depicted in Figure 6. It is a non-reversible four stroke in-line engine with a 320mm cylinder bore and a 440 mm piston stroke. This engine type is equipped with a common rail injection system and used as marine main drives. The engine has two camshafts—one for the actuation of the inlet and exhaust valves on the exhaust side and the other for the actuation of the high pressure pumps on the exhaust counter side. It is also equipped with MAN Diesel turbochargers from the TC series. The engines are interfaced with

Controllable Pitch Propeller (CPP) and operated at a fixed engine Revolution per Minute (RPM) of 7500.

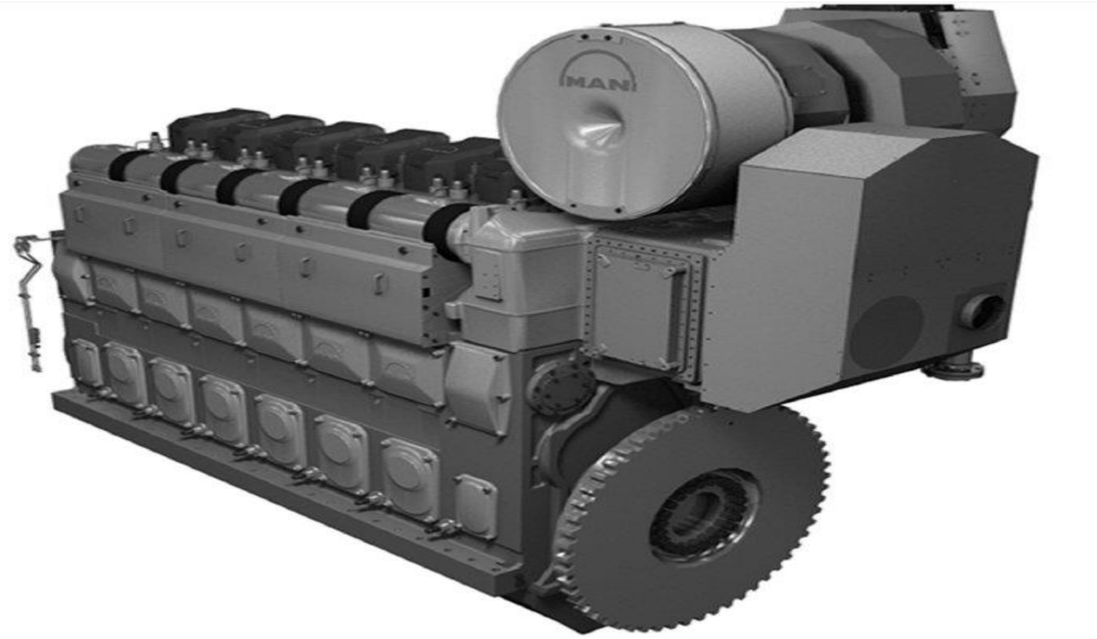
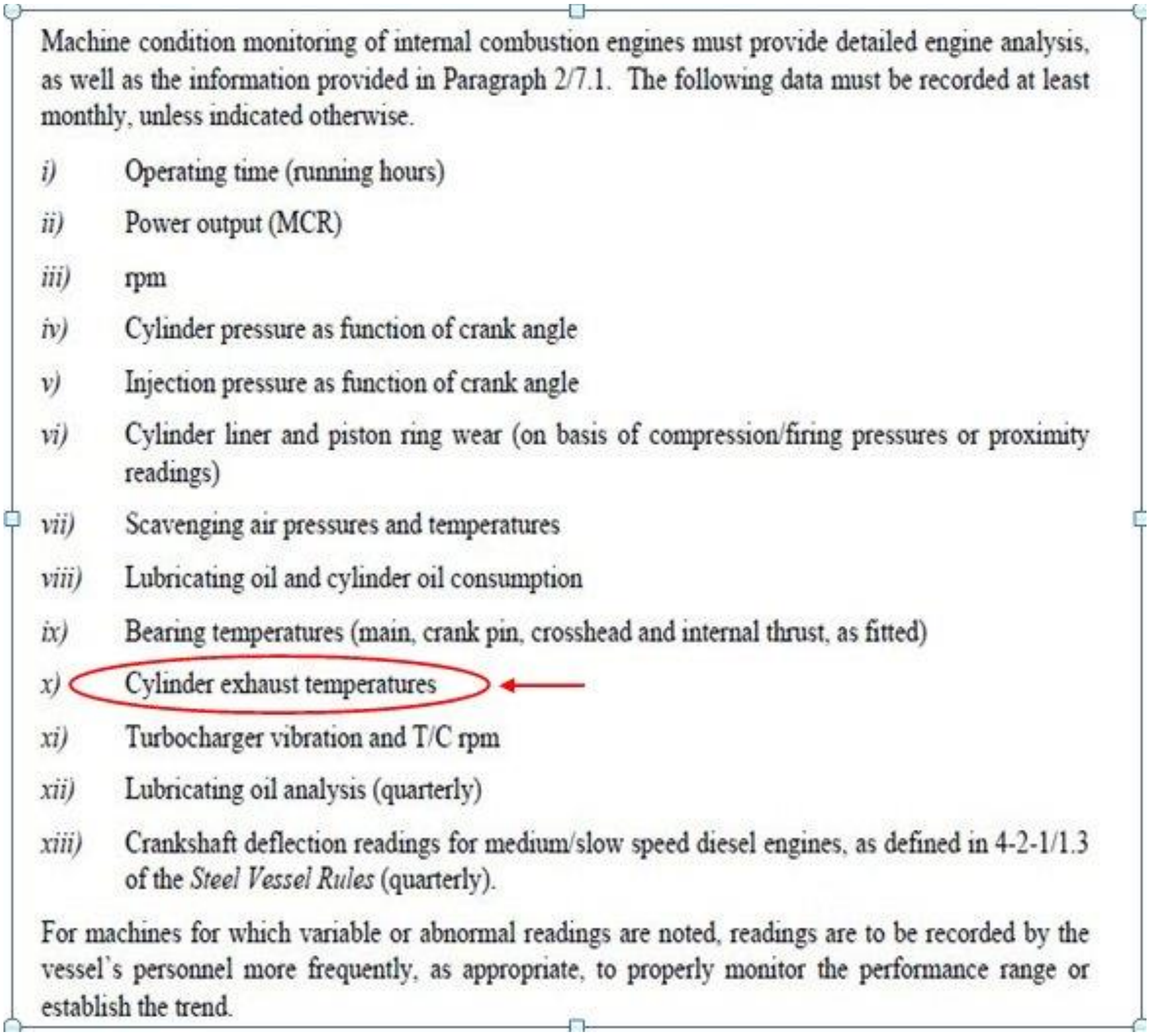


Figure 6. Four-stroke engine L 32/44, viewed from the inlet side (From MAN Diesel 2009).

The selection of the exhaust gas temperature for study, as a variable, was based on literature reviews and available classification documentation. The other reason for the selection was also dependent on the availability of data on hand. This decision was made after discussions with Professor Papoulias, a professional in the engine field, from the Naval Postgraduate School (NPS). Although the parameter seems like an unimportant parameter in the whole engine system, the failure of exhaust gas temperature has many implications on the rest of the subsystems of the engine as described in Table 2.

The American Bureau of Shipping (ABS) released a document, *Guide for Survey Based on Reliability-Centered Maintenance,* in 2003. This document justifies how temperature monitoring falls under the category of performance monitoring and suggests the use of temperature monitoring for condition-monitoring tasks. Figure 7 shows a snapshot of the parameters that ABS recommended for condition-monitoring.



Machine condition monitoring of internal combustion engines must provide detailed engine analysis, as well as the information provided in Paragraph 2/7.1. The following data must be recorded at least monthly, unless indicated otherwise.

i) Operating time (running hours)

ii) Power output (MCR)

iii) rpm

iv) Cylinder pressure as function of crank angle

v) Injection pressure as function of crank angle

vi) Cylinder liner and piston ring wear (on basis of compression/firing pressures or proximity readings)

vii) Scavenging air pressures and temperatures

viii) Lubricating oil and cylinder oil consumption

ix) Bearing temperatures (main, crank pin, crosshead and internal thrust, as fitted)

x) Cylinder exhaust temperatures

xi) Turbocharger vibration and T/C rpm

xii) Lubricating oil analysis (quarterly)

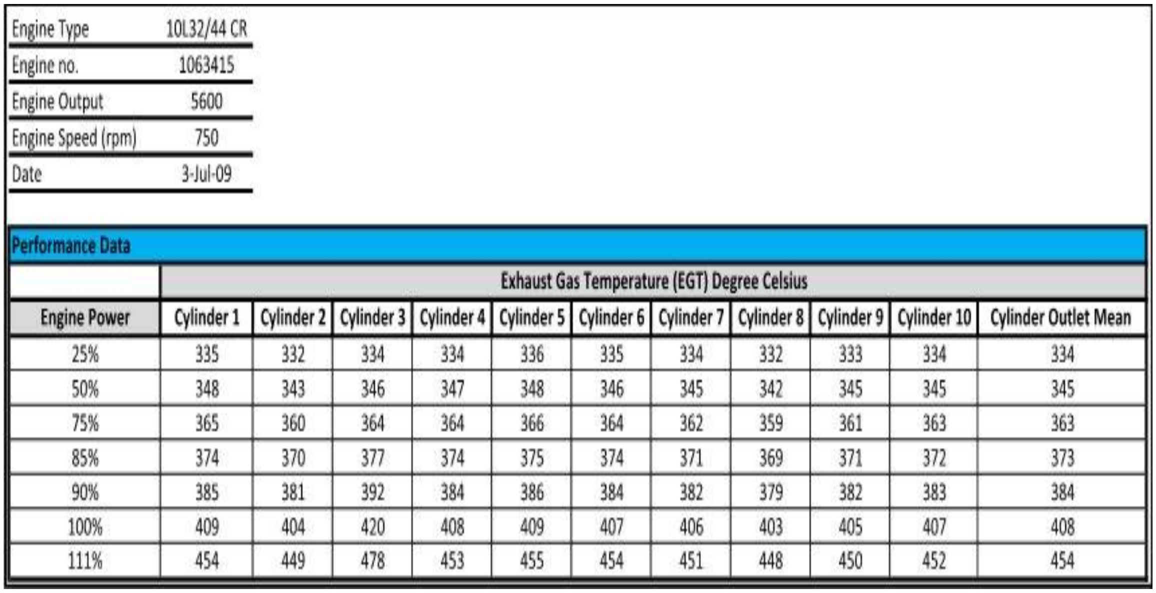
xiii) Crankshaft deflection readings for medium/slow speed diesel engines, as defined in 4-2-1/1.3 of the *Steel Vessel Rules* (quarterly).

For machines for which variable or abnormal readings are noted, readings are to be recorded by the vessel's personnel more frequently, as appropriate, to properly monitor the performance range or establish the trend.

Figure 7. Parameters to be monitored for condition-monitoring (After American Bureau of Shipping 2003).

D. DATA SETS

The baseline for comparison on EGT performance is taken from the Factory Acceptance Test (FAT) performed by the engine supplier, MAN Diesel. Figure 8 shows the baseline values of the EGT during the test. Figure 9 shows the graph for ME units' EGT against engine power while Figure 10 shows the graphs for the ME unit outlet mean EGT against engine power. It can be seen from the two graphs that EGT increases as the engine power increases. The relationship of the EGT with engine power may be fitted with a fourth degree polynomial function based on the highest adjusted R2 value as shown in Table 4. The high adjusted R^2 value accounts for the variability of the data captured by the model as well as accounts for the effect on the addition of new terms. The adjusted R-squared is a modified version of R-squared that has been adjusted for the number of predictors in the model. The adjusted R-squared increases only if the new term improves the model more than would be expected and decreases when a predictor improves the model by less than expected.



Engine Type	10L32/44 CR
Engine no.	1063415
Engine Output	5600
Engine Speed (rpm)	750
Date	3-Jul-09

Performance Data

	Exhaust Gas Temperature (EGT) Degree Celsius										
Engine Power	Cylinder 1	Cylinder 2	Cylinder 3	Cylinder 4	Cylinder 5	Cylinder 6	Cylinder 7	Cylinder 8	Cylinder 9	Cylinder 10	Cylinder Outlet Mean
25%	335	332	334	334	336	335	334	332	333	334	334
50%	348	343	346	347	348	346	345	342	345	345	345
75%	365	360	364	364	366	364	362	359	361	363	363
85%	374	370	377	374	375	374	371	369	371	372	373
90%	385	381	392	384	386	384	382	379	382	383	384
100%	409	404	420	408	409	407	406	403	405	407	408
111%	454	449	478	453	455	454	451	448	450	452	454

Figure 8. Performance data of EGT during FAT (After MAN Diesel 2009).

	Linear Trend	**Polynomial 2**	**polynomial 3**	**polynomial 4**	**polynomial 5**
R2	0.791519	0.967452	0.996848	0.999603	0.999622
Adjusted R2	0.749823	0.951178	0.993695	0.998810	0.997731

Table 4. Comparison of R^2 and adjusted R^2 value for curve fitting function.

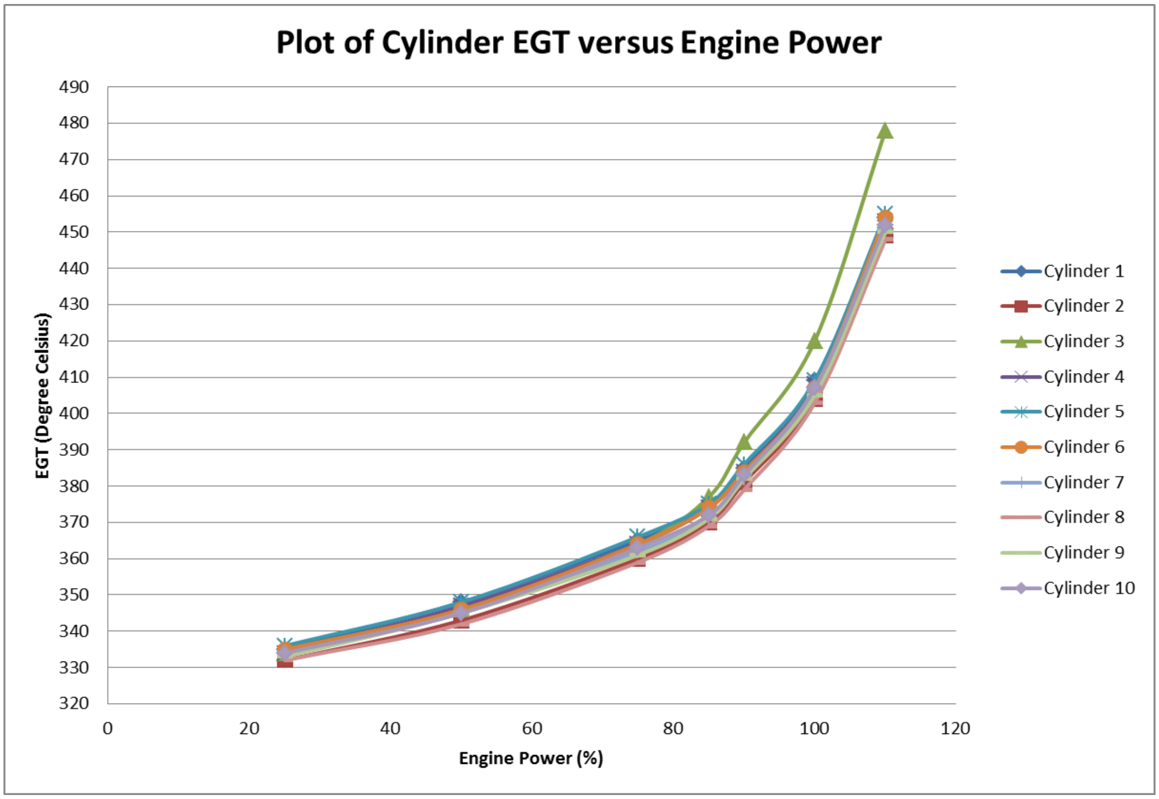


Figure 9. Graph of cylinder EGT against engine power.

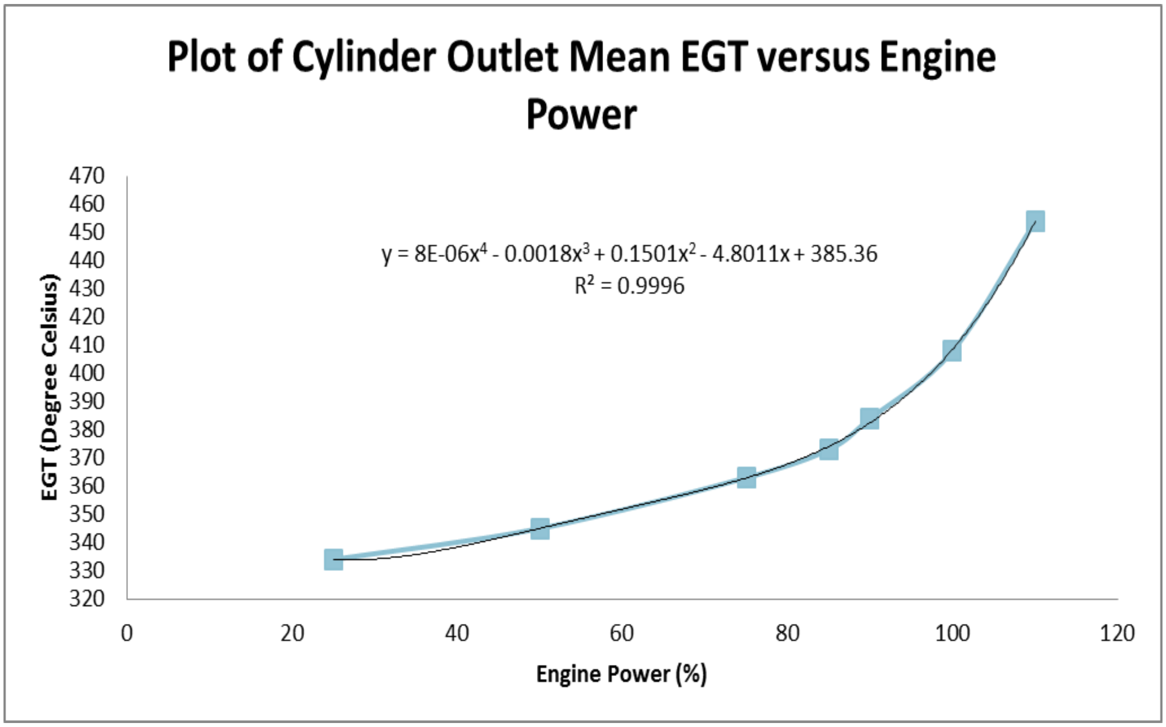
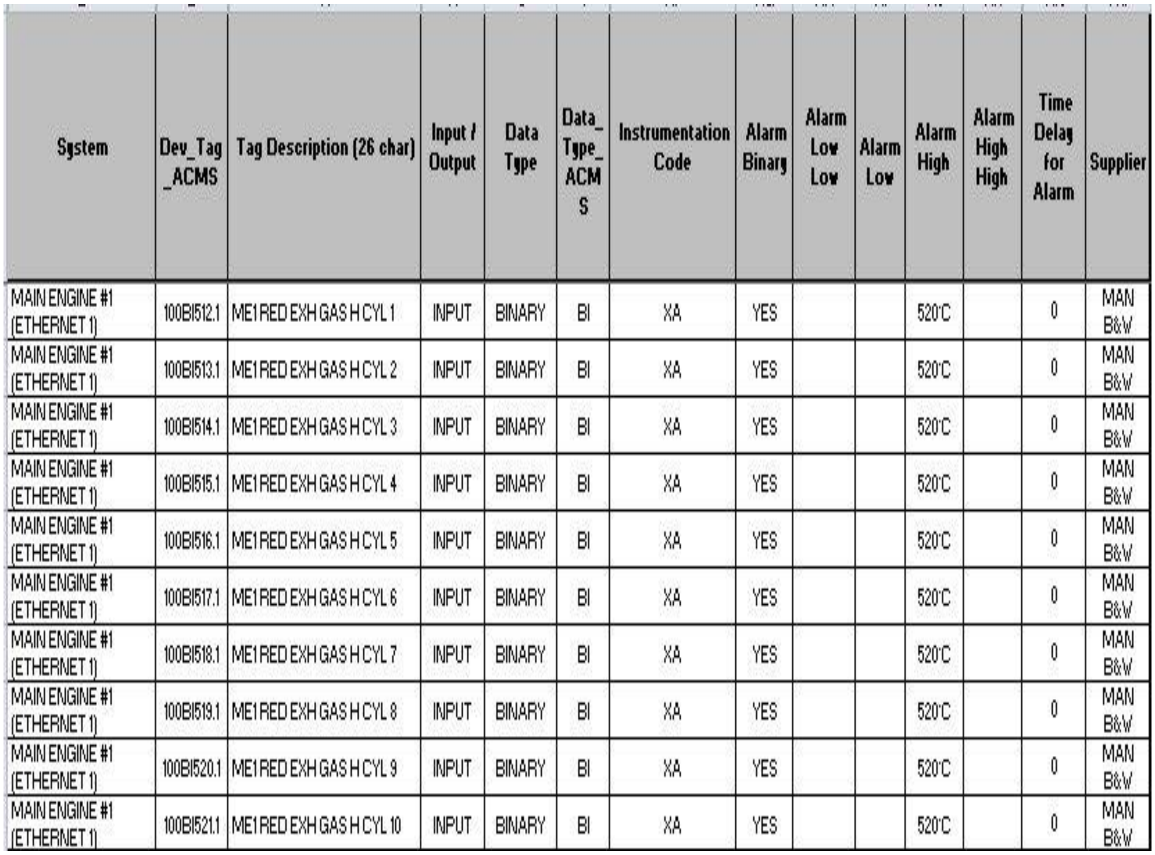


Figure 10. Graph of Cylinder outlet mean EGT against engine power.

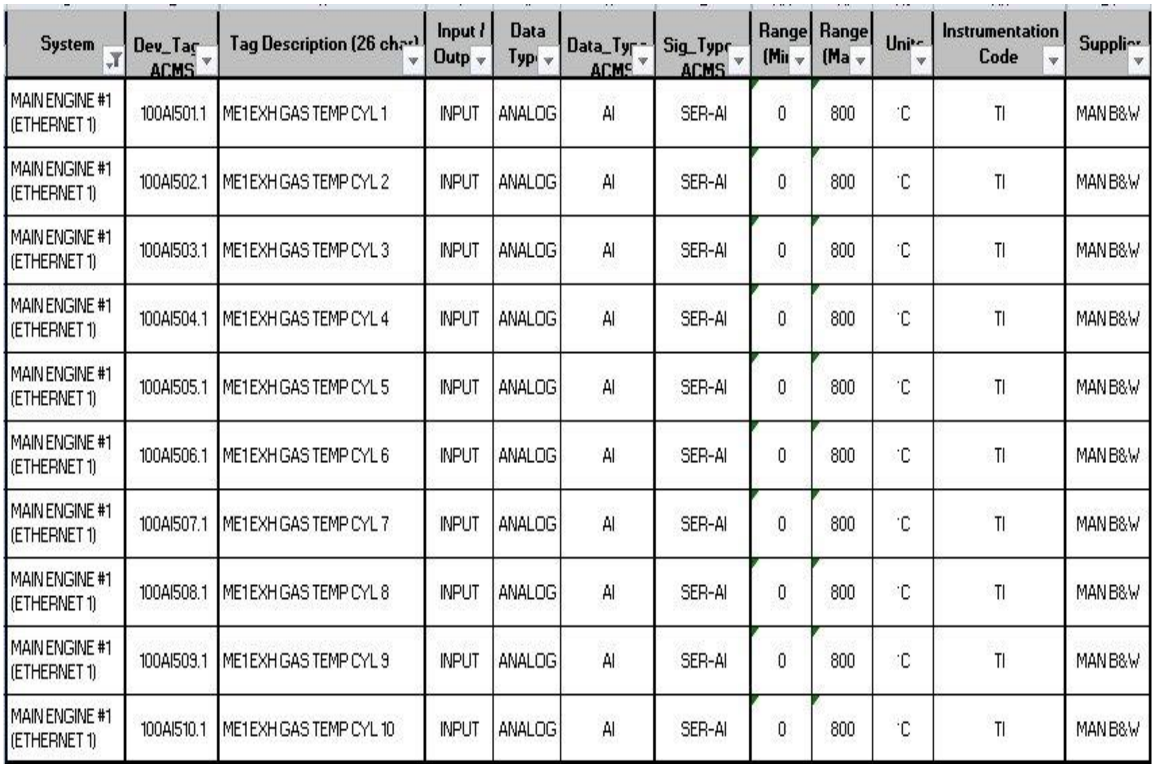
Figure 11 is a snapshot of an Input/output (IO) list document from the ACMS of the ROPAX project. It describes the interface details between ACMS and the ME. It shows their signal descriptions, data type, and alarm limits as well as the source of the information. The following signals basically indicate a load reduction being triggered by the Main Engine System due to the unit's high exhaust gas temperature. This is a binary signal which represents that the thresholds of the ME exhaust gas have exceeded its high limit set point. The alarm set-point is 520 degrees Celsius for each ME exhaust cylinder as shown in Figure 11.



System	Dev_Tag_ACMS	Tag Description (26 char)	Input / Output	Data Type	Data_Type_ACMS	Instrumentation Code	Alarm Binary	Alarm Low Low	Alarm Low	Alarm High	Alarm High High	Time Delay for Alarm	Supplier
MAIN ENGINE #1 (ETHERNET 1)	100BI512.1	ME1 RED EXH GAS H CYL 1	INPUT	BINARY	BI	XA	YES			520°C		0	MAN B&W
MAIN ENGINE #1 (ETHERNET 1)	100BI513.1	ME1 RED EXH GAS H CYL 2	INPUT	BINARY	BI	XA	YES			520°C		0	MAN B&W
MAIN ENGINE #1 (ETHERNET 1)	100BI514.1	ME1 RED EXH GAS H CYL 3	INPUT	BINARY	BI	XA	YES			520°C		0	MAN B&W
MAIN ENGINE #1 (ETHERNET 1)	100BI515.1	ME1 RED EXH GAS H CYL 4	INPUT	BINARY	BI	XA	YES			520°C		0	MAN B&W
MAIN ENGINE #1 (ETHERNET 1)	100BI516.1	ME1 RED EXH GAS H CYL 5	INPUT	BINARY	BI	XA	YES			520°C		0	MAN B&W
MAIN ENGINE #1 (ETHERNET 1)	100BI517.1	ME1 RED EXH GAS H CYL 6	INPUT	BINARY	BI	XA	YES			520°C		0	MAN B&W
MAIN ENGINE #1 (ETHERNET 1)	100BI518.1	ME1 RED EXH GAS H CYL 7	INPUT	BINARY	BI	XA	YES			520°C		0	MAN B&W
MAIN ENGINE #1 (ETHERNET 1)	100BI519.1	ME1 RED EXH GAS H CYL 8	INPUT	BINARY	BI	XA	YES			520°C		0	MAN B&W
MAIN ENGINE #1 (ETHERNET 1)	100BI520.1	ME1 RED EXH GAS H CYL 9	INPUT	BINARY	BI	XA	YES			520°C		0	MAN B&W
MAIN ENGINE #1 (ETHERNET 1)	100BI521.1	ME1 RED EXH GAS H CYL 10	INPUT	BINARY	BI	XA	YES			520°C		0	MAN B&W

Figure 11. EGT binary data from ACMS IO list document (After Singapore Technologies Marine, Ltd. 2010).

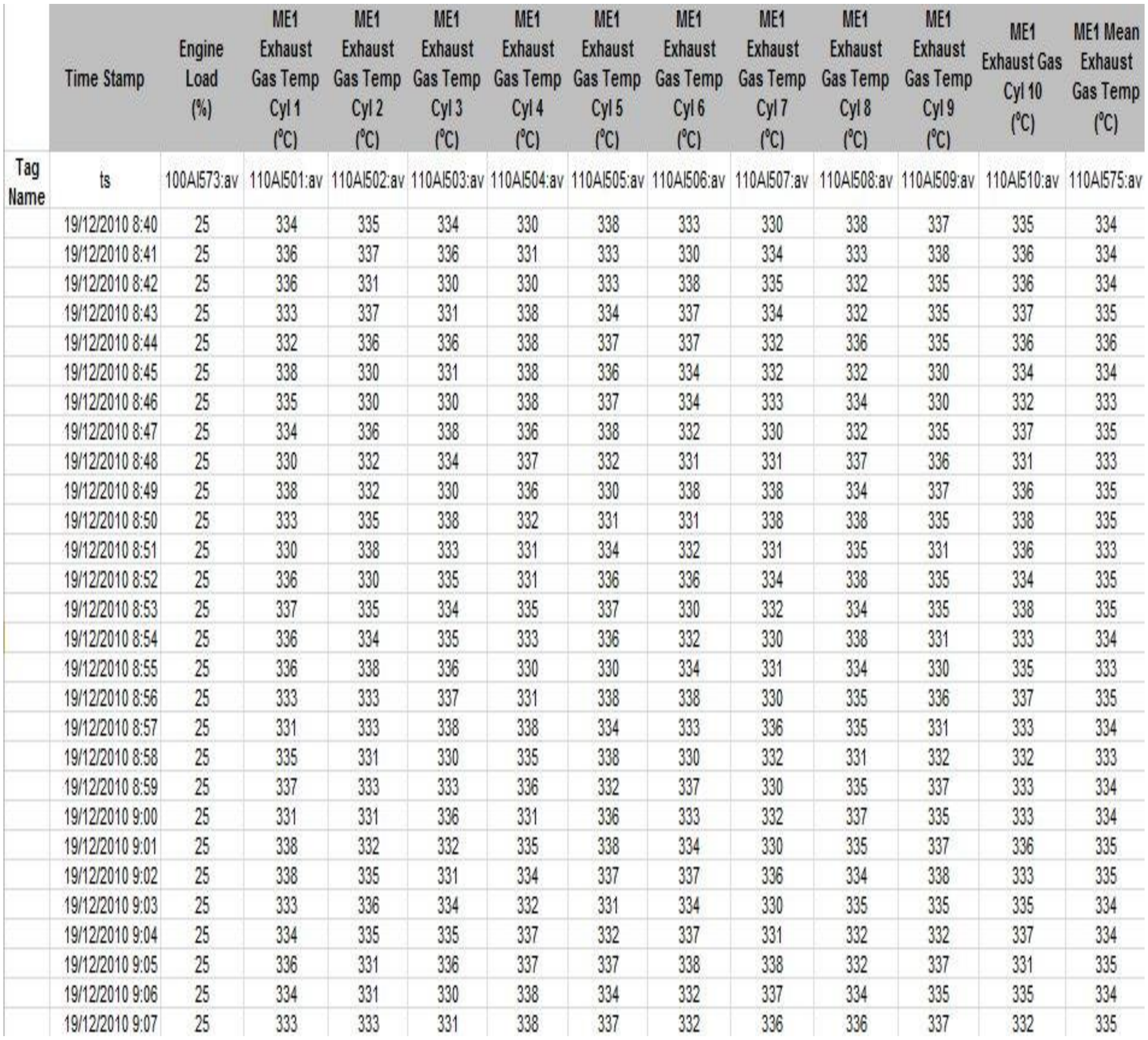
The interface detail between the ME and the ACMS for the analog values of the EGT is shown in Figure 12. The Dev_Tag_ACMS shown in the table is important information because it acts as an identification signal tag which is used to extract data from the trending folder within the ACMS. The temperature sensors used to monitor the EGT have a range of 0-800 degrees Celsius.



System	Dev_Tag ACMS	Tag Description (26 char)	Input / Outp	Data Typ	Data_Typ ACMS	Sig_Type ACMS	Range (Min	Range (Ma	Units	Instrumentation Code	Supplier
MAIN ENGINE #1 (ETHERNET 1)	100AI501.1	ME1 EXH GAS TEMP CYL 1	INPUT	ANALOG	AI	SER-AI	0	800	°C	TI	MAN B&W
MAIN ENGINE #1 (ETHERNET 1)	100AI502.1	ME1 EXH GAS TEMP CYL 2	INPUT	ANALOG	AI	SER-AI	0	800	°C	TI	MAN B&W
MAIN ENGINE #1 (ETHERNET 1)	100AI503.1	ME1 EXH GAS TEMP CYL 3	INPUT	ANALOG	AI	SER-AI	0	800	°C	TI	MAN B&W
MAIN ENGINE #1 (ETHERNET 1)	100AI504.1	ME1 EXH GAS TEMP CYL 4	INPUT	ANALOG	AI	SER-AI	0	800	°C	TI	MAN B&W
MAIN ENGINE #1 (ETHERNET 1)	100AI505.1	ME1 EXH GAS TEMP CYL 5	INPUT	ANALOG	AI	SER-AI	0	800	°C	TI	MAN B&W
MAIN ENGINE #1 (ETHERNET 1)	100AI506.1	ME1 EXH GAS TEMP CYL 6	INPUT	ANALOG	AI	SER-AI	0	800	°C	TI	MAN B&W
MAIN ENGINE #1 (ETHERNET 1)	100AI507.1	ME1 EXH GAS TEMP CYL 7	INPUT	ANALOG	AI	SER-AI	0	800	°C	TI	MAN B&W
MAIN ENGINE #1 (ETHERNET 1)	100AI508.1	ME1 EXH GAS TEMP CYL 8	INPUT	ANALOG	AI	SER-AI	0	800	°C	TI	MAN B&W
MAIN ENGINE #1 (ETHERNET 1)	100AI509.1	ME1 EXH GAS TEMP CYL 9	INPUT	ANALOG	AI	SER-AI	0	800	°C	TI	MAN B&W
MAIN ENGINE #1 (ETHERNET 1)	100AI510.1	ME1 EXH GAS TEMP CYL 10	INPUT	ANALOG	AI	SER-AI	0	800	°C	TI	MAN B&W

Figure 12. EGT Analogue data from ACMS IO list document (After Singapore Technologies Marine, Ltd. 2010).

Figure 13 shows the corresponding set of trending data captured from the trending folder of the ACMS. It depicts partially extracted data; the analog temperature values of the ME exhaust gas in each unit. These analog temperature values are used to generate the predictive model as well as for the validation of the model.



	Time Stamp	Engine Load (%)	ME1 Exhaust Gas Temp Cyl 1 (°C)	ME1 Exhaust Gas Temp Cyl 2 (°C)	ME1 Exhaust Gas Temp Cyl 3 (°C)	ME1 Exhaust Gas Temp Cyl 4 (°C)	ME1 Exhaust Gas Temp Cyl 5 (°C)	ME1 Exhaust Gas Temp Cyl 6 (°C)	ME1 Exhaust Gas Temp Cyl 7 (°C)	ME1 Exhaust Gas Temp Cyl 8 (°C)	ME1 Exhaust Gas Temp Cyl 9 (°C)	ME1 Exhaust Gas Cyl 10 (°C)	ME1 Mean Exhaust Gas Temp (°C)
Tag Name	ts	100AI573:av	110AI501:av	110AI502:av	110AI503:av	110AI504:av	110AI505:av	110AI506:av	110AI507:av	110AI508:av	110AI509:av	110AI510:av	110AI575:av
	19/12/2010 8:40	25	334	335	334	330	338	333	330	338	337	335	334
	19/12/2010 8:41	25	336	337	336	331	333	330	334	333	338	336	334
	19/12/2010 8:42	25	336	331	330	330	333	338	335	332	335	336	334
	19/12/2010 8:43	25	333	337	331	338	334	337	334	332	335	337	335
	19/12/2010 8:44	25	332	336	336	338	337	337	332	336	335	336	336
	19/12/2010 8:45	25	338	330	331	338	336	334	332	332	330	334	334
	19/12/2010 8:46	25	335	330	330	338	337	334	333	334	330	332	333
	19/12/2010 8:47	25	334	336	338	336	338	332	330	332	335	337	335
	19/12/2010 8:48	25	330	332	334	337	332	331	331	337	336	331	333
	19/12/2010 8:49	25	338	332	330	336	330	338	338	334	337	336	335
	19/12/2010 8:50	25	333	335	338	332	331	331	338	338	335	338	335
	19/12/2010 8:51	25	330	338	333	331	334	332	331	335	331	336	333
	19/12/2010 8:52	25	336	330	335	331	336	336	334	338	335	334	335
	19/12/2010 8:53	25	337	335	334	335	337	330	332	334	335	338	335
	19/12/2010 8:54	25	336	334	335	333	336	332	330	338	331	333	334
	19/12/2010 8:55	25	336	338	336	330	330	334	331	334	330	335	333
	19/12/2010 8:56	25	333	333	337	331	338	338	330	335	336	337	335
	19/12/2010 8:57	25	331	333	338	338	334	333	336	335	331	333	334
	19/12/2010 8:58	25	335	331	330	335	338	330	332	331	332	332	333
	19/12/2010 8:59	25	337	333	333	336	332	337	330	335	337	333	334
	19/12/2010 9:00	25	331	331	336	331	336	333	332	337	335	333	334
	19/12/2010 9:01	25	338	332	332	335	338	334	330	335	337	336	335
	19/12/2010 9:02	25	338	335	331	334	337	337	336	334	338	333	335
	19/12/2010 9:03	25	333	336	334	332	331	334	330	335	335	335	334
	19/12/2010 9:04	25	334	335	335	337	332	337	331	332	332	337	334
	19/12/2010 9:05	25	336	331	336	337	337	338	338	332	337	331	335
	19/12/2010 9:06	25	334	331	330	338	334	332	337	334	335	335	334
	19/12/2010 9:07	25	333	333	331	338	337	332	336	336	337	332	335

Figure 13. Trending data for EGT (After Singapore Technologies Marine, Ltd. 2010).

Two graphs, Engine Load and Mean EGT are plotted against time and are shown in Figure 14 and Figure 15, respectively. It shows the relationship between the two parameters. ME EGT increases as the ME load increases, and decreases when the engine load is reduced.

