Standardised Semi-Automated Estimation of Cost of Quality for Lubrication Practices

Taku Mtabeni

Melinda Hodkiewicz[1], Michael Stewart[2], Tyler Bikaun[2]
1. Mechanical Engineering
2. Mathematics and Statistics
University of Western Australia

Michael Beard
CEED Client: BHP Nickel West Pty Ltd

Abstract

There is no well-established method of quantifying quality control improvements for lubrication practices. This study develops a set of Cost of Quality (CoQ) indicators for lubrication management and determines their suitability in quantifying the effectiveness and efficiency of lubrication quality control improvements. Six CoQ measures are identified using the Prevention, Appraisal, and Failure (PAF) CoQ framework. To assess the validity of the measures, values are estimated using industry data from 29 compressors across four sites from BHP Nickel West over a ten-year time frame (2011 to 2021). This cost data was obtained from maintenance work orders and third-party contractor information. A Python code script was created to calculate the metrics, the output of which feeds to a visual interface. The CoQ pipeline includes state of the art Technical Language Processing (TLP) to automate the calculation of failure costs incurred through activities such as rework and repair, a task which had been laborious until recently. Out of the total amount spent on the maintenance of these assets, the analysis identified that 7% was spent on rework and repairing equipment that had failed due to lubrication-related issues. The CoQ measures developed and tested in this project provide a standardised, low human input and repeatable process for BHP Nickel West to quantify the effectiveness and efficiency of quality control improvements to their lubrication programs.

1. Introduction

Lubrication is integral to the functionality of rotating equipment by reducing heat and wear caused by friction between contacting surfaces in relative motion. The management and handling of lubricants is complex, involving many stakeholders, products, processes, and assets, with no clear lines of accountability. It is generally accepted within the maintenance community that over 60 percent of all mechanical failures of rotating equipment relate to poor lubrication practices (Bannister, 2006). Poor lubrication practices include the use of contaminated lubrication, insufficient lubrication quantity, or using the wrong type of lubrication. A well planned and coordinated lubrication program is a necessary prerequisite for any preventive maintenance scheme that may be established by a process plant. However, there is no well established method of quantifying quality control improvements for lubrication practices. There is need for a process to establish the cost and efficacy of past practice as a guide to future work.

ISO9000 "Quality Management Systems" (Standards Australia, 2016) promotes the adoption of Quality Management Systems (QMS) to help improve the overall performance of an organisation and to provide a sound basis for sustainable development initiatives. As part of QMS implementation, Cost of Quality (CoQ) is an effective quality management tool that can be used by organisations as a performance indicator to prioritize quality improvement initiatives. CoQ is widely understood as the sum of conformance and non-conformance cost. Conformance costs are the costs incurred to prevent and appraise (detect) poor quality whilst non-conformance costs are the costs incurred due to a product or service failure (Thomas & Schiffauerova, 2006).

The Prevention, Appraisal, and Failure (PAF) CoQ model developed by Feigenbaum in 1956 was adopted for this study (Feigenbaum, 1956). It classifies quality costs into prevention, appraisal, and failure costs. Prevention costs are the costs incurred to prevent failures. Appraisal costs are the costs incurred to detect defects in products via testing, inspection, and examination ahead of their delivery to customers. The conformance costs of an organisation's lubrication program can be obtained from purchase records, parts, and cost information, third party contractor information, and maintenance work orders (MWOs). MWOs are records that capture information about maintenance tasks that need to be performed on assets at processing plants. Failure costs are the costs associated with correcting nonconforming products. A wealth of data on lubrication related (LR) failures is captured in the unstructured short text descriptions of MWOs. Until now, the unstructured text fields of MWOs have not been machine readable.

Natural Language Processing (NLP) is a range of computational techniques for analysing and representing naturally occurring texts for the purpose of achieving human like language processing for a range of tasks (Liddy, 2001). Technical Language Processing (TLP) is the counterpart to NLP and is used for analysing technical language which includes language that appears in industry specific contexts such as the MWOs of mining companies (Brundage et al., 2021). TLP can be used to identify MWOs that are associated with LR failures from an organisation's computerised maintenance management system, a task that had been manual and laborious to complete in the past.

