Physical assets reliability through a mix of surveillance and scheduled maintenance

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Abstract

The maintenance of physical assets in asset intensive organizations entails different techniques to ensure high equipment uptime and reliability. The selection of a mix of maintenance strategies that are deployed in a firm is highly influenced by diverse organizational factors such as resources availability. This study was undertaken to assess the types and depth of scheduled and surveillance maintenance that a manufacturing firm embarked on. The effectiveness of the maintenance actions emanating from the scheduled and surveillance maintenance scheme was studied to ascertain the ability of the maintenance mix to improve the physical assets' reliability, and to assess whether the maintenance mix was adequate to ensure the required assets performance. The missing aspects of maintenance strategic actions to ensure high physical assets reliability were also examined as a means to improve the reliability performance on the ground.

Keywords
Availability; reliability; maintenance actions; scheduled maintenance; surveillance maintenance.

1. Introduction

Nowadays with the evolution of more and more complex systems, is the paralleled evolution and application of surveillance/condition monitoring technology such as sensors, timers and computational apparatuses, and this is in addition to improved optimization techniques (Olde Keizer et al., 2017:405) (Alaswad and Xiang, 2017:54). Broadly, there is continuous monitoring and intermittent monitoring systems that are applied in industry (Golmakani and Moakedi, 2012:540). Contemporary developments allow components/systems to be monitored continuously, but there still remain particular components/systems that still need physical inspections (Olde Keizer et al., 2017:406). Although systems are monitored continuously, sometimes the manual interventions to check system integrity are necessary at discrete intervals (Olde Keizer et al., 2017:406). The components of control systems, that include actuators and sensors, are also subject to deterioration when functioning under austere operational circumstances (Mo et al., 2018:398). The motivation to apply surveillance, and consequently, condition based maintenance (CBM) should come from the relative benefits derived that should outweigh the efforts and costs incurred during a specified time horizon (de Jonge, 2017:21). The rudiments to shift from time-based maintenance to CBM encompass condition monitoring apparatuses and software to store, evaluate and generate decisions on repair actions (de Jonge, 2017:21). Attention should be rendered to skills requirements to effectively implement CBM, as this can be a high risk area (de Jonge, 2017:21).

Surveillance maintenance or condition monitoring applies real-time data pertaining to component system's health status, its strategic application yields to Condition Based Maintenance (CBM) which is broadly a cost-effective system that reduces operational costs significantly more than the conventional age-based or block-based maintenance philosophies (Liu et al., 2017:879). The structural composition of CBM is three-fold: acquiring the data around component(s) condition(s), reliability/remaining-useful-life (RUL) approximation, and optimized CBM decision-making (Liu et al., 2017:879). CBM aims to lessen the risk of catastrophic failures and in tandem reducing operational expenditures by eradicating needless maintenance activities (Liu et al., 2017:879). The key modes of inspection schedules in CBM are continuous monitoring, periodic, and non-periodic inspections. In continuous monitoring, a continuous alarm system constantly monitors the condition of the machine and triggers a warning whenever something wrong is detected (Alaswad and Xiang, 2017:55). Continuous/online monitoring is the optimum strategy for high risk and high failure-rate systems, though it is usually allied with high costs and information overload which might culminate in inaccurate diagnostics (Alaswad and Xiang, 2017:55). The selection of the inspection interims clearly effects the maintenance function performance through costs, reliability and availability, and sometimes it is not even worthy to carry out inspection of the system periodically, more so if the inspection protocol is exorbitant (Alaswad and Xiang, 2017:55). There has been consideration of irregular inspection plans in other CBM models, as costs can be saved, though there can be additional scheduling work resulting and a high possibility of human errors.

The performance measures for CBM include cost reduction, reliability or availability heightening, and safety/environment performance. The degree of maintenance, that is whether perfect or limited repair is to be executed for the scheduled tasks under the CBM strategy, have a momentous impact on the ensuing system reliability (Alaswad and Xiang, 2017:55).