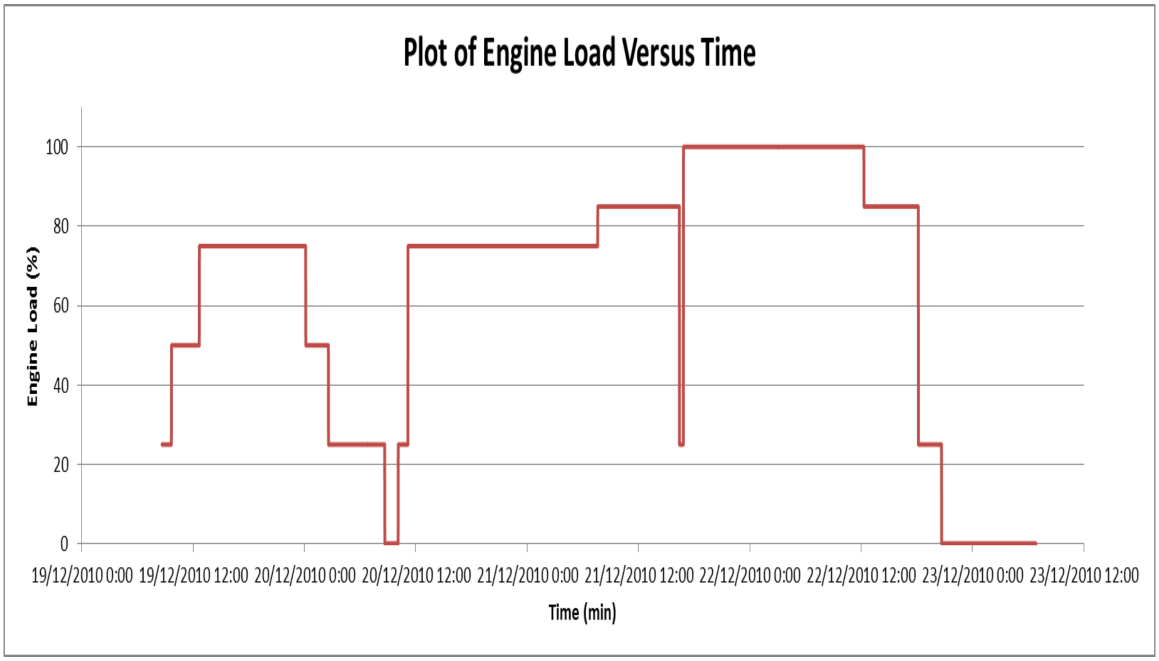


Figure 14. Graph of engine load against time.

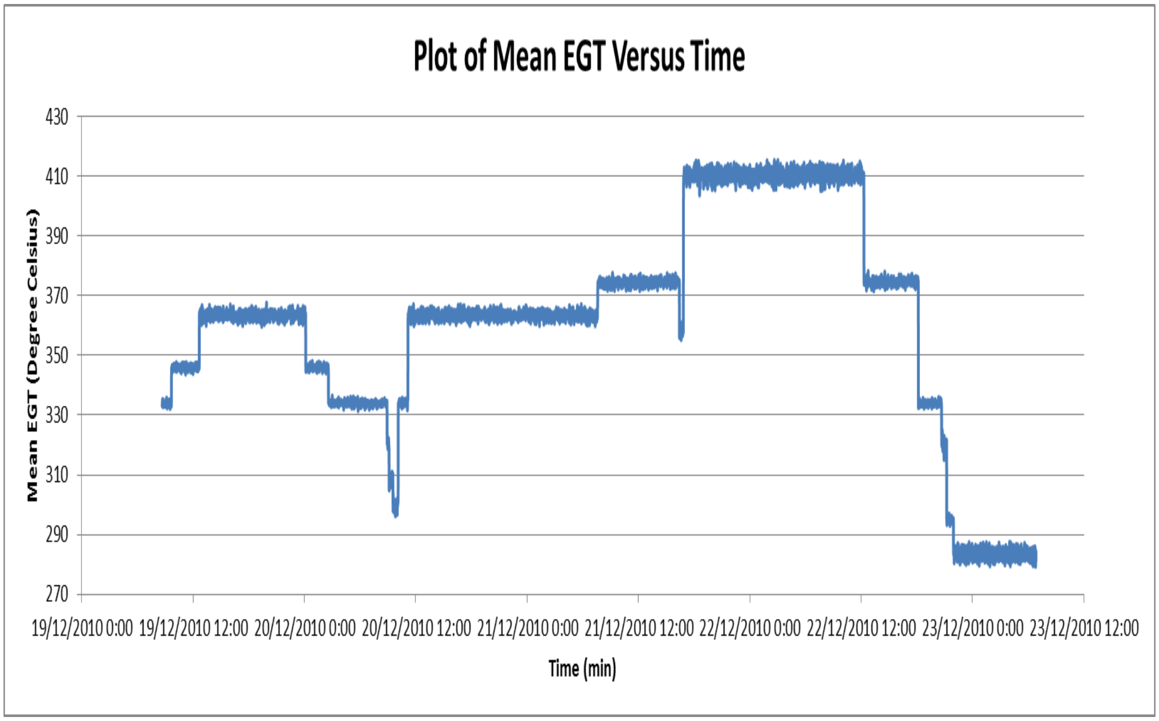


Figure 15. Graph of Mean EGT against time.

Figure 16 shows the relationship of the EGT for cylinder 1 at various engine loads against the running hours of the ME. It can be observed that there is degradation of the system performance and the EGT increases as the running hours increase. The degradation appears to shown visible signs in the curve after about 2000 hours. From the graph, the threshold limit of 520 degree Celsius for the Unit's EGT will be reached at about 5000 hours. This is consistent with the maintenance manual from the engine maker, which recommends maintenance of exhaust manifolds and related measuring and control regulation system of exhaust gas system at around 5000-6000 hours of engine run time (MAN Diesel 2009). After maintenance, the EGT should be operating at the expected temperature (approximately 334 degree Celsius for 25% Load), re-starting at zero running hours, and "Good as New."

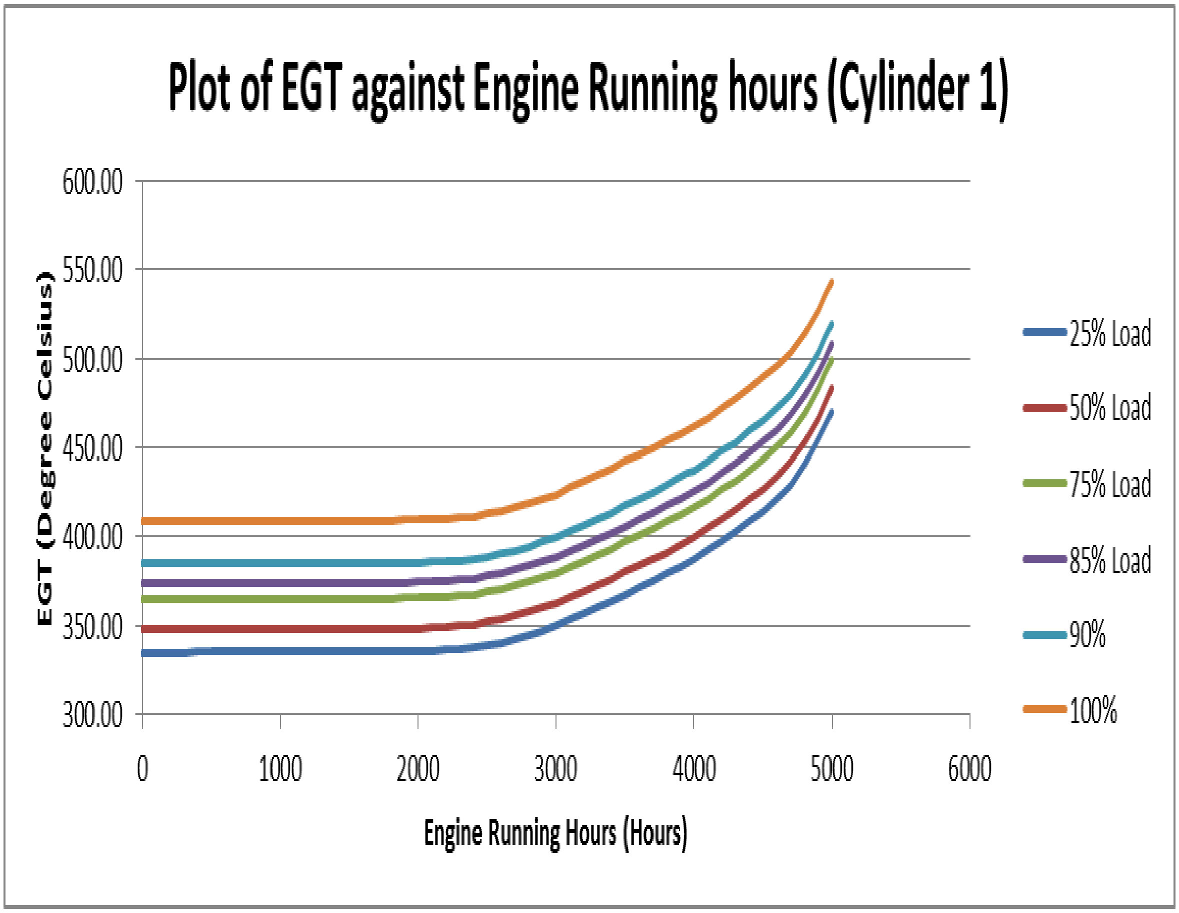


Figure 16. Plot of EGT against Engine Running hours for ME cylinder 1.

Figure 17 shows the plot for individual cylinders of the ME with respect to engine running hours at 100% engine load. It can be observed that cylinder 3 exhibits the highest temperature, and cylinder 6 exhibits the lowest temperature amongst the ten cylinders. This is an inherent behavior for this particular engine, and it does not pose any problem during operation. Also, this behavior differs for every engine. From the plot of EGT against engine running hours in both Figure 16 and Figure 17, the data for cylinder 3 at 100% engine load can be used for prediction of the worst case scenario.

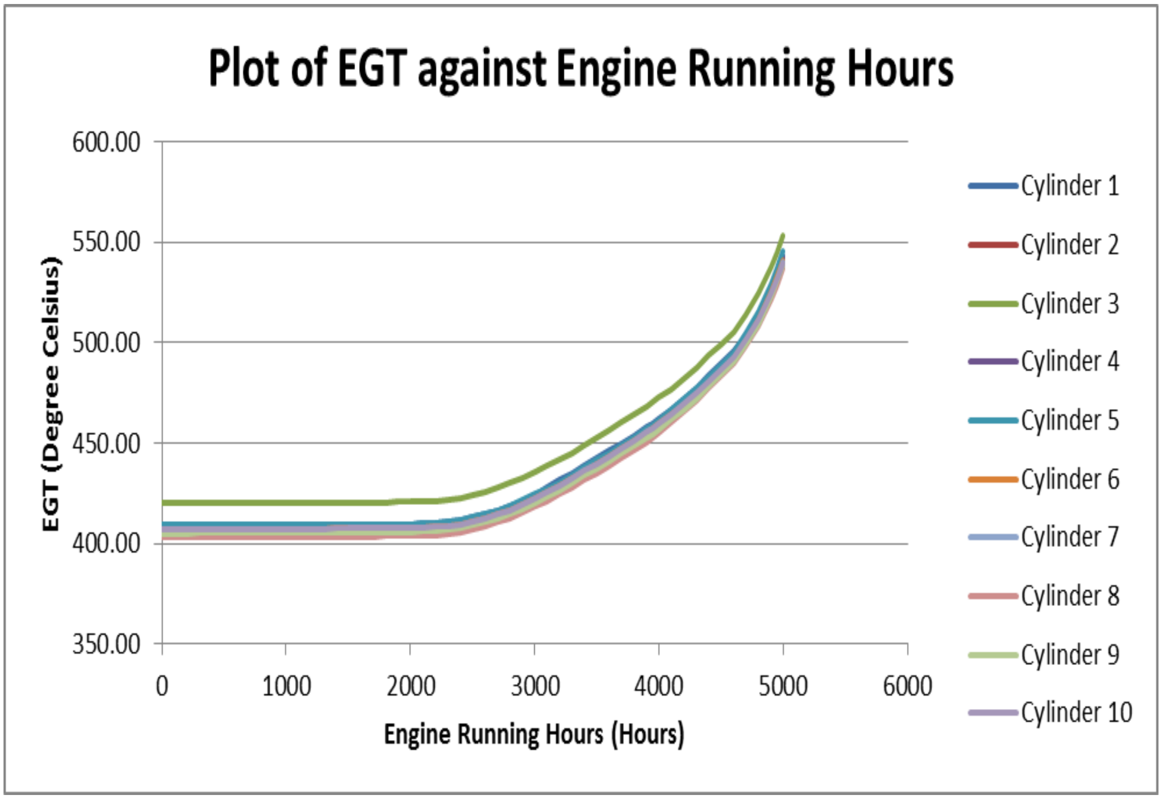
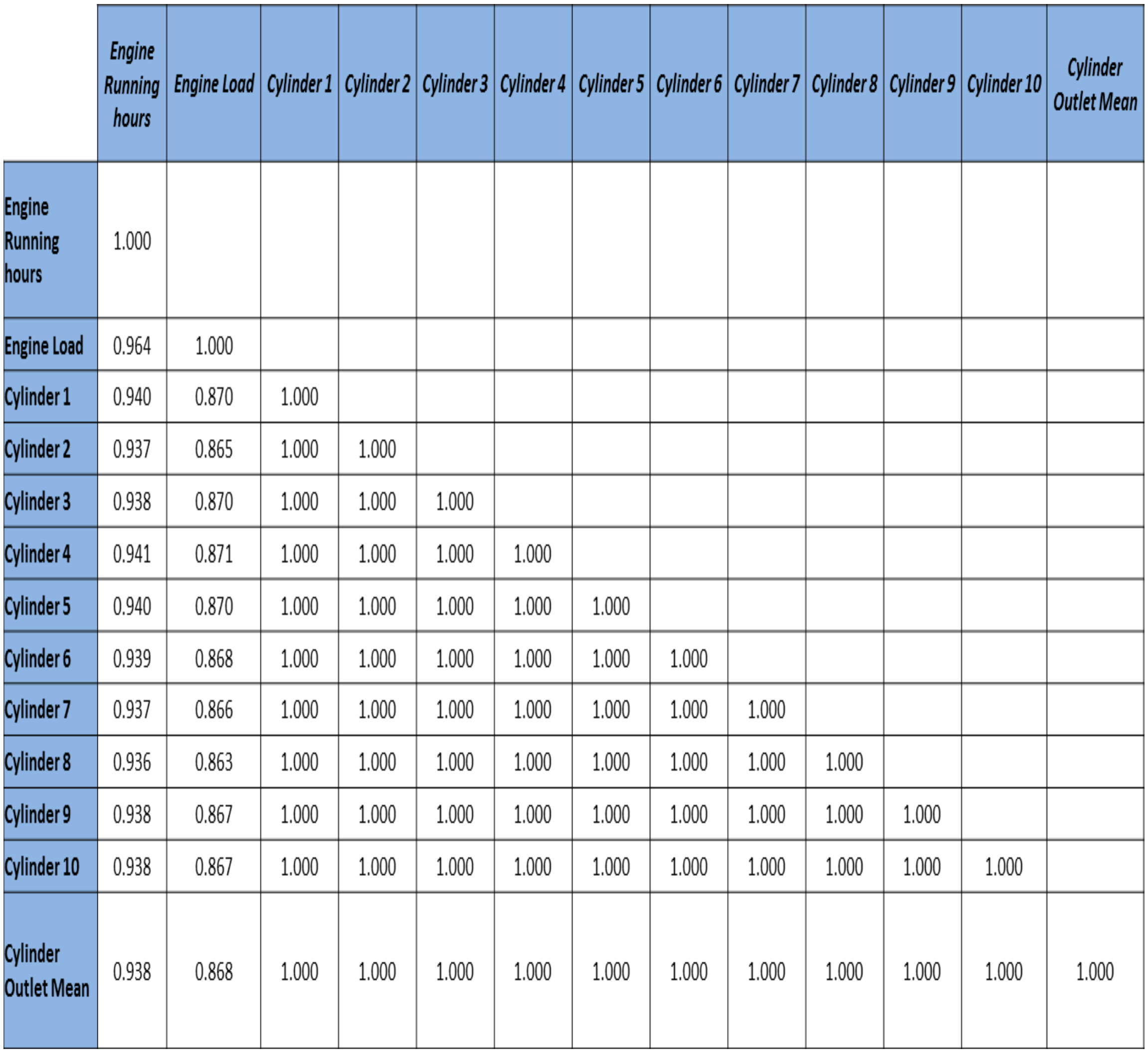


Figure 17. Plot of EGT against engine running hours at 100% engine load (After Singapore Technologies Marine, Ltd. 2010).

Figure 18 shows the correlation between the parameters Engine Load, Engine Running Hours, Units' EGT, and Mean EGT generated using Excel Data Analysis Correlation function. The correlation between engine load, engine running hours, units' EGT, and mean EGT is strong at values between 0.863 and 0.964. This shows that there is an increasing linear relationship between the parameters.



	Engine Running hours	Engine Load	Cylinder 1	Cylinder 2	Cylinder 3	Cylinder 4	Cylinder 5	Cylinder 6	Cylinder 7	Cylinder 8	Cylinder 9	Cylinder 10	Cylinder Outlet Mean
Engine Running hours	1.000												
Engine Load	0.964	1.000											
Cylinder 1	0.940	0.870	1.000										
Cylinder 2	0.937	0.865	1.000	1.000									
Cylinder 3	0.938	0.870	1.000	1.000	1.000								
Cylinder 4	0.941	0.871	1.000	1.000	1.000	1.000							
Cylinder 5	0.940	0.870	1.000	1.000	1.000	1.000	1.000						
Cylinder 6	0.939	0.868	1.000	1.000	1.000	1.000	1.000	1.000					
Cylinder 7	0.937	0.866	1.000	1.000	1.000	1.000	1.000	1.000	1.000				
Cylinder 8	0.936	0.863	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000			
Cylinder 9	0.938	0.867	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000		
Cylinder 10	0.938	0.867	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	
Cylinder Outlet Mean	0.938	0.868	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Figure 18. Correlation coefficient between engine load, units’ EGT and mean EGT.

IV. RESULTS AND DISCUSSION

The analytical results for prediction of engine failure employing the two different methodologies described in Chapter II will be discussed individually in Sections B and C, and subsequently compared collectively in Section D.

A. VALIDATION TECHNIQUE USED FOR THE MODELS

The internal validation of the model’s performance is supported with the data-splitting method. A random portion of the sample, usually between two thirds and three quarters, is used for model development. The obtained model is then “frozen” and applied as it is to the remaining portion of the sample for assessing the model’s performance (Harrell et al. 1996; Picard and Berk 1990).

B. TIME SERIES MODELS

Figure 19 shows the plot of the mean EGT against engine running hours for different engine load levels of an engine testing event. The plot shows a particular profile and how it differs depending on the operation. It is difficult to model this type of curve behavior with the application of a single time series model without splitting it into various load level predictive models due to the step behavior of the engine load. To illustrate this, Figure 20 shows an instance of such an example using a 2-month moving average forecasting technique, whereby the forecast starts after engine running hours of 3400. The accuracy of the prediction, using a single predictive model, performs poorly especially at the boundary after the step increase in engine load. The weight coefficient for forecast (Alpha) and coefficient for trend (Beta) are 1 and 0.5005, respectively, for this model. The MSE obtained is 71.09, and the difference between expected temperature and forecast temperature is at a maximum value of 24.04 degree Celsius. To tackle this issue, individual engine load levels are modeled. The engine load level models are further refined into time period (1-2000hrs, 2001-3000hrs, 3001-4000hrs, 4001-4500hrs and 4501-5000hrs) to capture the variability of the data within that period. The model stops at engine running hours of 5000. This is reasonable because the EGT and related components are due for maintenance after this mark. The original data curve is therefore split into piece-wise section, analyzed with the different time series predictive models, and integrated back for an accurate prediction.

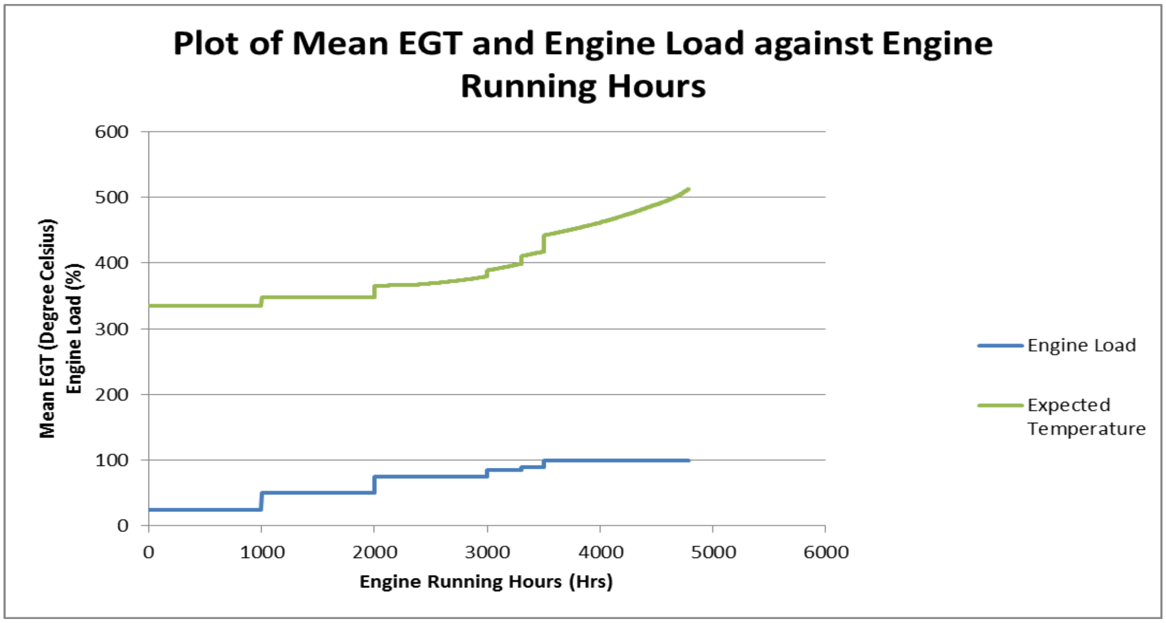


Figure 19. Graph of Mean EGT and Engine Load against Engine Running Hours.

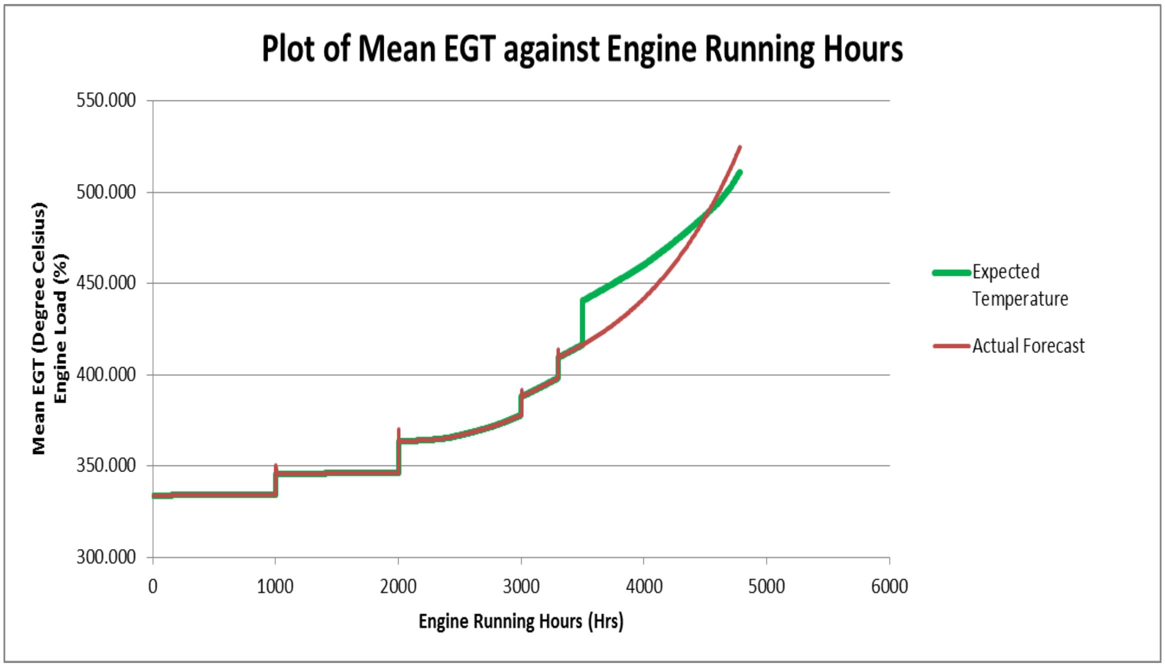


Figure 20. Graph of Mean EGT against Engine Running Hours using single predictive model (without using different models for the various load level).

The Alpha and Beta values are weights for the forecast and trend values to smooth the curve for the model. The Alpha and Beta values of the individual models are as shown in Table 5. The values of Alpha and Beta are obtained by performing a minimization of the MSE by varying Alpha and Beta. The solver tool in Excel is invoked to obtain the respective result.

Predictive Model	Alpha	Beta
25_M1	0.2861	0.3025
25_M2	1.0000	1.0000
25_M3	0.0909	0.0404
25_M4	1.0000	0.1255
25_M5	0.1188	0.3819
50_M1	0.2861	0.3025
50_M2	0.0464	1.0000
50_M3	0.6807	0.7027
50_M4	0.2592	1.0000
50_M5	0.1990	1.0000
75_M1	0.2861	0.3025
75_M2	0.3961	1.0000
75_M3	0.8057	1.0000
75_M4	1.0000	0.2795
75_M5	0.7840	1.0000
85_M1	0.5464	0.0324
85_M2	0.0010	0.5000
85_M3	0.1964	0.0337
85_M4	0.4354	1.0000
85_M5	0.0158	0.1268
90_M1	1.0000	1.0000
90_M2	1.0000	1.0000
90_M3	0.9932	0.4893
90_M4	1.0000	1.0000
90_M5	0.0097	0.9208
100_M1	0.6867	1.0000
100_M2	0.5779	1.0000
100_M3	1.0000	0.5598
100_M4	0.2274	0.0430
100_M5	0.02107198	0.094924199

Table 5. Alpha and Beta values for the respective models.

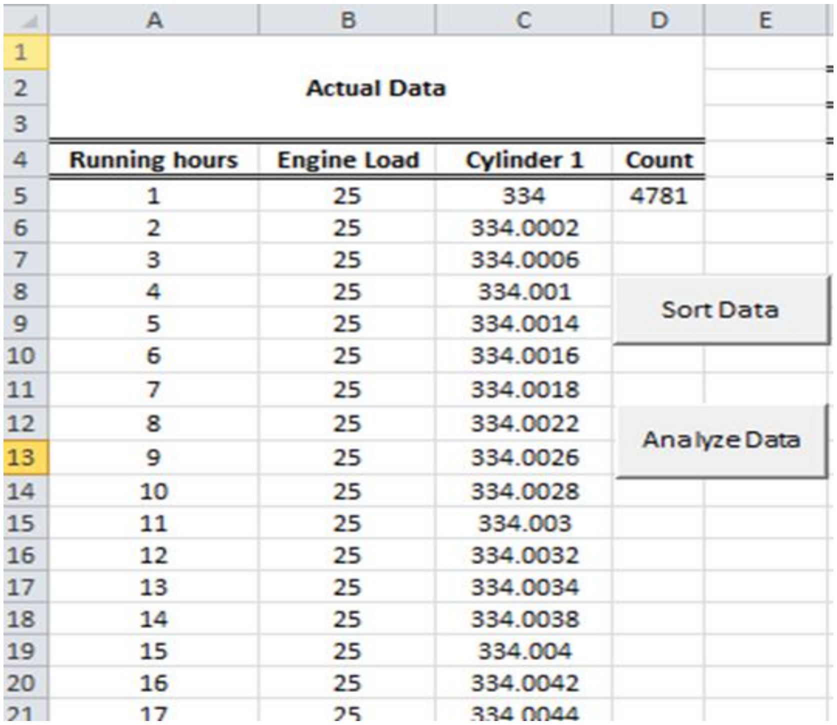
The results for the individual predictive models using Mean EGT as a baseline model are summarized as shown in Table 6.

Load (%)	Engine Running Hours (Hours)	Predictive Model	Difference Between Actual Data and forecasted Data (Error)					
			Mean	Standard Error	Standard Deviation	Min	Max	Mean Square Error
25	1-2000	25_M1	-3.208E-05	4.203E-06	1.879E-04	-1.408E-03	6.419E-04	3.634E-08
	2001-3000	25_M2	3.729E-02	3.673E-03	1.161E-01	-1.000E-02	6.305E-01	1.487E-02
	3001-4000	25_M3	4.166E-02	2.814E-03	8.899E-02	-2.368E-02	4.248E-01	9.648E-03
	4001-4500	25_M4	1.848E-03	4.065E-04	9.089E-03	-1.838E-02	5.039E-02	8.587E-05
	4501-5000	25_M5	-4.936E-03	4.144E-03	9.248E-02	-3.286E-01	3.726E-01	8.559E-03
50	1-2000	50_M1	-1.660E-04	1.304E-05	5.830E-04	-3.466E-03	6.212E-04	3.673E-07
	2001-3000	50_M2	3.192E-02	3.233E-03	1.022E-01	-2.646E-02	5.526E-01	1.146E-02
	3001-4000	50_M3	-1.107E-03	4.649E-04	1.470E-02	-5.478E-02	1.041E-01	2.172E-04
	4001-4500	50_M4	4.919E-02	4.971E-03	1.112E-01	-3.542E-02	3.995E-01	1.475E-02
	4501-5000	50_M5	1.854E-01	6.267E-03	1.398E-01	2.966E-02	9.030E-01	5.391E-02
75	1-2000	75_M1	4.252E-06	1.616E-06	7.225E-05	-3.246E-04	6.276E-04	5.236E-09
	2001-3000	75_M2	4.917E-02	4.306E-03	1.362E-01	-8.023E-03	7.079E-01	2.094E-02
	3001-4000	75_M3	-1.971E-03	6.599E-04	2.087E-02	-6.974E-02	1.071E-01	4.389E-04
	4001-4500	75_M4	-1.214E-04	3.992E-04	8.927E-03	-2.990E-02	4.667E-02	7.954E-05
	4501-5000	75_M5	2.187E-01	8.566E-03	1.912E-01	6.507E-02	1.135E+00	8.428E-02
85	1-2000	85_M1	-9.666E-06	2.410E-06	1.078E-04	-6.207E-04	5.426E-04	1.170E-08
	2001-3000	85_M2	6.169E-02	3.385E-03	1.070E-01	-1.242E-01	3.722E-01	1.525E-02
	3001-4000	85_M3	3.526E-02	2.775E-03	8.775E-02	-1.978E-02	4.862E-01	8.935E-03
	4001-4500	85_M4	6.683E-03	7.636E-04	1.707E-02	-2.134E-02	7.382E-02	3.356E-04
	4501-5000	85_M5	3.271E-01	1.617E-02	3.610E-01	-4.627E-01	1.195E+00	2.370E-01
90	1-2000	90_M1	1.125E-05	2.340E-06	1.047E-04	-4.400E-04	5.400E-04	1.107E-08
	2001-3000	90_M2	1.120E-01	8.962E-03	2.834E-01	-7.500E-03	1.329E+00	9.277E-02
	3001-4000	90_M3	-2.823E-03	4.981E-04	1.575E-02	-5.493E-02	6.179E-02	2.558E-04
	4001-4500	90_M4	3.715E-02	3.418E-03	7.644E-02	-2.414E-02	3.494E-01	7.211E-03
	4501-5000	90_M5	8.015E-02	1.572E-02	3.507E-01	-5.378E-01	9.072E-01	1.292E-01
100	1-2000	100_M1	-7.086E-04	3.808E-05	1.703E-03	-7.271E-03	3.200E-04	3.400E-06
	2001-3000	100_M2	8.459E-03	1.953E-03	6.177E-02	-1.068E-01	3.480E-01	3.883E-03
	3001-4000	100_M3	-3.287E-03	6.370E-04	2.014E-02	-6.579E-02	1.044E-01	4.161E-04
	4001-4500	100_M4	4.216E-02	3.168E-03	7.084E-02	-2.327E-02	2.495E-01	6.786E-03
	4501-5000	100_M5	3.287E-01	1.531E-02	3.417E-01	-3.972E-01	1.179E+00	2.246E-01

Table 6. Summary of results for individual predictive model.

From the summary as shown in Table 6, it can be concluded that the predictive models are highly accurate in forecasting the future values of the EGT. This is supported by the small MSE value of 0.237 (highest MSE value from the predictive models). With this model, we can forecast forward to see when the EGT will exceed its limit of 520 degrees Celsius and recommend an appropriate period for maintenance.

The process of splitting the data into piece-wise region for analysis with associated models and then re-integrating it for results is tedious and error-prone. Therefore, the process is being automated for this thesis. The tool for this analysis is done through Excel VBA, and the codes can be found in Appendix. The baseline model is tested with data from Main Engine Cylinder 3. In this study, 70% of the data are used for the model and 30% of remaining data for validation of the model. Figure 21 shows a snapshot of the program where actual data is input into Column A to Column C.

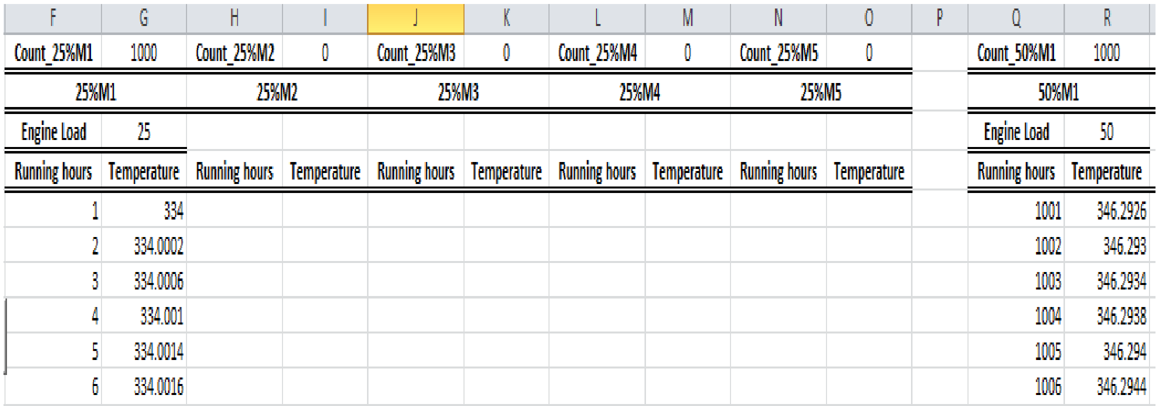


Actual Data

Running hours	Engine Load	Cylinder 1	Count
1	25	334	4781
2	25	334.0002	
3	25	334.0006	
4	25	334.001	
5	25	334.0014	
6	25	334.0016	
7	25	334.0018	
8	25	334.0022	
9	25	334.0026	
10	25	334.0028	
11	25	334.003	
12	25	334.0032	
13	25	334.0034	
14	25	334.0038	
15	25	334.004	
16	25	334.0042	
17	25	334.0044	

Figure 21. Snapshot showing the column for data input.

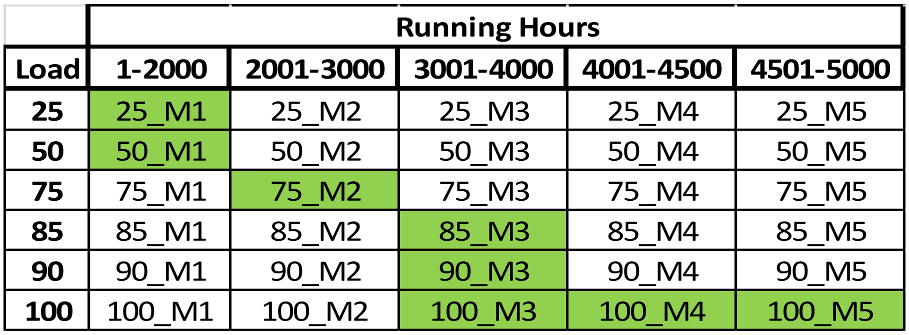
The Sort Data button can be clicked to sort the data into various engine loads and temperature ranges as shown in Figure 22.



F	G	H	I	J	K	L	M	N	O	P	Q	R
Count_25%M1	1000	Count_25%M2	0	Count_25%M3	0	Count_25%M4	0	Count_25%M5	0		Count_50%M1	1000
25%M1		25%M2		25%M3		25%M4		25%M5			50%M1	
Engine Load	25										Engine Load	50
Running hours	Temperature	Running hours	Temperature	Running hours	Temperature	Running hours	Temperature	Running hours	Temperature		Running hours	Temperature
1	334										1001	346.2926
2	334.0002										1002	346.293
3	334.0006										1003	346.2934
4	334.001										1004	346.2938
5	334.0014										1005	346.294
6	334.0016										1006	346.2944

Figure 22. Snapshot showing portion of sorted data.

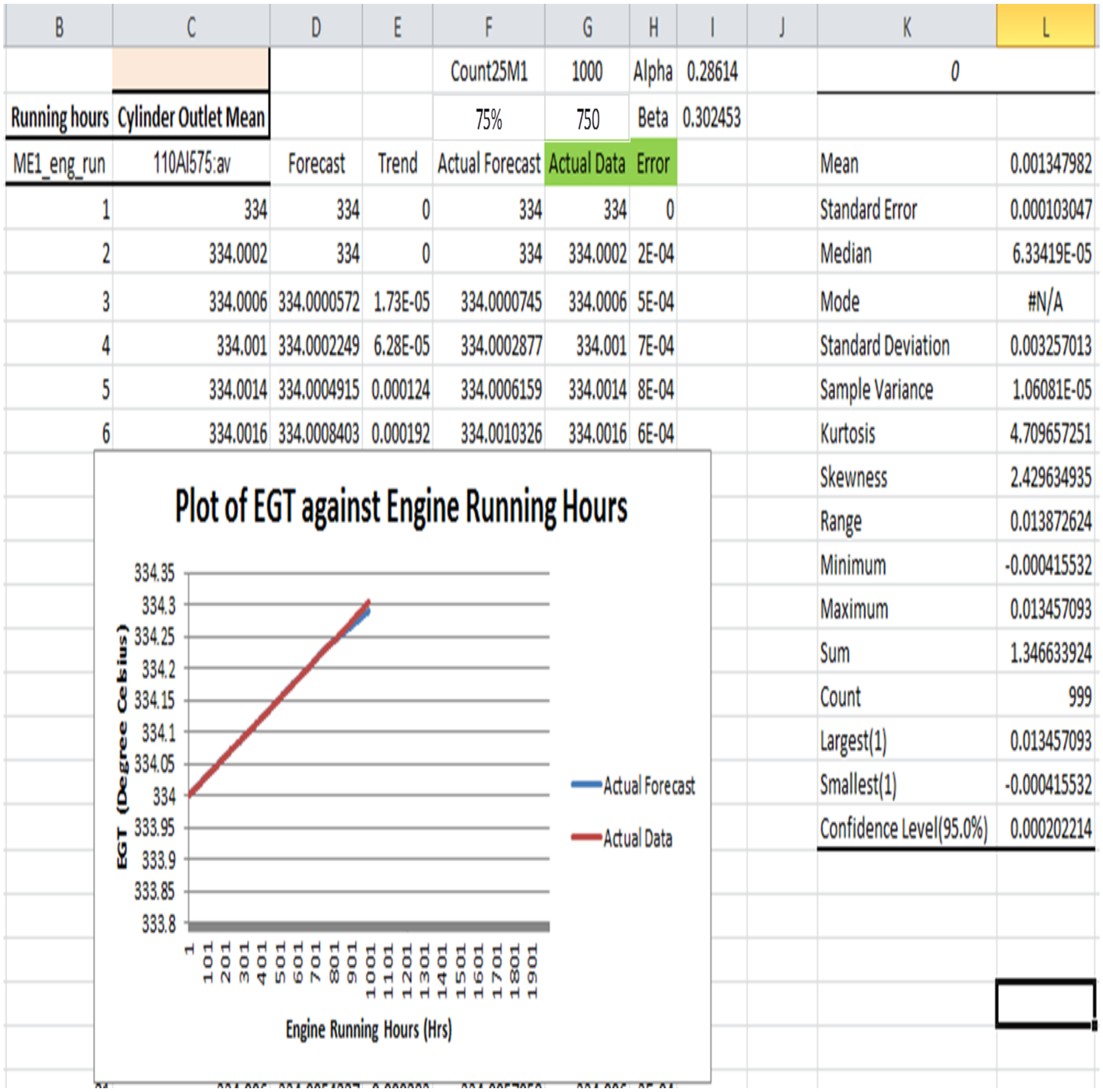
Once sorting is done, mapping on how the data is split and the respective models are invoked, as highlighted in green in Figure 23.



