Moving to a Condition Based Maintenance Regime

Scott White

School of Mechanical Engineering

CEED Partner: Defence Science and Technology Organisation

Abstract

This paper presents a framework for assessing the quality of data for implementation of a Condition Based Maintenance (CBM) program. The framework includes (1) a methodology for conducting a data audit to determine whether the data is of adequate quality for a CBM program and (2) a process based on Root Cause Analysis (RCA) to determine the best course of action if the data quality is unacceptable. This framework has been applied to the oil analysis and data collection program run by the Royal Australian Navy's ANZAC Systems Programs Office (SPO).

1.0 Introduction

The aim of this paper is to develop and test a methodology to identify issues of data quality that may affect the implementation of a Condition Based Maintenance (CBM) program. The project is driven by the desire of the SPO and DSTO to reduce costs, manage risks and maintain capability of the Propulsion Diesel Engines (PDE) onboard the ANZAC class frigates. One of the main aims of the CBM program is to manage costs by extending service intervals where appropriate. In the context of this study the services of interest are the W5 and W6 maintenance echelons. A W5 repair every 8000 engine hours involves the partial disassembly of the PDE and a W6 every 24,000 hours involves a complete engine rebuild and partial removal of part of the frigates structure. With a W5 costing at least $150,000 and a W6 costing $800,000 [1] there are obvious cost benefits if these tasks occur less frequently Currently oil is changed between 500 and 750 hours of engine operation [2] regardless of condition. There have been suggestions that the oil change period can be extended as much as 6000 hours [3].

2.0 Data Quality: Assessing the Current System

The assessment of the systems current state is divided into 4 main stages. (1) Define a goal, in this case the CBM data collection program is to be optimised. (2) Define the required data attributes, this step determines how the data will deliver the specified goal. (3) Evaluate where the data is failing to meet these attributes. (4) Perform a Root Cause Analysis (RCA) on the failures identified in (3).

In the context of this framework RCA has 4 steps, (a) determine the causal factors behind the failures identified in (3), (b) develop solutions which address the causal factors identified in (a), (c) implement solutions developed in (b) and (d) assess if the solutions implemented in (c) have been successful. If the solutions have not been successful then the RCA process must be repeated.

The purpose of RCA is to identify and rectify the root causes behind data failing to meet quality requirements. RCA is an iterative process used to determine the root causes of failures as opposed to only addressing their symptoms [4]. The advantage of rectifying root causes to problems is that their chance of reoccurring is minimised. One downside is that partial reoccurrence of failures may occur or new failures may occur. For this reason if the failure is not rectified, then the RCA process starts again. The structure of this process is shown in Figure 1, this framework was developed with the aid of existing data quality and RCA literature[5].