CBM culminated due to the existing pressure on decreasing needless inspections and/or repair actions and their accompanying costs pertaining to added data gathering, recordings and assessments (Alaswad and Xiang, 2017:55). This has been attained through optimization modelling of CBM strategies. CBM defines a maintenance program that optimizes system's performance according to the costs, availability and reliability criteria, and the endgame is inspection schedules or paradigms like continuous monitoring, and scheduled repair actions thresholds (Alaswad and Xiang, 2017:55). The different types of CBM stochastic modelling are displayed in the figure below.

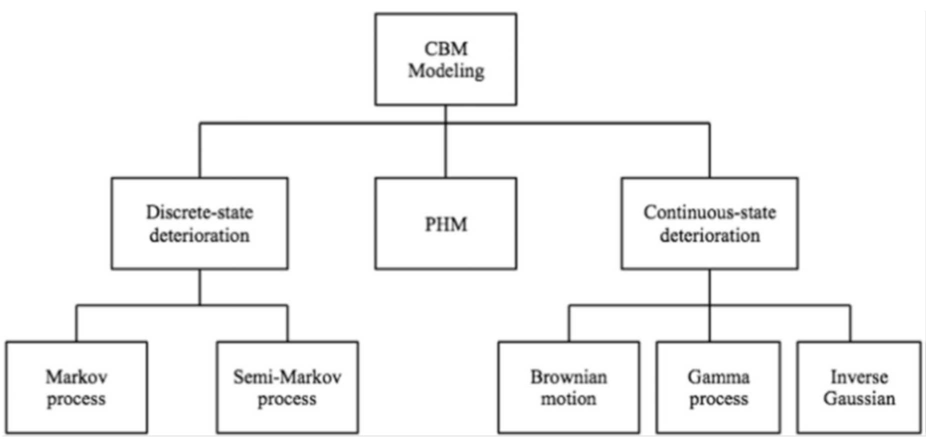


Fig. 1: Various CBM stochastic modelling options (Alaswad and Xiang, 2017:55).

CBM is commonly applied by utilizing a threshold, and inspections are carried out that expose the defective conditions or degradation levels of individual components (Olde Keizer et al., 2017:412). A scheduled maintenance action is assigned if an inspection divulges that the component's deterioration has exceeded a specified threshold level, or when the reliability has dropped below expected levels (Olde Keizer et al., 2017:412).

2. Technical drivers for surveillance and scheduled maintenance

The surveillance of equipment reliability performance status has become a major area of focus to prevent unforeseen failures and determining the optimality of maintenance actions to secure optimum system reliability (Golmakani and Moakedi, 2012:540). The periodicity of reliability surveillance intervals has come into focus (Golmakani and Moakedi, 2012:540).

2.1. Failure traits

The drive for surveillance maintenance is basically prompted by failure consequences as the surveillance regime is failure interactive in different ways, and the two broad failure traits are:

- Soft failure, which is when the component malfunction, it does not result in a stoppage, but it can resultantly lessen the system performance and inversely escalate the system's operational expenditures. Generally soft failures are not self-announcing, and after they are detected, they can be rectified during scheduled maintenance.
- A hard failure, which is when immediately after the failure occurs, the component/system malfunctions promptly. A hard failure is self-announcing. (Golmakani and Moakedi, 2012:540) (Taghipour et al., 2010:944).

Equally components with soft and hard failures have to generally be integrated in creating inspection optimization modelling for multifaceted repairable systems (Taghipour et al., 2010:945). There is a time delay between the actual development of a soft failure and its recognition, and this delay notion has been extensively applied for sculpting the problems of surveillance maintenance and scheduled maintenance interventions (Golmakani and Moakedi, 2012:541) (Hu et al., 2017:105). The delay time is defined in two stages, which is firstly from a new component operating until the detection of a hidden defect, and then secondly, from the time of hidden defect detection until functional failure (Golmakani and Moakedi, 2012:541) (Hu et al., 2017:105). This is the window period when scheduled maintenance can be planned for the purpose of defect eradication or limited repair to prolong the remaining useful lifetime of the system/component. The proper modeling of the durations of the two delay phases, render the opportunity for identification of optimum inspection intermissions and scheduled repair actions to heighten the reliability of the overall system (Golmakani and Moakedi, 2012:541). This scenario prompts the application of specific maintenance action regime to prevent a hard failure situation.