	Running Hours				
Load	**1-2000**	**2001-3000**	**3001-4000**	**4001-4500**	**4501-5000**
25	25_M1	25_M2	25_M3	25_M4	25_M5
50	50_M1	50_M2	50_M3	50_M4	50_M5
75	75_M1	75_M2	75_M3	75_M4	75_M5
85	85_M1	85_M2	85_M3	85_M4	85_M5
90	90_M1	90_M2	90_M3	90_M4	90_M5
100	100_M1	100_M2	100_M3	100_M4	100_M5

Figure 23. Mapping of sorted data to its associated predictive models.

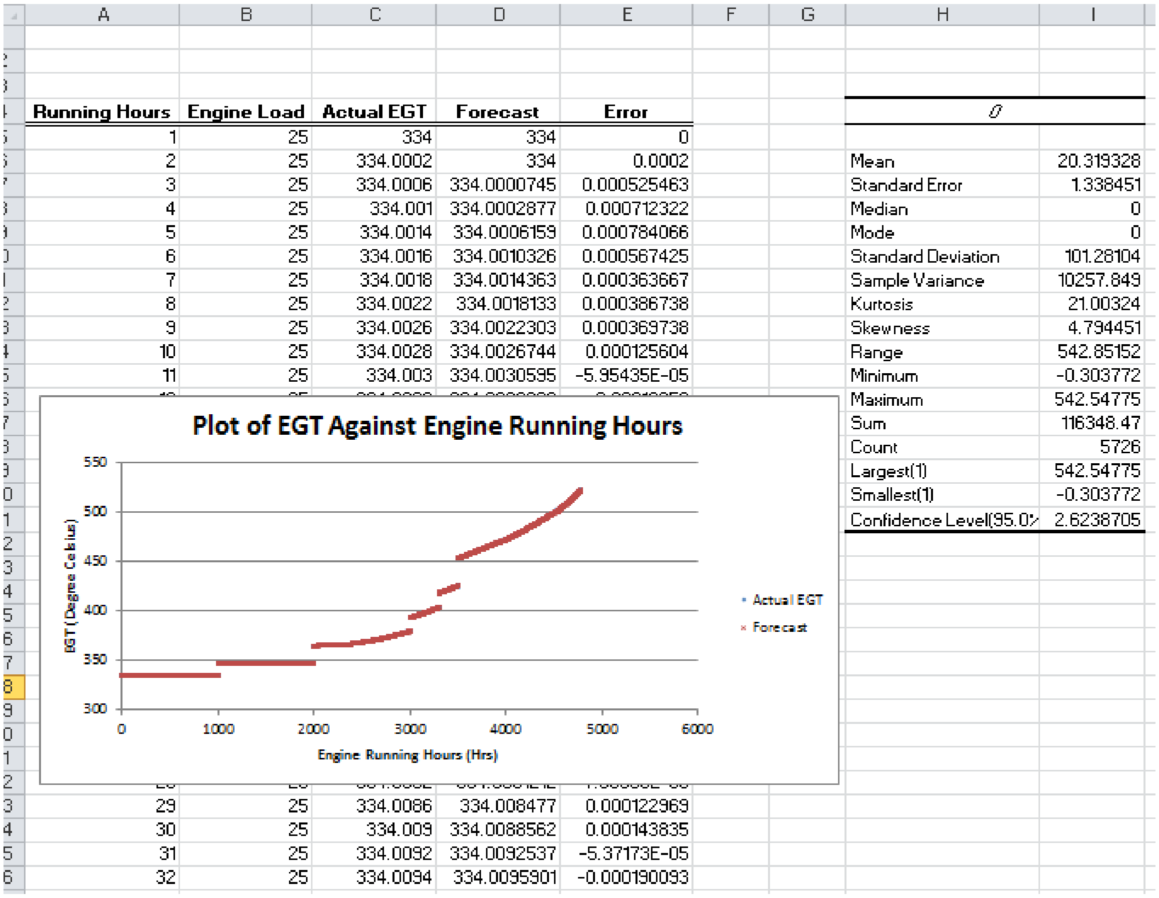
The Analyze Data button can then be clicked to extract the data into their respective models. The result for the respective models can be viewed from the various worksheets in Excel. Figure 24 shows the result (25% Engine Load with running hours from 1-2000hrs) for one of the predictive models.



B	C	D	E	F	G	H	I	J	K	L
				Count25M1	1000	Alpha	0.28614		0	
Running hours	Cylinder Outlet Mean			75%	750	Beta	0.302453			
ME1_eng_run	110AI575:av	Forecast	Trend	Actual Forecast	Actual Data	Error			Mean	0.001347982
1	334	334	0	334	334	0			Standard Error	0.000103047
2	334.0002	334	0	334	334.0002	2E-04			Median	6.33419E-05
3	334.0006	334.0000572	1.73E-05	334.0000745	334.0006	5E-04			Mode	#N/A
4	334.001	334.0002249	6.28E-05	334.0002877	334.001	7E-04			Standard Deviation	0.003257013
5	334.0014	334.0004915	0.000124	334.0006159	334.0014	8E-04			Sample Variance	1.06081E-05
6	334.0016	334.0008403	0.000192	334.0010326	334.0016	6E-04			Kurtosis	4.709657251
									Skewness	2.429634935
									Range	0.013872624
									Minimum	-0.000415532
									Maximum	0.013457093
									Sum	1.346633924
									Count	999
									Largest(1)	0.013457093
									Smallest(1)	-0.000415532
									Confidence Level(95.0%)	0.000202214

Figure 24. Result for Model 25_M1 (25% Engine Load and engine running hours between 1-2000hours).

These individual models' results will automatically be aggregated back to the original format and displayed in "Result for test" worksheet as shown in Figure 25.



Running Hours	Engine Load	Actual EGT	Forecast	Error
1	25	334	334	0
2	25	334.0002	334	0.0002
3	25	334.0006	334.0000745	0.000525463
4	25	334.001	334.0002877	0.000712322
5	25	334.0014	334.0006159	0.000784066
6	25	334.0016	334.0010326	0.000567425
7	25	334.0018	334.0014363	0.000363667
8	25	334.0022	334.0018133	0.000386738
9	25	334.0026	334.0022303	0.000369738
10	25	334.0028	334.0026744	0.000125604
11	25	334.003	334.0030595	-5.95435E-05
29	25	334.0086	334.008477	0.000122969
30	25	334.009	334.0088562	0.000143835
31	25	334.0092	334.0092537	-5.37173E-05
32	25	334.0094	334.0095901	-0.000190093

0	
Mean	20.319328
Standard Error	1.338451
Median	0
Mode	0
Standard Deviation	101.28104
Sample Variance	10257.849
Kurtosis	21.00324
Skewness	4.794451
Range	542.85152
Minimum	-0.303772
Maximum	542.54775
Sum	116348.47
Count	5726
Largest(1)	542.54775
Smallest(1)	-0.303772
Confidence Level(95.0%	2.6238705

Figure 25. Final aggregated forecast result of the analyzed data based on the engine loads of Figure 19.

Figure 26 shows the results for the individual models, and Figure 27 shows the result after the individual models are integrated. The plot is discontinuous because it is a function of time and load. The various steps accounts for the various engine load that it is operating in. The result shows that it is consistent with the profile shown in Figure 19 and gives a better result as compared to using a single predictive model shown in Figure 20. The summary of the results obtained from the predictive models is shown in Table 7. It can be seen that the MSE for the overall result is 0.02368. The small MSE is good and shows that the model exhibits high "goodness of fit" to the original data. Furthermore, the result is close to the mean EGT value that was established earlier. It should be noted that the model 100M_5 shows a higher MSE value of 0.29880 as compared to the rest of the models. This is because the forecast for the earlier hours of the data have a higher MSE.

It can also mean that the data exhibits greater variation as compared to the baseline model.

It is imperative to know at this point that although MSE is used as a measure for accuracy, it is sometimes wise to compute the MSE using the most recent values. This is because the lowest MSE may result from fitting older values very well, but it fits recent values poorly. Therefore, care should be taken when comparing the MSE.

With this model, the user can observe the trend from the graph when the predicted temperature will exceed the threshold temperature of 520 degree Celsius based on their expected operating scenario. The user can then plan their maintenance activities accordingly, for example, allocation of manpower, booking of facilities and ordering of parts when the predicted temperature reaches 500 degree Celsius.

The result from the forecast model can also serves as a warning to user if the predicted temperature deviates too much from the expected temperature. In that situation, the user can look at the CUSUM control chart, which will be discuss in Chapter IV Section C, and confirms if there are any anomalies.

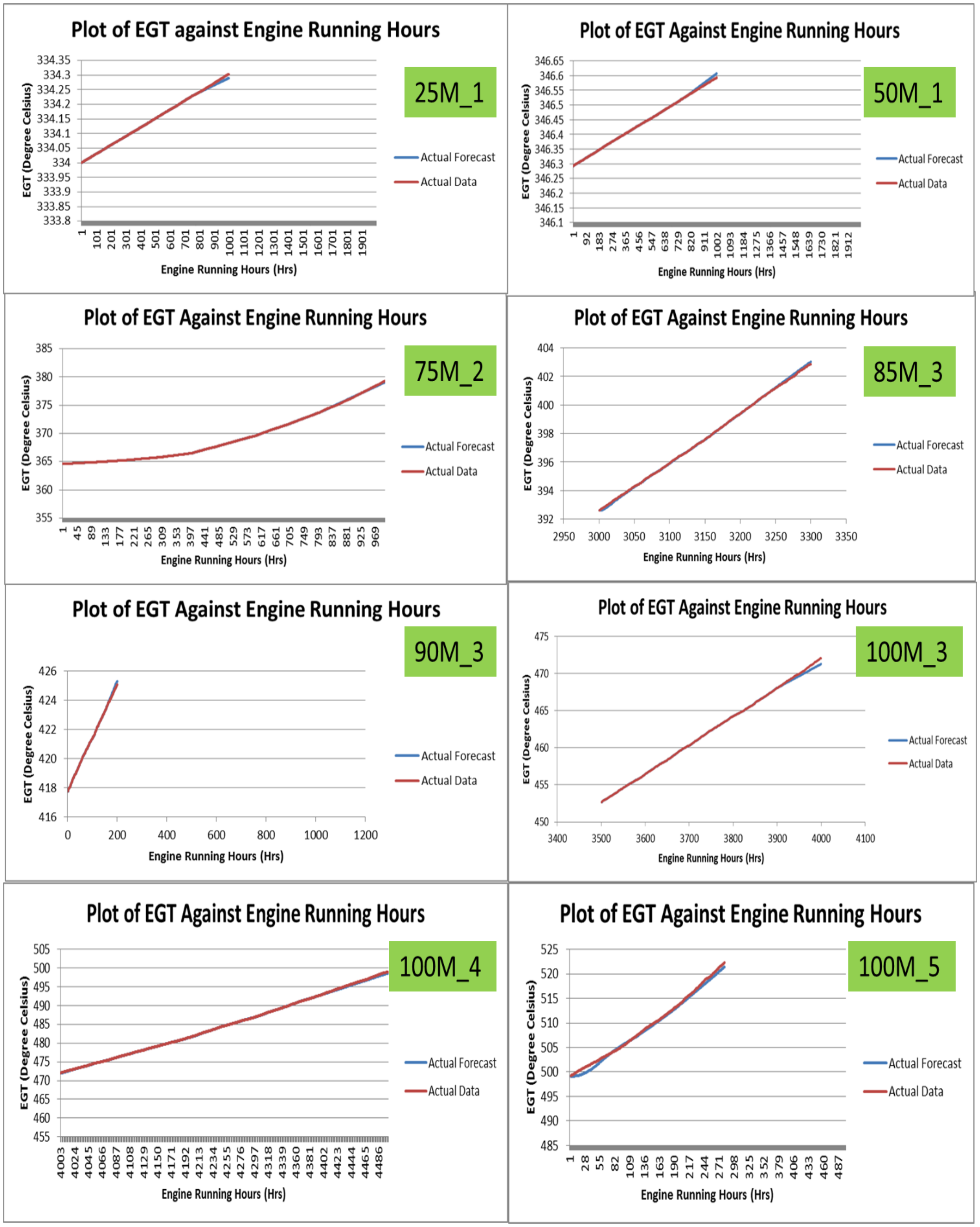


Figure 26. Results for individual predictive models.

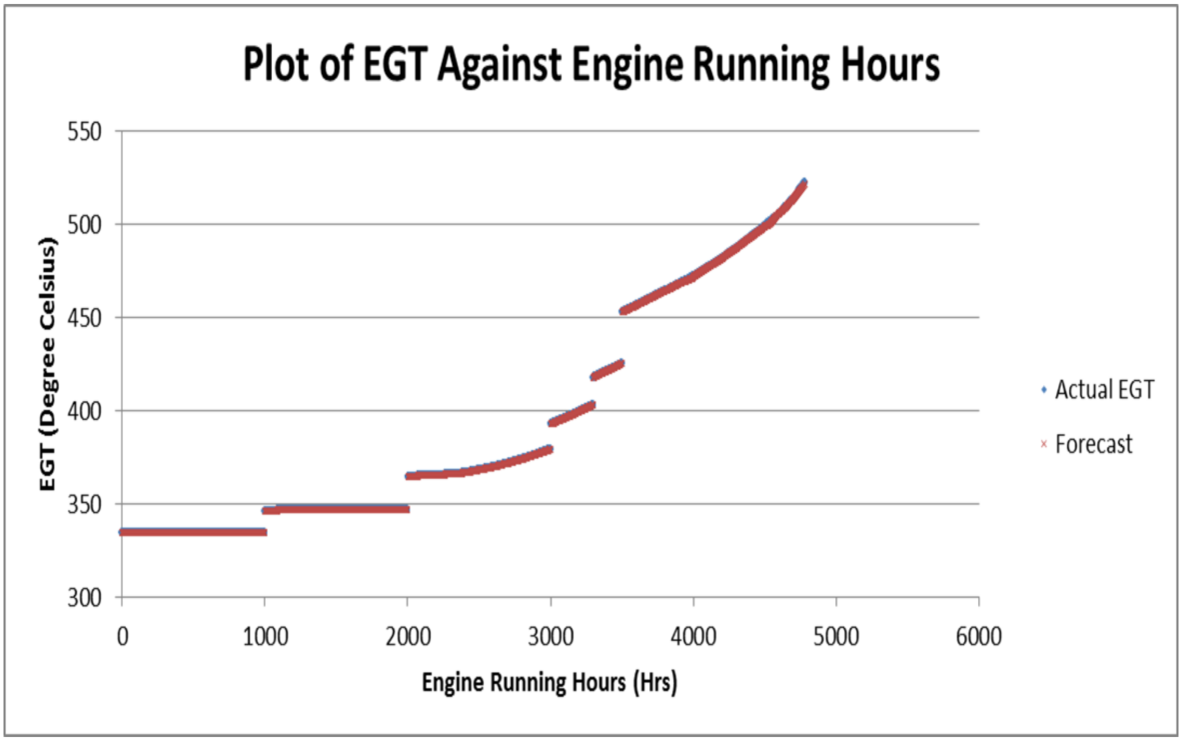


Figure 27. Result of aggregated model, for the operation profile in Figure 19.

Load (%)	Engine Running Hours (Hrs)	Predictive Model	Mean	Standard Error	Standard Deviation	Min	Max	MSE
25	1-2000	25_M1	0.00135	0.00010	0.00326	-0.00042	0.01346	0.00001
50	1-2000	50_M1	-0.00143	0.00011	0.00333	-0.01436	0.00077	0.00001
75	2001-3000	75_M2	0.00287	0.00125	0.03940	-0.10968	0.22866	0.00156
85	3001-4000	85_M3	-0.00032	0.00358	0.06200	-0.16327	0.15084	0.00383
90	3001-4000	90_M3	-0.02725	0.00467	0.06603	-0.24927	0.04762	0.00508
100	3001-4000	100_M3	0.07183	0.00800	0.17883	-0.02686	0.82074	0.03708
100	4001-4500	100_M4	0.05762	0.00468	0.10458	-0.07855	0.43118	0.01423
100	4501-5000	100_M5	0.40098	0.02228	0.37218	-0.30377	1.18455	0.29880
Final Result			0.03656	0.00216	0.14950	-0.30377	1.18455	0.02368

Table 7. Results from predictive model program for engine cylinder 3 analysis.

C. CUMULATIVE SUM (CUSUM) CONTROL CHARTS

The Shewhart Xbar chart is a time-ordered plot of the Xbar values with three horizontal lines. There is a center line which is the mean operating temperature (shown in blue), an upper control limit line and a lower control limit line which is not shown in this chart. Figure 28 shows an overview of Xbar chart for the operation of a sea going events. There are different operating EGT mean temperatures corresponding to different engine loads, which describe the different mean operating temperature, shown by the blue horizontal lines. The mean operating expected temperature for 100% engine load is observed to be higher then the data obtained throughout for that particular sea-going event. The data is expected to fluctuate around its mean at 420 degree Celsius, which is not happening. It could mean that the the expected temperature obtained during FAT is not correct or there is a consistent problem for operation at 100% engine load.

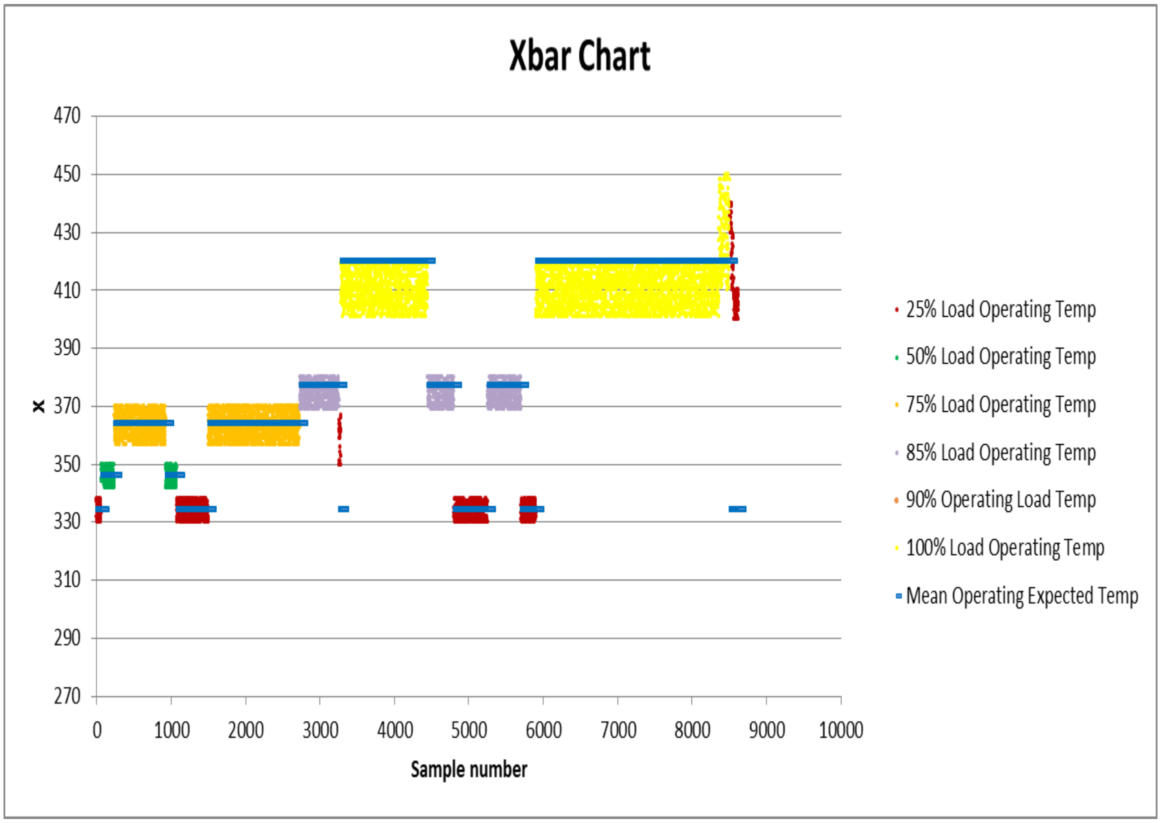


Figure 28. Shewhart Xbar chart for the sea-going event.

Figure 29 shows a zoom-in version of the event between samples 7500 to 8385. The control limits are located three standard deviation of the mean, above and below the center line. The standard deviation is 7.55 degree Celsius. The limits are determined to be at 397 and 443 degree Celsius. When the points are within the two limits, it means that the process is in control and should be left to run as it is. When the points are out of the control limit, it means that the process is out of control. It signifies a problem and a need to look at the problem seriously. The problem with using Xbar chart for this particular application is that it grows increasingly confusing with the different load levels, its corresponding mean operating temperatures (center lines), and their associated lower and upper control limit lines.

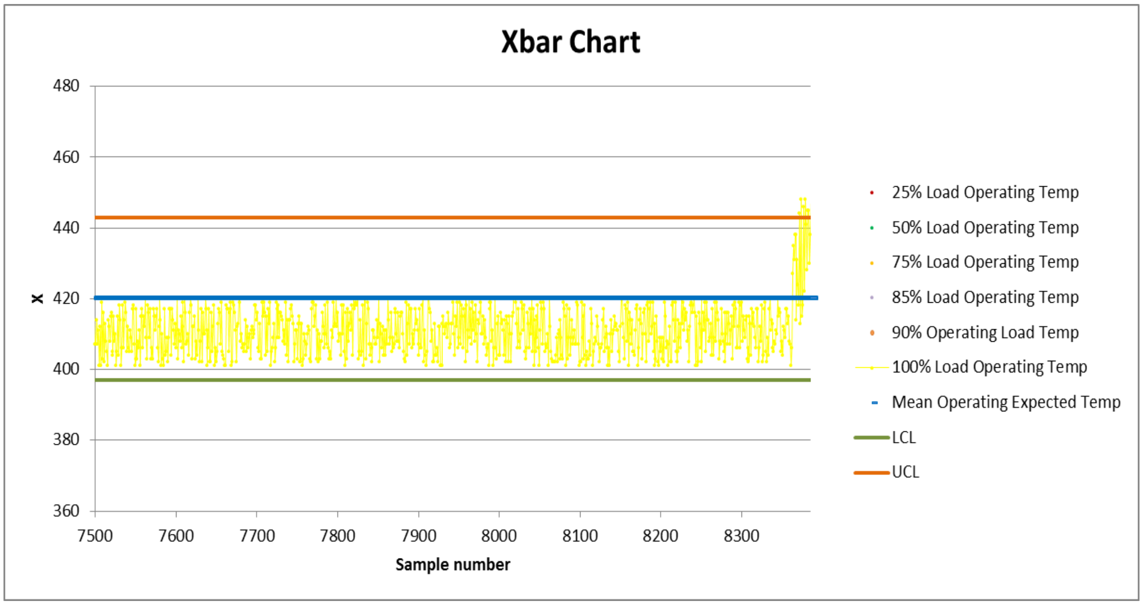
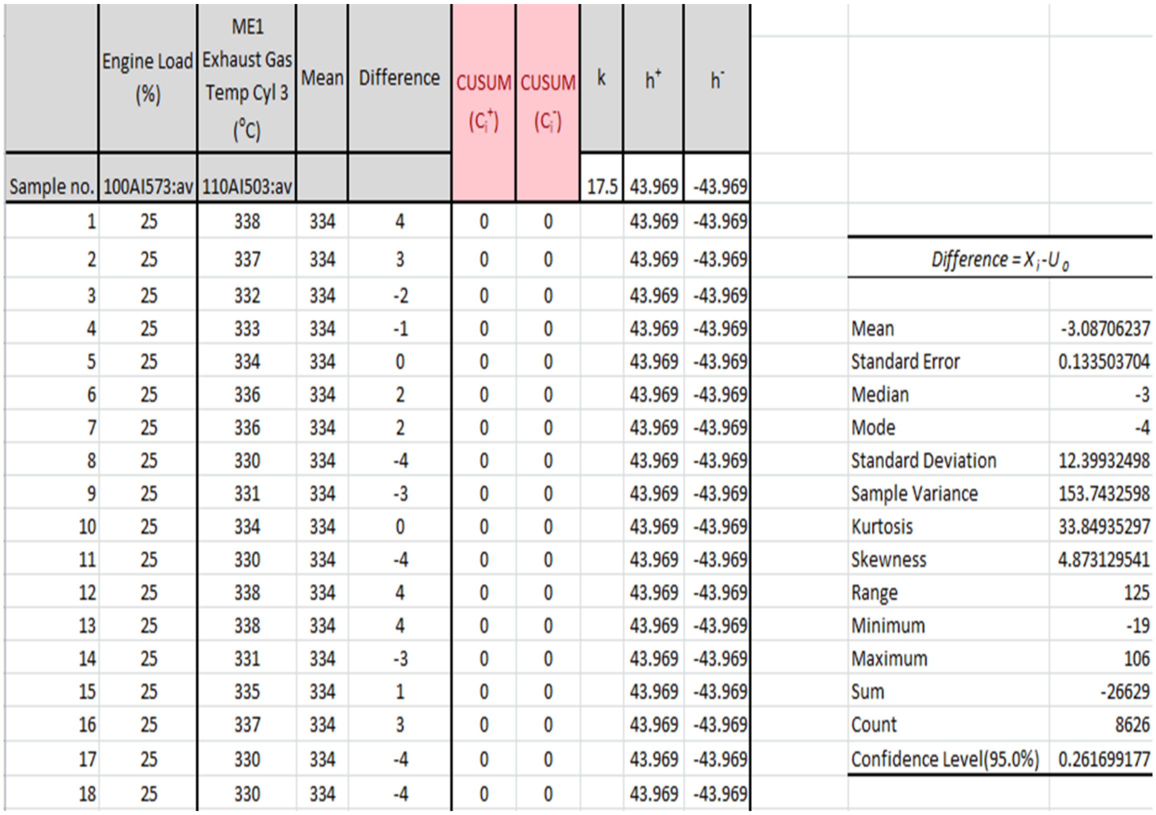


Figure 29. Shewhart Xbar chart for samples between 7500 and 8385.

The DI CUSUM chart is used in this study instead as it accounts for the different load level mean operating temperatures, simply by monitoring if the points stays within the decision intervals, h^+ and h^- . The exhaust gas temperature for cylinder three is studied with the use of Excel. A sample of the setup is as shown in Figure 30. The data analysis tool from Excel is used to generate the descriptive statistics for the difference between X_i and the mean operating temperature, U_0. The in-control standard deviation is obtained to be 12.3993. This parameter is important as it helps to determine the subsequent *k* and *h* values derived from another program, anygeth. The program is obtained from the CUSUM website of the School of Statistics, University of Minnesota (www.stat.umn.edu).

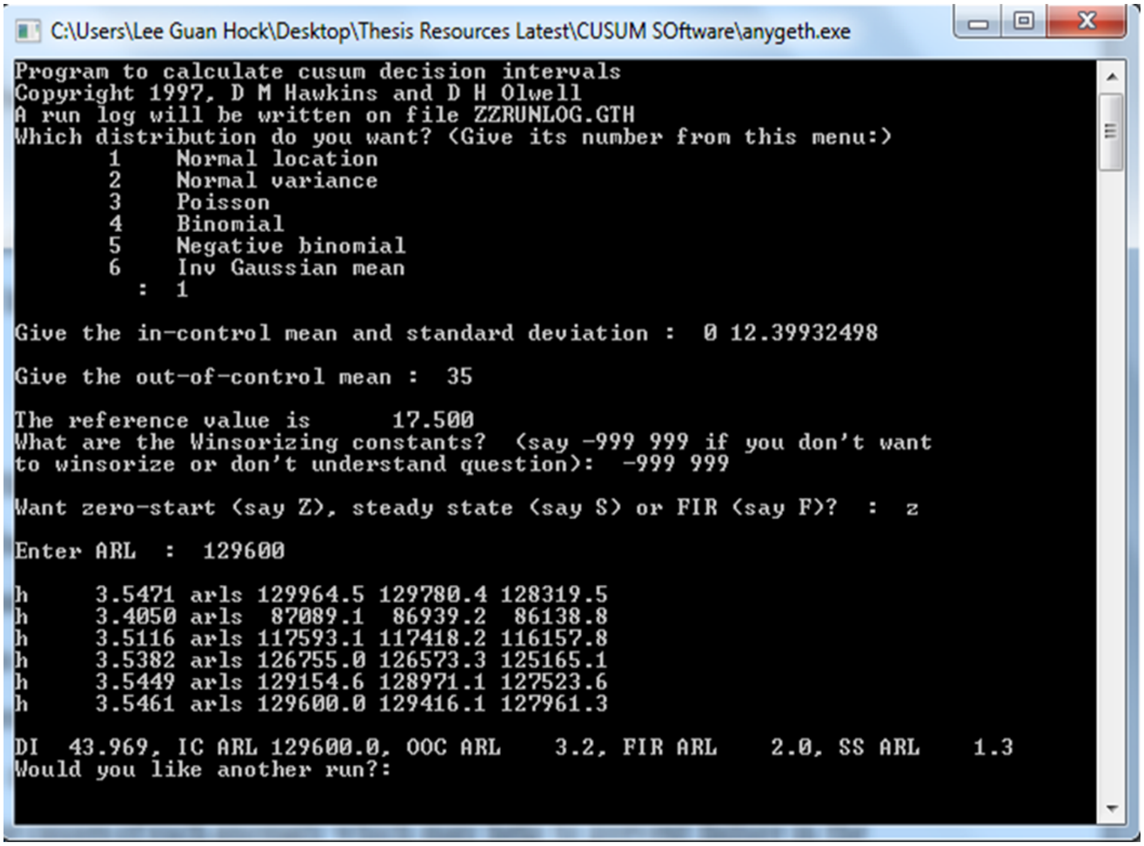


	Engine Load (%)	ME1 Exhaust Gas Temp Cyl 3 (°C)	Mean	Difference	CUSUM (C_i^+)	CUSUM (C_i^-)	k	h^+	h^-
Sample no.	100AI573:av	110AI503:av					17.5	43.969	-43.969
1	25	338	334	4	0	0		43.969	-43.969
2	25	337	334	3	0	0		43.969	-43.969
3	25	332	334	-2	0	0		43.969	-43.969
4	25	333	334	-1	0	0		43.969	-43.969
5	25	334	334	0	0	0		43.969	-43.969
6	25	336	334	2	0	0		43.969	-43.969
7	25	336	334	2	0	0		43.969	-43.969
8	25	330	334	-4	0	0		43.969	-43.969
9	25	331	334	-3	0	0		43.969	-43.969
10	25	334	334	0	0	0		43.969	-43.969
11	25	330	334	-4	0	0		43.969	-43.969
12	25	338	334	4	0	0		43.969	-43.969
13	25	338	334	4	0	0		43.969	-43.969
14	25	331	334	-3	0	0		43.969	-43.969
15	25	335	334	1	0	0		43.969	-43.969
16	25	337	334	3	0	0		43.969	-43.969
17	25	330	334	-4	0	0		43.969	-43.969
18	25	330	334	-4	0	0		43.969	-43.969

Difference = X_i-U_0	
Mean	-3.08706237
Standard Error	0.133503704
Median	-3
Mode	-4
Standard Deviation	12.39932498
Sample Variance	153.7432598
Kurtosis	33.84935297
Skewness	4.873129541
Range	125
Minimum	-19
Maximum	106
Sum	-26629
Count	8626
Confidence Level(95.0%)	0.261699177

Figure 30. Excel setup for the study of DI CUSUM for EGT Cylinder 3.

The distribution used is the Normal location with in-control mean of zero, standard deviation of 12.3993 and out-of-control mean of 35. The out of control mean can be varied to determine the sensitivity of the detection of possible problems in the process. The lower the out-of-control mean value, the more sensitivity it is to detection of change. The Average Run Length (ARL) is set at 90 days or 129600 minutes. The ARL sets the time interval between false alarms. The self-starting CUSUM is used, which means the CUSUM resets itself after detection of change. With the values above, it is entered into the anygeth software program as shown in Figure 31. The program returns a reference, *k* value and the DI or *h* value. The *k* value is 17.5 and the *h* value is 43.969.


C:\Users\Lee Guan Hock\Desktop\Thesis Resources Latest\CUSUM SOftware\anygeth.exe

```
Program to calculate cusum decision intervals
Copyright 1997, D M Hawkins and D H Olwell
A run log will be written on file ZZRUNLOG.GTH
Which distribution do you want? (Give its number from this menu:)
       1    Normal location
       2    Normal variance
       3    Poisson
       4    Binomial
       5    Negative binomial
       6    Inv Gaussian mean
         :  1

Give the in-control mean and standard deviation :  0 12.39932498

Give the out-of-control mean :  35

The reference value is      17.500
What are the Winsorizing constants?  (say -999 999 if you don't want
to winsorize or don't understand question):  -999 999

Want zero-start (say Z), steady state (say S) or FIR (say F)?  :  z

Enter ARL  :  129600

h     3.5471 arls 129964.5 129780.4 128319.5
h     3.4050 arls  87089.1  86939.2  86138.8
h     3.5116 arls 117593.1 117418.2 116157.8
h     3.5382 arls 126755.0 126573.3 125165.1
h     3.5449 arls 129154.6 128971.1 127523.6
h     3.5461 arls 129600.0 129416.1 127961.3

DI  43.969, IC ARL 129600.0, OOC ARL    3.2, FIR ARL    2.0, SS ARL    1.3
Would you like another run?:
```

Figure 31. Anygeth software program for obtaining k and h value. (After Hawkins and Olwell 1998)

Both the *k* and *h* value are entered into Excel and the calculation of both Ci^+ and Ci^- performed. The h^+ and h^- values form the upper and lower in-control limits.

$$C_i^+ = \max(0, C_{i-1}{}^+ + U_i - k) \tag{1.18}$$

$$C_i^- = \min(0, C_{i-1}{}^- + U_i + k) \tag{1.19}$$

A sample of the DI CUSUM EGT plot is as shown in Figure 32. Figure 33 shows a zoom in plot showing that the process is operating in-control until sample number 8500, where it starts to trend upwards. The points went above the h^+ limit at sample number 8504. This signifies a need to take a look at what is the problem since there is a persistent shift in the control process. The change in process indicates an abnormal behavior of the process and it does not necessary means that there is a failure in the engine. It helps operator to look at the causes of such anomaly which may help to prevent failure in the worst case scenario.

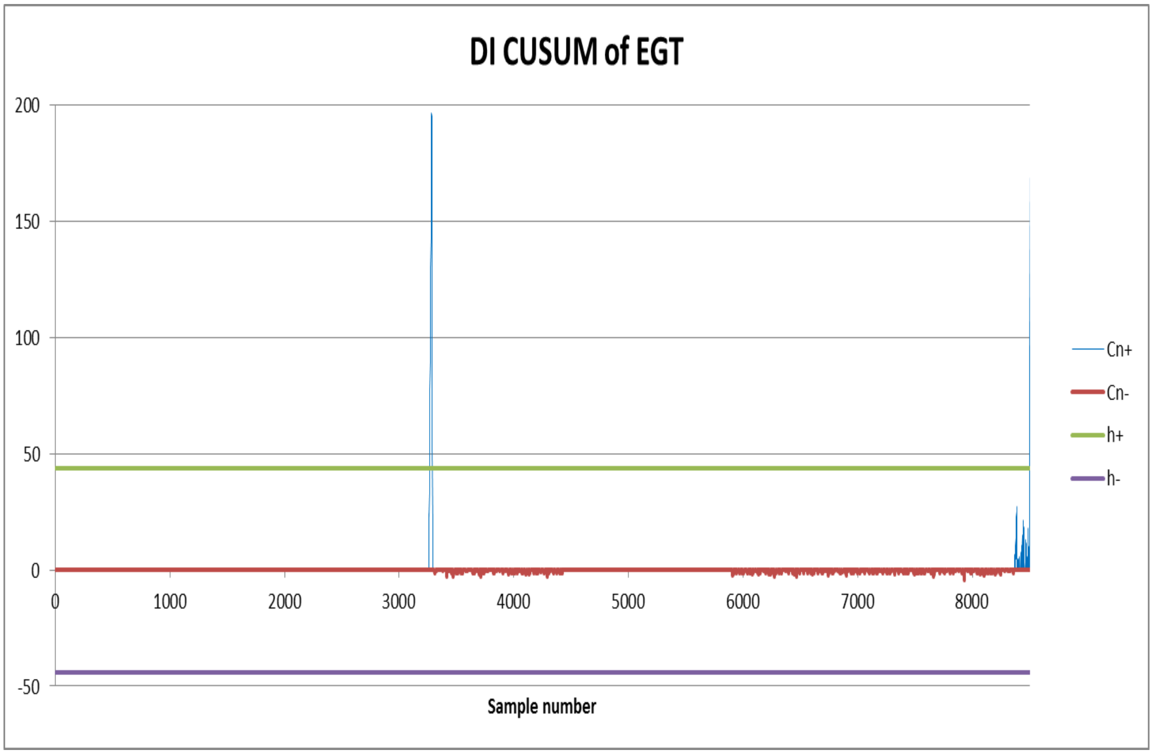


Figure 32. DI CUSUM of cylinder three EGT.