2. Process

The CoQ study was performed using industry data from 29 screw and centrifugal compressors (henceforth referred to just as compressors) across four sites (henceforth denoted as Site A, B, C and D) across BHP Nickel West over a ten-year time frame from 2011 to 2021 as a case study. Reliability engineers from each site were interviewed to better understand the supply chain for compressor oil at their site. Following the interviews, four process maps were created to map out each site's lubrication practices. The process maps highlighted the complexity involved in managing and handling lubricants which require multiple stakeholders, assets, and processes. Points along the oil supply chain that are critical to quality were then identified. These points were used to develop the lubrication CoQ measures. Finally, a Python script was written in Jupyter Notebook to calculate the CoQ metrics the output of which feeds to a PowerBI dashboard. The script is not specific to the compressor data and allows the metrics to be calculated for other asset types.

The Python script requires five csv files:

1. A list of the asset IDs of the equipment under examination
2. Their MWO records
3. Their material movements
4. Their oil analysis data
5. The output MWO records from the TLP pipeline

MWOs are classified according to their maintenance type as either corrective (PM01), prevention (PM02), or unscheduled breakdown (PM03). PM02 MWOs were used to calculate the prevention measures as well as cost and numerical data from third party contractors. PM01 and PM03 MWOs that contained LR terms in their unstructured short texts were used to calculate failure costs. The TLP pipeline was used to identify such MWOs. A summary of the pipeline is shown in Figure 1. The TLP pipeline is comprised of two stages. The first stage uses machine learning to perform Named Entity Recognition (NER), a subtask of information extraction that classifies words and phrases in the unstructured short text descriptions of MWOs into their corresponding entity types (Stewart et al., 2021). Figure 2 shows an example of two MWOs on which NER has been performed. The deep learning model learns how to perform NER by training on a dataset that has been labelled by human expertise on Redcoat (https://nlp-tlp.org/redcoat/), a web-based NER annotation tool (Stewart et al., 2021). With enough training, the deep learning model is able to perform NER on unseen MWO data and is capable of classifying previously unseen words or phrases by utilising the context around them. The second stage aims to link these entities together to form a knowledge graph, accomplished by creating a set of triples and importing these triples into Neo4j, a graph database management system.

The NER stage of the TLP pipeline identified over 1000 unique tokens. This list of tokens was examined in search for LR terms. A query was ran in Neo4j to filter MWOs that contained any terms identified as LR in their short text. The query used required a strict match on tokens in the short text, ignoring any sub-string matches. For example, searching for the term "oil" would match the short text "change out motor oil" but would ignore "boiler repairs".

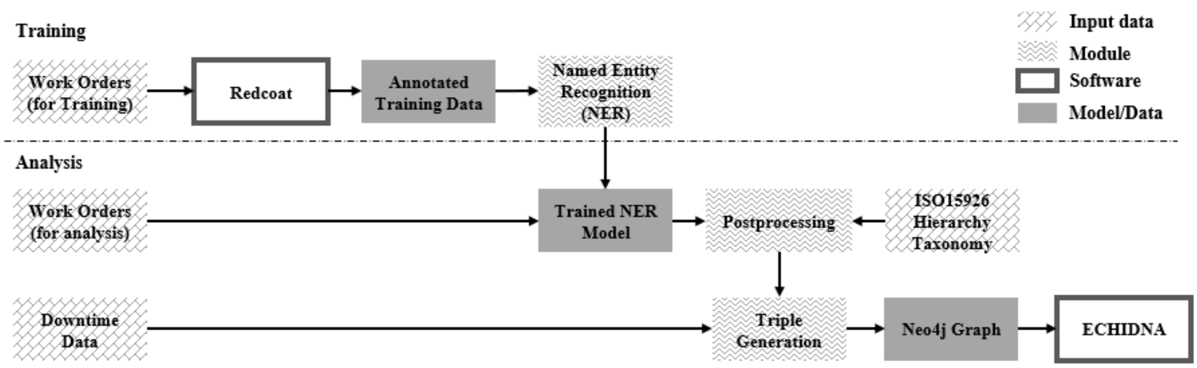

Figure 1 Technical Language Processing (TLP) pipeline (Stewart et al., 2021).

Figure 2 Entity tagging on Redcoat (https://nlp-tlp.org/redcoat/).

3. Results and Discussion

Six lubrication CoQ measures were identified. They are shown in Table 1.