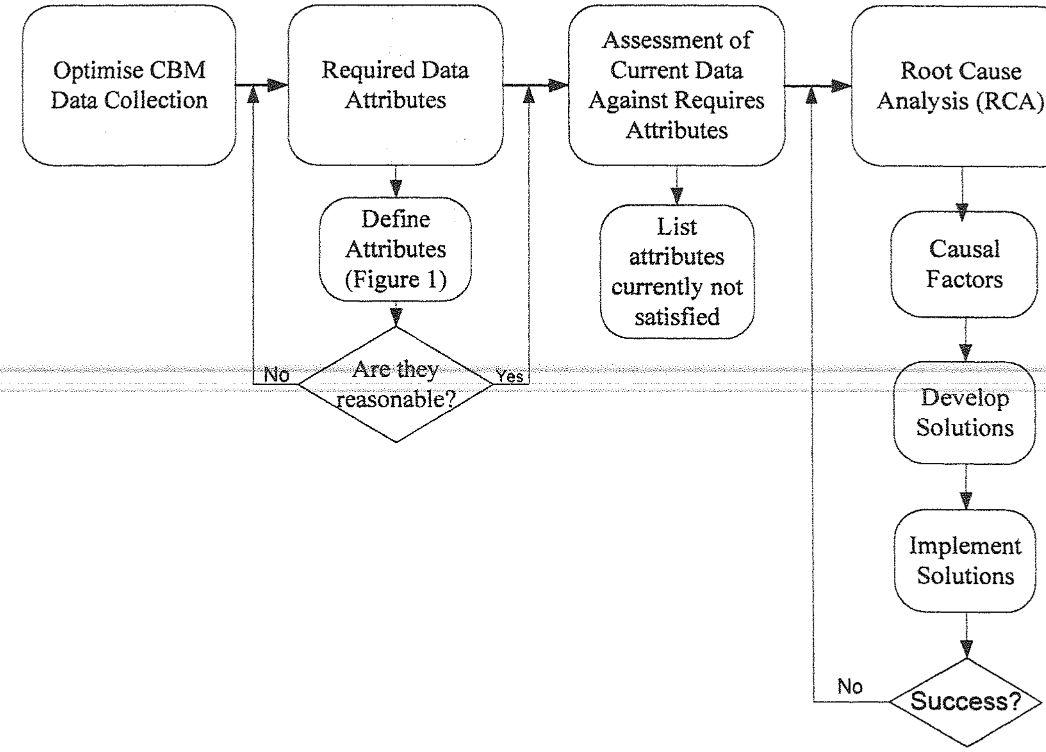


Figure 1: Assessment Framework

3.0 Data Quality: Application of the Assessment Framework

3.1 Expectations and Assessment of Current Data

To facilitate the optimisation of the CBM data collection program the following expectations were developed. The data must be accurate, complete, consistent, available and relevant. To assess the current state of the Royal Australian Navy's (RAN) data, two data sets were audited. The first of these were photocopies of HMAS Arunta's daily oil tests, the second was the RAN's SOAP database containing all the laboratory oil test data.

The data set from HMAS Arunta is of poor quality in terms of Accuracy, Completeness, Consistency and Accessibility. Accuracy is questionable because viscosity appears to vary for no apparent reason between oil changes. In addition, insolubles decrease in between oil changes for no apparent reason. However, Completeness and consistency are the two largest problems. Often, not all of the tests are completed and of those that are, only viscosity is completed on a daily basis. The SOAP data also suffer from completeness problems, when an oil sample is sent for analysis the crew often fail to note the running hours since the oil was last changed and if oil has been added [3]. Without this information, trending analysis is extremely difficult, if not impossible. Accessibility of data has posed a large problem for the DSTO and SPO. Only three out of eight frigates responded to a data quality questionnaire and only one ship that responded entered their data into a computer. To access daily test data , it would be necessary to obtain photocopies of the data retained onboard the ships.

3.2 RCA: Determining Causal Factors – Technical

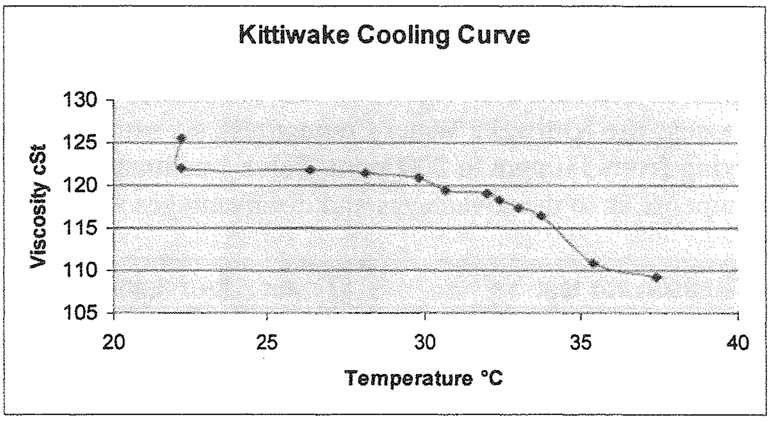
Experiments were conducted to quantify and identify the factors causing poor data accuracy. As part of this study, experiments were conducted under laboratory conditions to evaluate the performance of the Kittiwake onboard testing equipment. The Kittiwake Oil testing centre is capable of testing (1) viscosity, (2) Total Base Number (TBN), (3) insolubles and (4) water content. Kittiwake was used to evaluate 48 samples of used crankcase oil, at various stages of its life, which were previously analysed at SGS Oil testing laboratories. This previous analysis provided a basis for comparison, although SGS did not analyse these samples for TBN. Water in oil is rarely encountered onboard the Frigates so the 48 samples of used oil were not tested for water content. To assess the Kittiwake Water Content test, six samples were prepared with water contamination varying from 110ppm to 2000ppm. Table 1 summarises the results of the author's tests and some comments as to the advantages and disadvantages with each test.