2.2. Degradation Process

The conventional way of time-dependent maintenance strategies involve the analysis of historic failure data that is then used to approximate the failure intervals, but this is now being scampered by the heightened equipment reliability and lessened assets life cycles, which renders meaningful failure data acquisition difficult (Liu et al., 2017:879). This has given way to the proliferation of degradation modelling concepts for highly reliable physical assets, and more so, quite a significant quantity of equipment failures are traceable to degradation (Liu et al., 2017:879). Some researchers have proposed an indiscriminate age and block replacement modelling for some multi-component systems with failure interaction tenets (Golmakani and Moakedi, 2012:541). The majority of equipment components are exposed to degradation before malfunctioning and the indicative measures of degradation can be quantified over a specified horizon, and this has been aided by the fast-paced development of sensing systems, whose cost of application is plummeting (Liu et al., 2017:879). Sensory technology allows the characterization of the degradation process of the component systems by applying continuous-time stochastic modelling, and this is where the surveillance part of condition monitoring has depicted its prowess and dominance in preventing unforeseen failures. The deterioration progression can be categorized relative to the degradation statuses of discrete or continuous modes, whereby Markov chain modelling is generally applied to systems with discrete degradation states to explain the degradation scope, although it has the disadvantage of arbitrarily classifying the degradation states (Liu et al., 2017:879). For continuous-degradation-states systems, there has been witnessed an escalating trend in applying stochastic process-based modelling (Liu et al., 2017:880).

3. The Impact of Scheduled Maintenance on degradation process

The degradation surveillance is rendered to allow for planned maintenance actions versus reactive maintenance actions. This renders the maintenance planner the time to allocate resources for corrective maintenance actions that prevent the hard failure of the system/component. Thus, the reliability of the system is tracked according to the surveillance maintenance regime to give the plant breakdown free physical assets. The figure below shows the impact of scheduled maintenance.

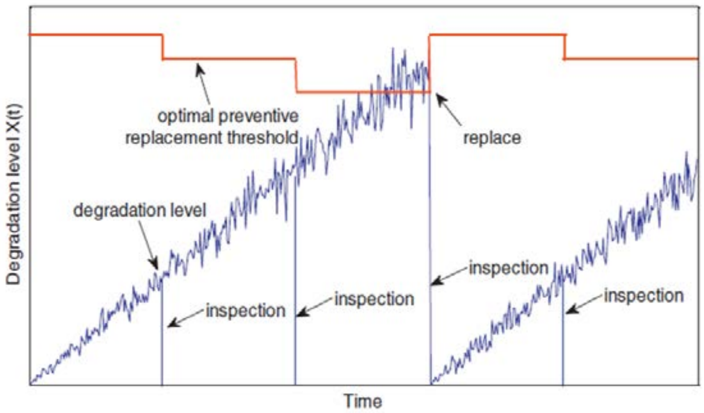


Fig. 2: The Impact of Maintenance Actions on degradation arresting (Liu et al., 2017:882).

Likewise, under a repair/replace mode or imperfect/perfect repair mode, the trend of the degradation process tends to take a different route as a consequence of the impact of the actions that are rendered. The figure below shows the trend of system degradation that is subjected to repair/replace mode of maintenance.