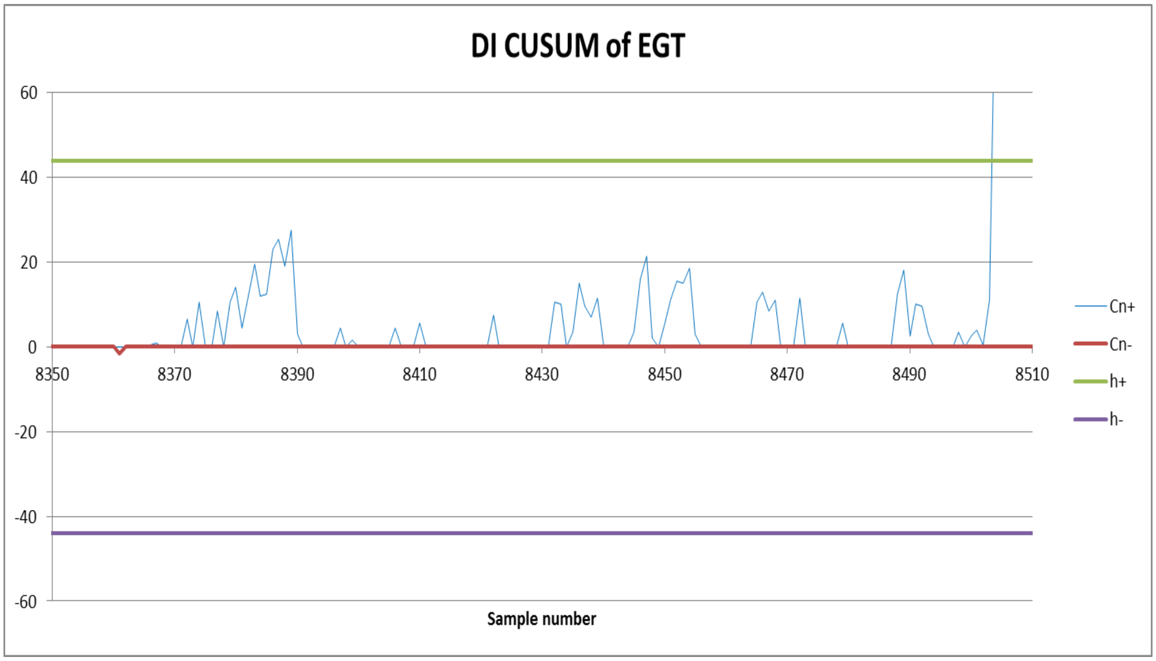


Figure 33. DI CUSUM of cylinder three EGT from samples 8350 to 8510.

Figure 34 shows the DI CUSUM of the same cylinder three EGT with out-of-control mean of 20 and its corresponding *k* value of 10, and *h* values of 78.29 and -78.29. Comparing Figure 32 to Figure 34, it can be shown that a smaller value of *k* will make the detection of change more sensitive. It is imperative to choose a suitable value for the out-of-control mean, *k* and *h* values depending on the system under monitoring. If a small change is going to have a huge impact on the system, the value of *k* must be set as small as possible. If a small change will not impact the system critically, then the *k* value can be set higher.

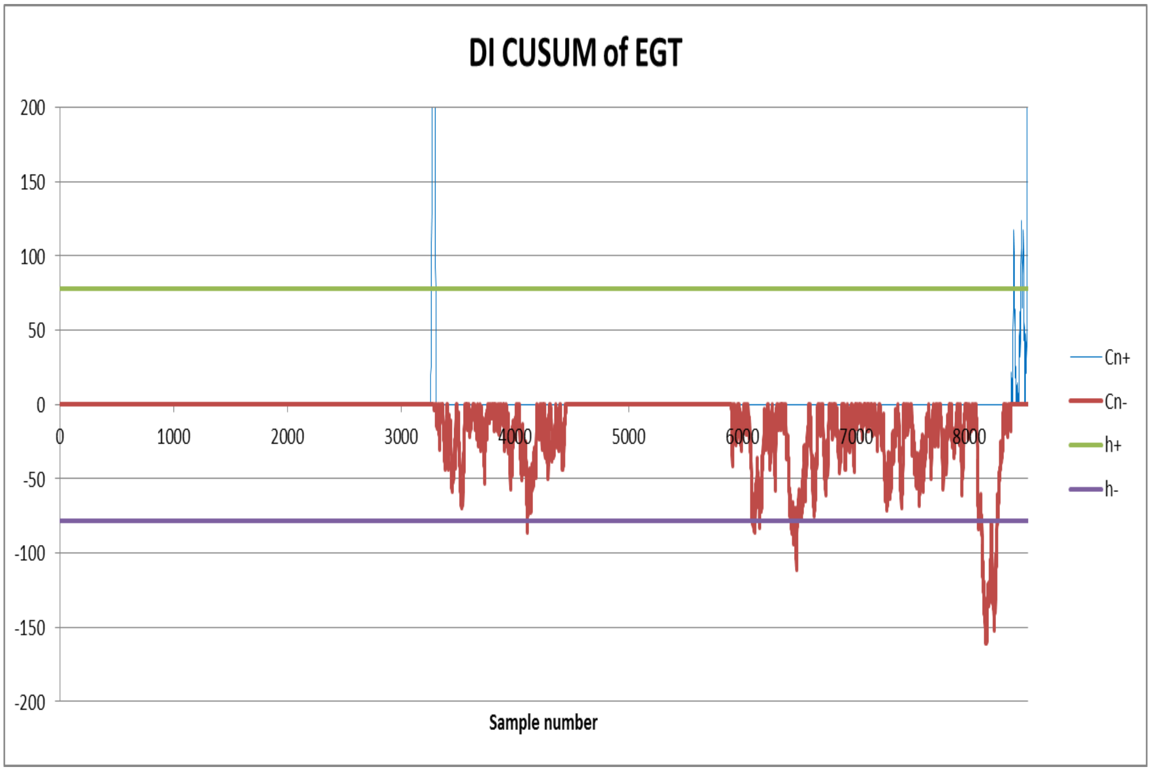


Figure 34. DI CUSUM of cylinder three EGT for out-of-control mean of 20.

Figure 35 shows a zoom in plot showing that the EGT starts to have abnormal behavior starting at sample number 8375. It oscillates about the h^+ limit for around 110 samples before it continues its trend upwards. The behavior at sample number 8500 is the same as seen from Figure 33. This example depicts the advantage of setting a smaller value of *k* because it captures the anomaly as early as in sample 8375. Due to its sensitivity, it captures small persistent change very quickly.

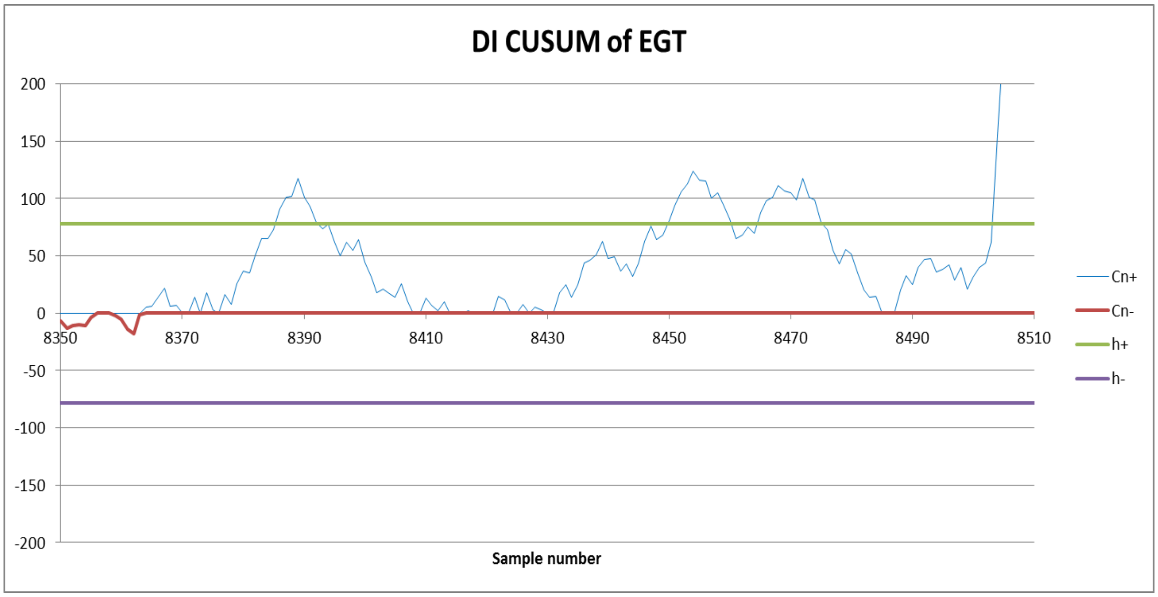


Figure 35. DI CUSUM of cylinder three EGT from samples 8350 to 8510.

Figure 36 shows another instance where the process starts to trend upwards above the h^+ limit after sample number 3258. This is consistent with the result when the out-of-control mean is set at 35 as shown in Figure 32. It is also interesting to observe that when we set the out-of-control mean to be 20, C_n^- actually trends downwards below the h^- limit as shown in Figure 34. This means that at some point of time, the EGT is actually running colder than it should have been. This may be attributed by poor combustion or cooler ambient temperature from the surrounding.

From the results, it can be seen that by setting an appropriate out-of-control mean, and getting the corresponding *h* and *k* values, CUSUM control chart is highly sensitive to small changes in process. CUSUM proves to be capable of detecting anomalies, which serves to warn user that it is time they check on the system before possible failures arises.

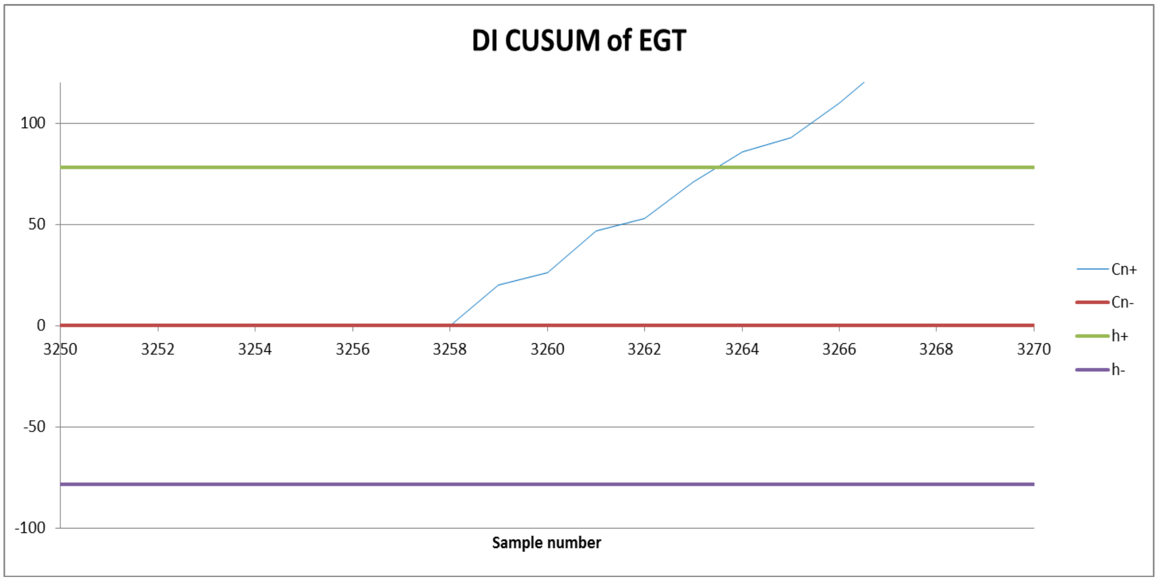


Figure 36. DI CUSUM of cylinder three EGT from samples 3250-3270.

D. COMPARISONS BETWEEN THE TWO METHODOLOGIES

In the prediction of engine failures, both time series forecasting as well as CUSUM control charts are shown to be capable of detecting anomalies. Looking at the nature of the time series forecasting method, it would be better applied to offline analysis. The application for real-time online use during operation does not seem to have much benefit since there is nothing much the operators can do while out at sea. Instead, it should be used prior to sea-going events and forecast for future possible failure and planned for maintenance accordingly.

Forecasting relies on the assumption that the temporal behavior observed in past observations persists in the near future. Hence, a usually large prediction error is an indicator of a change in the monitored random variable. The prediction errors are also known as residuals because they represent the variability not explained by the forecasting model. Changes to operation methods will also affect the result for the trends and, eventually, the forecasted result. This is due to the intrinsic nature of how the individual models are derived. For example, if the engine load were to operate at 60% instead of those specified for the model, the behavior of the forecast model might be different and the variability of the data might not be captured by the model.

Generally, the more a priori knowledge is available, the easier it is to detect any changes with a high accuracy. Parametric methods typically have more power than non-parametric methods, which means that they allow for the detection of more true anomalies at the same false alarm level (probability of an alarm in absence of any significant change). However, if the assumption is incorrect, parametric methods lose their decisive power and may lead to wrong decisions. In the case of EGT anomaly detection, it is not totally correct to assume that the monitored variable follows a specific distribution; thus the detection should be non-parametric or at least robust enough against non-normality. Furthermore, changes should be detected very swiftly while online without requiring any prior knowledge about their magnitude. This is due to the lack of readily available information for different operation scenarios.

CUSUM control chart, in this case, is a practical solution to statistical online change detection. In a control chart, the mean and variability of a monitored variable are characterized by a centerline (CL), an upper control limit (UCL), and a lower control limit (LCL). A change is detected if the measured value exceeds one of the control limits. CUSUM control charts can therefore be used as online tools to look at anomalies and can serve as a form of warning to the operator for possible failures.

The comparison between these two methods is pretty distinct although both allow prediction on the detection of failure. Time series forecasting tends toward prediction used for future planning for maintenance (offline mode) while the CUSUM control chart serves as an online monitoring and control tool, observing the anomaly of the process for an operation.

V. CONCLUSION AND RECOMMENDATIONS

The study of the predictive methodology, both time series forecasting and CUSUM, displays potential means on how it can be applied to ship machinery maintenance. Both methodologies display accuracy in predicting machinery failures, and this can be used to the advantage of the users. Time series forecasting can be used as an offline analysis tool while CUSUM can be used as a real-time monitoring tool. A combination of both methods allows greater capability to predict ship machinery failures and allows "just in time" maintenance as compared to the traditional maintenance strategy that is considered both preventive and corrective.

With prior knowledge of possible future failure, administrators responsible for the purchase of parts, delivery of components, docking of vessel, if required, and other logistical work can plan well ahead. It reduces the risk of corrective maintenance, the shortage of parts, and last minute purchases. It could also allow lower quantities of spares to be purchased since inventory can be planned ahead of time based on prediction. This in turn reduces the need for storage space as well as for resources to maintain the huge inventory. Overall, this will increase the turn-around time for maintenance, reduce the operational downtime, and improve the overall effectiveness of the ship maintenance program.

The results from the modeling done in this paper display the potential means on how both predictive methodologies can be applied to ship machinery maintenance. Both methodologies display accuracy in predicting failures in machinery, and this can be used to the advantage of the users.

In the time series results, the relationship between the two parameters, ME EGT and ME load was established: ME EGT increases as the ME load increases and decreases when the engine load is reduced. From this relationship, a mean EGT value was derived, and the results for the mean EGT produced were close. MSE was used as a measure for accuracy in this modeling. The small MSE derived shows that the time series model exhibits high "goodness of fit" to the original data. However, one should exercise caution when computing the MSE as lowest MSE may result from fitting older values very well, but it fits recent values poorly.

The time series forecast model allows the user to observe the trend of the predicted temperature and plan for their maintenance activity before it exceeds the high temperature limit of 520 degree Celsius.

For the CUSUM results, the control limits are established for the parameters. In this paper, DI CUSUM was used instead as it accounts for the different load level mean operating temperatures, simply by monitoring if the points stays within the decision intervals, h^+ and h^-. The results shows that a smaller value of *k* will make the detection of change more sensitive, and hence it is imperative to choose a suitable value for the out-of-control mean, *k* and *h* values depending on the system under monitoring.

The CUSUM results also shows that there were two instances of abnormal behaviors (most likely failure), that occurs around the same point (sample number 3258 and 8500) for both *k* values of 17.5 and 10. This confirmed that the control chart is capable of detecting anomalies accurately. Furthermore, there were more symptoms displayed prior to the upward departure of the data around its mean of zero at sample number 8500, when a *k* value of 10 was used. This shows that a smaller *k* value is more sensitive to chnge and can detect the anomalies earlier.

The study of predictive analytics for commercial vessel main engines exhaust gas temperature shows the possibility of and reasonable accuracy in predicting failures. As such, this methodology possesses qualities that can be adopted and extended for a more effective ship maintenance program for naval vessels.

The study has confirmed that the predictive methodology is feasible in its limited parameters analysis. Some recommendations for future work may include the following for a more conclusive model.

i. The study of turbocharger pressure and temperature in relation to the failure of the main engine.

ii. The study of turbocharger vibration and RPM in relation to the failure of the main engine.

iii. The study of air flow that affects the combustion process and the operation of the main engine.

iv. The study of bearing temperature in relation to the failure of the main engine.

v. An enhanced version of the automated time series forecasting method with graphical user interface, allowing more parameters to be selected and analyzed. It can also incorporate auto calculation of predicted time to failure which offers greater ease of comprehension.

vi. An enhanced version of the automated time series forecasting with various forecasting techniques templates, allowing operators the flexibility to select and fit the best model for the application.

vii. The architecture for an integrated, real-time, online CUSUM process control monitoring and alarm system.

viii. An automated CUSUM program with graphical user interface for the operator to varies the input parameters and plot a graph. It should be flexible enough to incorporate other types of distributions.

ix. The exploration of multivariate quality control using Shewhart charting – Hotelling's T^2. This is to account for increased sensitivity to departures from the in-control. The study could measure how the different EGT cylinders may affect the overall behavior of the system.

A combination of both methods allows greater capability to predict ship machinery failures and allows "just in time" maintenance as compared to the traditional maintenance strategy that is considered both preventive and corrective.