Number	PAF Category	Name	Formula
1	P	Cost of Performing Oil Analysis	= Number of Oil Samples Taken × (Average Time to Take One Oil Sample × Technician Wage Rate + Cost of Performing Oil Analysis at Tribology Lab + Cost of One Oil Sample Kit)
2	P	Cost of Performing LR Services	= Number of LR Services × Average Time to Perform One Service × Technician Wage Rate
3	P	Cost of Oil Change Outs	= Number of Oil Change Outs × Average Time to Change Oil × Technician Wage Rate + Cost of Oil
4	P	Cost of LR House Keeping	= Number of Times Lubrication Shed is Cleaned × Average Time Spent Cleaning Lubrication Shed × Technician Wage Rate × Percent of Cost Allocated to Compressors
5	A	Cost of LR Audits	= Time Taken to Perform Audit × Combined Wage Rate of Personnel Involved × Percent of Cost Allocated to Compressors
6	F	Cost of LR Failures	PM01 and PM03 MWOs that Contain LR Terms in their Unstructured Short Text Descriptions

Table 1 Lubrication CoQ measures.

Figure 3 shows a detailed breakdown of the prevention and appraisal costs vs failure costs for each site from 2011 to 2021. The costs are calculated per compressor to allow comparison amongst the different sites. Quality costs at Site B, which has the largest sized compressors, are dominated by episodic failure costs. Quality costs at Sites A, C and D, which primarily have small compressors, are dominated by prevention and appraisal costs. Quality costs, particularly failure costs, are greater for large compressors.

All of the formulated measures play an integral role in providing a holistic overview of BHP Nickel West's lubrication CoQ. Although the majority of the prevention and appraisal measures that were identified make up a small percentage of quality costs, they are important to consider as they give reliability engineers the ability to monitor whether integral LR preventative maintenance activities are being performed or neglected. For example, cleaning lubrication sheds and housekeeping is an important preventative measure that is often overlooked but can have far-reaching consequences if not performed on a regular basis. If lubrication sheds are left uncleaned, dirt and dust can ingress into oil drums which can be detrimental to machine health if the contaminated oil is used.

The CoQ measures are calculated by a Python script the output of which feeds to a PowerBI dashboard, shown in Figure 4. The dashboard has four visualisations controlled by five filters. The filters allow the user to filter quality costs based on a particular asset(s), site(s), year(s), CoQ measure(s) as well as to display the total cost or the cost per equipment. The visualisations allow the user to obtain a holistic view of the total CoQ across the organisation over a specified timeframe, compare conformance and non-conformance costs across all sites, see cumulative costs, and obtain a detailed breakdown of the CoQ measures at each site.

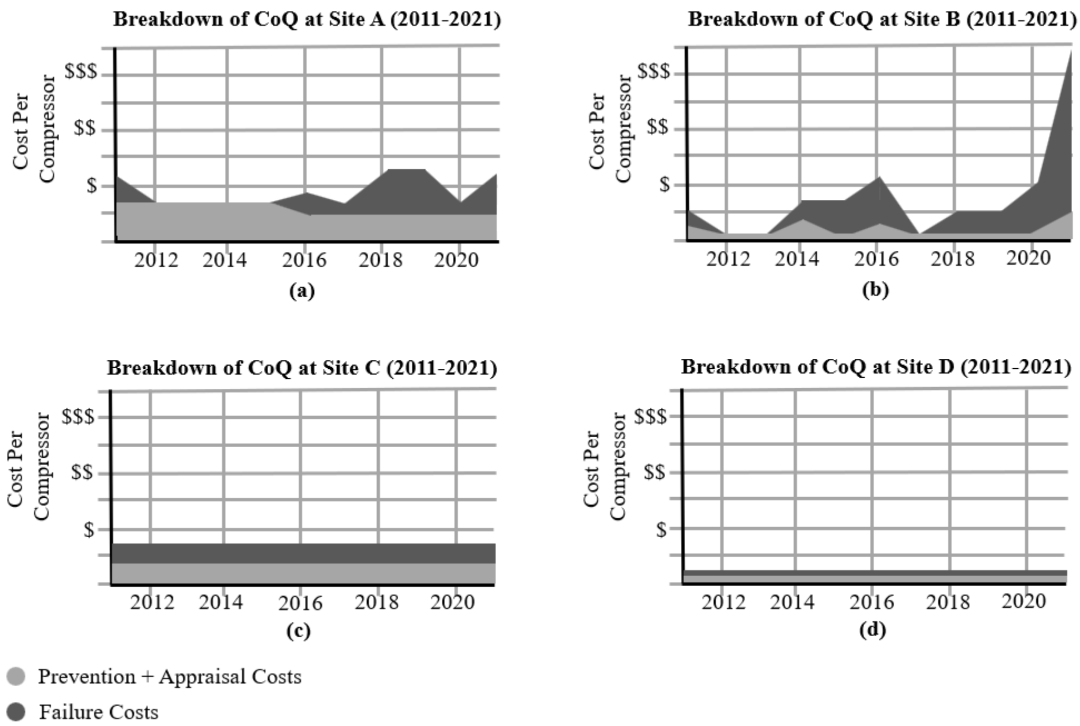

Figure 3 Breakdown of prevention and appraisal costs vs failure costs for compressors at Sites A, B, C and D from 2011 to 2021. Dollar figures have been omitted for confidentiality reasons.