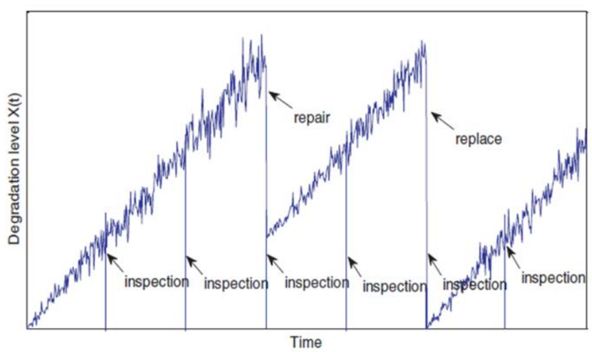


Fig. 3: The system status subjected to limited repair and perfect replacement (Liu et al., 2017:883).

Failure defects are not only observed through inspections, they can also reveal themselves. The significance of surveillance and scheduled maintenance is much higher for aged assets compared to new ones as the probability of failure rises with usage age, and subsequently, maintenance plans need to be adjusted as the asset ages within specific finite horizons (Golmakani and Moakedi, 2012:541). The scheduled maintenance actions can migrate from limited repairs, to block/simple replacement and to perfect repair (Golmakani and Moakedi, 2012:541).

4. Constraints of applying Surveillance and scheduled maintenance in industry

The optimality of inspection intervals is usually derived from an overall-cost-over-a-finite-time horizon perspective, as organizations are seeking for minimal maintenance and operational costs (Golmakani and Moakedi, 2012:542). Many businesses track financial objectives as their key objectives, and therefore the tracking of maintenance costs is one of their key prerogatives. Most firms therefore track costs for the application of surveillance maintenance and the separate costs include the costs related to inspections, repairs and penalty costs due to the unforeseen failures, as depicted in the figure below.

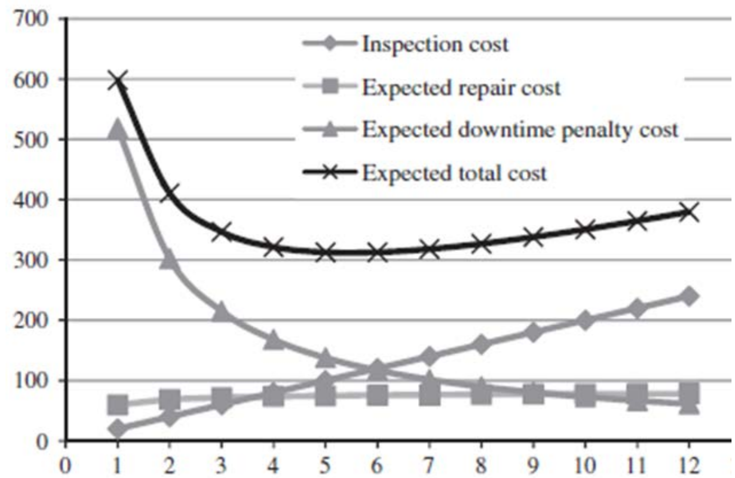


Fig. 4: Costs associated with surveillance maintenance (Golmakani and Moakedi, 2012:545).

Within CBM, the cost centres encompass inspection, repair and replacement costs, and the penalty costs suffered during unanticipated failures, and the assumption is that no added costs are suffered during the operational phase as far as the system does not malfunction, irrespective of its deterioration status (Liu et al., 2017:880). But practically, when the component deteriorates, its performance may decrease as well, and this results in increased associated operational costs (Liu et al., 2017:880). The trend of increasing operational costs as the system deteriorates is shown in the figure below.