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APPENDIX

The following is the VBA source code to the automated time series focasting program used in this thesis. These codes must be used in conjunction with the Excel-Macro enabled file (Time Series Forecasting Program) provided since there are named cells programmed in the worksheets. The instructions for the use of this program are described under “instructions” worksheet in the Excel-Macro enabled file.

```
Sub Sort_Data()
‘These source code must work together with the Excel file provided because of the referencing to
named ‘cells.
'Delete all previous data under the different model header
Worksheets("Data for test").Activate
count_data = Range("count")
Worksheets("Data for test").Range("F5:BR1048576").Clear
'Declaration of variable
Dim count25_1 As Integer, count25_2 As Integer, count25_3 As Integer
Dim count25_4 As Integer, count25_5 As Integer, count50_1 As Integer
Dim count50_2 As Integer, count50_3 As Integer, count50_4 As Integer
Dim count50_5 As Integer, count75_1 As Integer, count75_2 As Integer
Dim count75_3 As Integer, count75_4 As Integer, count75_5 As Integer
Dim count85_1 As Integer, count85_2 As Integer, count85_3 As Integer
Dim count85_4 As Integer, count85_5 As Integer, count90_1 As Integer
Dim count90_2 As Integer, count90_3 As Integer, count90_4 As Integer
Dim count90_5 As Integer, count100_1 As Integer, count100_2 As Integer
Dim count100_3 As Integer, count100_4 As Integer, count100_5 As Integer
Dim Column_value As Integer
Column_value = 5

 'Sorting algorithm to put original data into their respective model and header
 For i = 1 To (count_data)
      'Model 25_M1
      IfRange("Eng_Load").Offset(i)=Range("Eng_Load_25")And Range("Running_hr").Offset(i)
      <= 2000 Then
      Range("Running_hr").Offset(i).Copy
      count25_1 = Application.WorksheetFunction.Count(Range("F5:F1048576"))
      Set Curcell = Worksheets("Data for test").Cells(count25_1 + Column_value, 6)
      Curcell.PasteSpecial xlPasteValues
      Range("Cyl_temp").Offset(i).Copy
      Set Curcell = Worksheets("Data for test").Cells(count25_1 + Column_value, 7)
      Curcell.PasteSpecial xlPasteValues

      'Model 25_M2
      ElseIf Range("Eng_Load").Offset(i) = Range("Eng_Load_25") And
        Range("Running_hr").Offset(i) >= 2001 And Range("Running_hr").Offset(i) <= 3000 Then
        Range("Running_hr").Offset(i).Copy
       count25_2 = Application.WorksheetFunction.Count(Range("H5:H1048576"))
 Set Curcell = Worksheets("Data for test").Cells(count25_2 + Column_value, 8)
 Curcell.PasteSpecial xlPasteValues
 Range("Cyl_temp").Offset(i).Copy
 Set Curcell = Worksheets("Data for test").Cells(count25_2 + Column_value, 9)
 Curcell.PasteSpecial xlPasteValues

'Model 25_M3
ElseIf Range("Eng_Load").Offset(i) = Range("Eng_Load_25") And
  Range("Running_hr").Offset(i) >= 3001 And Range("Running_hr").Offset(i) <= 4000 Then
 Range("Running_hr").Offset(i).Copy
 count25_3 = Application.WorksheetFunction.Count(Range("J5:J1048576"))
 Set Curcell = Worksheets("Data for test").Cells(count25_3 + Column_value, 10)
 Curcell.PasteSpecial xlPasteValues
 Range("Cyl_temp").Offset(i).Copy
 Set Curcell = Worksheets("Data for test").Cells(count25_3 + Column_value, 11)
 Curcell.PasteSpecial xlPasteValues

'Model 25_M4
ElseIf Range("Eng_Load").Offset(i) = Range("Eng_Load_25") And
  Range("Running_hr").Offset(i) >= 4001 And Range("Running_hr").Offset(i) <=  4500
  Then
  Range("Running_hr").Offset(i).Copy
  count25_4 = Application.WorksheetFunction.Count(Range("L5:L1048576"))
  Set Curcell = Worksheets("Data for test").Cells(count25_4 + Column_value, 12)
  Curcell.PasteSpecial xlPasteValues
  Range("Cyl_temp").Offset(i).Copy
  Set Curcell = Worksheets("Data for test").Cells(count25_4 + Column_value, 13)
  Curcell.PasteSpecial xlPasteValues

'Model 25_M5
ElseIf Range("Eng_Load").Offset(i) = Range("Eng_Load_25") And
  Range("Running_hr").Offset(i) >= 4501 And Range("Running_hr").Offset(i) <= 5000 Then
  Range("Running_hr").Offset(i).Copy
  count25_5 = Application.WorksheetFunction.Count(Range("N5:N1048576"))
  Set Curcell = Worksheets("Data for test").Cells(count25_5 + Column_value, 14)
  Curcell.PasteSpecial xlPasteValues
  Range("Cyl_temp").Offset(i).Copy
  Set Curcell = Worksheets("Data for test").Cells(count25_5 + Column_value, 15)
  Curcell.PasteSpecial xlPasteValues

'Model 50_M1
ElseIf Range("Eng_Load").Offset(i) = Range("Eng_Load_50") And
  Range("Running_hr").Offset(i) <= 2000 Then
   Range("Running_hr").Offset(i).Copy
   count50_1 = Application.WorksheetFunction.Count(Range("Q5:Q1048576"))
   Set Curcell = Worksheets("Data for test").Cells(count50_1 + Column_value, 17)
   Curcell.PasteSpecial xlPasteValues
   Range("Cyl_temp").Offset(i).Copy
   Set Curcell = Worksheets("Data for test").Cells(count50_1 + Column_value, 18)
   Curcell.PasteSpecial xlPasteValues

'Model 50_M2
ElseIf Range("Eng_Load").Offset(i) = Range("Eng_Load_50") And
Range("Running_hr").Offset(i) >= 2001 And Range("Running_hr").Offset(i) <= 3000 Then
   Range("Running_hr").Offset(i).Copy
   count50_2 = Application.WorksheetFunction.Count(Range("S5:S1048576"))
   Set Curcell = Worksheets("Data for test").Cells(count50_2 + Column_value, 19)
   Curcell.PasteSpecial xlPasteValues
   Range("Cyl_temp").Offset(i).Copy
   Set Curcell = Worksheets("Data for test").Cells(count50_2 + Column_value, 20)
   Curcell.PasteSpecial xlPasteValues

'Model 50_M3
ElseIf Range("Eng_Load").Offset(i) = Range("Eng_Load_50") And
  Range("Running_hr").Offset(i) >= 3001 And Range("Running_hr").Offset(i) <= 4000 Then
   Range("Running_hr").Offset(i).Copy
   count50_3 = Application.WorksheetFunction.Count(Range("U5:U1048576"))
   Set Curcell = Worksheets("Data for test").Cells(count50_3 + Column_value, 21)
   Curcell.PasteSpecial xlPasteValues
   Range("Cyl_temp").Offset(i).Copy
   Set Curcell = Worksheets("Data for test").Cells(count50_3 + Column_value, 22)
   Curcell.PasteSpecial xlPasteValues

'Model 50_M4
ElseIf Range("Eng_Load").Offset(i) = Range("Eng_Load_50") And
  Range("Running_hr").Offset(i) >= 4001 And Range("Running_hr").Offset(i) <= 4500 Then
   Range("Running_hr").Offset(i).Copy
   count50_4 = Application.WorksheetFunction.Count(Range("W5:W1048576"))
   Set Curcell = Worksheets("Data for test").Cells(count50_4 + Column_value, 23)
   Curcell.PasteSpecial xlPasteValues
   Range("Cyl_temp").Offset(i).Copy
   Set Curcell = Worksheets("Data for test").Cells(count50_4 + Column_value, 24)
   Curcell.PasteSpecial xlPasteValues

'Model 50_M5
 ElseIf Range("Eng_Load").Offset(i) = Range("Eng_Load_50") And
  Range("Running_hr").Offset(i) >= 4501 And Range("Running_hr").Offset(i) <= 5000 Then
   Range("Running_hr").Offset(i).Copy
   count50_5 = Application.WorksheetFunction.Count(Range("Y5:Y1048576"))
   Set Curcell = Worksheets("Data for test").Cells(count50_5 + Column_value, 25)
   Curcell.PasteSpecial xlPasteValues
   Range("Cyl_temp").Offset(i).Copy
   Set Curcell = Worksheets("Data for test").Cells(count50_5 + Column_value, 26)
   Curcell.PasteSpecial xlPasteValues

'Model 75_M1
ElseIf Range("Eng_Load").Offset(i) = Range("Eng_Load_75") And
  Range("Running_hr").Offset(i) <= 2000 Then
   Range("Running_hr").Offset(i).Copy
   count75_1 = Application.WorksheetFunction.Count(Range("AB5:AB1048576"))
   Set Curcell = Worksheets("Data for test").Cells(count75_1 + Column_value, 28)
   Curcell.PasteSpecial xlPasteValues
   Range("Cyl_temp").Offset(i).Copy
   Set Curcell = Worksheets("Data for test").Cells(count75_1 + Column_value, 29)
   Curcell.PasteSpecial xlPasteValues

'Model 75_M2
ElseIf Range("Eng_Load").Offset(i) = Range("Eng_Load_75") And
  Range("Running_hr").Offset(i) >= 2001 And Range("Running_hr").Offset(i) <= 3000 Then
   Range("Running_hr").Offset(i).Copy
```

```
    count75_2 = Application.WorksheetFunction.Count(Range("AD5:AD1048576"))
    Set Curcell = Worksheets("Data for test").Cells(count75_2 + Column_value, 30)
    Curcell.PasteSpecial xlPasteValues
    Range("Cyl_temp").Offset(i).Copy
    Set Curcell = Worksheets("Data for test").Cells(count75_2 + Column_value, 31)
    Curcell.PasteSpecial xlPasteValues

'Model 75_M3
ElseIf Range("Eng_Load").Offset(i) = Range("Eng_Load_75") And
   Range("Running_hr").Offset(i) >= 3001 And Range("Running_hr").Offset(i) <= 4000 Then
    Range("Running_hr").Offset(i).Copy
    count75_3 = Application.WorksheetFunction.Count(Range("AF5:AF1048576"))
    Set Curcell = Worksheets("Data for test").Cells(count75_3 + Column_value, 32)
    Curcell.PasteSpecial xlPasteValues
    Range("Cyl_temp").Offset(i).Copy
    Set Curcell = Worksheets("Data for test").Cells(count75_3 + Column_value, 33)
    Curcell.PasteSpecial xlPasteValues

'Model 75_M4
ElseIf Range("Eng_Load").Offset(i) = Range("Eng_Load_75") And
   Range("Running_hr").Offset(i) >= 4001 And Range("Running_hr").Offset(i) <= 4500 Then
    Range("Running_hr").Offset(i).Copy
    count75_4 = Application.WorksheetFunction.Count(Range("AH5:AH1048576"))
    Set Curcell = Worksheets("Data for test").Cells(count75_4 + Column_value, 34)
    Curcell.PasteSpecial xlPasteValues
    Range("Cyl_temp").Offset(i).Copy
    Set Curcell = Worksheets("Data for test").Cells(count75_4 + Column_value, 35)
    Curcell.PasteSpecial xlPasteValues

'Model 75_M5
ElseIf Range("Eng_Load").Offset(i) = Range("Eng_Load_75") And
   Range("Running_hr").Offset(i) >= 4501 And Range("Running_hr").Offset(i) <= 5000 Then
    Range("Running_hr").Offset(i).Copy
    count75_5 = Application.WorksheetFunction.Count(Range("AJ5:AJ1048576"))
    Set Curcell = Worksheets("Data for test").Cells(count75_5 + Column_value, 36)
    Curcell.PasteSpecial xlPasteValues
    Range("Cyl_temp").Offset(i).Copy
    Set Curcell = Worksheets("Data for test").Cells(count75_5 + Column_value, 37)
    Curcell.PasteSpecial xlPasteValues

'Model 85_M1
ElseIf Range("Eng_Load").Offset(i) = Range("Eng_Load_85") And
   Range("Running_hr").Offset(i) <= 2000 Then
    Range("Running_hr").Offset(i).Copy
    count85_1 = Application.WorksheetFunction.Count(Range("AM5:AM1048576"))
    Set Curcell = Worksheets("Data for test").Cells(count85_1 + Column_value, 39)
    Curcell.PasteSpecial xlPasteValues
    Range("Cyl_temp").Offset(i).Copy
    Set Curcell = Worksheets("Data for test").Cells(count85_1 + Column_value, 40)
    Curcell.PasteSpecial xlPasteValues

 'Model 85_M2
 ElseIf Range("Eng_Load").Offset(i) = Range("Eng_Load_85") And
   Range("Running_hr").Offset(i) >= 2001 And Range("Running_hr").Offset(i) <= 3000 Then
    Range("Running_hr").Offset(i).Copy
    count85_2 = Application.WorksheetFunction.Count(Range("AO5:AO1048576"))
    Set Curcell = Worksheets("Data for test").Cells(count85_2 + Column_value, 41)
    Curcell.PasteSpecial xlPasteValues
    Range("Cyl_temp").Offset(i).Copy
    Set Curcell = Worksheets("Data for test").Cells(count85_2 + Column_value, 42)
    Curcell.PasteSpecial xlPasteValues

 'Model 85_M3
ElseIf Range("Eng_Load").Offset(i) = Range("Eng_Load_85") And
   Range("Running_hr").Offset(i) >= 3001 And Range("Running_hr").Offset(i) <= 4000 Then
    Range("Running_hr").Offset(i).Copy
    count85_3 = Application.WorksheetFunction.Count(Range("AQ5:AQ1048576"))
    Set Curcell = Worksheets("Data for test").Cells(count85_3 + Column_value, 43)
    Curcell.PasteSpecial xlPasteValues
    Range("Cyl_temp").Offset(i).Copy
    Set Curcell = Worksheets("Data for test").Cells(count85_3 + Column_value, 44)
    Curcell.PasteSpecial xlPasteValues

 'Model 85_M4
ElseIf Range("Eng_Load").Offset(i) = Range("Eng_Load_85") And
   Range("Running_hr").Offset(i) >= 4001 And Range("Running_hr").Offset(i) <= 4500 Then
    Range("Running_hr").Offset(i).Copy
    count85_4 = Application.WorksheetFunction.Count(Range("AS5:AS1048576"))
    Set Curcell = Worksheets("Data for test").Cells(count85_4 + Column_value, 45)
    Curcell.PasteSpecial xlPasteValues
    Range("Cyl_temp").Offset(i).Copy
    Set Curcell = Worksheets("Data for test").Cells(count85_4 + Column_value, 46)
    Curcell.PasteSpecial xlPasteValues

 'Model 85_M5
ElseIf Range("Eng_Load").Offset(i) = Range("Eng_Load_85") And
   Range("Running_hr").Offset(i) >= 4501 And Range("Running_hr").Offset(i) <= 5000 Then
    Range("Running_hr").Offset(i).Copy
    count85_5 = Application.WorksheetFunction.Count(Range("AU5:AU1048576"))
    Set Curcell = Worksheets("Data for test").Cells(count85_5 + Column_value, 47)
    Curcell.PasteSpecial xlPasteValues
    Range("Cyl_temp").Offset(i).Copy
    Set Curcell = Worksheets("Data for test").Cells(count85_5 + Column_value, 48)
    Curcell.PasteSpecial xlPasteValues

 'Model 90_M1
ElseIf Range("Eng_Load").Offset(i) = Range("Eng_Load_90") And
   Range("Running_hr").Offset(i) <= 2000 Then
    Range("Running_hr").Offset(i).Copy
    count90_1 = Application.WorksheetFunction.Count(Range("AX5:AX1048576"))
    Set Curcell = Worksheets("Data for test").Cells(count90_1 + Column_value, 50)
    Curcell.PasteSpecial xlPasteValues
    Range("Cyl_temp").Offset(i).Copy
    Set Curcell = Worksheets("Data for test").Cells(count90_1 + Column_value, 51)
    Curcell.PasteSpecial xlPasteValues

 'Model 90_M2
ElseIf Range("Eng_Load").Offset(i) = Range("Eng_Load_90") And
   Range("Running_hr").Offset(i) >= 2001 And Range("Running_hr").Offset(i) <= 3000 Then
    Range("Running_hr").Offset(i).Copy
    count90_2 = Application.WorksheetFunction.Count(Range("AZ5:AZ1048576"))
    Set Curcell = Worksheets("Data for test").Cells(count90_2 + Column_value, 52)
    Curcell.PasteSpecial xlPasteValues
    Range("Cyl_temp").Offset(i).Copy
    Set Curcell = Worksheets("Data for test").Cells(count90_2 + Column_value, 53)
    Curcell.PasteSpecial xlPasteValues

 'Model 90_M3
ElseIf Range("Eng_Load").Offset(i) = Range("Eng_Load_90") And
   Range("Running_hr").Offset(i) >= 3001 And Range("Running_hr").Offset(i) <= 4000 Then
    Range("Running_hr").Offset(i).Copy
    count90_3 = Application.WorksheetFunction.Count(Range("BB5:BB1048576"))
    Set Curcell = Worksheets("Data for test").Cells(count90_3 + Column_value, 54)
    Curcell.PasteSpecial xlPasteValues
    Range("Cyl_temp").Offset(i).Copy
    Set Curcell = Worksheets("Data for test").Cells(count90_3 + Column_value, 55)
    Curcell.PasteSpecial xlPasteValues

 'Model 90_M4
ElseIf Range("Eng_Load").Offset(i) = Range("Eng_Load_90") And
   Range("Running_hr").Offset(i) >= 4001 And Range("Running_hr").Offset(i) <= 4500 Then
    Range("Running_hr").Offset(i).Copy
    count90_4 = Application.WorksheetFunction.Count(Range("BD5:BD1048576"))
    Set Curcell = Worksheets("Data for test").Cells(count90_4 + Column_value, 56)
    Curcell.PasteSpecial xlPasteValues
    Range("Cyl_temp").Offset(i).Copy
    Set Curcell = Worksheets("Data for test").Cells(count90_4 + Column_value, 57)
    Curcell.PasteSpecial xlPasteValues

 'Model 90_M5
ElseIf Range("Eng_Load").Offset(i) = Range("Eng_Load_90") And
   Range("Running_hr").Offset(i) >= 4501 And Range("Running_hr").Offset(i) <= 5000 Then
    Range("Running_hr").Offset(i).Copy
    count90_5 = Application.WorksheetFunction.Count(Range("BF5:BF1048576"))
    Set Curcell = Worksheets("Data for test").Cells(count90_5 + Column_value, 58)
    Curcell.PasteSpecial xlPasteValues
    Range("Cyl_temp").Offset(i).Copy
    Set Curcell = Worksheets("Data for test").Cells(count90_5 + Column_value, 59)
    Curcell.PasteSpecial xlPasteValues

'Model 100_M1
ElseIf Range("Eng_Load").Offset(i) = Range("Eng_Load_100") And
   Range("Running_hr").Offset(i) <= 2000 Then
    Range("Running_hr").Offset(i).Copy
    count100_1 = Application.WorksheetFunction.Count(Range("BI5:BI1048576"))
    Set Curcell = Worksheets("Data for test").Cells(count100_1 + Column_value, 61)
    Curcell.PasteSpecial xlPasteValues
    Range("Cyl_temp").Offset(i).Copy
    Set Curcell = Worksheets("Data for test").Cells(count100_1 + Column_value, 62)
    Curcell.PasteSpecial xlPasteValues

    'Model 100_M2
    ElseIf Range("Eng_Load").Offset(i) = Range("Eng_Load_100") And
   Range("Running_hr").Offset(i) >= 2001 And Range("Running_hr").Offset(i) <= 3000 Then
    Range("Running_hr").Offset(i).Copy
```

```
      count100_2 = Application.WorksheetFunction.Count(Range("BK5:BK1048576"))
      Set Curcell = Worksheets("Data for test").Cells(count100_2 + Column_value, 63)
      Curcell.PasteSpecial xlPasteValues
      Range("Cyl_temp").Offset(i).Copy
      Set Curcell = Worksheets("Data for test").Cells(count100_2 + Column_value, 64)
      Curcell.PasteSpecial xlPasteValues

      'Model 100_M3
      ElseIf Range("Eng_Load").Offset(i) = Range("Eng_Load_100") And
     Range("Running_hr").Offset(i) >= 3001 And Range("Running_hr").Offset(i) <= 4000 Then
      Range("Running_hr").Offset(i).Copy
      count100_3 = Application.WorksheetFunction.Count(Range("BM5:BM1048576"))
      Set Curcell = Worksheets("Data for test").Cells(count100_3 + Column_value, 65)
      Curcell.PasteSpecial xlPasteValues
      Range("Cyl_temp").Offset(i).Copy
      Set Curcell = Worksheets("Data for test").Cells(count100_3 + Column_value, 66)
      Curcell.PasteSpecial xlPasteValues

      'Model 100_M4
      ElseIf Range("Eng_Load").Offset(i) = Range("Eng_Load_100") And
     Range("Running_hr").Offset(i) >= 4001 And Range("Running_hr").Offset(i) <= 4500 Then
      Range("Running_hr").Offset(i).Copy
      count100_4 = Application.WorksheetFunction.Count(Range("BO5:BO1048576"))
      Set Curcell = Worksheets("Data for test").Cells(count100_4 + Column_value, 67)
      Curcell.PasteSpecial xlPasteValues
      Range("Cyl_temp").Offset(i).Copy
      Set Curcell = Worksheets("Data for test").Cells(count100_4 + Column_value, 68)
      Curcell.PasteSpecial xlPasteValues

      'Model 100_M5
     ElseIf Range("Eng_Load").Offset(i) = Range("Eng_Load_100") And
     Range("Running_hr").Offset(i) >= 4501 And Range("Running_hr").Offset(i) <= 5000 Then
      Range("Running_hr").Offset(i).Copy
      count100_5 = Application.WorksheetFunction.Count(Range("BQ5:BQ1048576"))
      Set Curcell = Worksheets("Data for test").Cells(count100_5 + Column_value, 69)
      Curcell.PasteSpecial xlPasteValues
      Range("Cyl_temp").Offset(i).Copy
      Set Curcell = Worksheets("Data for test").Cells(count100_5 + Column_value, 70)
      Curcell.PasteSpecial xlPasteValues

    'If the data does not belongs to any of the category, ignore and move to the next data.
    ElseIf Range("Eng_Load").Offset(i) <> Range("Eng_Load_25") Or Range("Eng_Load_50")
    Or Range("Eng_Load_75") Or Range("Eng_Load_85") Or Range("Eng_Load_90") Or
    Range("Eng_Load_100") Then
      Range("Eng_Load").Offset(i) = Range("Eng_Load").Offset(i + 1)
    End If
  Next i
End Sub

Sub Analyze_Data()
'Note: For the program to run properly, both solver and Data Analysis Toolpak need to be enabled
under ‘Tools ->References-> Solver and atpvbaen.xls. This must be added in Excel also under
Options-> Add-‘Ins-> Analysis ToolPak, Analysis ToolPak-VBA, Solver Add-In
'Calling initialize sub-routine
Initialize
```

```
'Declaration of variable
Dim count_result As Integer
Dim arg1 As Integer, arg3 As Integer
Dim LookRange As Range
Dim arg4 As Boolean

'Copying original data (Running hours, Engine Load and Cylinder Temperature)from
'"Data for test" worksheet to "Result for test" worksheet.
    Worksheets("Data for test").Activate
     ActiveSheet.Range("Running_hr:" &
     ActiveSheet.Range("Cyl_temp").End(xlDown).Address).Offset(1).Select
    Selection.Copy
    Worksheets("Result for test").Activate
    count_result = Application.WorksheetFunction.Count(Range("A5:A1048576"))
    Set Curcell = Worksheets("Result for test").Cells(count_result + 5, 1)
    Curcell.PasteSpecial xlPasteValues
    Worksheets("Data for test").Activate

'Using Vlookup to determine which predictive model to run by comparing with the table shown in
"Data for test"
'worksheet cell (BT25:BY30)
    Set LookRange = Sheets("Data for test").Range("$BT$25:$BY$30")
    arg4 = False

    'Run Model 25M1
    If Application.VLookup(25, LookRange, 2, arg4) = 1 Then
       Model_25M1
    End If
     'Run Model 25M2
    If Application.VLookup(25, LookRange, 3, arg4) = 1 Then
       Model_25M2
    End If
     'Run Model 25M3
    If Application.VLookup(25, LookRange, 4, arg4) = 1 Then
       Model_25M3
    End If
     'Run Model 25M4
    If Application.VLookup(25, LookRange, 5, arg4) = 1 Then
       Model_25M4
    End If
     'Run Model 25M5
    If Application.VLookup(25, LookRange, 6, arg4) = 1 Then
       Model_25M5
    End If
     'Run Model 50M1
    If Application.VLookup(50, LookRange, 2, arg4) = 1 Then
       Model_50M1
    End If
    'Run Model 50M2
    If Application.VLookup(50, LookRange, 3, arg4) = 1 Then
       Model_50M2
    End If
    'Run Model 50M3
    If Application.VLookup(50, LookRange, 4, arg4) = 1 Then
       Model_50M3
```

```
End If
'Run Model 50M4
If Application.VLookup(50, LookRange, 5, arg4) = 1 Then
   Model_50M4
End If
'Run Model 50M5
If Application.VLookup(50, LookRange, 6, arg4) = 1 Then
   Model_50M5
End If
'Run Model 75M1
If Application.VLookup(75, LookRange, 2, arg4) = 1 Then
   Model_75M1
End If
'Run Model 75M2
If Application.VLookup(75, LookRange, 3, arg4) = 1 Then
   Model_75M2
End If
'Run Model 75M3
If Application.VLookup(75, LookRange, 4, arg4) = 1 Then
     Model_75M3
End If
'Run Model 75M4
If Application.VLookup(75, LookRange, 5, arg4) = 1 Then
   Model_75M4
End If
'Run Model 75M5
If Application.VLookup(75, LookRange, 6, arg4) = 1 Then
   Model_75M5
End If
'Run Model 85M1
If Application.VLookup(85, LookRange, 2, arg4) = 1 Then
   Model_85M1
End If
'Run Model 85M2
If Application.VLookup(85, LookRange, 3, arg4) = 1 Then
   Model_85M2
End If
'Run Model 85M3
If Application.VLookup(85, LookRange, 4, arg4) = 1 Then
   Model_85M3
End If
'Run Model 85M4
If Application.VLookup(85, LookRange, 5, arg4) = 1 Then
   Model_85M4
End If
'Run Model 85M5
If Application.VLookup(85, LookRange, 6, arg4) = 1 Then
   Model_85M5
End If
'Run Model 90M1
If Application.VLookup(90, LookRange, 2, arg4) = 1 Then
   Model_90M1
End If
'Run Model 90M2
If Application.VLookup(90, LookRange, 3, arg4) = 1 Then
```

```
      Model_90M2
    End If
    'Run Model 90M3
    If Application.VLookup(90, LookRange, 4, arg4) = 1 Then
      Model_90M3
    End If
    'Run Model 90M4
    If Application.VLookup(90, LookRange, 5, arg4) = 1 Then
      Model_90M4
    End If
    'Run Model 90M5
    If Application.VLookup(90, LookRange, 6, arg4) = 1 Then
      Model_90M5
    End If
    'Run Model 100M1
    If Application.VLookup(100, LookRange, 2, arg4) = 1 Then
      Model_100M1
    End If
    'Run Model 100M2
    If Application.VLookup(100, LookRange, 3, arg4) = 1 Then
       Model_100M2
    End If
    'Run Model 100M3
    If Application.VLookup(100, LookRange, 4, arg4) = 1 Then
      Model_100M3
    End If
    'Run Model 100M4
    If Application.VLookup(100, LookRange, 5, arg4) = 1 Then
      Model_100M4
    End If
    'Run Model 100M5
    If Application.VLookup(100, LookRange, 6, arg4) = 1 Then
      Model_100M5
    End If
    'Show worksheet "Result for test"
    Worksheets("Result for test").Activate
    'Call up Data Analysis Toolpak descriptive statistics
    Application.Run "ATPVBAEN.XLAM!Descr", ActiveSheet.Range("$E$4:$E$1048576" _
    ), ActiveSheet.Range("$H$5"), "C", True, True, , , 95

End Sub

Sub Initialize()
'Deleting past records from all the individual predictive model worksheet before performing any
‘analysis.
'Data that are cleared belongs to the following header:
'Running hours, Cylinder temperature, Forecast, Trend, Actual Forecast, Actual Data, Error
    Worksheets("25_M1").Activate
    Range("B4:B1048576").Select
    Selection.Clear
    Range("C4:C1048576").Select
    Selection.Clear
    Range("D4:D1048576").Select
    Selection.Clear
    Range("E4:E1048576").Select
```

```
Selection.Clear
Range("F4:F1048576").Select
Selection.Clear
Range("G4:G1048576").Select
Selection.Clear
Range("H4:H1048576").Select
Selection.Clear
Range("K1:L18").Select
Selection.Clear

Worksheets("25_M2").Activate
Range("B4:B1048576").Select
Selection.Clear
Range("C4:C1048576").Select
Selection.Clear
Range("D4:D1048576").Select
Selection.Clear
Range("E4:E1048576").Select
Selection.Clear
Range("F4:F1048576").Select
Selection.Clear
Range("G4:G1048576").Select
Selection.Clear
Range("H4:H1048576").Select
Selection.Clear
Range("K1:L18").Select
Selection.Clear

Worksheets("25_M3").Activate
Range("B4:B1048576").Select
Selection.Clear
Range("C4:C1048576").Select
Selection.Clear
Range("D4:D1048576").Select
Selection.Clear
Range("E4:E1048576").Select
Selection.Clear
Range("F4:F1048576").Select
Selection.Clear
Range("G4:G1048576").Select
Selection.Clear
Range("H4:H1048576").Select
Selection.Clear
Range("K1:L18").Select
Selection.Clear

Worksheets("25_M4").Activate
Range("B4:B1048576").Select
Selection.Clear
Range("C4:C1048576").Select
Selection.Clear
Range("D4:D1048576").Select
Selection.Clear
Range("E4:E1048576").Select
Selection.Clear
```

```
Range("F4:F1048576").Select
Selection.Clear
Range("G4:G1048576").Select
Selection.Clear
Range("H4:H1048576").Select
Selection.Clear
Range("K1:L18").Select
Selection.Clear

Worksheets("25_M5").Activate
Range("B4:B1048576").Select
Selection.Clear
Range("C4:C1048576").Select
Selection.Clear
Range("D4:D1048576").Select
Selection.Clear
Range("E4:E1048576").Select
Selection.Clear
Range("F4:F1048576").Select
Selection.Clear
Range("G4:G1048576").Select
Selection.Clear
Range("H4:G1048576").Select
Selection.Clear
Range("I4:H1048576").Select
Selection.Clear
Range("K1:L18").Select
Selection.Clear

Worksheets("50_M1").Activate
Range("B4:B1048576").Select
Selection.Clear
Range("C4:C1048576").Select
Selection.Clear
Range("D4:D1048576").Select
Selection.Clear
Range("E4:E1048576").Select
Selection.Clear
Range("F4:F1048576").Select
Selection.Clear
Range("G4:G1048576").Select
Selection.Clear
Range("H4:H1048576").Select
Selection.Clear
Range("K1:L18").Select
Selection.Clear

Worksheets("50_M2").Activate
Range("B4:B1048576").Select
Selection.Clear
Range("C4:C1048576").Select
Selection.Clear
Range("D4:D1048576").Select
Selection.Clear
Range("E4:E1048576").Select
```

```
Selection.Clear
Range("F4:F1048576").Select
Selection.Clear
Range("G4:G1048576").Select
Selection.Clear
Range("H4:H1048576").Select
Selection.Clear
Range("K1:L18").Select
Selection.Clear

Worksheets("50_M3").Activate
Range("B4:B1048576").Select
Selection.Clear
Range("C4:C1048576").Select
Selection.Clear
Range("D4:D1048576").Select
Selection.Clear
Range("E4:E1048576").Select
Selection.Clear
Range("F4:F1048576").Select
Selection.Clear
Range("G4:G1048576").Select
Selection.Clear
Range("H4:H1048576").Select
Selection.Clear
Range("K1:L18").Select
Selection.Clear
Worksheets("50_M4").Activate
Range("B4:B1048576").Select
Selection.Clear
Range("C4:C1048576").Select
Selection.Clear
Range("D4:D1048576").Select
Selection.Clear
Range("E4:E1048576").Select
Selection.Clear
Range("F4:F1048576").Select
Selection.Clear
Range("G4:G1048576").Select
Selection.Clear
Range("H4:H1048576").Select
Selection.Clear
Range("K1:L18").Select
Selection.Clear

Worksheets("50_M5").Activate
Range("B4:B1048576").Select
Selection.Clear
Range("C4:C1048576").Select
Selection.Clear
Range("D4:D1048576").Select
Selection.Clear
Range("E4:E1048576").Select
Selection.Clear
Range("F4:F1048576").Select
```

```
Selection.Clear
Range("G4:G1048576").Select
Selection.Clear
Range("H4:G1048576").Select
Selection.Clear
Range("I4:H1048576").Select
Selection.Clear
Range("K1:L18").Select
Selection.Clear

Worksheets("75_M1").Activate
Range("B4:B1048576").Select
Selection.Clear
Range("C4:C1048576").Select
Selection.Clear
Range("D4:D1048576").Select
Selection.Clear
Range("E4:E1048576").Select
Selection.Clear
Range("F4:F1048576").Select
Selection.Clear
Range("G4:G1048576").Select
Selection.Clear
Range("H4:H1048576").Select
Selection.Clear
Range("K1:L18").Select
Selection.Clear

Worksheets("75_M2").Activate
Range("B4:B1048576").Select
Selection.Clear
Range("C4:C1048576").Select
Selection.Clear
Range("D4:D1048576").Select
Selection.Clear
Range("E4:E1048576").Select
Selection.Clear
Range("F4:F1048576").Select
Selection.Clear
Range("G4:G1048576").Select
Selection.Clear
Range("H4:H1048576").Select
Selection.Clear
Range("K1:L18").Select
Selection.Clear

Worksheets("75_M3").Activate
Range("B4:B1048576").Select
Selection.Clear
Range("C4:C1048576").Select
Selection.Clear
Range("D4:D1048576").Select
Selection.Clear
Range("E4:E1048576").Select
Selection.Clear
```

```
Range("F4:F1048576").Select
Selection.Clear
Range("G4:G1048576").Select
Selection.Clear
Range("H4:H1048576").Select
Selection.Clear
Range("K1:L18").Select
Selection.Clear

Worksheets("75_M4").Activate
Range("B4:B1048576").Select
Selection.Clear
Range("C4:C1048576").Select
Selection.Clear
Range("D4:D1048576").Select
Selection.Clear
Range("E4:E1048576").Select
Selection.Clear
Range("F4:F1048576").Select
Selection.Clear
Range("G4:G1048576").Select
Selection.Clear
Range("H4:H1048576").Select
Selection.Clear
Range("K1:L18").Select
Selection.Clear

Worksheets("75_M5").Activate
Range("B4:B1048576").Select
Selection.Clear
Range("C4:C1048576").Select
Selection.Clear
Range("D4:D1048576").Select
Selection.Clear
Range("E4:E1048576").Select
Selection.Clear
Range("F4:F1048576").Select
Selection.Clear
Range("G4:G1048576").Select
Selection.Clear
Range("H4:G1048576").Select
Selection.Clear
Range("I4:H1048576").Select
Selection.Clear
Range("K1:L18").Select
Selection.Clear

Worksheets("85_M1").Activate
Range("B4:B1048576").Select
Selection.Clear
Range("C4:C1048576").Select
Selection.Clear
Range("D4:D1048576").Select
Selection.Clear
Range("E4:E1048576").Select
```

```
Selection.Clear
Range("F4:F1048576").Select
Selection.Clear
Range("G4:G1048576").Select
Selection.Clear
Range("H4:H1048576").Select
Selection.Clear
Range("K1:L18").Select
Selection.Clear

Worksheets("85_M2").Activate
Range("B4:B1048576").Select
Selection.Clear
Range("C4:C1048576").Select
Selection.Clear
Range("D4:D1048576").Select
Selection.Clear
Range("E4:E1048576").Select
Selection.Clear
Range("F4:F1048576").Select
Selection.Clear
Range("G4:G1048576").Select
Selection.Clear
Range("H4:H1048576").Select
Selection.Clear
Range("K1:L18").Select
Selection.Clear

Worksheets("85_M3").Activate
Range("B4:B1048576").Select
Selection.Clear
Range("C4:C1048576").Select
Selection.Clear
Range("D4:D1048576").Select
Selection.Clear
Range("E4:E1048576").Select
Selection.Clear
Range("F4:F1048576").Select
Selection.Clear
Range("G4:G1048576").Select
Selection.Clear
Range("H4:H1048576").Select
Selection.Clear
Range("K1:L18").Select
Selection.Clear

Worksheets("85_M4").Activate
Range("B4:B1048576").Select
Selection.Clear
Range("C4:C1048576").Select
Selection.Clear
Range("D4:D1048576").Select
Selection.Clear
Range("E4:E1048576").Select
Selection.Clear
```

```
Range("F4:F1048576").Select
Selection.Clear
Range("G4:G1048576").Select
Selection.Clear
Range("H4:H1048576").Select
Selection.Clear
Range("K1:L18").Select
Selection.Clear

Worksheets("85_M5").Activate
Range("B4:B1048576").Select
Selection.Clear
Range("C4:C1048576").Select
Selection.Clear
Range("D4:D1048576").Select
Selection.Clear
Range("E4:E1048576").Select
Selection.Clear
Range("F4:F1048576").Select
Selection.Clear
Range("G4:G1048576").Select
Selection.Clear
Range("H4:G1048576").Select
Selection.Clear
Range("I4:H1048576").Select
Selection.Clear
Range("K1:L18").Select
Selection.Clear

Worksheets("90_M1").Activate
Range("B4:B1048576").Select
Selection.Clear
Range("C4:C1048576").Select
Selection.Clear
Range("D4:D1048576").Select
Selection.Clear
Range("E4:E1048576").Select
Selection.Clear
Range("F4:F1048576").Select
Selection.Clear
Range("G4:G1048576").Select
Selection.Clear
Range("H4:H1048576").Select
Selection.Clear
Range("K1:L18").Select
Selection.Clear

Worksheets("90_M2").Activate
Range("B4:B1048576").Select
Selection.Clear
Range("C4:C1048576").Select
Selection.Clear
Range("D4:D1048576").Select
Selection.Clear
Range("E4:E1048576").Select
```

```
Selection.Clear
Range("F4:F1048576").Select
Selection.Clear
Range("G4:G1048576").Select
Selection.Clear
Range("H4:H1048576").Select
Selection.Clear
Range("K1:L18").Select
Selection.Clear

Worksheets("90_M3").Activate
Range("B4:B1048576").Select
Selection.Clear
Range("C4:C1048576").Select
Selection.Clear
Range("D4:D1048576").Select
Selection.Clear
Range("E4:E1048576").Select
Selection.Clear
Range("F4:F1048576").Select
Selection.Clear
Range("G4:G1048576").Select
Selection.Clear
Range("H4:H1048576").Select
Selection.Clear
Range("K1:L18").Select
Selection.Clear

Worksheets("90_M4").Activate
Range("B4:B1048576").Select
Selection.Clear
Range("C4:C1048576").Select
Selection.Clear
Range("D4:D1048576").Select
Selection.Clear
Range("E4:E1048576").Select
Selection.Clear
Range("F4:F1048576").Select
Selection.Clear
Range("G4:G1048576").Select
Selection.Clear
Range("H4:H1048576").Select
Selection.Clear
Range("K1:L18").Select
Selection.Clear

Worksheets("90_M5").Activate
Range("B4:B1048576").Select
Selection.Clear
Range("C4:C1048576").Select
Selection.Clear
Range("D4:D1048576").Select
Selection.Clear
Range("E4:E1048576").Select
Selection.Clear
```

```
Range("F4:F1048576").Select
Selection.Clear
Range("G4:G1048576").Select
Selection.Clear
Range("H4:G1048576").Select
Selection.Clear
Range("I4:H1048576").Select
Selection.Clear
Range("K1:L18").Select
Selection.Clear

Worksheets("100_M1").Activate
Range("B4:B1048576").Select
Selection.Clear
Range("C4:C1048576").Select
Selection.Clear
Range("D4:D1048576").Select
Selection.Clear
Range("E4:E1048576").Select
Selection.Clear
Range("F4:F1048576").Select
Selection.Clear
Range("G4:G1048576").Select
Selection.Clear
Range("H4:H1048576").Select
Selection.Clear
Range("K1:L18").Select
Selection.Clear

Worksheets("100_M2").Activate
Range("B4:B1048576").Select
Selection.Clear
Range("C4:C1048576").Select
Selection.Clear
Range("D4:D1048576").Select
Selection.Clear
Range("E4:E1048576").Select
Selection.Clear
Range("F4:F1048576").Select
Selection.Clear
Range("G4:G1048576").Select
Selection.Clear
Range("H4:H1048576").Select
Selection.Clear
Range("K1:L18").Select
Selection.Clear

Worksheets("100_M3").Activate
Range("B4:B1048576").Select
Selection.Clear
Range("C4:C1048576").Select
Selection.Clear
Range("D4:D1048576").Select
Selection.Clear
Range("E4:E1048576").Select
```

```
    Selection.Clear
    Range("F4:F1048576").Select
    Selection.Clear
    Range("G4:G1048576").Select
    Selection.Clear
    Range("H4:H1048576").Select
    Selection.Clear
    Range("K1:L18").Select
    Selection.Clear

    Worksheets("100_M4").Activate
    Range("B4:B1048576").Select
    Selection.Clear
    Range("C4:C1048576").Select
    Selection.Clear
    Range("D4:D1048576").Select
    Selection.Clear
    Range("E4:E1048576").Select
    Selection.Clear
    Range("F4:F1048576").Select
    Selection.Clear
    Range("G4:G1048576").Select
    Selection.Clear
    Range("H4:H1048576").Select
    Selection.Clear
    Range("K1:L18").Select
    Selection.Clear

    Worksheets("100_M5").Activate
    Range("B4:B1048576").Select
    Selection.Clear
    Range("C4:C1048576").Select
    Selection.Clear
    Range("D4:D1048576").Select
    Selection.Clear
    Range("E4:E1048576").Select
    Selection.Clear
    Range("F4:F1048576").Select
    Selection.Clear
    Range("G4:G1048576").Select
    Selection.Clear
    Range("H4:G1048576").Select
    Selection.Clear
    Range("I4:H1048576").Select
    Selection.Clear
    Range("K1:L18").Select
    Selection.Clear

'Deleting past records from the Result for test worksheet before performing any analysis.
'Data that are cleared belongs to the following header:
'Running hours, Engine Load, Actual EGT, Actual Forecast, Error
    Worksheets("Result for test").Activate
    Range("A5:A1048576").Select
    Selection.Clear
    Worksheets("Result for test").Activate
    Range("B5:B1048576").Select
    Selection.Clear
    Worksheets("Result for test").Activate
    Range("C5:C1048576").Select
    Selection.Clear
    Worksheets("Result for test").Activate
    Range("D5:D1048576").Select
    Selection.Clear
    Worksheets("Result for test").Activate
    Range("H1:I21").Select
    Selection.Clear

End Sub

Sub Model_25M1()
'Model_25M1 is the predictive model for 25% Main Engine Load with running hours from 1-
‘2000.
'Declaration of variables
Dim count25_M1 As Integer
Dim count_result As Integer
Dim Column_value As Integer
Dim count_pos As Integer
Dim arg1 As Integer, arg3 As Integer
Dim LookRange As Range
Dim arg4 As Boolean
'Column value is used to control cell position for data to be input or extract
Column_value = 4

    'Copy original data from "Data for test" worksheet to "25_M1" worksheet for model analysis.
    Worksheets("Data for test").Activate
    ActiveSheet.Range("Run_25M1:" &
    ActiveSheet.Range("Temp_25M1").End(xlDown).Address).Offset(1).Select
    Selection.Copy
    Worksheets("25_M1").Activate
    count25_M1 = Application.WorksheetFunction.Count(Range("B4:B1048576"))
    Set Curcell = Worksheets("25_M1").Cells(count25_M1 + Column_value, 2)
    Curcell.PasteSpecial xlPasteValues

    'Set the first forecast value to be the same as the first cylinder temperature value.
    Range("Forecast").Offset(1).Formula = "=C4"
    'Set the trend to be zero since there is no previous data for trend.
    Range("Trend").Offset(1) = 0
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF").Offset(1).Formula = "=D4+E4"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD").Offset(1).Formula = "=C4"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error").Offset(1).Formula = "=G4-F4"

    'count_data1 is used to control cell position for data to be input or extract
    count_data1 = Range("count25M1_80").Value - 1
    'The Forecast is the result of Alpha*past cylinder temp + (1-Alpha)*Actual Forecast
    Range("Forecast").Offset(2).Formula = "= $I$1 * C4 + (1 -$I$1 ) * F4"
    'The trend is the result of Beta * Difference of past forecast + (1-Beta)*Previous Trend
    Range("Trend").Offset(2).Formula = "=$I$2 * (D5-D4)+ (1 - $I$2) * E4"
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF").Offset(2).Formula = "= D5 + E5"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD").Offset(2).Formula = "=C5"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error").Offset(2).Formula = "= G5 -F5"
    'Counting the position of the last data cell
    LR = Range("count25M1").Value + 3
    'Copy the formula from 2nd row of the cells which contains data to end of the data.
    Range("D5:H5").AutoFill Destination:=Range("D5:H" & LR)

    'This set of data is used for validation purpose. It will highlight the cell in yellow.
    'It copy the previous Actual Forcast value to the new forecast cell. This will repeat till end of
    ‘data and
    'then used to validate the goodness of fit for the model.
    Range("Forecast").Offset(count_data1 + 2).Value = "=F" & (count_data1 + 4)
    Range("Forecast").Offset(count_data1 + 2).Interior.Color = RGB(255, 255, 51)
    Range("Forecast").Offset(count_data1 + 2).Select
    ActiveCell.AutoFill Destination:=Range(ActiveCell.Offset(0, -1), ActiveCell.Offset(0, -
    1).End(xlDown)).Offset(0, 1)

    'Call up Solver tool to obtain minumum value of MSE, and set the Alpha and Beta Values.
    solversolve userfinish:=True

    'Call up Data Analysis Toolpak descriptive statistics
    Application.Run "ATPVBAEN.XLAM!Descr", ActiveSheet.Range("$H$3:$H$1048576" _
    ), ActiveSheet.Range("$K$1"), "C", True, True, , , 95

    'Copying the Actual Forcast result from the model to the "Result for test" worksheet
    Worksheets("Result for test").Activate
    count_result = Application.WorksheetFunction.Count(Range("A5:A1048576"))
    count_pos = Application.WorksheetFunction.Count(Range("D5:D1048576"))
    For i = 1 To (count_result - count_pos)
    Set LookRange = Sheets("25_M1").Range("B4:F1048576")
    arg4 = False
    x = ActiveSheet.Range("Result_Running_hr").Offset(count_pos + i).Value
    Range("Result_Forecast").Offset(count_pos + i) = Application.VLookup(x, LookRange, 5,
    arg4)
    Next i
    Worksheets("Data for test").Activate

End Sub

Sub Model_25M2()
'Model_25M2 is the predictive model for 25% Main Engine Load with running hours from 2001-
‘3000.
'Declaration of variables
Dim count25_M2 As Integer
Dim count_result As Integer
Dim Column_value As Integer
Dim count_pos As Integer
Dim arg1 As Integer, arg3 As Integer
Dim LookRange As Range
Dim arg4 As Boolean
'Column value is used to control cell position for data to be input or extract
```

```
Column_value = 4

    'Copy original data from "Data for test" worksheet to "25_M2" worksheet for model analysis.
    Worksheets("Data for test").Activate
    ActiveSheet.Range("Run_25M2:" &
    ActiveSheet.Range("Temp_25M2").End(xlDown).Address).Offset(1).Select
    Selection.Copy
    Worksheets("25_M2").Activate
    count25_M2 = Application.WorksheetFunction.Count(Range("B4:B1048576"))
    Set Curcell = Worksheets("25_M2").Cells(count25_M2 + Column_value, 2)
    Curcell.PasteSpecial xlPasteValues

    'Set the first forecast value to be the same as the first cylinder temperature value.
    Range("Forecast_25M2").Offset(1).Formula = "=C4"
     'Set the trend to be zero since there is no previous data for trend.
    Range("Trend_25M2").Offset(1) = 0
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_25M2").Offset(1).Formula = "=D4+E4"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_25M2").Offset(1).Formula = "=C4"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_25M2").Offset(1).Formula = "=G4-F4"

    'count_data1 is used to control cell position for data to be input or extract
    count_data1 = Range("count25M2_80").Value - 1
    'The Forecast is the result of Alpha*past cylinder temp + (1-Alpha)*Actual Forecast
    Range("Forecast_25M2").Offset(2).Formula = "= $I$1 * C4 + (1 -$I$1 ) * F4"
    'The trend is the result of Beta * Difference of past forecast + (1-Beta)*Previous Trend
    Range("Trend_25M2").Offset(2).Formula = "=$I$2 * (D5-D4)+ (1 - $I$2) * E4"
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_25M2").Offset(2).Formula = "= D5 + E5"
     'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_25M2").Offset(2).Formula = "=C5"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_25M2").Offset(2).Formula = "= G5 -F5"
    'Counting the position of the last data cell
    LR = Range("count25M2").Value + 3
    'Copy the formula from 2nd row of the cells which contains data to end of the data.
    Range("D5:H5").AutoFill Destination:=Range("D5:H" & LR)

    'This set of data is used for validation purpose. It will highlight the cell in yellow.
    'It copy the previous Actual Forcast value to the new forecast cell. This will repeat till end of
    ‘data and
    'then used to validate the goodness of fit for the model.
    Range("Forecast_25M2").Offset(count_data1 + 2).Value = "=F" & (count_data1 + 4)
    Range("Forecast_25M2").Offset(count_data1 + 2).Interior.Color = RGB(255, 255, 51)
    Range("Forecast_25M2").Offset(count_data1 + 2).Select
    ActiveCell.AutoFill Destination:=Range(ActiveCell.Offset(0, -1), ActiveCell.Offset(0, -
    1).End(xlDown)).Offset(0, 1)

    'Call up Solver tool to obtain minumum value of MSE, and set the Alpha and Beta Values.
    solversolve userfinish:=True

    'Call up Data Analysis Toolpak descriptive statistics
    Application.Run "ATPVBAEN.XLAM!Descr", ActiveSheet.Range("$H$3:$H$1048576" _
    ), ActiveSheet.Range("$K$1"), "C", True, True, , , 95

    'Copying the Actual Forcast result from the model to the "Result for test" worksheet
    Worksheets("Result for test").Activate
    count_result = Application.WorksheetFunction.Count(Range("A5:A1048576"))
    count_pos = Application.WorksheetFunction.Count(Range("D5:D1048576"))
    For i = 1 To (count_result - count_pos)
    Set LookRange = Sheets("25_M2").Range("B4:F1048576")
    arg4 = False
    x = ActiveSheet.Range("Result_Running_hr").Offset(count_pos + i).Value
    Range("Result_Forecast").Offset(count_pos + i) = Application.VLookup(x, LookRange, 5,
    arg4)
    Next i
    Worksheets("Data for test").Activate

End Sub

Sub Model_25M3()

'Model_25M3 is the predictive model for 25% Main Engine Load with running hours from 3001-
‘4000.
'Declaration of variables
Dim count25_M3 As Integer
Dim count_result As Integer
Dim Column_value As Integer
Dim count_pos As Integer
Dim arg1 As Integer, arg3 As Integer
Dim LookRange As Range
Dim arg4 As Boolean
'Column value is used to control cell position for data to be input or extract
Column_value = 4

    'Copy original data from "Data for test" worksheet to "25_M3" worksheet for model analysis.
    Worksheets("Data for test").Activate
    ActiveSheet.Range("Run_25M3:" &
    ActiveSheet.Range("Temp_25M3").End(xlDown).Address).Offset(1).Select
    Selection.Copy
    Worksheets("25_M3").Activate
    count25_M3 = Application.WorksheetFunction.Count(Range("B4:B1048576"))
    Set Curcell = Worksheets("25_M3").Cells(count25_M3 + Column_value, 2)
    Curcell.PasteSpecial xlPasteValues

    'Set the first forecast value to be the same as the first cylinder temperature value.
    Range("Forecast_25M3").Offset(1).Formula = "=C4"
    'Set the trend to be zero since there is no previous data for trend.
    Range("Trend_25M3").Offset(1) = 0
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_25M3").Offset(1).Formula = "=D4+E4"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_25M3").Offset(1).Formula = "=C4"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_25M3").Offset(1).Formula = "=G4-F4"

    'count_data1 is used to control cell position for data to be input or extract
    count_data1 = Range("count25M3_80").Value - 1
    'The Forecast is the result of Alpha*past cylinder temp + (1-Alpha)*Actual Forecast
    Range("Forecast_25M3").Offset(2).Formula = "= $I$1 * C4 + (1 -$I$1 ) * F4"
    'The trend is the result of Beta * Difference of past forecast + (1-Beta)*Previous Trend
    Range("Trend_25M3").Offset(2).Formula = "=$I$2 * (D5-D4)+ (1 - $I$2) * E4"
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_25M3").Offset(2).Formula = "= D5 + E5"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_25M3").Offset(2).Formula = "=C5"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_25M3").Offset(2).Formula = "= G5 -F5"
    'Counting the position of the last data cell
    LR = Range("count25M3").Value + 3
    'Copy the formula from 2nd row of the cells which contains data to end of the data.
    Range("D5:H5").AutoFill Destination:=Range("D5:H" & LR)

    'This set of data is used for validation purpose. It will highlight the cell in yellow.
    'It copy the previous Actual Forcast value to the new forecast cell. This will repeat till end of
    ‘data and
    'then used to validate the goodness of fit for the model.
    Range("Forecast_25M3").Offset(count_data1 + 2).Value = "=F" & (count_data1 + 4)
    Range("Forecast_25M3").Offset(count_data1 + 2).Interior.Color = RGB(255, 255, 51)
    Range("Forecast_25M3").Offset(count_data1 + 2).Select
    ActiveCell.AutoFill Destination:=Range(ActiveCell.Offset(0, -1), ActiveCell.Offset(0, -
    1).End(xlDown)).Offset(0, 1)


    'Call up Solver tool to obtain minumum value of MSE, and set the Alpha and Beta Values.
    solversolve userfinish:=True

    'Call up Data Analysis Toolpak descriptive statistics
    Application.Run "ATPVBAEN.XLAM!Descr", ActiveSheet.Range("$H$3:$H$1048576" _
    ), ActiveSheet.Range("$K$1"), "C", True, True, , , 95

    'Copying the Actual Forcast result from the model to the "Result for test" worksheet
    Worksheets("Result for test").Activate
    count_result = Application.WorksheetFunction.Count(Range("A5:A1048576"))
    count_pos = Application.WorksheetFunction.Count(Range("D5:D1048576"))
    For i = 1 To (count_result - count_pos)
    Set LookRange = Sheets("25_M3").Range("B4:F1048576")
    arg4 = False
    x = ActiveSheet.Range("Result_Running_hr").Offset(count_pos + i).Value
    Range("Result_Forecast").Offset(count_pos + i) = Application.VLookup(x, LookRange, 5,
    arg4)
    Next i
    Worksheets("Data for test").Activate

End Sub
Sub Model_25M4()

'Model_25M4 is the predictive model for 25% Main Engine Load with running hours from 4001-
‘4500.
'Declaration of variables
Dim count25_M4 As Integer
Dim count_result As Integer
Dim Column_value As Integer
Dim count_pos As Integer
Dim arg1 As Integer, arg3 As Integer
Dim LookRange As Range
Dim arg4 As Boolean
'Column value is used to control cell position for data to be input or extract
Column_value = 4

    'Copy original data from "Data for test" worksheet to "25_M4" worksheet for model analysis.
    Worksheets("Data for test").Activate
    ActiveSheet.Range("Run_25M4:" &
    ActiveSheet.Range("Temp_25M4").End(xlDown).Address).Offset(1).Select
    Selection.Copy
    Worksheets("25_M4").Activate
    count25_M4 = Application.WorksheetFunction.Count(Range("B4:B1048576"))
    Set Curcell = Worksheets("25_M4").Cells(count25_M4 + Column_value, 2)
    Curcell.PasteSpecial xlPasteValues

    'Set the first forecast value to be the same as the first cylinder temperature value.
    Range("Forecast_25M4").Offset(1).Formula = "=C4"
    'Set the trend to be zero since there is no previous data for trend.
    Range("Trend_25M4").Offset(1) = 0
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_25M4").Offset(1).Formula = "=D4+E4"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_25M4").Offset(1).Formula = "=C4"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_25M4").Offset(1).Formula = "=G4-F4"

    'count_data1 is used to control cell position for data to be input or extract
    count_data1 = Range("count25M4_80").Value - 1
    'The Forecast is the result of Alpha*past cylinder temp + (1-Alpha)*Actual Forecast
    Range("Forecast_25M4").Offset(2).Formula = "= $I$1 * C4 + (1 -$I$1 ) * F4"
    'The trend is the result of Beta * Difference of past forecast + (1-Beta)*Previous Trend
    Range("Trend_25M4").Offset(2).Formula = "=$I$2 * (D5-D4)+ (1 - $I$2) * E4"
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_25M4").Offset(2).Formula = "= D5 + E5"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_25M4").Offset(2).Formula = "=C5"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_25M4").Offset(2).Formula = "= G5 -F5"
    'Counting the position of the last data cell
    LR = Range("count25M4").Value + 3
    'Copy the formula from 2nd row of the cells which contains data to end of the data.
    Range("D5:H5").AutoFill Destination:=Range("D5:H" & LR)

    'This set of data is used for validation purpose. It will highlight the cell in yellow.
    'It copy the previous Actual Forcast value to the new forecast cell. This will repeat till end of
    ‘data and
    'then used to validate the goodness of fit for the model.
    Range("Forecast_25M4").Offset(count_data1 + 2).Value = "=F" & (count_data1 + 4)
    Range("Forecast_25M4").Offset(count_data1 + 2).Interior.Color = RGB(255, 255, 51)
    Range("Forecast_25M4").Offset(count_data1 + 2).Select
    ActiveCell.AutoFill Destination:=Range(ActiveCell.Offset(0, -1), ActiveCell.Offset(0, -
    1).End(xlDown)).Offset(0, 1)
    'Call up Solver tool to obtain minumum value of MSE, and set the Alpha and Beta Values.
    solversolve userfinish:=True

    'Call up Data Analysis Toolpak descriptive statistics
    Application.Run "ATPVBAEN.XLAM!Descr", ActiveSheet.Range("$H$3:$H$1048576" _
    ), ActiveSheet.Range("$K$1"), "C", True, True, , , 95

    'Copying the Actual Forcast result from the model to the "Result for test" worksheet
    Worksheets("Result for test").Activate
    count_result = Application.WorksheetFunction.Count(Range("A5:A1048576"))
    count_pos = Application.WorksheetFunction.Count(Range("D5:D1048576"))
    For i = 1 To (count_result - count_pos)
    Set LookRange = Sheets("25_M4").Range("B4:F1048576")
    arg4 = False
    x = ActiveSheet.Range("Result_Running_hr").Offset(count_pos + i).Value
    Range("Result_Forecast").Offset(count_pos + i) = Application.VLookup(x, LookRange, 5,
    arg4)
    Next i
    Worksheets("Data for test").Activate

End Sub

Sub Model_25M5()

'Model_25M5 is the predictive model for 25% Main Engine Load with running hours from 4501-
‘5000.
'Declaration of variables
Dim count25_M5 As Integer
Dim count_result As Integer
Dim Column_value As Integer
Dim count_pos As Integer
Dim arg1 As Integer, arg3 As Integer
Dim LookRange As Range
Dim arg4 As Boolean
'Column value is used to control cell position for data to be input or extract
Column_value = 4

    'Copy original data from "Data for test" worksheet to "25_M5" worksheet for model analysis.
    Worksheets("Data for test").Activate
    ActiveSheet.Range("Run_25M5:" &
    ActiveSheet.Range("Temp_25M5").End(xlDown).Address).Offset(1).Select
    Selection.Copy
    Worksheets("25_M5").Activate
    count25_M5 = Application.WorksheetFunction.Count(Range("B4:B1048576"))
    Set Curcell = Worksheets("25_M5").Cells(count25_M5 + Column_value, 2)
    Curcell.PasteSpecial xlPasteValues

    'Getting the average of the previous two values
    Range("MA_25").Offset(3).Formula = "=Average(C4:C5)"
    'Finding the position for the last data
    LR = Range("count25M5").Value + 3
    'Copy the formula to the end of the data.
    Range("D6").AutoFill Destination:=Range("D6:D" & LR)
```

```
'Set the first forecast value to be the same as the first moving average temperature value.
Range("Forecast_25M5").Offset(1).Formula = "=D4"
Range("Forecast_25M5").Offset(2).Formula = "=D5"
Range("Forecast_25M5").Offset(3).Formula = "=D6"
'Set the trend to be zero since there is no previous data for trend.
Range("Trend_25M5").Offset(1) = 0
Range("Trend_25M5").Offset(2) = 0
Range("Trend_25M5").Offset(3) = 0
'The Actual Forecast will be the sum of Forecast and Trend.
Range("AF_25M5").Offset(1).Formula = "=E6+F6"
Range("AF_25M5").Offset(2).Formula = "=E6+F6"
Range("AF_25M5").Offset(3).Formula = "=E6+F6"
 'The Actual Data will be copied over from the data in cylinder temperature cell.
Range("AD_25M5").Offset(1).Formula = "=C6"
Range("AD_25M5").Offset(2).Formula = "=C6"
Range("AD_25M5").Offset(3).Formula = "=C6"
 'The error is the difference between Actual Data and Actual Forecast.
Range("Error_25M5").Offset(1).Formula = "=H6-G6"
Range("Error_25M5").Offset(2).Formula = "=H6-G6"
Range("Error_25M5").Offset(3).Formula = "=H6-G6"

'count_data1 is used to control cell position for data to be input or extract
count_data1 = Range("count25M5_80").Value - 1
'The Forecast is the result of Alpha*past MA cylinder temp + (1-Alpha)*Actual Forecast
Range("Forecast_25M5").Offset(4).Formula = "= $J$1 * D6 + (1 -$J$1 ) * G6"
'The trend is the result of Beta * Difference of past forecast + (1-Beta)*Previous Trend
Range("Trend_25M5").Offset(4).Formula = "=$J$2 * (E7-E6)+ (1 - $J$2) * E6"
'The Actual Forecast will be the sum of Forecast and Trend.
Range("AF_25M5").Offset(4).Formula = "= E7 + F7"
 'The Actual Data will be copied over from the data in cylinder temperature cell.
Range("AD_25M5").Offset(4).Formula = "=C7"
 'The error is the difference between Actual Data and Actual Forecast.
Range("Error_25M5").Offset(4).Formula = "= H7 -G7"
'Counting the position of the last data cell
LR = Range("count25M5").Value + 3
'Copy the formula from 2nd row of the cells which contains data to end of the data.
Range("E7:I7").AutoFill Destination:=Range("E7:I" & LR)

'This set of data is used for validation purpose. It will highlight the cell in yellow.
'It copy the previous Actual Forcast value to the new forecast cell. This will repeat till end of
‘data and
'then used to validate the goodness of fit for the model.
Range("Forecast_25M5").Offset(count_data1 + 2).Value = "=G" & (count_data1 + 4)
Range("Forecast_25M5").Offset(count_data1 + 2).Interior.Color = RGB(255, 255, 51)
Range("Forecast_25M5").Offset(count_data1 + 2).Select
ActiveCell.AutoFill Destination:=Range(ActiveCell.Offset(0, -1), ActiveCell.Offset(0, -
1).End(xlDown)).Offset(0, 1)

'Call up Solver tool to obtain minumum value of MSE, and set the Alpha and Beta Values.
solversolve userfinish:=True

'Call up Data Analysis Toolpak descriptive statistics
Application.Run "ATPVBAEN.XLAM!Descr", ActiveSheet.Range("$I$3:$I$1048576" _
), ActiveSheet.Range("$K$1"), "C", True, True, , , 95
```

```
    'Copying the Actual Forcast result from the model to the "Result for test" worksheet
    Worksheets("Result for test").Activate
    count_result = Application.WorksheetFunction.Count(Range("A5:A1048576"))
    count_pos = Application.WorksheetFunction.Count(Range("D5:D1048576"))
    For i = 1 To (count_result - count_pos)
    Set LookRange = Sheets("25_M5").Range("B4:G1048576")
    arg4 = False
    x = ActiveSheet.Range("Result_Running_hr").Offset(count_pos + i).Value
    Range("Result_Forecast").Offset(count_pos + i) = Application.VLookup(x, LookRange, 6,
    arg4)
    Next i
    Worksheets("Data for test").Activate

End Sub

Sub Model_50M1()
'Model_50M1 is the predictive model for 50% Main Engine Load with running hours from 1-
‘2000.
'Declaration of variables
Dim count50_M1 As Integer
Dim count_result As Integer
Dim Column_value As Integer
Dim count_pos As Integer
Dim arg1 As Integer, arg3 As Integer
Dim LookRange As Range
Dim arg4 As Boolean
'Column value is used to control cell position for data to be input or extract
Column_value = 4

    'Copy original data from "Data for test" worksheet to "50_M1" worksheet for model analysis.
    Worksheets("Data for test").Activate
    ActiveSheet.Range("Run_50M1:" &
    ActiveSheet.Range("Temp_50M1").End(xlDown).Address).Offset(1).Select
    Selection.Copy
    Worksheets("50_M1").Activate
    count50_M1 = Application.WorksheetFunction.Count(Range("B4:B1048576"))
    Set Curcell = Worksheets("50_M1").Cells(count50_M1 + Column_value, 2)
    Curcell.PasteSpecial xlPasteValues

    'Set the first forecast value to be the same as the first cylinder temperature value.
    Range("Forecast_50M1").Offset(1).Formula = "=C4"
    'Set the trend to be zero since there is no previous data for trend.
    Range("Trend_50M1").Offset(1) = 0
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_50M1").Offset(1).Formula = "=D4+E4"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_50M1").Offset(1).Formula = "=C4"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_50M1").Offset(1).Formula = "=G4-F4"

    'count_data1 is used to control cell position for data to be input or extract
    count_data1 = Range("count50M1_80").Value - 1
    'The Forecast is the result of Alpha*past cylinder temp + (1-Alpha)*Actual Forecast
    Range("Forecast_50M1").Offset(2).Formula = "= $I$1 * C4 + (1 -$I$1 ) * F4"
    'The trend is the result of Beta * Difference of past forecast + (1-Beta)*Previous Trend
    Range("Trend_50M1").Offset(2).Formula = "=$I$2 * (D5-D4)+ (1 - $I$2) * E4"
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_50M1").Offset(2).Formula = "= D5 + E5"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_50M1").Offset(2).Formula = "=C5"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_50M1").Offset(2).Formula = "= G5 -F5"
    'Counting the position of the last data cell
    LR = Range("count50M1").Value + 3
    'Copy the formula from 2nd row of the cells which contains data to end of the data.
    Range("D5:H5").AutoFill Destination:=Range("D5:H" & LR)

    'This set of data is used for validation purpose. It will highlight the cell in yellow.
    'It copy the previous Actual Forcast value to the new forecast cell. This will repeat till end of
    ‘data and
    'then used to validate the goodness of fit for the model.
    Range("Forecast_50M1").Offset(count_data1 + 2).Value = "=F" & (count_data1 + 4)
    Range("Forecast_50M1").Offset(count_data1 + 2).Interior.Color = RGB(255, 255, 51)
    Range("Forecast_50M1").Offset(count_data1 + 2).Select
    ActiveCell.AutoFill Destination:=Range(ActiveCell.Offset(0, -1), ActiveCell.Offset(0, -
    1).End(xlDown)).Offset(0, 1)

    'Call up Solver tool to obtain minumum value of MSE, and set the Alpha and Beta Values.
    solversolve userfinish:=True

    'Call up Data Analysis Toolpak descriptive statistics
    Application.Run "ATPVBAEN.XLAM!Descr", ActiveSheet.Range("$H$3:$H$1048576" _
    ), ActiveSheet.Range("$K$1"), "C", True, True, , , 95

    'Copying the Actual Forcast result from the model to the "Result for test" worksheet
    Worksheets("Result for test").Activate
    count_result = Application.WorksheetFunction.Count(Range("A5:A1048576"))
    count_pos = Application.WorksheetFunction.Count(Range("D5:D1048576"))
    For i = 1 To (count_result - count_pos)
    Set LookRange = Sheets("50_M1").Range("B4:F1048576")
    arg4 = False
    x = ActiveSheet.Range("Result_Running_hr").Offset(count_pos + i).Value
    Range("Result_Forecast").Offset(count_pos + i) = Application.VLookup(x, LookRange, 5,
    arg4)
    Next i
    Worksheets("Data for test").Activate

End Sub

Sub Model_50M2()
'Model_50M2 is the predictive model for 50% Main Engine Load with running hours from 2001-
‘3000.
'Declaration of variables
Dim count50_M2 As Integer
Dim count_result As Integer
Dim Column_value As Integer
Dim count_pos As Integer
Dim arg1 As Integer, arg3 As Integer
Dim LookRange As Range
Dim arg4 As Boolean
```

```
'Column value is used to control cell position for data to be input or extract
Column_value = 4

    'Copy original data from "Data for test" worksheet to "50_M2" worksheet for model analysis.
    Worksheets("Data for test").Activate
    ActiveSheet.Range("Run_50M2:" &
    ActiveSheet.Range("Temp_50M2").End(xlDown).Address).Offset(1).Select
    Selection.Copy
    Worksheets("50_M2").Activate
    count50_M2 = Application.WorksheetFunction.Count(Range("B4:B1048576"))
    Set Curcell = Worksheets("50_M2").Cells(count50_M2 + Column_value, 2)
    Curcell.PasteSpecial xlPasteValues

    'Set the first forecast value to be the same as the first cylinder temperature value.
    Range("Forecast_50M2").Offset(1).Formula = "=C4"
     'Set the trend to be zero since there is no previous data for trend.
    Range("Trend_50M2").Offset(1) = 0
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_50M2").Offset(1).Formula = "=D4+E4"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_50M2").Offset(1).Formula = "=C4"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_50M2").Offset(1).Formula = "=G4-F4"

    'count_data1 is used to control cell position for data to be input or extract
    count_data1 = Range("count50M2_80").Value - 1
    'The Forecast is the result of Alpha*past cylinder temp + (1-Alpha)*Actual Forecast
    Range("Forecast_50M2").Offset(2).Formula = "= $I$1 * C4 + (1 -$I$1 ) * F4"
    'The trend is the result of Beta * Difference of past forecast + (1-Beta)*Previous Trend
    Range("Trend_50M2").Offset(2).Formula = "=$I$2 * (D5-D4)+ (1 - $I$2) * E4"
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_50M2").Offset(2).Formula = "= D5 + E5"
     'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_50M2").Offset(2).Formula = "=C5"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_50M2").Offset(2).Formula = "= G5 -F5"
    'Counting the position of the last data cell
    LR = Range("count50M2").Value + 3
    'Copy the formula from 2nd row of the cells which contains data to end of the data.
    Range("D5:H5").AutoFill Destination:=Range("D5:H" & LR)

    'This set of data is used for validation purpose. It will highlight the cell in yellow.
    'It copy the previous Actual Forcast value to the new forecast cell. This will repeat till end of
    ‘data and
    'then used to validate the goodness of fit for the model.
    Range("Forecast_50M2").Offset(count_data1 + 2).Value = "=F" & (count_data1 + 4)
    Range("Forecast_50M2").Offset(count_data1 + 2).Interior.Color = RGB(255, 255, 51)
    Range("Forecast_50M2").Offset(count_data1 + 2).Select
    ActiveCell.AutoFill Destination:=Range(ActiveCell.Offset(0, -1), ActiveCell.Offset(0, -
    1).End(xlDown)).Offset(0, 1)

    'Call up Solver tool to obtain minumum value of MSE, and set the Alpha and Beta Values.
    solversolve userfinish:=True

    'Call up Data Analysis Toolpak descriptive statistics
    Application.Run "ATPVBAEN.XLAM!Descr", ActiveSheet.Range("$H$3:$H$1048576" _
    ), ActiveSheet.Range("$K$1"), "C", True, True, , , 95

    'Copying the Actual Forcast result from the model to the "Result for test" worksheet
    Worksheets("Result for test").Activate
    count_result = Application.WorksheetFunction.Count(Range("A5:A1048576"))
    count_pos = Application.WorksheetFunction.Count(Range("D5:D1048576"))
    For i = 1 To (count_result - count_pos)
    Set LookRange = Sheets("50_M2").Range("B4:F1048576")
    arg4 = False
    x = ActiveSheet.Range("Result_Running_hr").Offset(count_pos + i).Value
    Range("Result_Forecast").Offset(count_pos + i) = Application.VLookup(x, LookRange, 5,
    arg4)
    Next i
    Worksheets("Data for test").Activate

End Sub

Sub Model_50M3()

'Model_50M3 is the predictive model for 50% Main Engine Load with running hours from 3001-
‘4000.
'Declaration of variables
Dim count50_M3 As Integer
Dim count_result As Integer
Dim Column_value As Integer
Dim count_pos As Integer
Dim arg1 As Integer, arg3 As Integer
Dim LookRange As Range
Dim arg4 As Boolean
'Column value is used to control cell position for data to be input or extract
Column_value = 4

    'Copy original data from "Data for test" worksheet to "50_M3" worksheet for model analysis.
    Worksheets("Data for test").Activate
    ActiveSheet.Range("Run_50M3:" &
    ActiveSheet.Range("Temp_50M3").End(xlDown).Address).Offset(1).Select
    Selection.Copy
    Worksheets("50_M3").Activate
    count50_M3 = Application.WorksheetFunction.Count(Range("B4:B1048576"))
    Set Curcell = Worksheets("50_M3").Cells(count50_M3 + Column_value, 2)
    Curcell.PasteSpecial xlPasteValues

    'Set the first forecast value to be the same as the first cylinder temperature value.
    Range("Forecast_50M3").Offset(1).Formula = "=C4"
    'Set the trend to be zero since there is no previous data for trend.
    Range("Trend_50M3").Offset(1) = 0
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_50M3").Offset(1).Formula = "=D4+E4"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_50M3").Offset(1).Formula = "=C4"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_50M3").Offset(1).Formula = "=G4-F4"

    'count_data1 is used to control cell position for data to be input or extract
    count_data1 = Range("count50M3_80").Value - 1
    'The Forecast is the result of Alpha*past cylinder temp + (1-Alpha)*Actual Forecast
    Range("Forecast_50M3").Offset(2).Formula = "= $I$1 * C4 + (1 -$I$1 ) * F4"
    'The trend is the result of Beta * Difference of past forecast + (1-Beta)*Previous Trend
    Range("Trend_50M3").Offset(2).Formula = "=$I$2 * (D5-D4)+ (1 - $I$2) * E4"
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_50M3").Offset(2).Formula = "= D5 + E5"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_50M3").Offset(2).Formula = "=C5"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_50M3").Offset(2).Formula = "= G5 -F5"
    'Counting the position of the last data cell
    LR = Range("count50M3").Value + 3
    'Copy the formula from 2nd row of the cells which contains data to end of the data.
    Range("D5:H5").AutoFill Destination:=Range("D5:H" & LR)

    'This set of data is used for validation purpose. It will highlight the cell in yellow.
    'It copy the previous Actual Forcast value to the new forecast cell. This will repeat till end of
    ‘data and
    'then used to validate the goodness of fit for the model.
    Range("Forecast_50M3").Offset(count_data1 + 2).Value = "=F" & (count_data1 + 4)
    Range("Forecast_50M3").Offset(count_data1 + 2).Interior.Color = RGB(255, 255, 51)
    Range("Forecast_50M3").Offset(count_data1 + 2).Select
    ActiveCell.AutoFill Destination:=Range(ActiveCell.Offset(0, -1), ActiveCell.Offset(0, -
    1).End(xlDown)).Offset(0, 1)

    'Call up Solver tool to obtain minumum value of MSE, and set the Alpha and Beta Values.
    solversolve userfinish:=True

    'Call up Data Analysis Toolpak descriptive statistics
    Application.Run "ATPVBAEN.XLAM!Descr", ActiveSheet.Range("$H$3:$H$1048576" _
    ), ActiveSheet.Range("$K$1"), "C", True, True, , , 95

    'Copying the Actual Forcast result from the model to the "Result for test" worksheet
    Worksheets("Result for test").Activate