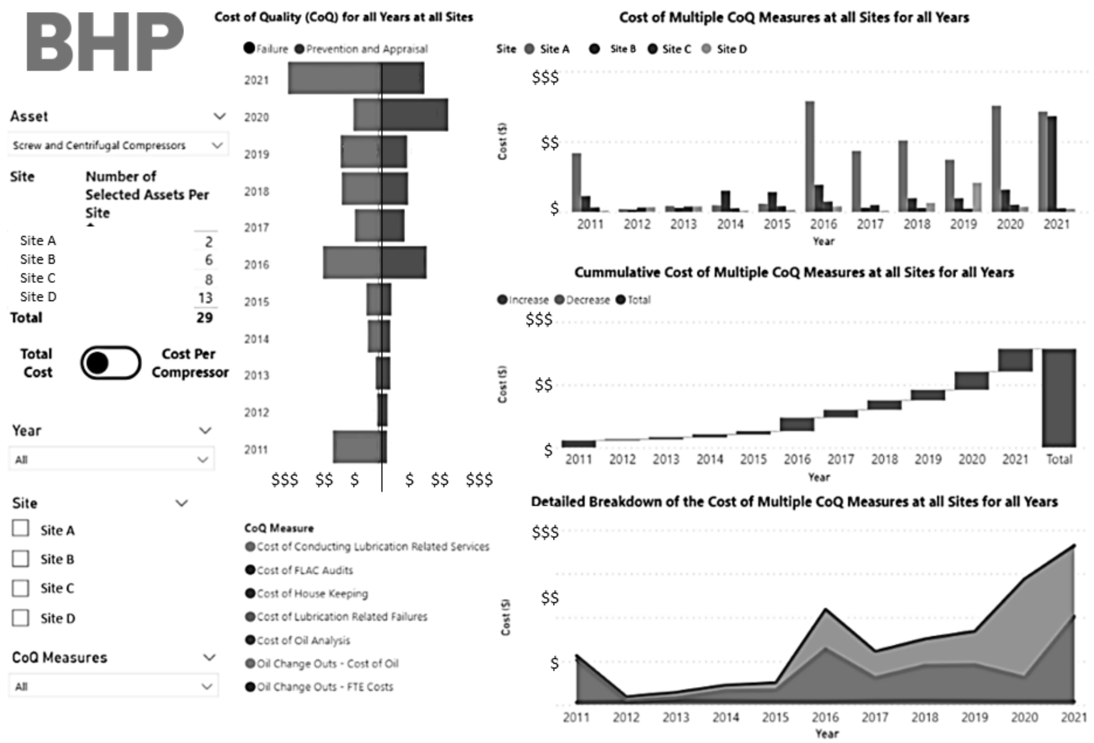

Figure 4 Lubrication CoQ dashboard. Dollar figures have been omitted for confidentiality reasons.

One of the goals of this study was to see if there is a relationship between prevention and appraisal (P+A) costs vs failure (F) costs, and how increasing or decreasing P+A impacts F. A Stock and Flow System Dynamics diagram, which highlights the various activities that are related to P+A costs and F costs, was created. The System Dynamics diagram showed that there are links between P+A costs and F costs. It showed that not performing P+A activities leads to an increase in F costs.

4. Conclusions and Future Work

The CoQ framework that has been developed gives management and reliability engineers the ability to gain oversight into their organisation's lubrication practices and identify gaps. The framework provides a basis for measuring quality control improvements to BHP Nickel West's lubrication programs, thus it can be used to understand the cost and efficacy of past practice to guide future work. Future work includes expanding the PAF framework to other assets across BHP Nickel West and making the PowerBI dashboard dynamic by having the data update automatically in real-time. The CoQ measures can also be calculated at the equipment level so that problem areas can be more easily targeted. The framework can be expanded to incorporate the production or revenue lost when a piece of equipment stops functioning due to LR issues (ie downtime costs), thus taking the form of the Opportunity CoQ model. Finally, the TLP pipeline can be used to analyse the long text descriptions of MWOs to capture LR-MWOs that do not contain any LR phrases in their short text descriptions but contain such terms in their long text.

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