Test	Reason for test	Tester	Advantages/Disadvantages
Viscosity Test	Viscosity must within specifications to lubricate effectively and is used to gauge fuel contamination	Onboard test, SGS	- Kittiwake Viscosity test is highly sensitive to oil initial temperature. + Results are unambiguous
TBN Test	Check for oil corrosiveness	Onboard test, SGS	+ Unambiguous Results + Simple
Insolubles	Excess insolubles can cause oil path ways to block	Onboard test, SGS	- Results from the ship based Kittiwake unit appear to be approximately half the value of those obtained by SGS.
Water Content	Free water decreases oils effectiveness as a lubricant.	Onboard test, SGS	- Ship based Kittiwake unit can take up to 10 minutes to stabilise and in some cases never appears to stabilise.
Spot	Checks the oils ability to disperse soot	Onboard test	- Results are ambiguous + Test is simple to conduct
Flashpoint	Fuel Dilution	SGS	+ Given the correct setting this appears to be a valid way of gauging fuel dilution
FTIR	FTIR checks the amount of wear materials in the oil.	SGS	- Oil operating hours was not always sent with sample

Table 1

(1) The Kittiwake viscosity test uses an unheated viscometer. As a result, the viscosity test is conducted when the oil is at room temperature. Since the viscosity of oil varies with temperature, a viscosity measurement is only useful if the temperature the test was conducted at is known. To allow a standard basis for comparison viscosities at 40°C and 100°C are generally quoted. Due to Kittiwake conducting the viscosity test at room temperature the result must be correlated to 40°C, this is done to ASTM D445/IP71 standards. To assess the accuracy of the correction factor, oil of approximately 70°C was poured into the Kittiwake Viscometer and allowed to stabilise. Stabilisation occurred at approximately 37°C. From this point on the temperature decreased slowly and took approximately 30 minutes to reach 22°C. Graph 1 demonstrates the variation that can occur if the oil is not left to cool before being tested. This could be a possible explanation for the random variation in the Arunta data set. The reduction in volume as the oil cooled also introduced error, the effect of the volume reduction was a reduction in the viscosity reading. This is demonstrated by the spike on the left hand side of Graph 1, the highpoint of the

spike is a reading after additional oil was added to compensate for the reduction in volume caused by the oil cooling.



Graph 1

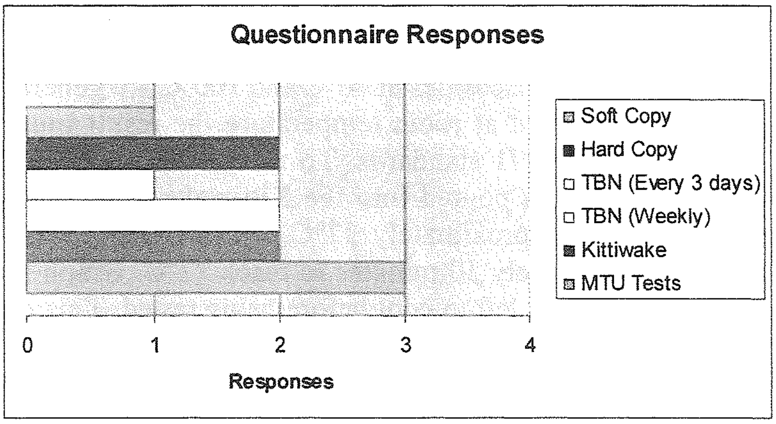
(2) and (3) were both found to be repeatable with little variance. However, there is concern as to the accuracy of the insolubles test. The Kittiwake insolubles results were always approximately half the results of the SGS insolubles tests for the same sample. This is possibly due to equipment being out of calibration .The SGS soot test uses the same technology as the Kittiwake test, albeit their machine calibrates itself against a kerosene sample [6].

(4) The water content test took excessively long to stabilise and the point of stabilisation was ambiguous. As a result, it would be entirely possible for two different sailors to get two different results.

3.3 RCA: Determining Causal Factors – Human Factors

Human factors in a data quality context refer to any issues or discrepancies that arise due to human involvement. Determining these and their respective causes is not as intuitive to an engineer as determining the root causes behind technical factors. The data quality problems relating to (1) completeness and consistency, (2) accessibility and (3) lack of equipment calibration are driven by human factors.

To identify causal factors behind the lack of (1) completeness and consistency a questionnaire was issued to all the ANZAC frigates to determine their testing regime, how they store data and their thoughts on CBM. The questions asked in the questionnaire allowed the sailors to answer in their own words. This provided a qualitative assessment of various practices carried out on ships.



Graph 2

Only three of the eight ANZAC Frigates responded to the questionnaire. Of these three, only one frigate stores their data electronically. The questionnaire responses illustrate that onboard testing methodologies are not uniform across the fleet, neither are their data storage methods nor their thoughts on CBM [7-9]. The differences may possibly in part be attributed to the hierarchy and management structure of the RAN.