    count_result = Application.WorksheetFunction.Count(Range("A5:A1048576"))
    count_pos = Application.WorksheetFunction.Count(Range("D5:D1048576"))
    For i = 1 To (count_result - count_pos)
    Set LookRange = Sheets("50_M3").Range("B4:F1048576")
    arg4 = False
    x = ActiveSheet.Range("Result_Running_hr").Offset(count_pos + i).Value
    Range("Result_Forecast").Offset(count_pos + i) = Application.VLookup(x, LookRange, 5,
    arg4)
    Next i
    Worksheets("Data for test").Activate

End Sub

Sub Model_50M4()

'Model_50M4 is the predictive model for 50% Main Engine Load with running hours from 4001-
‘4500.
'Declaration of variables
Dim count50_M4 As Integer
Dim count_result As Integer
Dim Column_value As Integer
Dim count_pos As Integer
Dim arg1 As Integer, arg3 As Integer
Dim LookRange As Range
Dim arg4 As Boolean
'Column value is used to control cell position for data to be input or extract
Column_value = 4

    'Copy original data from "Data for test" worksheet to "50_M4" worksheet for model analysis.
    Worksheets("Data for test").Activate
    ActiveSheet.Range("Run_50M4:" &
    ActiveSheet.Range("Temp_50M4").End(xlDown).Address).Offset(1).Select
    Selection.Copy
    Worksheets("50_M4").Activate
    count50_M4 = Application.WorksheetFunction.Count(Range("B4:B1048576"))
    Set Curcell = Worksheets("50_M4").Cells(count50_M4 + Column_value, 2)
    Curcell.PasteSpecial xlPasteValues

    'Set the first forecast value to be the same as the first cylinder temperature value.
    Range("Forecast_50M4").Offset(1).Formula = "=C4"
    'Set the trend to be zero since there is no previous data for trend.
    Range("Trend_50M4").Offset(1) = 0
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_50M4").Offset(1).Formula = "=D4+E4"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_50M4").Offset(1).Formula = "=C4"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_50M4").Offset(1).Formula = "=G4-F4"

    'count_data1 is used to control cell position for data to be input or extract
    count_data1 = Range("count50M4_80").Value - 1
    'The Forecast is the result of Alpha*past cylinder temp + (1-Alpha)*Actual Forecast
    Range("Forecast_50M4").Offset(2).Formula = "= $I$1 * C4 + (1 -$I$1 ) * F4"
    'The trend is the result of Beta * Difference of past forecast + (1-Beta)*Previous Trend
    Range("Trend_50M4").Offset(2).Formula = "=$I$2 * (D5-D4)+ (1 - $I$2) * E4"
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_50M4").Offset(2).Formula = "= D5 + E5"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_50M4").Offset(2).Formula = "=C5"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_50M4").Offset(2).Formula = "= G5 -F5"
    'Counting the position of the last data cell
    LR = Range("count50M4").Value + 3
    'Copy the formula from 2nd row of the cells which contains data to end of the data.
    Range("D5:H5").AutoFill Destination:=Range("D5:H" & LR)

    'This set of data is used for validation purpose. It will highlight the cell in yellow.
    'It copy the previous Actual Forcast value to the new forecast cell. This will repeat till end of
    ‘data and
    'then used to validate the goodness of fit for the model.
    Range("Forecast_50M4").Offset(count_data1 + 2).Value = "=F" & (count_data1 + 4)
    Range("Forecast_50M4").Offset(count_data1 + 2).Interior.Color = RGB(255, 255, 51)
    Range("Forecast_50M4").Offset(count_data1 + 2).Select
    ActiveCell.AutoFill Destination:=Range(ActiveCell.Offset(0, -1), ActiveCell.Offset(0, -
    1).End(xlDown)).Offset(0, 1)
    'Call up Solver tool to obtain minumum value of MSE, and set the Alpha and Beta Values.
    solversolve userfinish:=True

    'Call up Data Analysis Toolpak descriptive statistics
    Application.Run "ATPVBAEN.XLAM!Descr", ActiveSheet.Range("$H$3:$H$1048576" _
    ), ActiveSheet.Range("$K$1"), "C", True, True, , , 95

    'Copying the Actual Forcast result from the model to the "Result for test" worksheet
    Worksheets("Result for test").Activate
    count_result = Application.WorksheetFunction.Count(Range("A5:A1048576"))
    count_pos = Application.WorksheetFunction.Count(Range("D5:D1048576"))
    For i = 1 To (count_result - count_pos)
    Set LookRange = Sheets("50_M4").Range("B4:F1048576")
    arg4 = False
    x = ActiveSheet.Range("Result_Running_hr").Offset(count_pos + i).Value
    Range("Result_Forecast").Offset(count_pos + i) = Application.VLookup(x, LookRange, 5,
    arg4)
    Next i
    Worksheets("Data for test").Activate

End Sub

Sub Model_50M5()

'Model_50M5 is the predictive model for 50% Main Engine Load with running hours from 4501-
‘5000.
'Declaration of variables
Dim count50_M5 As Integer
Dim count_result As Integer
Dim Column_value As Integer
Dim count_pos As Integer
Dim arg1 As Integer, arg3 As Integer
Dim LookRange As Range
Dim arg4 As Boolean
'Column value is used to control cell position for data to be input or extract
Column_value = 4

    'Copy original data from "Data for test" worksheet to "50_M5" worksheet for model analysis.
    Worksheets("Data for test").Activate
    ActiveSheet.Range("Run_50M5:" &
    ActiveSheet.Range("Temp_50M5").End(xlDown).Address).Offset(1).Select
    Selection.Copy
    Worksheets("50_M5").Activate
    count50_M5 = Application.WorksheetFunction.Count(Range("B4:B1048576"))
    Set Curcell = Worksheets("50_M5").Cells(count50_M5 + Column_value, 2)
    Curcell.PasteSpecial xlPasteValues

    'Getting the average of the previous two values
    Range("MA_50").Offset(3).Formula = "=Average(C4:C5)"
    'Finding the position for the last data
    LR = Range("count50M5").Value + 3
    'Copy the formula to the end of the data.
    Range("D6").AutoFill Destination:=Range("D6:D" & LR)
```

```
 'Set the first forecast value to be the same as the first moving average temperature value.
Range("Forecast_50M5").Offset(1).Formula = "=D4"
Range("Forecast_50M5").Offset(2).Formula = "=D5"
Range("Forecast_50M5").Offset(3).Formula = "=D6"
'Set the trend to be zero since there is no previous data for trend.
Range("Trend_50M5").Offset(1) = 0
Range("Trend_50M5").Offset(2) = 0
Range("Trend_50M5").Offset(3) = 0
'The Actual Forecast will be the sum of Forecast and Trend.
Range("AF_50M5").Offset(1).Formula = "=E6+F6"
Range("AF_50M5").Offset(2).Formula = "=E6+F6"
Range("AF_50M5").Offset(3).Formula = "=E6+F6"
 'The Actual Data will be copied over from the data in cylinder temperature cell.
Range("AD_50M5").Offset(1).Formula = "=C6"
Range("AD_50M5").Offset(2).Formula = "=C6"
Range("AD_50M5").Offset(3).Formula = "=C6"
 'The error is the difference between Actual Data and Actual Forecast.
Range("Error_50M5").Offset(1).Formula = "=H6-G6"
Range("Error_50M5").Offset(2).Formula = "=H6-G6"
Range("Error_50M5").Offset(3).Formula = "=H6-G6"

'count_data1 is used to control cell position for data to be input or extract
count_data1 = Range("count50M5_80").Value - 1
'The Forecast is the result of Alpha*past MA cylinder temp + (1-Alpha)*Actual Forecast
Range("Forecast_50M5").Offset(4).Formula = "= $J$1 * D6 + (1 -$J$1 ) * G6"
'The trend is the result of Beta * Difference of past forecast + (1-Beta)*Previous Trend
Range("Trend_50M5").Offset(4).Formula = "=$J$2 * (E7-E6)+ (1 - $J$2) * E6"
'The Actual Forecast will be the sum of Forecast and Trend.
Range("AF_50M5").Offset(4).Formula = "= E7 + F7"
 'The Actual Data will be copied over from the data in cylinder temperature cell.
Range("AD_50M5").Offset(4).Formula = "=C7"
 'The error is the difference between Actual Data and Actual Forecast.
Range("Error_50M5").Offset(4).Formula = "= H7 -G7"
'Counting the position of the last data cell
LR = Range("count50M5").Value + 3
'Copy the formula from 2nd row of the cells which contains data to end of the data.
Range("E7:I7").AutoFill Destination:=Range("E7:I" & LR)

'This set of data is used for validation purpose. It will highlight the cell in yellow.
'It copy the previous Actual Forcast value to the new forecast cell. This will repeat till end of
‘data and
'then used to validate the goodness of fit for the model.
Range("Forecast_50M5").Offset(count_data1 + 2).Value = "=G" & (count_data1 + 4)
Range("Forecast_50M5").Offset(count_data1 + 2).Interior.Color = RGB(255, 255, 51)
Range("Forecast_50M5").Offset(count_data1 + 2).Select
ActiveCell.AutoFill Destination:=Range(ActiveCell.Offset(0, -1), ActiveCell.Offset(0, -
1).End(xlDown)).Offset(0, 1)

'Call up Solver tool to obtain minumum value of MSE, and set the Alpha and Beta Values.
solversolve userfinish:=True

'Call up Data Analysis Toolpak descriptive statistics
Application.Run "ATPVBAEN.XLAM!Descr", ActiveSheet.Range("$I$3:$I$1048576" _
), ActiveSheet.Range("$K$1"), "C", True, True, , , 95
```

```
    'Copying the Actual Forcast result from the model to the "Result for test" worksheet
    Worksheets("Result for test").Activate
    count_result = Application.WorksheetFunction.Count(Range("A5:A1048576"))
    count_pos = Application.WorksheetFunction.Count(Range("D5:D1048576"))
    For i = 1 To (count_result - count_pos)
    Set LookRange = Sheets("50_M5").Range("B4:G1048576")
    arg4 = False
    x = ActiveSheet.Range("Result_Running_hr").Offset(count_pos + i).Value
    Range("Result_Forecast").Offset(count_pos + i) = Application.VLookup(x, LookRange, 6,
    arg4)
    Next i
    Worksheets("Data for test").Activate

End Sub

Sub Model_75M1()
'Model_75M1 is the predictive model for 75% Main Engine Load with running hours from 1-
‘2000.
'Declaration of variables
Dim count75_M1 As Integer
Dim count_result As Integer
Dim Column_value As Integer
Dim count_pos As Integer
Dim arg1 As Integer, arg3 As Integer
Dim LookRange As Range
Dim arg4 As Boolean
'Column value is used to control cell position for data to be input or extract
Column_value = 4

    'Copy original data from "Data for test" worksheet to "75_M1" worksheet for model analysis.
    Worksheets("Data for test").Activate
    ActiveSheet.Range("Run_75M1:" &
    ActiveSheet.Range("Temp_75M1").End(xlDown).Address).Offset(1).Select
    Selection.Copy
    Worksheets("75_M1").Activate
    count75_M1 = Application.WorksheetFunction.Count(Range("B4:B1048576"))
    Set Curcell = Worksheets("75_M1").Cells(count75_M1 + Column_value, 2)
    Curcell.PasteSpecial xlPasteValues

    'Set the first forecast value to be the same as the first cylinder temperature value.
    Range("Forecast_75M1").Offset(1).Formula = "=C4"
    'Set the trend to be zero since there is no previous data for trend.
    Range("Trend_75M1").Offset(1) = 0
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_75M1").Offset(1).Formula = "=D4+E4"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_75M1").Offset(1).Formula = "=C4"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_75M1").Offset(1).Formula = "=G4-F4"

    'count_data1 is used to control cell position for data to be input or extract
    count_data1 = Range("count75M1_80").Value - 1
    'The Forecast is the result of Alpha*past cylinder temp + (1-Alpha)*Actual Forecast
    Range("Forecast_75M1").Offset(2).Formula = "= $I$1 * C4 + (1 -$I$1 ) * F4"
    'The trend is the result of Beta * Difference of past forecast + (1-Beta)*Previous Trend
    Range("Trend_75M1").Offset(2).Formula = "=$I$2 * (D5-D4)+ (1 - $I$2) * E4"
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_75M1").Offset(2).Formula = "= D5 + E5"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_75M1").Offset(2).Formula = "=C5"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_75M1").Offset(2).Formula = "= G5 -F5"
    'Counting the position of the last data cell
    LR = Range("count75M1").Value + 3
    'Copy the formula from 2nd row of the cells which contains data to end of the data.
    Range("D5:H5").AutoFill Destination:=Range("D5:H" & LR)

    'This set of data is used for validation purpose. It will highlight the cell in yellow.
    'It copy the previous Actual Forcast value to the new forecast cell. This will repeat till end of
    ‘data and
    'then used to validate the goodness of fit for the model.
    Range("Forecast_75M1").Offset(count_data1 + 2).Value = "=F" & (count_data1 + 4)
    Range("Forecast_75M1").Offset(count_data1 + 2).Interior.Color = RGB(255, 255, 51)
    Range("Forecast_75M1").Offset(count_data1 + 2).Select
    ActiveCell.AutoFill Destination:=Range(ActiveCell.Offset(0, -1), ActiveCell.Offset(0, -
    1).End(xlDown)).Offset(0, 1)

    'Call up Solver tool to obtain minumum value of MSE, and set the Alpha and Beta Values.
    solversolve userfinish:=True

    'Call up Data Analysis Toolpak descriptive statistics
    Application.Run "ATPVBAEN.XLAM!Descr", ActiveSheet.Range("$H$3:$H$1048576" _
    ), ActiveSheet.Range("$K$1"), "C", True, True, , , 95

    'Copying the Actual Forcast result from the model to the "Result for test" worksheet
    Worksheets("Result for test").Activate
    count_result = Application.WorksheetFunction.Count(Range("A5:A1048576"))
    count_pos = Application.WorksheetFunction.Count(Range("D5:D1048576"))
    For i = 1 To (count_result - count_pos)
    Set LookRange = Sheets("75_M1").Range("B4:F1048576")
    arg4 = False
    x = ActiveSheet.Range("Result_Running_hr").Offset(count_pos + i).Value
    Range("Result_Forecast").Offset(count_pos + i) = Application.VLookup(x, LookRange, 5,
    arg4)
    Next i
    Worksheets("Data for test").Activate

End Sub

Sub Model_75M2()
'Model_75M2 is the predictive model for 75% Main Engine Load with running hours from 2001-
‘3000.
'Declaration of variables
Dim count75_M2 As Integer
Dim count_result As Integer
Dim Column_value As Integer
Dim count_pos As Integer
Dim arg1 As Integer, arg3 As Integer
Dim LookRange As Range
Dim arg4 As Boolean
```

```
'Column value is used to control cell position for data to be input or extract
Column_value = 4

    'Copy original data from "Data for test" worksheet to "75_M2" worksheet for model analysis.
    Worksheets("Data for test").Activate
    ActiveSheet.Range("Run_75M2:" &
    ActiveSheet.Range("Temp_75M2").End(xlDown).Address).Offset(1).Select
    Selection.Copy
    Worksheets("75_M2").Activate
    count75_M2 = Application.WorksheetFunction.Count(Range("B4:B1048576"))
    Set Curcell = Worksheets("75_M2").Cells(count75_M2 + Column_value, 2)
    Curcell.PasteSpecial xlPasteValues

    'Set the first forecast value to be the same as the first cylinder temperature value.
    Range("Forecast_75M2").Offset(1).Formula = "=C4"
     'Set the trend to be zero since there is no previous data for trend.
    Range("Trend_75M2").Offset(1) = 0
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_75M2").Offset(1).Formula = "=D4+E4"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_75M2").Offset(1).Formula = "=C4"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_75M2").Offset(1).Formula = "=G4-F4"

    'count_data1 is used to control cell position for data to be input or extract
    count_data1 = Range("count75M2_80").Value - 1
    'The Forecast is the result of Alpha*past cylinder temp + (1-Alpha)*Actual Forecast
    Range("Forecast_75M2").Offset(2).Formula = "= $I$1 * C4 + (1 -$I$1 ) * F4"
    'The trend is the result of Beta * Difference of past forecast + (1-Beta)*Previous Trend
    Range("Trend_75M2").Offset(2).Formula = "=$I$2 * (D5-D4)+ (1 - $I$2) * E4"
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_75M2").Offset(2).Formula = "= D5 + E5"
     'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_75M2").Offset(2).Formula = "=C5"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_75M2").Offset(2).Formula = "= G5 -F5"
    'Counting the position of the last data cell
    LR = Range("count75M2").Value + 3
    'Copy the formula from 2nd row of the cells which contains data to end of the data.
    Range("D5:H5").AutoFill Destination:=Range("D5:H" & LR)

    'This set of data is used for validation purpose. It will highlight the cell in yellow.
    'It copy the previous Actual Forcast value to the new forecast cell. This will repeat till end of
    ‘data and
    'then used to validate the goodness of fit for the model.
    Range("Forecast_75M2").Offset(count_data1 + 2).Value = "=F" & (count_data1 + 4)
    Range("Forecast_75M2").Offset(count_data1 + 2).Interior.Color = RGB(255, 255, 51)
    Range("Forecast_75M2").Offset(count_data1 + 2).Select
    ActiveCell.AutoFill Destination:=Range(ActiveCell.Offset(0, -1), ActiveCell.Offset(0, -
    1).End(xlDown)).Offset(0, 1)

    'Call up Solver tool to obtain minumum value of MSE, and set the Alpha and Beta Values.
    solversolve userfinish:=True

    'Call up Data Analysis Toolpak descriptive statistics
    Application.Run "ATPVBAEN.XLAM!Descr", ActiveSheet.Range("$H$3:$H$1048576" _
    ), ActiveSheet.Range("$K$1"), "C", True, True, , , 95

    'Copying the Actual Forcast result from the model to the "Result for test" worksheet
    Worksheets("Result for test").Activate
    count_result = Application.WorksheetFunction.Count(Range("A5:A1048576"))
    count_pos = Application.WorksheetFunction.Count(Range("D5:D1048576"))
    For i = 1 To (count_result - count_pos)
    Set LookRange = Sheets("75_M2").Range("B4:F1048576")
    arg4 = False
    x = ActiveSheet.Range("Result_Running_hr").Offset(count_pos + i).Value
    Range("Result_Forecast").Offset(count_pos + i) = Application.VLookup(x, LookRange, 5,
    arg4)
    Next i
    Worksheets("Data for test").Activate

End Sub

Sub Model_75M3()

'Model_75M3 is the predictive model for 75% Main Engine Load with running hours from 3001-
‘4000.
'Declaration of variables
Dim count75_M3 As Integer
Dim count_result As Integer
Dim Column_value As Integer
Dim count_pos As Integer
Dim arg1 As Integer, arg3 As Integer
Dim LookRange As Range
Dim arg4 As Boolean
'Column value is used to control cell position for data to be input or extract
Column_value = 4

    'Copy original data from "Data for test" worksheet to "75_M3" worksheet for model analysis.
    Worksheets("Data for test").Activate
    ActiveSheet.Range("Run_75M3:" &
    ActiveSheet.Range("Temp_75M3").End(xlDown).Address).Offset(1).Select
    Selection.Copy
    Worksheets("75_M3").Activate
    count75_M3 = Application.WorksheetFunction.Count(Range("B4:B1048576"))
    Set Curcell = Worksheets("75_M3").Cells(count75_M3 + Column_value, 2)
    Curcell.PasteSpecial xlPasteValues

    'Set the first forecast value to be the same as the first cylinder temperature value.
    Range("Forecast_75M3").Offset(1).Formula = "=C4"
    'Set the trend to be zero since there is no previous data for trend.
    Range("Trend_75M3").Offset(1) = 0
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_75M3").Offset(1).Formula = "=D4+E4"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_75M3").Offset(1).Formula = "=C4"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_75M3").Offset(1).Formula = "=G4-F4"

    'count_data1 is used to control cell position for data to be input or extract
    count_data1 = Range("count75M3_80").Value - 1
    'The Forecast is the result of Alpha*past cylinder temp + (1-Alpha)*Actual Forecast
    Range("Forecast_75M3").Offset(2).Formula = "= $I$1 * C4 + (1 -$I$1 ) * F4"
    'The trend is the result of Beta * Difference of past forecast + (1-Beta)*Previous Trend
    Range("Trend_75M3").Offset(2).Formula = "=$I$2 * (D5-D4)+ (1 - $I$2) * E4"
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_75M3").Offset(2).Formula = "= D5 + E5"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_75M3").Offset(2).Formula = "=C5"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_75M3").Offset(2).Formula = "= G5 -F5"
    'Counting the position of the last data cell
    LR = Range("count75M3").Value + 3
    'Copy the formula from 2nd row of the cells which contains data to end of the data.
    Range("D5:H5").AutoFill Destination:=Range("D5:H" & LR)

    'This set of data is used for validation purpose. It will highlight the cell in yellow.
    'It copy the previous Actual Forcast value to the new forecast cell. This will repeat till end of
    ‘data and
    'then used to validate the goodness of fit for the model.
    Range("Forecast_75M3").Offset(count_data1 + 2).Value = "=F" & (count_data1 + 4)
    Range("Forecast_75M3").Offset(count_data1 + 2).Interior.Color = RGB(255, 255, 51)
    Range("Forecast_75M3").Offset(count_data1 + 2).Select
    ActiveCell.AutoFill Destination:=Range(ActiveCell.Offset(0, -1), ActiveCell.Offset(0, -
    1).End(xlDown)).Offset(0, 1)

    'Call up Solver tool to obtain minumum value of MSE, and set the Alpha and Beta Values.
    solversolve userfinish:=True

    'Call up Data Analysis Toolpak descriptive statistics
    Application.Run "ATPVBAEN.XLAM!Descr", ActiveSheet.Range("$H$3:$H$1048576" _
    ), ActiveSheet.Range("$K$1"), "C", True, True, , , 95

    'Copying the Actual Forcast result from the model to the "Result for test" worksheet
    Worksheets("Result for test").Activate
    count_result = Application.WorksheetFunction.Count(Range("A5:A1048576"))
    count_pos = Application.WorksheetFunction.Count(Range("D5:D1048576"))
    For i = 1 To (count_result - count_pos)
    Set LookRange = Sheets("75_M3").Range("B4:F1048576")
    arg4 = False
    x = ActiveSheet.Range("Result_Running_hr").Offset(count_pos + i).Value
    Range("Result_Forecast").Offset(count_pos + i) = Application.VLookup(x, LookRange, 5,
    arg4)
    Next i
    Worksheets("Data for test").Activate

End Sub

Sub Model_75M4()

'Model_75M4 is the predictive model for 75% Main Engine Load with running hours from 4001-
‘4500.
'Declaration of variables
Dim count75_M4 As Integer
Dim count_result As Integer
Dim Column_value As Integer
Dim count_pos As Integer
Dim arg1 As Integer, arg3 As Integer
Dim LookRange As Range
Dim arg4 As Boolean
'Column value is used to control cell position for data to be input or extract
Column_value = 4

    'Copy original data from "Data for test" worksheet to "75_M4" worksheet for model analysis.
    Worksheets("Data for test").Activate
    ActiveSheet.Range("Run_75M4:" &
    ActiveSheet.Range("Temp_75M4").End(xlDown).Address).Offset(1).Select
    Selection.Copy
    Worksheets("75_M4").Activate
    count75_M4 = Application.WorksheetFunction.Count(Range("B4:B1048576"))
    Set Curcell = Worksheets("75_M4").Cells(count75_M4 + Column_value, 2)
    Curcell.PasteSpecial xlPasteValues

    'Set the first forecast value to be the same as the first cylinder temperature value.
    Range("Forecast_75M4").Offset(1).Formula = "=C4"
    'Set the trend to be zero since there is no previous data for trend.
    Range("Trend_75M4").Offset(1) = 0
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_75M4").Offset(1).Formula = "=D4+E4"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_75M4").Offset(1).Formula = "=C4"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_75M4").Offset(1).Formula = "=G4-F4"

    'count_data1 is used to control cell position for data to be input or extract
    count_data1 = Range("count75M4_80").Value - 1
    'The Forecast is the result of Alpha*past cylinder temp + (1-Alpha)*Actual Forecast
    Range("Forecast_75M4").Offset(2).Formula = "= $I$1 * C4 + (1 -$I$1 ) * F4"
    'The trend is the result of Beta * Difference of past forecast + (1-Beta)*Previous Trend
    Range("Trend_75M4").Offset(2).Formula = "=$I$2 * (D5-D4)+ (1 - $I$2) * E4"
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_75M4").Offset(2).Formula = "= D5 + E5"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_75M4").Offset(2).Formula = "=C5"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_75M4").Offset(2).Formula = "= G5 -F5"
    'Counting the position of the last data cell
    LR = Range("count75M4").Value + 3
    'Copy the formula from 2nd row of the cells which contains data to end of the data.
    Range("D5:H5").AutoFill Destination:=Range("D5:H" & LR)

    'This set of data is used for validation purpose. It will highlight the cell in yellow.
    'It copy the previous Actual Forcast value to the new forecast cell. This will repeat till end of
    ‘data and
    'then used to validate the goodness of fit for the model.
    Range("Forecast_75M4").Offset(count_data1 + 2).Value = "=F" & (count_data1 + 4)
    Range("Forecast_75M4").Offset(count_data1 + 2).Interior.Color = RGB(255, 255, 51)
    Range("Forecast_75M4").Offset(count_data1 + 2).Select
    ActiveCell.AutoFill Destination:=Range(ActiveCell.Offset(0, -1), ActiveCell.Offset(0, -
    1).End(xlDown)).Offset(0, 1)
    'Call up Solver tool to obtain minumum value of MSE, and set the Alpha and Beta Values.
    solversolve userfinish:=True

    'Call up Data Analysis Toolpak descriptive statistics
    Application.Run "ATPVBAEN.XLAM!Descr", ActiveSheet.Range("$H$3:$H$1048576" _
    ), ActiveSheet.Range("$K$1"), "C", True, True, , , 95

    'Copying the Actual Forcast result from the model to the "Result for test" worksheet
    Worksheets("Result for test").Activate
    count_result = Application.WorksheetFunction.Count(Range("A5:A1048576"))
    count_pos = Application.WorksheetFunction.Count(Range("D5:D1048576"))
    For i = 1 To (count_result - count_pos)
    Set LookRange = Sheets("75_M4").Range("B4:F1048576")
    arg4 = False
    x = ActiveSheet.Range("Result_Running_hr").Offset(count_pos + i).Value
    Range("Result_Forecast").Offset(count_pos + i) = Application.VLookup(x, LookRange, 5,
    arg4)
    Next i
    Worksheets("Data for test").Activate

End Sub

Sub Model_75M5()

'Model_75M5 is the predictive model for 75% Main Engine Load with running hours from 4501-
'5000.
'Declaration of variables
Dim count75_M5 As Integer
Dim count_result As Integer
Dim Column_value As Integer
Dim count_pos As Integer
Dim arg1 As Integer, arg3 As Integer
Dim LookRange As Range
Dim arg4 As Boolean
'Column value is used to control cell position for data to be input or extract
Column_value = 4

    'Copy original data from "Data for test" worksheet to "75_M5" worksheet for model analysis.
    Worksheets("Data for test").Activate
    ActiveSheet.Range("Run_75M5:" &
    ActiveSheet.Range("Temp_75M5").End(xlDown).Address).Offset(1).Select
    Selection.Copy
    Worksheets("75_M5").Activate
    count75_M5 = Application.WorksheetFunction.Count(Range("B4:B1048576"))
    Set Curcell = Worksheets("75_M5").Cells(count75_M5 + Column_value, 2)
    Curcell.PasteSpecial xlPasteValues

    'Getting the average of the previous two values
    Range("MA_75").Offset(3).Formula = "=Average(C4:C5)"
    'Finding the position for the last data
    LR = Range("count75M5").Value + 3
    'Copy the formula to the end of the data.
    Range("D6").AutoFill Destination:=Range("D6:D" & LR)
```

```
 'Set the first forecast value to be the same as the first moving average temperature value.
Range("Forecast_75M5").Offset(1).Formula = "=D4"
Range("Forecast_75M5").Offset(2).Formula = "=D5"
Range("Forecast_75M5").Offset(3).Formula = "=D6"
'Set the trend to be zero since there is no previous data for trend.
Range("Trend_75M5").Offset(1) = 0
Range("Trend_75M5").Offset(2) = 0
Range("Trend_75M5").Offset(3) = 0
'The Actual Forecast will be the sum of Forecast and Trend.
Range("AF_75M5").Offset(1).Formula = "=E6+F6"
Range("AF_75M5").Offset(2).Formula = "=E6+F6"
Range("AF_75M5").Offset(3).Formula = "=E6+F6"
 'The Actual Data will be copied over from the data in cylinder temperature cell.
Range("AD_75M5").Offset(1).Formula = "=C6"
Range("AD_75M5").Offset(2).Formula = "=C6"
Range("AD_75M5").Offset(3).Formula = "=C6"
 'The error is the difference between Actual Data and Actual Forecast.
Range("Error_75M5").Offset(1).Formula = "=H6-G6"
Range("Error_75M5").Offset(2).Formula = "=H6-G6"
Range("Error_75M5").Offset(3).Formula = "=H6-G6"

'count_data1 is used to control cell position for data to be input or extract
count_data1 = Range("count75M5_80").Value - 1
'The Forecast is the result of Alpha*past MA cylinder temp + (1-Alpha)*Actual Forecast
Range("Forecast_75M5").Offset(4).Formula = "= $J$1 * D6 + (1 -$J$1 ) * G6"
'The trend is the result of Beta * Difference of past forecast + (1-Beta)*Previous Trend
Range("Trend_75M5").Offset(4).Formula = "=$J$2 * (E7-E6)+ (1 - $J$2) * E6"
'The Actual Forecast will be the sum of Forecast and Trend.
Range("AF_75M5").Offset(4).Formula = "= E7 + F7"
 'The Actual Data will be copied over from the data in cylinder temperature cell.
Range("AD_75M5").Offset(4).Formula = "=C7"
 'The error is the difference between Actual Data and Actual Forecast.
Range("Error_75M5").Offset(4).Formula = "= H7 -G7"
'Counting the position of the last data cell
LR = Range("count75M5").Value + 3
'Copy the formula from 2nd row of the cells which contains data to end of the data.
Range("E7:I7").AutoFill Destination:=Range("E7:I" & LR)

'This set of data is used for validation purpose. It will highlight the cell in yellow.
 'It copy the previous Actual Forcast value to the new forecast cell. This will repeat till end of
‘data and
'then used to validate the goodness of fit for the model.
Range("Forecast_75M5").Offset(count_data1 + 2).Value = "=G" & (count_data1 + 4)
Range("Forecast_75M5").Offset(count_data1 + 2).Interior.Color = RGB(255, 255, 51)
Range("Forecast_75M5").Offset(count_data1 + 2).Select
ActiveCell.AutoFill Destination:=Range(ActiveCell.Offset(0, -1), ActiveCell.Offset(0, -
1).End(xlDown)).Offset(0, 1)

'Call up Solver tool to obtain minumum value of MSE, and set the Alpha and Beta Values.
solversolve userfinish:=True

'Call up Data Analysis Toolpak descriptive statistics
Application.Run "ATPVBAEN.XLAM!Descr", ActiveSheet.Range("$I$3:$I$1048576" _
), ActiveSheet.Range("$K$1"), "C", True, True, , , 95
```

```
    'Copying the Actual Forcast result from the model to the "Result for test" worksheet
    Worksheets("Result for test").Activate
    count_result = Application.WorksheetFunction.Count(Range("A5:A1048576"))
    count_pos = Application.WorksheetFunction.Count(Range("D5:D1048576"))
    For i = 1 To (count_result - count_pos)
    Set LookRange = Sheets("75_M5").Range("B4:G1048576")
    arg4 = False
    x = ActiveSheet.Range("Result_Running_hr").Offset(count_pos + i).Value
    Range("Result_Forecast").Offset(count_pos + i) = Application.VLookup(x, LookRange, 6,
    arg4)
    Next i
    Worksheets("Data for test").Activate

End Sub

Sub Model_85M1()
'Model_85M1 is the predictive model for 85% Main Engine Load with running hours from 1-
‘2000.
'Declaration of variables
Dim count85_M1 As Integer
Dim count_result As Integer
Dim Column_value As Integer
Dim count_pos As Integer
Dim arg1 As Integer, arg3 As Integer
Dim LookRange As Range
Dim arg4 As Boolean
'Column value is used to control cell position for data to be input or extract
Column_value = 4

    'Copy original data from "Data for test" worksheet to "85_M1" worksheet for model analysis.
    Worksheets("Data for test").Activate
    ActiveSheet.Range("Run_85M1:" &
    ActiveSheet.Range("Temp_85M1").End(xlDown).Address).Offset(1).Select
    Selection.Copy
    Worksheets("85_M1").Activate
    count85_M1 = Application.WorksheetFunction.Count(Range("B4:B1048576"))
    Set Curcell = Worksheets("85_M1").Cells(count85_M1 + Column_value, 2)
    Curcell.PasteSpecial xlPasteValues

    'Set the first forecast value to be the same as the first cylinder temperature value.
    Range("Forecast_85M1").Offset(1).Formula = "=C4"
    'Set the trend to be zero since there is no previous data for trend.
    Range("Trend_85M1").Offset(1) = 0
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_85M1").Offset(1).Formula = "=D4+E4"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_85M1").Offset(1).Formula = "=C4"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_85M1").Offset(1).Formula = "=G4-F4"
    'count_data1 is used to control cell position for data to be input or extract
    count_data1 = Range("count85M1_80").Value - 1
    'The Forecast is the result of Alpha*past cylinder temp + (1-Alpha)*Actual Forecast
    Range("Forecast_85M1").Offset(2).Formula = "= $I$1 * C4 + (1 -$I$1 ) * F4"
    'The trend is the result of Beta * Difference of past forecast + (1-Beta)*Previous Trend
    Range("Trend_85M1").Offset(2).Formula = "=$I$2 * (D5-D4)+ (1 - $I$2) * E4"
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_85M1").Offset(2).Formula = "= D5 + E5"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_85M1").Offset(2).Formula = "=C5"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_85M1").Offset(2).Formula = "= G5 -F5"
    'Counting the position of the last data cell
    LR = Range("count85M1").Value + 3
    'Copy the formula from 2nd row of the cells which contains data to end of the data.
    Range("D5:H5").AutoFill Destination:=Range("D5:H" & LR)

    'This set of data is used for validation purpose. It will highlight the cell in yellow.
    'It copy the previous Actual Forcast value to the new forecast cell. This will repeat till end of
    ‘data and
    'then used to validate the goodness of fit for the model.
    Range("Forecast_85M1").Offset(count_data1 + 2).Value = "=F" & (count_data1 + 4)
    Range("Forecast_85M1").Offset(count_data1 + 2).Interior.Color = RGB(255, 255, 51)
    Range("Forecast_85M1").Offset(count_data1 + 2).Select
    ActiveCell.AutoFill Destination:=Range(ActiveCell.Offset(0, -1), ActiveCell.Offset(0, -
    1).End(xlDown)).Offset(0, 1)

    'Call up Solver tool to obtain minumum value of MSE, and set the Alpha and Beta Values.
    solversolve userfinish:=True

    'Call up Data Analysis Toolpak descriptive statistics
    Application.Run "ATPVBAEN.XLAM!Descr", ActiveSheet.Range("$H$3:$H$1048576" _
    ), ActiveSheet.Range("$K$1"), "C", True, True, , , 95

    'Copying the Actual Forcast result from the model to the "Result for test" worksheet
    Worksheets("Result for test").Activate
    count_result = Application.WorksheetFunction.Count(Range("A5:A1048576"))
    count_pos = Application.WorksheetFunction.Count(Range("D5:D1048576"))
    For i = 1 To (count_result - count_pos)
    Set LookRange = Sheets("85_M1").Range("B4:F1048576")
    arg4 = False
    x = ActiveSheet.Range("Result_Running_hr").Offset(count_pos + i).Value
    Range("Result_Forecast").Offset(count_pos + i) = Application.VLookup(x, LookRange, 5,
    arg4)
    Next i
    Worksheets("Data for test").Activate

End Sub

Sub Model_85M2()
'Model_85M2 is the predictive model for 85% Main Engine Load with running hours from 2001-
‘3000.
'Declaration of variables
Dim count85_M2 As Integer
Dim count_result As Integer
Dim count_pos As Integer
Dim Column_value As Integer
Dim arg1 As Integer, arg3 As Integer
Dim LookRange As Range
Dim arg4 As Boolean
'Column value is used to control cell position for data to be input or extract
```

```
Column_value = 4

    'Copy original data from "Data for test" worksheet to "85_M2" worksheet for model analysis.
    Worksheets("Data for test").Activate
    ActiveSheet.Range("Run_85M2:" &
    ActiveSheet.Range("Temp_85M2").End(xlDown).Address).Offset(1).Select
    Selection.Copy
    Worksheets("85_M2").Activate
    count85_M2 = Application.WorksheetFunction.Count(Range("B4:B1048576"))
    Set Curcell = Worksheets("85_M2").Cells(count85_M2 + Column_value, 2)
    Curcell.PasteSpecial xlPasteValues

    'Set the first forecast value to be the same as the first cylinder temperature value.
    Range("Forecast_85M2").Offset(1).Formula = "=C4"
     'Set the trend to be zero since there is no previous data for trend.
    Range("Trend_85M2").Offset(1) = 0
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_85M2").Offset(1).Formula = "=D4+E4"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_85M2").Offset(1).Formula = "=C4"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_85M2").Offset(1).Formula = "=G4-F4"

    'count_data1 is used to control cell position for data to be input or extract
    count_data1 = Range("count85M2_80").Value - 1
    'The Forecast is the result of Alpha*past cylinder temp + (1-Alpha)*Actual Forecast
    Range("Forecast_85M2").Offset(2).Formula = "= $I$1 * C4 + (1 -$I$1 ) * F4"
    'The trend is the result of Beta * Difference of past forecast + (1-Beta)*Previous Trend
    Range("Trend_85M2").Offset(2).Formula = "=$I$2 * (D5-D4)+ (1 - $I$2) * E4"
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_85M2").Offset(2).Formula = "= D5 + E5"
     'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_85M2").Offset(2).Formula = "=C5"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_85M2").Offset(2).Formula = "= G5 -F5"
    'Counting the position of the last data cell
    LR = Range("count85M2").Value + 3
    'Copy the formula from 2nd row of the cells which contains data to end of the data.
    Range("D5:H5").AutoFill Destination:=Range("D5:H" & LR)

    'This set of data is used for validation purpose. It will highlight the cell in yellow.
    'It copy the previous Actual Forcast value to the new forecast cell. This will repeat till end of
    ‘data and
    'then used to validate the goodness of fit for the model.
    Range("Forecast_85M2").Offset(count_data1 + 2).Value = "=F" & (count_data1 + 4)
    Range("Forecast_85M2").Offset(count_data1 + 2).Interior.Color = RGB(255, 255, 51)
    Range("Forecast_85M2").Offset(count_data1 + 2).Select
    ActiveCell.AutoFill Destination:=Range(ActiveCell.Offset(0, -1), ActiveCell.Offset(0, -
    1).End(xlDown)).Offset(0, 1)

    'Call up Solver tool to obtain minumum value of MSE, and set the Alpha and Beta Values.
    solversolve userfinish:=True

    'Call up Data Analysis Toolpak descriptive statistics
    Application.Run "ATPVBAEN.XLAM!Descr", ActiveSheet.Range("$H$3:$H$1048576" _
        ), ActiveSheet.Range("$K$1"), "C", True, True, , , 95

        'Copying the Actual Forcast result from the model to the "Result for test" worksheet
        Worksheets("Result for test").Activate
        count_result = Application.WorksheetFunction.Count(Range("A5:A1048576"))
        count_pos = Application.WorksheetFunction.Count(Range("D5:D1048576"))
        For i = 1 To (count_result - count_pos)
        Set LookRange = Sheets("85_M2").Range("B4:F1048576")
        arg4 = False
        x = ActiveSheet.Range("Result_Running_hr").Offset(count_pos + i).Value
        Range("Result_Forecast").Offset(count_pos + i) = Application.VLookup(x, LookRange, 5,
        arg4)
        Next i
        Worksheets("Data for test").Activate

End Sub

Sub Model_85M3()

'Model_85M3 is the predictive model for 85% Main Engine Load with running hours from 3001-
‘4000.
'Declaration of variables
Dim count85_M3 As Integer
Dim count_result As Integer
Dim Column_value As Integer
Dim count_pos As Integer
Dim arg1 As Integer, arg3 As Integer
Dim LookRange As Range
Dim arg4 As Boolean
'Column value is used to control cell position for data to be input or extract
Column_value = 4

        'Copy original data from "Data for test" worksheet to "85_M3" worksheet for model analysis.
        Worksheets("Data for test").Activate
        ActiveSheet.Range("Run_85M3:" &
        ActiveSheet.Range("Temp_85M3").End(xlDown).Address).Offset(1).Select
        Selection.Copy
        Worksheets("85_M3").Activate
        count85_M3 = Application.WorksheetFunction.Count(Range("B4:B1048576"))
        Set Curcell = Worksheets("85_M3").Cells(count85_M3 + Column_value, 2)
        Curcell.PasteSpecial xlPasteValues

        'Set the first forecast value to be the same as the first cylinder temperature value.
        Range("Forecast_85M3").Offset(1).Formula = "=C4"
        'Set the trend to be zero since there is no previous data for trend.
        Range("Trend_85M3").Offset(1) = 0
        'The Actual Forecast will be the sum of Forecast and Trend.
        Range("AF_85M3").Offset(1).Formula = "=D4+E4"
        'The Actual Data will be copied over from the data in cylinder temperature cell.
        Range("AD_85M3").Offset(1).Formula = "=C4"
        'The error is the difference between Actual Data and Actual Forecast.
        Range("Error_85M3").Offset(1).Formula = "=G4-F4"

        'count_data1 is used to control cell position for data to be input or extract
        count_data1 = Range("count85M3_80").Value - 1
```

```
    'The Forecast is the result of Alpha*past cylinder temp + (1-Alpha)*Actual Forecast
    Range("Forecast_85M3").Offset(2).Formula = "= $I$1 * C4 + (1 -$I$1 ) * F4"
    'The trend is the result of Beta * Difference of past forecast + (1-Beta)*Previous Trend
    Range("Trend_85M3").Offset(2).Formula = "=$I$2 * (D5-D4)+ (1 - $I$2) * E4"
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_85M3").Offset(2).Formula = "= D5 + E5"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_85M3").Offset(2).Formula = "=C5"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_85M3").Offset(2).Formula = "= G5 -F5"
    'Counting the position of the last data cell
    LR = Range("count85M3").Value + 3
    'Copy the formula from 2nd row of the cells which contains data to end of the data.
    Range("D5:H5").AutoFill Destination:=Range("D5:H" & LR)

    'This set of data is used for validation purpose. It will highlight the cell in yellow.
    'It copy the previous Actual Forcast value to the new forecast cell. This will repeat till end of
    ‘data and
    'then used to validate the goodness of fit for the model.
    Range("Forecast_85M3").Offset(count_data1 + 2).Value = "=F" & (count_data1 + 4)
    Range("Forecast_85M3").Offset(count_data1 + 2).Interior.Color = RGB(255, 255, 51)
    Range("Forecast_85M3").Offset(count_data1 + 2).Select
    ActiveCell.AutoFill Destination:=Range(ActiveCell.Offset(0, -1), ActiveCell.Offset(0, -
    1).End(xlDown)).Offset(0, 1)

    'Call up Solver tool to obtain minumum value of MSE, and set the Alpha and Beta Values.
    solversolve userfinish:=True

    'Call up Data Analysis Toolpak descriptive statistics
    Application.Run "ATPVBAEN.XLAM!Descr", ActiveSheet.Range("$H$3:$H$1048576" _
    ), ActiveSheet.Range("$K$1"), "C", True, True, , , 95

    'Copying the Actual Forcast result from the model to the "Result for test" worksheet
    Worksheets("Result for test").Activate
    count_result = Application.WorksheetFunction.Count(Range("A5:A1048576"))
    count_pos = Application.WorksheetFunction.Count(Range("D5:D1048576"))
    For i = 1 To (count_result - count_pos)
    Set LookRange = Sheets("85_M3").Range("B4:F1048576")
    arg4 = False
    x = ActiveSheet.Range("Result_Running_hr").Offset(count_pos + i).Value
    Range("Result_Forecast").Offset(count_pos + i) = Application.VLookup(x, LookRange, 5,
    arg4)
    Next i
    Worksheets("Data for test").Activate

End Sub

Sub Model_85M4()

'Model_85M4 is the predictive model for 85% Main Engine Load with running hours from 4001-
‘4500.
'Declaration of variables
Dim count85_M4 As Integer
Dim count_result As Integer
Dim Column_value As Integer
Dim count_pos As Integer
Dim arg1 As Integer, arg3 As Integer
Dim LookRange As Range
Dim arg4 As Boolean
'Column value is used to control cell position for data to be input or extract
Column_value = 4

    'Copy original data from "Data for test" worksheet to "85_M4" worksheet for model analysis.
    Worksheets("Data for test").Activate
    ActiveSheet.Range("Run_85M4:" &
    ActiveSheet.Range("Temp_85M4").End(xlDown).Address).Offset(1).Select
    Selection.Copy
    Worksheets("85_M4").Activate
    count85_M4 = Application.WorksheetFunction.Count(Range("B4:B1048576"))
    Set Curcell = Worksheets("85_M4").Cells(count85_M4 + Column_value, 2)
    Curcell.PasteSpecial xlPasteValues

    'Set the first forecast value to be the same as the first cylinder temperature value.
    Range("Forecast_85M4").Offset(1).Formula = "=C4"
    'Set the trend to be zero since there is no previous data for trend.
    Range("Trend_85M4").Offset(1) = 0
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_85M4").Offset(1).Formula = "=D4+E4"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_85M4").Offset(1).Formula = "=C4"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_85M4").Offset(1).Formula = "=G4-F4"

    'count_data1 is used to control cell position for data to be input or extract
    count_data1 = Range("count85M4_80").Value - 1
    'The Forecast is the result of Alpha*past cylinder temp + (1-Alpha)*Actual Forecast
    Range("Forecast_85M4").Offset(2).Formula = "= $I$1 * C4 + (1 -$I$1 ) * F4"
    'The trend is the result of Beta * Difference of past forecast + (1-Beta)*Previous Trend
    Range("Trend_85M4").Offset(2).Formula = "=$I$2 * (D5-D4)+ (1 - $I$2) * E4"
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_85M4").Offset(2).Formula = "= D5 + E5"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_85M4").Offset(2).Formula = "=C5"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_85M4").Offset(2).Formula = "= G5 -F5"
    'Counting the position of the last data cell
    LR = Range("count85M4").Value + 3
    'Copy the formula from 2nd row of the cells which contains data to end of the data.
    Range("D5:H5").AutoFill Destination:=Range("D5:H" & LR)

    'This set of data is used for validation purpose. It will highlight the cell in yellow.
    'It copy the previous Actual Forcast value to the new forecast cell. This will repeat till end of
    ‘data and
    'then used to validate the goodness of fit for the model.
    Range("Forecast_85M4").Offset(count_data1 + 2).Value = "=F" & (count_data1 + 4)
    Range("Forecast_85M4").Offset(count_data1 + 2).Interior.Color = RGB(255, 255, 51)
    Range("Forecast_85M4").Offset(count_data1 + 2).Select
    ActiveCell.AutoFill Destination:=Range(ActiveCell.Offset(0, -1), ActiveCell.Offset(0, -
    1).End(xlDown)).Offset(0, 1)
    'Call up Solver tool to obtain minumum value of MSE, and set the Alpha and Beta Values.
    solversolve userfinish:=True

    'Call up Data Analysis Toolpak descriptive statistics
    Application.Run "ATPVBAEN.XLAM!Descr", ActiveSheet.Range("$H$3:$H$1048576" _
    ), ActiveSheet.Range("$K$1"), "C", True, True, , , 95

    'Copying the Actual Forcast result from the model to the "Result for test" worksheet
    Worksheets("Result for test").Activate
    count_result = Application.WorksheetFunction.Count(Range("A5:A1048576"))
    count_pos = Application.WorksheetFunction.Count(Range("D5:D1048576"))
    For i = 1 To (count_result - count_pos)
    Set LookRange = Sheets("85_M4").Range("B4:F1048576")
    arg4 = False
    x = ActiveSheet.Range("Result_Running_hr").Offset(count_pos + i).Value
    Range("Result_Forecast").Offset(count_pos + i) = Application.VLookup(x, LookRange, 5,
    arg4)
    Next i
    Worksheets("Data for test").Activate

End Sub

Sub Model_85M5()

'Model_85M5 is the predictive model for 85% Main Engine Load with running hours from 4501-
‘5000.
'Declaration of variables
Dim count85_M5 As Integer
Dim count_result As Integer
Dim Column_value As Integer
Dim count_pos As Integer
Dim arg1 As Integer, arg3 As Integer
Dim LookRange As Range
Dim arg4 As Boolean
'Column value is used to control cell position for data to be input or extract
Column_value = 4

    'Copy original data from "Data for test" worksheet to "85_M5" worksheet for model analysis.
    Worksheets("Data for test").Activate
    ActiveSheet.Range("Run_85M5:" &
    ActiveSheet.Range("Temp_85M5").End(xlDown).Address).Offset(1).Select
    Selection.Copy
    Worksheets("85_M5").Activate
    count85_M5 = Application.WorksheetFunction.Count(Range("B4:B1048576"))
    Set Curcell = Worksheets("85_M5").Cells(count85_M5 + Column_value, 2)
    Curcell.PasteSpecial xlPasteValues

    'Getting the average of the previous two values
    Range("MA_85").Offset(3).Formula = "=Average(C4:C5)"
    'Finding the position for the last data
    LR = Range("count85M5").Value + 3
    'Copy the formula to the end of the data.
    Range("D6").AutoFill Destination:=Range("D6:D" & LR)

     'Set the first forecast value to be the same as the first moving average temperature value.
```

```
Range("Forecast_85M5").Offset(1).Formula = "=D4"
Range("Forecast_85M5").Offset(2).Formula = "=D5"
Range("Forecast_85M5").Offset(3).Formula = "=D6"
'Set the trend to be zero since there is no previous data for trend.
Range("Trend_85M5").Offset(1) = 0
Range("Trend_85M5").Offset(2) = 0
Range("Trend_85M5").Offset(3) = 0
'The Actual Forecast will be the sum of Forecast and Trend.
Range("AF_85M5").Offset(1).Formula = "=E6+F6"
Range("AF_85M5").Offset(2).Formula = "=E6+F6"
Range("AF_85M5").Offset(3).Formula = "=E6+F6"
 'The Actual Data will be copied over from the data in cylinder temperature cell.
Range("AD_85M5").Offset(1).Formula = "=C6"
Range("AD_85M5").Offset(2).Formula = "=C6"
Range("AD_85M5").Offset(3).Formula = "=C6"
 'The error is the difference between Actual Data and Actual Forecast.
Range("Error_85M5").Offset(1).Formula = "=H6-G6"
Range("Error_85M5").Offset(2).Formula = "=H6-G6"
Range("Error_85M5").Offset(3).Formula = "=H6-G6"

'count_data1 is used to control cell position for data to be input or extract
count_data1 = Range("count85M5_80").Value - 1
'The Forecast is the result of Alpha*past MA cylinder temp + (1-Alpha)*Actual Forecast
Range("Forecast_85M5").Offset(4).Formula = "= $J$1 * D6 + (1 -$J$1 ) * G6"
'The trend is the result of Beta * Difference of past forecast + (1-Beta)*Previous Trend
Range("Trend_85M5").Offset(4).Formula = "=$J$2 * (E7-E6)+ (1 - $J$2) * E6"
'The Actual Forecast will be the sum of Forecast and Trend.
Range("AF_85M5").Offset(4).Formula = "= E7 + F7"
 'The Actual Data will be copied over from the data in cylinder temperature cell.
Range("AD_85M5").Offset(4).Formula = "=C7"
 'The error is the difference between Actual Data and Actual Forecast.
Range("Error_85M5").Offset(4).Formula = "= H7 -G7"
'Counting the position of the last data cell
LR = Range("count85M5").Value + 3
'Copy the formula from 2nd row of the cells which contains data to end of the data.
Range("E7:I7").AutoFill Destination:=Range("E7:I" & LR)

'This set of data is used for validation purpose. It will highlight the cell in yellow.
'It copy the previous Actual Forcast value to the new forecast cell. This will repeat till end of
‘data and
'then used to validate the goodness of fit for the model.
Range("Forecast_85M5").Offset(count_data1 + 2).Value = "=G" & (count_data1 + 4)
Range("Forecast_85M5").Offset(count_data1 + 2).Interior.Color = RGB(255, 255, 51)
Range("Forecast_85M5").Offset(count_data1 + 2).Select
ActiveCell.AutoFill Destination:=Range(ActiveCell.Offset(0, -1), ActiveCell.Offset(0, -
1).End(xlDown)).Offset(0, 1)

'Call up Solver tool to obtain minumum value of MSE, and set the Alpha and Beta Values.
solversolve userfinish:=True

'Call up Data Analysis Toolpak descriptive statistics
Application.Run "ATPVBAEN.XLAM!Descr", ActiveSheet.Range("$I$3:$I$1048576" _
), ActiveSheet.Range("$K$1"), "C", True, True, , , 95

'Copying the Actual Forcast result from the model to the "Result for test" worksheet
```

```
    Worksheets("Result for test").Activate
    count_result = Application.WorksheetFunction.Count(Range("A5:A1048576"))
    count_pos = Application.WorksheetFunction.Count(Range("D5:D1048576"))
    For i = 1 To (count_result - count_pos)
    Set LookRange = Sheets("85_M5").Range("B4:G1048576")
    arg4 = False
    x = ActiveSheet.Range("Result_Running_hr").Offset(count_pos + i).Value
    Range("Result_Forecast").Offset(count_pos + i) = Application.VLookup(x, LookRange, 6,
    arg4)
    Next i
    Worksheets("Data for test").Activate


End Sub
Sub Model_90M1()
'Model_90M1 is the predictive model for 90% Main Engine Load with running hours from 1-
‘2000.
'Declaration of variables
Dim count90_M1 As Integer
Dim count_result As Integer
Dim Column_value As Integer
Dim count_pos As Integer
Dim arg1 As Integer, arg3 As Integer
Dim LookRange As Range
Dim arg4 As Boolean
'Column value is used to control cell position for data to be input or extract
Column_value = 4

    'Copy original data from "Data for test" worksheet to "90_M1" worksheet for model analysis.
    Worksheets("Data for test").Activate
    ActiveSheet.Range("Run_90M1:" &
    ActiveSheet.Range("Temp_90M1").End(xlDown).Address).Offset(1).Select
    Selection.Copy
    Worksheets("90_M1").Activate
    count90_M1 = Application.WorksheetFunction.Count(Range("B4:B1048576"))
    Set Curcell = Worksheets("90_M1").Cells(count90_M1 + Column_value, 2)
    Curcell.PasteSpecial xlPasteValues

    'Set the first forecast value to be the same as the first cylinder temperature value.
    Range("Forecast_90M1").Offset(1).Formula = "=C4"
    'Set the trend to be zero since there is no previous data for trend.
    Range("Trend_90M1").Offset(1) = 0
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_90M1").Offset(1).Formula = "=D4+E4"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_90M1").Offset(1).Formula = "=C4"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_90M1").Offset(1).Formula = "=G4-F4"

    'count_data1 is used to control cell position for data to be input or extract
    count_data1 = Range("count90M1_80").Value - 1
    'The Forecast is the result of Alpha*past cylinder temp + (1-Alpha)*Actual Forecast
    Range("Forecast_90M1").Offset(2).Formula = "= $I$1 * C4 + (1 -$I$1 ) * F4"
    'The trend is the result of Beta * Difference of past forecast + (1-Beta)*Previous Trend
    Range("Trend_90M1").Offset(2).Formula = "=$I$2 * (D5-D4)+ (1 - $I$2) * E4"
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_90M1").Offset(2).Formula = "= D5 + E5"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_90M1").Offset(2).Formula = "=C5"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_90M1").Offset(2).Formula = "= G5 -F5"
    'Counting the position of the last data cell
    LR = Range("count90M1").Value + 3
    'Copy the formula from 2nd row of the cells which contains data to end of the data.
    Range("D5:H5").AutoFill Destination:=Range("D5:H" & LR)

    'This set of data is used for validation purpose. It will highlight the cell in yellow.
    'It copy the previous Actual Forcast value to the new forecast cell. This will repeat till end of
    ‘data and
    'then used to validate the goodness of fit for the model.
    Range("Forecast_90M1").Offset(count_data1 + 2).Value = "=F" & (count_data1 + 4)
    Range("Forecast_90M1").Offset(count_data1 + 2).Interior.Color = RGB(255, 255, 51)
    Range("Forecast_90M1").Offset(count_data1 + 2).Select
    ActiveCell.AutoFill Destination:=Range(ActiveCell.Offset(0, -1), ActiveCell.Offset(0, -
    1).End(xlDown)).Offset(0, 1)

    'Call up Solver tool to obtain minumum value of MSE, and set the Alpha and Beta Values.
    solversolve userfinish:=True

    'Call up Data Analysis Toolpak descriptive statistics
    Application.Run "ATPVBAEN.XLAM!Descr", ActiveSheet.Range("$H$3:$H$1048576" _
    ), ActiveSheet.Range("$K$1"), "C", True, True, , , 95

    'Copying the Actual Forcast result from the model to the "Result for test" worksheet
    Worksheets("Result for test").Activate
    count_result = Application.WorksheetFunction.Count(Range("A5:A1048576"))
    count_pos = Application.WorksheetFunction.Count(Range("D5:D1048576"))
    For i = 1 To (count_result - count_pos)
    Set LookRange = Sheets("90_M1").Range("B4:F1048576")
    arg4 = False
    x = ActiveSheet.Range("Result_Running_hr").Offset(count_pos + i).Value
    Range("Result_Forecast").Offset(count_pos + i) = Application.VLookup(x, LookRange, 5,
    arg4)
    Next i
    Worksheets("Data for test").Activate

End Sub

Sub Model_90M2()
'Model_90M2 is the predictive model for 90% Main Engine Load with running hours from 2001-
‘3000.
'Declaration of variables
Dim count90_M2 As Integer
Dim count_result As Integer
Dim Column_value As Integer
Dim count_pos As Integer
Dim arg1 As Integer, arg3 As Integer
Dim LookRange As Range
Dim arg4 As Boolean
'Column value is used to control cell position for data to be input or extract
```

```
Column_value = 4

    'Copy original data from "Data for test" worksheet to "90_M2" worksheet for model analysis.
    Worksheets("Data for test").Activate
    ActiveSheet.Range("Run_90M2:" &
    ActiveSheet.Range("Temp_90M2").End(xlDown).Address).Offset(1).Select
    Selection.Copy
    Worksheets("90_M2").Activate
    count90_M2 = Application.WorksheetFunction.Count(Range("B4:B1048576"))
    Set Curcell = Worksheets("90_M2").Cells(count90_M2 + Column_value, 2)
    Curcell.PasteSpecial xlPasteValues

    'Set the first forecast value to be the same as the first cylinder temperature value.
    Range("Forecast_90M2").Offset(1).Formula = "=C4"
     'Set the trend to be zero since there is no previous data for trend.
    Range("Trend_90M2").Offset(1) = 0
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_90M2").Offset(1).Formula = "=D4+E4"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_90M2").Offset(1).Formula = "=C4"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_90M2").Offset(1).Formula = "=G4-F4"

    'count_data1 is used to control cell position for data to be input or extract
    count_data1 = Range("count90M2_80").Value - 1
    'The Forecast is the result of Alpha*past cylinder temp + (1-Alpha)*Actual Forecast
    Range("Forecast_90M2").Offset(2).Formula = "= $I$1 * C4 + (1 -$I$1 ) * F4"
    'The trend is the result of Beta * Difference of past forecast + (1-Beta)*Previous Trend
    Range("Trend_90M2").Offset(2).Formula = "=$I$2 * (D5-D4)+ (1 - $I$2) * E4"
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_90M2").Offset(2).Formula = "= D5 + E5"
     'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_90M2").Offset(2).Formula = "=C5"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_90M2").Offset(2).Formula = "= G5 -F5"
    'Counting the position of the last data cell
    LR = Range("count90M2").Value + 3
    'Copy the formula from 2nd row of the cells which contains data to end of the data.
    Range("D5:H5").AutoFill Destination:=Range("D5:H" & LR)

    'This set of data is used for validation purpose. It will highlight the cell in yellow.
    'It copy the previous Actual Forcast value to the new forecast cell. This will repeat till end of
    ‘data and
    'then used to validate the goodness of fit for the model.
    Range("Forecast_90M2").Offset(count_data1 + 2).Value = "=F" & (count_data1 + 4)
    Range("Forecast_90M2").Offset(count_data1 + 2).Interior.Color = RGB(255, 255, 51)
    Range("Forecast_90M2").Offset(count_data1 + 2).Select
    ActiveCell.AutoFill Destination:=Range(ActiveCell.Offset(0, -1), ActiveCell.Offset(0, -
    1).End(xlDown)).Offset(0, 1)

    'Call up Solver tool to obtain minumum value of MSE, and set the Alpha and Beta Values.
    solversolve userfinish:=True

    'Call up Data Analysis Toolpak descriptive statistics
    Application.Run "ATPVBAEN.XLAM!Descr", ActiveSheet.Range("$H$3:$H$1048576" _
    ), ActiveSheet.Range("$K$1"), "C", True, True, , , 95

    'Copying the Actual Forcast result from the model to the "Result for test" worksheet
    Worksheets("Result for test").Activate
    count_result = Application.WorksheetFunction.Count(Range("A5:A1048576"))
    count_pos = Application.WorksheetFunction.Count(Range("D5:D1048576"))
    For i = 1 To (count_result - count_pos)
    Set LookRange = Sheets("90_M2").Range("B4:F1048576")
    arg4 = False
    x = ActiveSheet.Range("Result_Running_hr").Offset(count_pos + i).Value
    Range("Result_Forecast").Offset(count_pos + i) = Application.VLookup(x, LookRange, 5,
    arg4)
    Next i
    Worksheets("Data for test").Activate

End Sub

Sub Model_90M3()

'Model_90M3 is the predictive model for 90% Main Engine Load with running hours from 3001-
‘4000.
'Declaration of variables
Dim count90_M3 As Integer
Dim count_result As Integer
Dim Column_value As Integer
Dim count_pos As Integer
Dim arg1 As Integer, arg3 As Integer
Dim LookRange As Range
Dim arg4 As Boolean
'Column value is used to control cell position for data to be input or extract
Column_value = 4

    'Copy original data from "Data for test" worksheet to "90_M3" worksheet for model analysis.
    Worksheets("Data for test").Activate
    ActiveSheet.Range("Run_90M3:" &
    ActiveSheet.Range("Temp_90M3").End(xlDown).Address).Offset(1).Select
    Selection.Copy
    Worksheets("90_M3").Activate
    count90_M3 = Application.WorksheetFunction.Count(Range("B4:B1048576"))
    Set Curcell = Worksheets("90_M3").Cells(count90_M3 + Column_value, 2)
    Curcell.PasteSpecial xlPasteValues

    'Set the first forecast value to be the same as the first cylinder temperature value.
    Range("Forecast_90M3").Offset(1).Formula = "=C4"
    'Set the trend to be zero since there is no previous data for trend.
    Range("Trend_90M3").Offset(1) = 0
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_90M3").Offset(1).Formula = "=D4+E4"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_90M3").Offset(1).Formula = "=C4"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_90M3").Offset(1).Formula = "=G4-F4"

    'count_data1 is used to control cell position for data to be input or extract
    count_data1 = Range("count90M3_80").Value - 1
    'The Forecast is the result of Alpha*past cylinder temp + (1-Alpha)*Actual Forecast
    Range("Forecast_90M3").Offset(2).Formula = "= $I$1 * C4 + (1 -$I$1 ) * F4"
    'The trend is the result of Beta * Difference of past forecast + (1-Beta)*Previous Trend
    Range("Trend_90M3").Offset(2).Formula = "=$I$2 * (D5-D4)+ (1 - $I$2) * E4"
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_90M3").Offset(2).Formula = "= D5 + E5"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_90M3").Offset(2).Formula = "=C5"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_90M3").Offset(2).Formula = "= G5 -F5"
    'Counting the position of the last data cell
    LR = Range("count90M3").Value + 3
    'Copy the formula from 2nd row of the cells which contains data to end of the data.
    Range("D5:H5").AutoFill Destination:=Range("D5:H" & LR)

    'This set of data is used for validation purpose. It will highlight the cell in yellow.
    'It copy the previous Actual Forcast value to the new forecast cell. This will repeat till end of
    ‘data and
    'then used to validate the goodness of fit for the model.
    Range("Forecast_90M3").Offset(count_data1 + 2).Value = "=F" & (count_data1 + 4)
    Range("Forecast_90M3").Offset(count_data1 + 2).Interior.Color = RGB(255, 255, 51)
    Range("Forecast_90M3").Offset(count_data1 + 2).Select
    ActiveCell.AutoFill Destination:=Range(ActiveCell.Offset(0, -1), ActiveCell.Offset(0, -
    1).End(xlDown)).Offset(0, 1)

    'Call up Solver tool to obtain minumum value of MSE, and set the Alpha and Beta Values.
    solversolve userfinish:=True

    'Call up Data Analysis Toolpak descriptive statistics
    Application.Run "ATPVBAEN.XLAM!Descr", ActiveSheet.Range("$H$3:$H$1048576" _
    ), ActiveSheet.Range("$K$1"), "C", True, True, , , 95

    'Copying the Actual Forcast result from the model to the "Result for test" worksheet
    Worksheets("Result for test").Activate
    count_result = Application.WorksheetFunction.Count(Range("A5:A1048576"))
    count_pos = Application.WorksheetFunction.Count(Range("D5:D1048576"))
    For i = 1 To (count_result - count_pos)
    Set LookRange = Sheets("90_M3").Range("B4:F1048576")
    arg4 = False
    x = ActiveSheet.Range("Result_Running_hr").Offset(count_pos + i).Value
    Range("Result_Forecast").Offset(count_pos + i) = Application.VLookup(x, LookRange, 5,
    arg4)
    Next i
    Worksheets("Data for test").Activate

End Sub

Sub Model_90M4()

'Model_90M4 is the predictive model for 90% Main Engine Load with running hours from 4001-
‘4500.
'Declaration of variables
Dim count90_M4 As Integer
Dim count_result As Integer
Dim Column_value As Integer
Dim count_pos As Integer
Dim arg1 As Integer, arg3 As Integer
Dim LookRange As Range
Dim arg4 As Boolean
'Column value is used to control cell position for data to be input or extract
Column_value = 4

    'Copy original data from "Data for test" worksheet to "90_M4" worksheet for model analysis.
    Worksheets("Data for test").Activate
    ActiveSheet.Range("Run_90M4:" &
    ActiveSheet.Range("Temp_90M4").End(xlDown).Address).Offset(1).Select
    Selection.Copy
    Worksheets("90_M4").Activate
    count90_M4 = Application.WorksheetFunction.Count(Range("B4:B1048576"))
    Set Curcell = Worksheets("90_M4").Cells(count90_M4 + Column_value, 2)
    Curcell.PasteSpecial xlPasteValues

    'Set the first forecast value to be the same as the first cylinder temperature value.
    Range("Forecast_90M4").Offset(1).Formula = "=C4"
    'Set the trend to be zero since there is no previous data for trend.
    Range("Trend_90M4").Offset(1) = 0
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_90M4").Offset(1).Formula = "=D4+E4"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_90M4").Offset(1).Formula = "=C4"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_90M4").Offset(1).Formula = "=G4-F4"

    'count_data1 is used to control cell position for data to be input or extract
    count_data1 = Range("count90M4_80").Value - 1
    'The Forecast is the result of Alpha*past cylinder temp + (1-Alpha)*Actual Forecast
    Range("Forecast_90M4").Offset(2).Formula = "= $I$1 * C4 + (1 -$I$1 ) * F4"
    'The trend is the result of Beta * Difference of past forecast + (1-Beta)*Previous Trend
    Range("Trend_90M4").Offset(2).Formula = "=$I$2 * (D5-D4)+ (1 - $I$2) * E4"
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_90M4").Offset(2).Formula = "= D5 + E5"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_90M4").Offset(2).Formula = "=C5"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_90M4").Offset(2).Formula = "= G5 -F5"
    'Counting the position of the last data cell
    LR = Range("count90M4").Value + 3
    'Copy the formula from 2nd row of the cells which contains data to end of the data.
    Range("D5:H5").AutoFill Destination:=Range("D5:H" & LR)

    'This set of data is used for validation purpose. It will highlight the cell in yellow.
    'It copy the previous Actual Forcast value to the new forecast cell. This will repeat till end of
    ‘data and
    'then used to validate the goodness of fit for the model.
    Range("Forecast_90M4").Offset(count_data1 + 2).Value = "=F" & (count_data1 + 4)
    Range("Forecast_90M4").Offset(count_data1 + 2).Interior.Color = RGB(255, 255, 51)
    Range("Forecast_90M4").Offset(count_data1 + 2).Select
    ActiveCell.AutoFill Destination:=Range(ActiveCell.Offset(0, -1), ActiveCell.Offset(0, -
    1).End(xlDown)).Offset(0, 1)
    'Call up Solver tool to obtain minumum value of MSE, and set the Alpha and Beta Values.
    solversolve userfinish:=True

    'Call up Data Analysis Toolpak descriptive statistics
    Application.Run "ATPVBAEN.XLAM!Descr", ActiveSheet.Range("$H$3:$H$1048576" _
    ), ActiveSheet.Range("$K$1"), "C", True, True, , , 95

    'Copying the Actual Forcast result from the model to the "Result for test" worksheet
    Worksheets("Result for test").Activate
    count_result = Application.WorksheetFunction.Count(Range("A5:A1048576"))
    count_pos = Application.WorksheetFunction.Count(Range("D5:D1048576"))
    For i = 1 To (count_result - count_pos)
    Set LookRange = Sheets("90_M4").Range("B4:F1048576")
    arg4 = False
    x = ActiveSheet.Range("Result_Running_hr").Offset(count_pos + i).Value
    Range("Result_Forecast").Offset(count_pos + i) = Application.VLookup(x, LookRange, 5,
    arg4)
    Next i
    Worksheets("Data for test").Activate

End Sub

Sub Model_90M5()

'Model_90M5 is the predictive model for 90% Main Engine Load with running hours from 4501-
‘5000.
'Declaration of variables
Dim count90_M5 As Integer
Dim count_result As Integer
Dim Column_value As Integer
Dim count_pos As Integer
Dim arg1 As Integer, arg3 As Integer
Dim LookRange As Range
Dim arg4 As Boolean
'Column value is used to control cell position for data to be input or extract
Column_value = 4

    'Copy original data from "Data for test" worksheet to "90_M5" worksheet for model analysis.
    Worksheets("Data for test").Activate
    ActiveSheet.Range("Run_90M5:" &
    ActiveSheet.Range("Temp_90M5").End(xlDown).Address).Offset(1).Select
    Selection.Copy
    Worksheets("90_M5").Activate
    count90_M5 = Application.WorksheetFunction.Count(Range("B4:B1048576"))
    Set Curcell = Worksheets("90_M5").Cells(count90_M5 + Column_value, 2)
    Curcell.PasteSpecial xlPasteValues

    'Getting the average of the previous two values
    Range("MA_90").Offset(3).Formula = "=Average(C4:C5)"
    'Finding the position for the last data
    LR = Range("count90M5").Value + 3
    'Copy the formula to the end of the data.
    Range("D6").AutoFill Destination:=Range("D6:D" & LR)
```