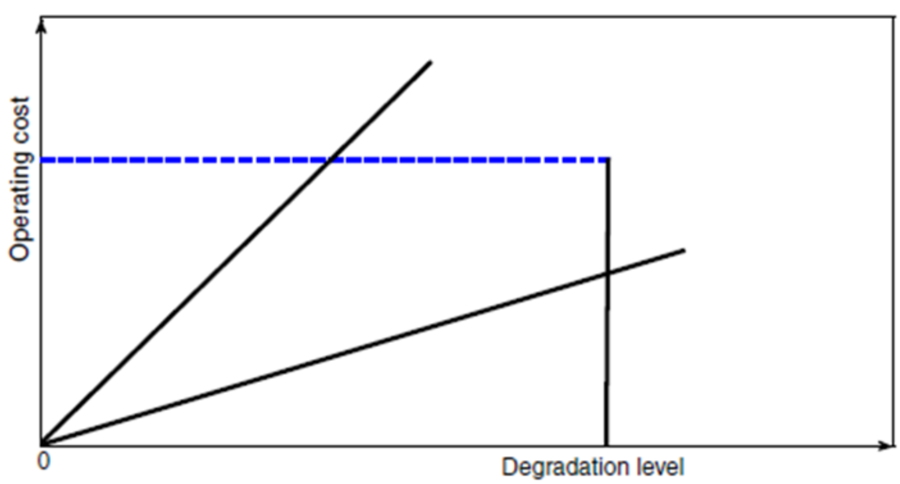


Fig.5: The evolvement of degradation and operational costs (Liu et al., 2017:880).

The frequent inspection of components or systems result in high inspection expenditures and probable repair costs in the event of defects detection, and the ultimate aim is to find the optimized inspection interims to minimize the total costs over a time horizon (Golmakani and Moakedi, 2012:542). Cost is one of the significant drivers that determine the surveillance mode and interims. The figure below depicts a sample of a system's inspection intervals.

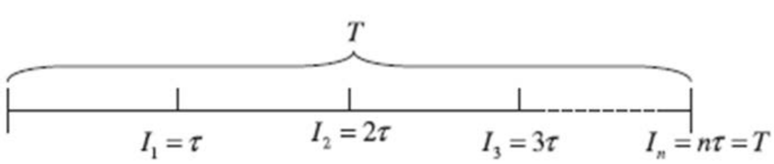


Fig. 6: Cyclic inspection interims for a system (Golmakani and Moakedi, 2012:542).

The inspection or surveillance regime considers whether a system consist of a single component or multi-component failure interactive system, and whether the failures of individual components is hard or soft (Golmakani and Moakedi, 2012:542). The issue of dependency affects the scheduling of maintenance actions around systems of components as structural and economic factors come into play (Golmakani and Moakedi, 2012:541). The kinds of dependencies that have been identified previously are economic, structural, and stochastic, but Olde Keizer et al. (2017:405) proposed an additional dependency termed resources dependence, whereby multiple components are linked through shared resources such as spares, tools or artisans.

Structural Dependence

Structural dependence refers to a scenario whereby the repair of a component involves some other component(s) to be disassembled or repaired concurrently. There exist situations where components are reliant on each other by virtue of the physical structure of the entire system, and this culminates in two categories of structural dependence, which are technical and performance dependencies (Olde Keizer et al., 2017:406).

Technical dependence **-** A specific technical system structure can evolve in repairs or usage constraints, during which the constraints emanate from repair actions on a specific component either requiring or prohibiting repair actions on different components, e.g. aircraft wheels that require simultaneous replacement in case of failure for one, as they require uniform profile height at all times. Also, accessing a component that requires repair can require the dismantling of other components that are obstructive of the way to reach the required component. There is also usage restriction during which the failure of or repairs on a specific component might have effects on the continued operations of other components/systems, e.g. hot work repairs on a tank might cause explosions unless upstream processes are isolated and the tank itself is emptied (Olde Keizer et al., 2017:406).

Performance dependence **-** The configuration of components within a system affects the performance of the whole system in case of a component failure. This depends whether the system configuration takes the series or parallel structure. In a series structure, any component failure is critical as it can result in high unavailability costs, so maintenance interventions are executed at a relatively early stage to avoid system malfunctions (Olde Keizer et al., 2017:406).