Defence has an unconventional hierarchy and management structure. For example, SPO personnel issuing instructions to ANZAC frigate crew for maintenance or inspection purposes may be junior to the crewmember concerned. A Platforms Systems Engineer may be a Lieutenant, whereas a Marine Engineering Officer maybe a Lieutenant Commander. In theory, staff at the SPO are performing their duties on behalf of the SPO director (the senior SPO manager), although in reality, the daily interactions between SPO and ship's crew may cause friction due to perceived rank/hierarchy issues. So in order to facilitate any change the ANZAC MEOs, for example must be convinced of the benefits the changes provide.

The next step in the process was to determine the level of communication occurring. This involved interviewing the sailors onboard the frigates. Interviews with three service personnel indicated (a) a low level of awareness of the current CBM initiative, (b) poor communication between the frigates and the SPO and (c) an unwillingness to share data and collaborate. The unwillingness to share data could possibly be the reason why only three out of eight frigates responded to the questionnaire and why (2) data accessibility problems exist.

To determine the calibration status of the Kittiwake equipment the Australian suppliers were contacted. This revealed no Kittiwake units have been returned for calibration in the 10 years [10] since the first ANZAC frigate was commissioned. The SPO's inventory department revealed that every year the ships should send their Kittiwake unit to a central depot so they can be sent off for recalibration.

3.4 RCA: Develop Solutions – Human Factors

The causal factors (a), (b) and (c) relate to the break down or lack of communication in one form or another while changes are being implemented. Implementing change in an organisation can be difficult at the best of times, however it is much more difficult in an organisation which is inherently resistant to change. Thus if the changes are to have any chance of success a comprehensive strategy needs to be developed. For the purposes of this argument, we will use the Kurt Lewinian [11] model incorporating three general stages of change – unfreezing, changing or moving and refreezing.

The first stage, unfreezing, has the primary communication objective of preparing organisational participants for change. This has been called readying the organisation. If old attitudes and values are to be challenged by the change, then it is likely resistance will be experienced. To overcome this, the benefits of the proposed change need to be communicated to the organisational personnel as well as dealing with any negative preconceptions. In this case, a preconception exists that more maintenance equates to higher reliability. The erasing of this preconception will require a multifaceted communications approach. Firstly, reports utilising successful CBM case studies will need to be issued to all personnel affected by the change, followed by a seminar session where experts are available to answer questions. The two-way communication available at a seminar encourages involvement in the process and aids in the clarification of any ambiguities. [11, 12]

The next stage of the process is changing or moving. In many ways, this is where the RAN is now. They are attempting to implement change without effectively educating the affected maintenance personnel about the change. The lack of initial communication has resulted in 'people talking in the corridors' and a wall to the change being built. To overcome this, a step back must be taken to the unfreezing stage. However, overcoming preconceptions is likely to be much more difficult as opinions will now be well developed. Once unfreezing has been successfully completed, then implementing the required changes to facilitate a move to CBM will become much easier.

Finally, refreezing needs to occur, this involves cementing the changes that have occurred in the organisational psyche. To do this the benefits the changes have provided need to be demonstrated to organisational personnel. To communicate this I would recommend issuing a report followed by a questions and answers session. If the benefits are not communicated then it is likely that attitudes will relapse and as a result, data quality will decline. There is a high risk of this occurring with the CBM project, as the personnel on the ground collecting the data will not see the benefits since this is primarily a cost saving initiative.

4.0 References

1. Hammond, L., *FW: [Spam Detected] Seminar Paper*, S. White, Editor. 2006.
2. MTU, *Maintenance Schedule: Diesel Engine 12V 1163 TB 83.*
3. *An Investigation into the oil management practices of the Royal Australian Navy.*
4. *Root cause analysis.* 2006, Wikipedia.
5. M.Hodkiewicz, P.K., J.Sikorska, L.Gouws, *A FRAMEWORK TO ASSESS DATA QUALITY FOR RELIABILITY VARIABLES.* submitted for publication at WCEAM, July 2006, 2006.
6. Elphick, B., *Soot/Fuel Info*, D. Smolinski, Editor. 2006.
7. Rollinson, C.A., *HMAS Stuart Questionnaire Response*, S. White, Editor. 2006.
8. Unknown, *HMAS Arunta Questionnaire Response*, S. White, Editor. 2006.
9. Unknown, *HMAS Parramatta Questionnaire Response*, S. White, Editor. 2006.
10. *Welcome Aboard - HMAS Anzac (Royal Australian Navy).* [cited 18/08/2006]; Available from: http://www.navy.gov.au/ships/anzac/default.html.
11. Klein, S.M., *Communication Strategies for Successful Organizational Change.* Industrial Management, 1994. **36**(1): p. 26-30.
12. Australia, S., *Risk Management Guildlines : Companion to AS4360.* 2004, Standards Australia