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'Set the first forecast value to be the same as the first moving average temperature value.
Range("Forecast_90M5").Offset(1).Formula = "=D4"
Range("Forecast_90M5").Offset(2).Formula = "=D5"
Range("Forecast_90M5").Offset(3).Formula = "=D6"
'Set the trend to be zero since there is no previous data for trend.
Range("Trend_90M5").Offset(1) = 0
Range("Trend_90M5").Offset(2) = 0
Range("Trend_90M5").Offset(3) = 0
'The Actual Forecast will be the sum of Forecast and Trend.
Range("AF_90M5").Offset(1).Formula = "=E6+F6"
Range("AF_90M5").Offset(2).Formula = "=E6+F6"
Range("AF_90M5").Offset(3).Formula = "=E6+F6"
 'The Actual Data will be copied over from the data in cylinder temperature cell.
Range("AD_90M5").Offset(1).Formula = "=C6"
Range("AD_90M5").Offset(2).Formula = "=C6"
Range("AD_90M5").Offset(3).Formula = "=C6"
 'The error is the difference between Actual Data and Actual Forecast.
Range("Error_90M5").Offset(1).Formula = "=H6-G6"
Range("Error_90M5").Offset(2).Formula = "=H6-G6"
Range("Error_90M5").Offset(3).Formula = "=H6-G6"