The surveillance system can be operated with alarm threshold levels that can be set at lower levels to prompt intervention at earlier stages, although they are modelled optimally to pursue cost-efficiency. The series configuration may entail a total stoppage for the entire system to enable repair actions to be instituted, thereby availing opportunistic maintenance time to other components, which can be regarded as a special scenario of economic dependence. Within a parallel system, a redundancy or by-pass system is available, and a failed component can be repaired without affecting the operations of other components within the system. Repair actions can then be done at a comparatively later stage, and even the surveillance system is typically applied using thresholds, they ought to be set higher to reduce the inspection frequency. A typical example of a parallel system is a tank with four pumps that are concurrently pumping a fluid from the tank, and failure of one pump will not stop the operation at all, but only the overall performance of the system drops. There are also combinations of series and parallel systems.

There is also an arbitrary structure that allows components to be configured in any setting, resulting in a complex system. This setting can culminate in a technical dependence, and if not investigated thoroughly and optimized, it might lead to over or under maintaining the system, and therefore compromising the overall system reliability. There is also redundancy in most industrial setups when more components than necessary are installed in the system as a means to heighten system availability. Redundancy can either be active or standby, where active redundancy refers to all components operating simultaneously and overally contributing to the system performance, whereas for standby redundancy, the components do not operate simultaneously and their only contribution to the system's performance is when they are activated. Moreover standby redundancy can further be classified as hot, warm or cold standby. Hot standby refers to when the redundant components can be activated at any time, so they are virtually live and subjected to failures when on standby. Cold standby is when the standby components are totally inactive and they are not subjected to degradation at all, whilst the midway scenario is the warm standby, whereby the components are subjected to degradation at lower rates than when the components are fully active (Olde Keizer et al., 2017:408).

Basically, most industrial practitioners subject redundancy systems to scheduled maintenance policies, without investing much in surveillance systems. There is more room to investigate further CBM requirements for redundancy systems.

Stochastic dependence

Stochastic dependence is when for instance, the degradation process of a particular component is partly/fully reliant on the deterioration state of another or other components. In essence, the component failures are partially dependent. Stochastic dependency comes in three ways.

- Failure-induced damage - when a single component's failure can culminate in a significant, one-time destruction to other components, causing an instantaneous intensification of the degradation levels or even abrupt failures of these components. For instance, vehicle tyre failure can cause a wheel hub bearing failure or even worse still, an accident that can result in many other components of the vehicle being damaged. Three failure scenarios may result and these are: no secondary damage is triggered and simply the failed component need to be replaced, the component failure triggers some other components to be repaired/replaced as well, or the component failure triggers an entire system repair/replacement. Using a stochastic approach, CBM is then applied through a degradation threshold for scheduled maintenance actions
- Load sharing – where a multiplicity of components might share the entire system's load. When one component fails, the system continues to operate but the strain is put on the functional units to maintain performance levels. This failure burdens the other functional components more, subjecting them to hastened degradation exposure. Neglecting such stochastic dependence as load sharing is costly and the costs increase considerably with both the quantity of components and the degree of dependence. Scheduled maintenance actions should be taken relatively early as soon as a defect is identified (Olde Keizer et al., 2017:408).
- Common-mode deterioration – entails numerous components failing or deteriorating concurrently, as a result of subjection to the same or comparable operational circumstances, for instance. Such association is ordinarily positive, signifying that an intensification in degradation for a particular component is regularly connected with a corresponding rise in degradation for the other components, e.g. windmills in an offshore farm can all be subjected to failure due to inclement weather conditions. A threshold policy applies coupled with the stochastic dependence to avoid under- or over-estimation of the associated costs, and reliability performance.

Economic Dependence

Economic dependence is applicable when the pooled repair of numerous components results in an alternative and minimized cost scenario as compared to individually repairing a component alone.

- Negative economic dependence – this is when repairing numerous components concurrently results in escalated costs than repairing them independently.
- Positive economic dependence – occurs when repairing numerous components simultaneously culminate in reduced overall costs than repairing them separately, e.g. during a shutdown when resources are all pooled together to repair several components (Olde Keizer et al., 2017:412).