'count_data1 is used to control cell position for data to be input or extract
count_data1 = Range("count90M5_80").Value - 1
'The Forecast is the result of Alpha*past MA cylinder temp + (1-Alpha)*Actual Forecast
Range("Forecast_90M5").Offset(4).Formula = "= $J$1 * D6 + (1 -$J$1 ) * G6"
'The trend is the result of Beta * Difference of past forecast + (1-Beta)*Previous Trend
Range("Trend_90M5").Offset(4).Formula = "=$J$2 * (E7-E6)+ (1 - $J$2) * E6"
'The Actual Forecast will be the sum of Forecast and Trend.
Range("AF_90M5").Offset(4).Formula = "= E7 + F7"
 'The Actual Data will be copied over from the data in cylinder temperature cell.
Range("AD_90M5").Offset(4).Formula = "=C7"
 'The error is the difference between Actual Data and Actual Forecast.
Range("Error_90M5").Offset(4).Formula = "= H7 -G7"
'Counting the position of the last data cell
LR = Range("count90M5").Value + 3
'Copy the formula from 2nd row of the cells which contains data to end of the data.
Range("E7:I7").AutoFill Destination:=Range("E7:I" & LR)

'This set of data is used for validation purpose. It will highlight the cell in yellow.
'It copy the previous Actual Forcast value to the new forecast cell. This will repeat till end of
‘data and
'then used to validate the goodness of fit for the model.
Range("Forecast_90M5").Offset(count_data1 + 2).Value = "=G" & (count_data1 + 4)
Range("Forecast_90M5").Offset(count_data1 + 2).Interior.Color = RGB(255, 255, 51)
Range("Forecast_90M5").Offset(count_data1 + 2).Select
ActiveCell.AutoFill Destination:=Range(ActiveCell.Offset(0, -1), ActiveCell.Offset(0, -
1).End(xlDown)).Offset(0, 1)

'Call up Solver tool to obtain minumum value of MSE, and set the Alpha and Beta Values.
solversolve userfinish:=True

'Call up Data Analysis Toolpak descriptive statistics
Application.Run "ATPVBAEN.XLAM!Descr", ActiveSheet.Range("$I$3:$I$1048576" _
), ActiveSheet.Range("$K$1"), "C", True, True, , , 95
```

```
    'Copying the Actual Forcast result from the model to the "Result for test" worksheet
    Worksheets("Result for test").Activate
    count_result = Application.WorksheetFunction.Count(Range("A5:A1048576"))
    count_pos = Application.WorksheetFunction.Count(Range("D5:D1048576"))
    For i = 1 To (count_result - count_pos)
    Set LookRange = Sheets("90_M5").Range("B4:G1048576")
    arg4 = False
    x = ActiveSheet.Range("Result_Running_hr").Offset(count_pos + i).Value
    Range("Result_Forecast").Offset(count_pos + i) = Application.VLookup(x, LookRange, 6,
    arg4)
    Next i
    Worksheets("Data for test").Activate

End Sub

Sub Model_100M1()
'Model_100M1 is the predictive model for 100% Main Engine Load with running hours from 1-
‘2000.
'Declaration of variables
Dim count100_M1 As Integer
Dim count_result As Integer
Dim Column_value As Integer
Dim count_pos As Integer
Dim arg1 As Integer, arg3 As Integer
Dim LookRange As Range
Dim arg4 As Boolean
'Column value is used to control cell position for data to be input or extract
Column_value = 4

    'Copy original data from "Data for test" worksheet to "100_M1" worksheet for model
    ‘analysis.
    Worksheets("Data for test").Activate
    ActiveSheet.Range("Run_100M1:" &
    ActiveSheet.Range("Temp_100M1").End(xlDown).Address).Offset(1).Select
    Selection.Copy
    Worksheets("100_M1").Activate
    count100_M1 = Application.WorksheetFunction.Count(Range("B4:B1048576"))
    Set Curcell = Worksheets("100_M1").Cells(count100_M1 + Column_value, 2)
    Curcell.PasteSpecial xlPasteValues

    'Set the first forecast value to be the same as the first cylinder temperature value.
    Range("Forecast_100M1").Offset(1).Formula = "=C4"
    'Set the trend to be zero since there is no previous data for trend.
    Range("Trend_100M1").Offset(1) = 0
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_100M1").Offset(1).Formula = "=D4+E4"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_100M1").Offset(1).Formula = "=C4"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_100M1").Offset(1).Formula = "=G4-F4"

    'count_data1 is used to control cell position for data to be input or extract
    count_data1 = Range("count100M1_80").Value - 1
    'The Forecast is the result of Alpha*past cylinder temp + (1-Alpha)*Actual Forecast
    Range("Forecast_100M1").Offset(2).Formula = "= $I$1 * C4 + (1 -$I$1 ) * F4"
    'The trend is the result of Beta * Difference of past forecast + (1-Beta)*Previous Trend
    Range("Trend_100M1").Offset(2).Formula = "=$I$2 * (D5-D4)+ (1 - $I$2) * E4"
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_100M1").Offset(2).Formula = "= D5 + E5"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_100M1").Offset(2).Formula = "=C5"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_100M1").Offset(2).Formula = "= G5 -F5"
    'Counting the position of the last data cell
    LR = Range("count100M1").Value + 3
    'Copy the formula from 2nd row of the cells which contains data to end of the data.
    Range("D5:H5").AutoFill Destination:=Range("D5:H" & LR)

    'This set of data is used for validation purpose. It will highlight the cell in yellow.
    'It copy the previous Actual Forcast value to the new forecast cell. This will repeat till end of
    ‘data and
    'then used to validate the goodness of fit for the model.
    Range("Forecast_100M1").Offset(count_data1 + 2).Value = "=F" & (count_data1 + 4)
    Range("Forecast_100M1").Offset(count_data1 + 2).Interior.Color = RGB(255, 255, 51)
    Range("Forecast_100M1").Offset(count_data1 + 2).Select
    ActiveCell.AutoFill Destination:=Range(ActiveCell.Offset(0, -1), ActiveCell.Offset(0, -
    1).End(xlDown)).Offset(0, 1)

    'Call up Solver tool to obtain minumum value of MSE, and set the Alpha and Beta Values.
    solversolve userfinish:=True

    'Call up Data Analysis Toolpak descriptive statistics
    Application.Run "ATPVBAEN.XLAM!Descr", ActiveSheet.Range("$H$3:$H$1048576" _
    ), ActiveSheet.Range("$K$1"), "C", True, True, , , 95

    'Copying the Actual Forcast result from the model to the "Result for test" worksheet
    Worksheets("Result for test").Activate
    count_result = Application.WorksheetFunction.Count(Range("A5:A1048576"))
    count_pos = Application.WorksheetFunction.Count(Range("D5:D1048576"))
    For i = 1 To (count_result - count_pos)
    Set LookRange = Sheets("100_M1").Range("B4:F1048576")
    arg4 = False
    x = ActiveSheet.Range("Result_Running_hr").Offset(count_pos + i).Value
    Range("Result_Forecast").Offset(count_pos + i) = Application.VLookup(x, LookRange, 5,
    arg4)
    Next i
    Worksheets("Data for test").Activate
End Sub

Sub Model_100M2()
'Model_100M2 is the predictive model for 100% Main Engine Load with running hours from
‘2001-3000.
'Declaration of variables
Dim count100_M2 As Integer
Dim count_result As Integer
Dim Column_value As Integer
Dim count_pos As Integer
Dim arg1 As Integer, arg3 As Integer
Dim LookRange As Range
Dim arg4 As Boolean
```

```
'Column value is used to control cell position for data to be input or extract
Column_value = 4

    'Copy original data from "Data for test" worksheet to "100_M2" worksheet for model
    ‘analysis.
    Worksheets("Data for test").Activate
    ActiveSheet.Range("Run_100M2:" &
    ActiveSheet.Range("Temp_100M2").End(xlDown).Address).Offset(1).Select
    Selection.Copy
    Worksheets("100_M2").Activate
    count100_M2 = Application.WorksheetFunction.Count(Range("B4:B1048576"))
    Set Curcell = Worksheets("100_M2").Cells(count100_M2 + Column_value, 2)
    Curcell.PasteSpecial xlPasteValues

    'Set the first forecast value to be the same as the first cylinder temperature value.
    Range("Forecast_100M2").Offset(1).Formula = "=C4"
     'Set the trend to be zero since there is no previous data for trend.
    Range("Trend_100M2").Offset(1) = 0
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_100M2").Offset(1).Formula = "=D4+E4"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_100M2").Offset(1).Formula = "=C4"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_100M2").Offset(1).Formula = "=G4-F4"

    'count_data1 is used to control cell position for data to be input or extract
    count_data1 = Range("count100M2_80").Value - 1
    'The Forecast is the result of Alpha*past cylinder temp + (1-Alpha)*Actual Forecast
    Range("Forecast_100M2").Offset(2).Formula = "= $I$1 * C4 + (1 -$I$1 ) * F4"
    'The trend is the result of Beta * Difference of past forecast + (1-Beta)*Previous Trend
    Range("Trend_100M2").Offset(2).Formula = "=$I$2 * (D5-D4)+ (1 - $I$2) * E4"
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_100M2").Offset(2).Formula = "= D5 + E5"
     'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_100M2").Offset(2).Formula = "=C5"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_100M2").Offset(2).Formula = "= G5 -F5"
    'Counting the position of the last data cell
    LR = Range("count100M2").Value + 3
    'Copy the formula from 2nd row of the cells which contains data to end of the data.
    Range("D5:H5").AutoFill Destination:=Range("D5:H" & LR)

    'This set of data is used for validation purpose. It will highlight the cell in yellow.
    'It copy the previous Actual Forcast value to the new forecast cell. This will repeat till end of
    ‘data and
    'then used to validate the goodness of fit for the model.
    Range("Forecast_100M2").Offset(count_data1 + 2).Value = "=F" & (count_data1 + 4)
    Range("Forecast_100M2").Offset(count_data1 + 2).Interior.Color = RGB(255, 255, 51)
    Range("Forecast_100M2").Offset(count_data1 + 2).Select
    ActiveCell.AutoFill Destination:=Range(ActiveCell.Offset(0, -1), ActiveCell.Offset(0, -
    1).End(xlDown)).Offset(0, 1)

    'Call up Solver tool to obtain minumum value of MSE, and set the Alpha and Beta Values.
    solversolve userfinish:=True
    'Call up Data Analysis Toolpak descriptive statistics
    Application.Run "ATPVBAEN.XLAM!Descr", ActiveSheet.Range("$H$3:$H$1048576" _
    ), ActiveSheet.Range("$K$1"), "C", True, True, , , 95

    'Copying the Actual Forcast result from the model to the "Result for test" worksheet
    Worksheets("Result for test").Activate
    count_result = Application.WorksheetFunction.Count(Range("A5:A1048576"))
    count_pos = Application.WorksheetFunction.Count(Range("D5:D1048576"))
    For i = 1 To (count_result - count_pos)
    Set LookRange = Sheets("100_M2").Range("B4:F1048576")
    arg4 = False
    x = ActiveSheet.Range("Result_Running_hr").Offset(count_pos + i).Value
    Range("Result_Forecast").Offset(count_pos + i) = Application.VLookup(x, LookRange, 5,
    arg4)
    Next i
    Worksheets("Data for test").Activate

End Sub

Sub Model_100M3()

'Model_100M3 is the predictive model for 100% Main Engine Load with running hours from
‘3001-4000.
'Declaration of variables
Dim count100_M3 As Integer
Dim count_result As Integer
Dim Column_value As Integer
Dim count_pos As Integer
Dim arg1 As Integer, arg3 As Integer
Dim LookRange As Range
Dim arg4 As Boolean
'Column value is used to control cell position for data to be input or extract
Column_value = 4

    'Copy original data from "Data for test" worksheet to "100_M3" worksheet for model
    ‘analysis.
    Worksheets("Data for test").Activate
    ActiveSheet.Range("Run_100M3:" &
    ActiveSheet.Range("Temp_100M3").End(xlDown).Address).Offset(1).Select
    Selection.Copy
    Worksheets("100_M3").Activate
    count100_M3 = Application.WorksheetFunction.Count(Range("B4:B1048576"))
    Set Curcell = Worksheets("100_M3").Cells(count100_M3 + Column_value, 2)
    Curcell.PasteSpecial xlPasteValues

    'Set the first forecast value to be the same as the first cylinder temperature value.
    Range("Forecast_100M3").Offset(1).Formula = "=C4"
    'Set the trend to be zero since there is no previous data for trend.
    Range("Trend_100M3").Offset(1) = 0
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_100M3").Offset(1).Formula = "=D4+E4"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_100M3").Offset(1).Formula = "=C4"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_100M3").Offset(1).Formula = "=G4-F4"
```

```
        'count_data1 is used to control cell position for data to be input or extract
        count_data1 = Range("count100M3_80").Value - 1
        'The Forecast is the result of Alpha*past cylinder temp + (1-Alpha)*Actual Forecast
        Range("Forecast_100M3").Offset(2).Formula = "= $I$1 * C4 + (1 -$I$1 ) * F4"
        'The trend is the result of Beta * Difference of past forecast + (1-Beta)*Previous Trend
        Range("Trend_100M3").Offset(2).Formula = "=$I$2 * (D5-D4)+ (1 - $I$2) * E4"
        'The Actual Forecast will be the sum of Forecast and Trend.
        Range("AF_100M3").Offset(2).Formula = "= D5 + E5"
        'The Actual Data will be copied over from the data in cylinder temperature cell.
        Range("AD_100M3").Offset(2).Formula = "=C5"
        'The error is the difference between Actual Data and Actual Forecast.
        Range("Error_100M3").Offset(2).Formula = "= G5 -F5"
        'Counting the position of the last data cell
        LR = Range("count100M3").Value + 3
        'Copy the formula from 2nd row of the cells which contains data to end of the data.
        Range("D5:H5").AutoFill Destination:=Range("D5:H" & LR)

        'This set of data is used for validation purpose. It will highlight the cell in yellow.
        'It copy the previous Actual Forcast value to the new forecast cell. This will repeat till end of
        ‘data and
        'then used to validate the goodness of fit for the model.
        Range("Forecast_100M3").Offset(count_data1 + 2).Value = "=F" & (count_data1 + 4)
        Range("Forecast_100M3").Offset(count_data1 + 2).Interior.Color = RGB(255, 255, 51)
        Range("Forecast_100M3").Offset(count_data1 + 2).Select
        ActiveCell.AutoFill Destination:=Range(ActiveCell.Offset(0, -1), ActiveCell.Offset(0, -
        1).End(xlDown)).Offset(0, 1)

        'Call up Solver tool to obtain minumum value of MSE, and set the Alpha and Beta Values.
        solversolve userfinish:=True

        'Call up Data Analysis Toolpak descriptive statistics
        Application.Run "ATPVBAEN.XLAM!Descr", ActiveSheet.Range("$H$3:$H$1048576" _
        ), ActiveSheet.Range("$K$1"), "C", True, True, , , 95

        'Copying the Actual Forcast result from the model to the "Result for test" worksheet
        Worksheets("Result for test").Activate
        count_result = Application.WorksheetFunction.Count(Range("A5:A1048576"))
        count_pos = Application.WorksheetFunction.Count(Range("D5:D1048576"))
        For i = 1 To (count_result - count_pos)
        Set LookRange = Sheets("100_M3").Range("B4:F1048576")
        arg4 = False
        x = ActiveSheet.Range("Result_Running_hr").Offset(count_pos + i).Value
        Range("Result_Forecast").Offset(count_pos + i) = Application.VLookup(x, LookRange, 5,
        arg4)
        Next i
        Worksheets("Data for test").Activate
End Sub

Sub Model_100M4()

'Model_100M4 is the predictive model for 100% Main Engine Load with running hours from
‘4001-4500.
'Declaration of variables
Dim count100_M4 As Integer
Dim count_result As Integer
Dim Column_value As Integer
Dim count_pos As Integer
Dim arg1 As Integer, arg3 As Integer
Dim LookRange As Range
Dim arg4 As Boolean
'Column value is used to control cell position for data to be input or extract
Column_value = 4

    'Copy original data from "Data for test" worksheet to "100_M4" worksheet for model
    ‘analysis.
    Worksheets("Data for test").Activate
    ActiveSheet.Range("Run_100M4:" &
    ActiveSheet.Range("Temp_100M4").End(xlDown).Address).Offset(1).Select
    Selection.Copy
    Worksheets("100_M4").Activate
    count100_M4 = Application.WorksheetFunction.Count(Range("B4:B1048576"))
    Set Curcell = Worksheets("100_M4").Cells(count100_M4 + Column_value, 2)
    Curcell.PasteSpecial xlPasteValues

    'Set the first forecast value to be the same as the first cylinder temperature value.
    Range("Forecast_100M4").Offset(1).Formula = "=C4"
    'Set the trend to be zero since there is no previous data for trend.
    Range("Trend_100M4").Offset(1) = 0
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_100M4").Offset(1).Formula = "=D4+E4"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_100M4").Offset(1).Formula = "=C4"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_100M4").Offset(1).Formula = "=G4-F4"

    'count_data1 is used to control cell position for data to be input or extract
    count_data1 = Range("count100M4_80").Value - 1
    'The Forecast is the result of Alpha*past cylinder temp + (1-Alpha)*Actual Forecast
    Range("Forecast_100M4").Offset(2).Formula = "= $I$1 * C4 + (1 -$I$1 ) * F4"
    'The trend is the result of Beta * Difference of past forecast + (1-Beta)*Previous Trend
    Range("Trend_100M4").Offset(2).Formula = "=$I$2 * (D5-D4)+ (1 - $I$2) * E4"
    'The Actual Forecast will be the sum of Forecast and Trend.
    Range("AF_100M4").Offset(2).Formula = "= D5 + E5"
    'The Actual Data will be copied over from the data in cylinder temperature cell.
    Range("AD_100M4").Offset(2).Formula = "=C5"
    'The error is the difference between Actual Data and Actual Forecast.
    Range("Error_100M4").Offset(2).Formula = "= G5 -F5"
    'Counting the position of the last data cell
    LR = Range("count100M4").Value + 3
    'Copy the formula from 2nd row of the cells which contains data to end of the data.
    Range("D5:H5").AutoFill Destination:=Range("D5:H" & LR)

    'This set of data is used for validation purpose. It will highlight the cell in yellow.
    'It copy the previous Actual Forcast value to the new forecast cell. This will repeat till end of
    ‘data and
    'then used to validate the goodness of fit for the model.
    Range("Forecast_100M4").Offset(count_data1 + 2).Value = "=F" & (count_data1 + 4)
    Range("Forecast_100M4").Offset(count_data1 + 2).Interior.Color = RGB(255, 255, 51)
    Range("Forecast_100M4").Offset(count_data1 + 2).Select
    ActiveCell.AutoFill Destination:=Range(ActiveCell.Offset(0, -1), ActiveCell.Offset(0, -
    1).End(xlDown)).Offset(0, 1)

    'Call up Solver tool to obtain minumum value of MSE, and set the Alpha and Beta Values.
    solversolve userfinish:=True

    'Call up Data Analysis Toolpak descriptive statistics
    Application.Run "ATPVBAEN.XLAM!Descr", ActiveSheet.Range("$H$3:$H$1048576" _
    ), ActiveSheet.Range("$K$1"), "C", True, True, , , 95

    'Copying the Actual Forcast result from the model to the "Result for test" worksheet
    Worksheets("Result for test").Activate
    count_result = Application.WorksheetFunction.Count(Range("A5:A1048576"))
    count_pos = Application.WorksheetFunction.Count(Range("D5:D1048576"))
    For i = 1 To (count_result - count_pos)
    Set LookRange = Sheets("100_M4").Range("B4:F1048576")
    arg4 = False
    x = ActiveSheet.Range("Result_Running_hr").Offset(count_pos + i).Value
    Range("Result_Forecast").Offset(count_pos + i) = Application.VLookup(x, LookRange, 5,
    arg4)
    Next i
    Worksheets("Data for test").Activate

End Sub

Sub Model_100M5()

'Model_100M5 is the predictive model for 100% Main Engine Load with running hours from
'4501-5000.
'Declaration of variables
Dim count100_M5 As Integer
Dim count_result As Integer
Dim Column_value As Integer
Dim count_pos As Integer
Dim arg1 As Integer, arg3 As Integer
Dim LookRange As Range
Dim arg4 As Boolean
'Column value is used to control cell position for data to be input or extract
Column_value = 4

    'Copy original data from "Data for test" worksheet to "100_M5" worksheet for model
    'analysis.
    Worksheets("Data for test").Activate
    ActiveSheet.Range("Run_100M5:" &
    ActiveSheet.Range("Temp_100M5").End(xlDown).Address).Offset(1).Select
    Selection.Copy
    Worksheets("100_M5").Activate
    count100_M5 = Application.WorksheetFunction.Count(Range("B4:B1048576"))
    Set Curcell = Worksheets("100_M5").Cells(count100_M5 + Column_value, 2)
    Curcell.PasteSpecial xlPasteValues

    'Getting the average of the previous two values
    Range("MA_100").Offset(3).Formula = "=Average(C4:C5)"
    'Finding the position for the last data
    LR = Range("count100M5").Value + 3
```

```
'Copy the formula to the end of the data.
Range("D6").AutoFill Destination:=Range("D6:D" & LR)

'Set the first forecast value to be the same as the first moving average temperature value.
Range("Forecast_100M5").Offset(1).Formula = "=D4"
Range("Forecast_100M5").Offset(2).Formula = "=D5"
Range("Forecast_100M5").Offset(3).Formula = "=D6"
'Set the trend to be zero since there is no previous data for trend.
Range("Trend_100M5").Offset(1) = 0
Range("Trend_100M5").Offset(2) = 0
Range("Trend_100M5").Offset(3) = 0
'The Actual Forecast will be the sum of Forecast and Trend.
Range("AF_100M5").Offset(1).Formula = "=E6+F6"
Range("AF_100M5").Offset(2).Formula = "=E6+F6"
Range("AF_100M5").Offset(3).Formula = "=E6+F6"
 'The Actual Data will be copied over from the data in cylinder temperature cell.
Range("AD_100M5").Offset(1).Formula = "=C6"
Range("AD_100M5").Offset(2).Formula = "=C6"
Range("AD_100M5").Offset(3).Formula = "=C6"
 'The error is the difference between Actual Data and Actual Forecast.
Range("Error_100M5").Offset(1).Formula = "=H6-G6"
Range("Error_100M5").Offset(2).Formula = "=H6-G6"
Range("Error_100M5").Offset(3).Formula = "=H6-G6"

'count_data1 is used to control cell position for data to be input or extract
count_data1 = Range("count100M5_80").Value - 1
'The Forecast is the result of Alpha*past MA cylinder temp + (1-Alpha)*Actual Forecast
Range("Forecast_100M5").Offset(4).Formula = "= $J$1 * D6 + (1 -$J$1 ) * G6"
'The trend is the result of Beta * Difference of past forecast + (1-Beta)*Previous Trend
Range("Trend_100M5").Offset(4).Formula = "=$J$2 * (E7-E6)+ (1 - $J$2) * E6"
'The Actual Forecast will be the sum of Forecast and Trend.
Range("AF_100M5").Offset(4).Formula = "= E7 + F7"
 'The Actual Data will be copied over from the data in cylinder temperature cell.
Range("AD_100M5").Offset(4).Formula = "=C7"
 'The error is the difference between Actual Data and Actual Forecast.
Range("Error_100M5").Offset(4).Formula = "= H7 -G7"
'Counting the position of the last data cell
LR = Range("count100M5").Value + 3
'Copy the formula from 2nd row of the cells which contains data to end of the data.
Range("E7:I7").AutoFill Destination:=Range("E7:I" & LR)

'This set of data is used for validation purpose. It will highlight the cell in yellow.
'It copy the previous Actual Forcast value to the new forecast cell. This will repeat till end of
‘data and
'then used to validate the goodness of fit for the model.
Range("Forecast_100M5").Offset(count_data1 + 2).Value = "=G" & (count_data1 + 4)
Range("Forecast_100M5").Offset(count_data1 + 2).Interior.Color = RGB(255, 255, 51)
Range("Forecast_100M5").Offset(count_data1 + 2).Select
ActiveCell.AutoFill Destination:=Range(ActiveCell.Offset(0, -1), ActiveCell.Offset(0, -1).End(xlDown)).Offset(0, 1)

'Call up Solver tool to obtain minumum value of MSE, and set the Alpha and Beta Values.
solversolve userfinish:=True

'Call up Data Analysis Toolpak descriptive statistics
```

```
    Application.Run "ATPVBAEN.XLAM!Descr", ActiveSheet.Range("$I$3:$I$1048576" _
    ), ActiveSheet.Range("$K$1"), "C", True, True, , , 95

    'Copying the Actual Forcast result from the model to the "Result for test" worksheet
    Worksheets("Result for test").Activate
    count_result = Application.WorksheetFunction.Count(Range("A5:A1048576"))
    count_pos = Application.WorksheetFunction.Count(Range("D5:D1048576"))
    For i = 1 To (count_result - count_pos)
    Set LookRange = Sheets("100_M5").Range("B4:G1048576")
    arg4 = False
    x = ActiveSheet.Range("Result_Running_hr").Offset(count_pos + i).Value
    Range("Result_Forecast").Offset(count_pos + i) = Application.VLookup(x, LookRange, 6,
    arg4)
    Next i
    Worksheets("Data for test").Activate

End Sub
```

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