Resource dependence

Maintenance interventions may only be scheduled subject to the availability of the required resources, such as spares or maintenance artisans. Several components can be interconnected through common spare(s) and optimization has to be developed around the spares as a major constraint.

In practice, many companies face constraints when it comes to the fiscal budget and to allocating maintenance artisans to perform CBM tasks. The scheduling of tasks according to the budget and to the artisans need to follow the threshold policy for defects that would have been identified. Likewise, this applies to spares allocations in the event of conflicting priorities in the face of scarcity.

Tools, transportation and material handling equipment form another category of resources that require scheduling for CBM tasks that are generated through a surveillance system. A threshold policy needs to be followed to make sure that resources are allocated according to the criticality levels of the thresholds (Olde Keizer et al., 2017:411).

4.1 Negative factors working against scheduled tasks effectiveness

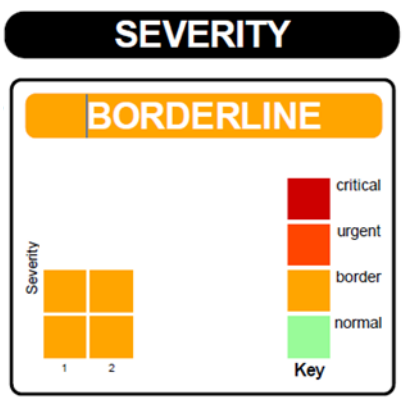
- Planning time – the availability of resources such as maintenance artisans, equipment spares and the machine availability time for maintenance always determine when the scheduled inspection or repair time can be carried out. The delay in carrying out a scheduled maintenance task can result in a breakdown if the action calls for an immediate reaction. A scheduling planning model should consider the defect threshold and time horizon for the scheduled action to take place (de Jonge, 2017:23).

- Imperfect condition information - the condition information may comprise of noise owing to inaccuracies of measurements and interpretations, and also owing to the inadequate precision of the measuring instrumentation, and this is prevalent in vibration and oil analysis, which are the broadly applied techniques in industry. These techniques may consequently be referred to as imperfect.

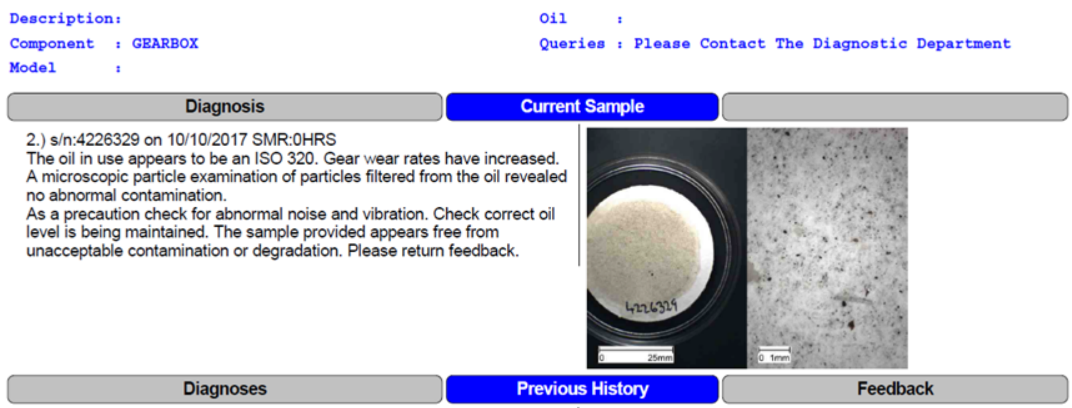
Practically, the failure threshold is complicated to define and typically, it is an arbitrary value that depends on the environment, state and the component's features (Liu et al., 2017:200).

5. Practical Assessment of Scheduled and Surveillance Maintenance

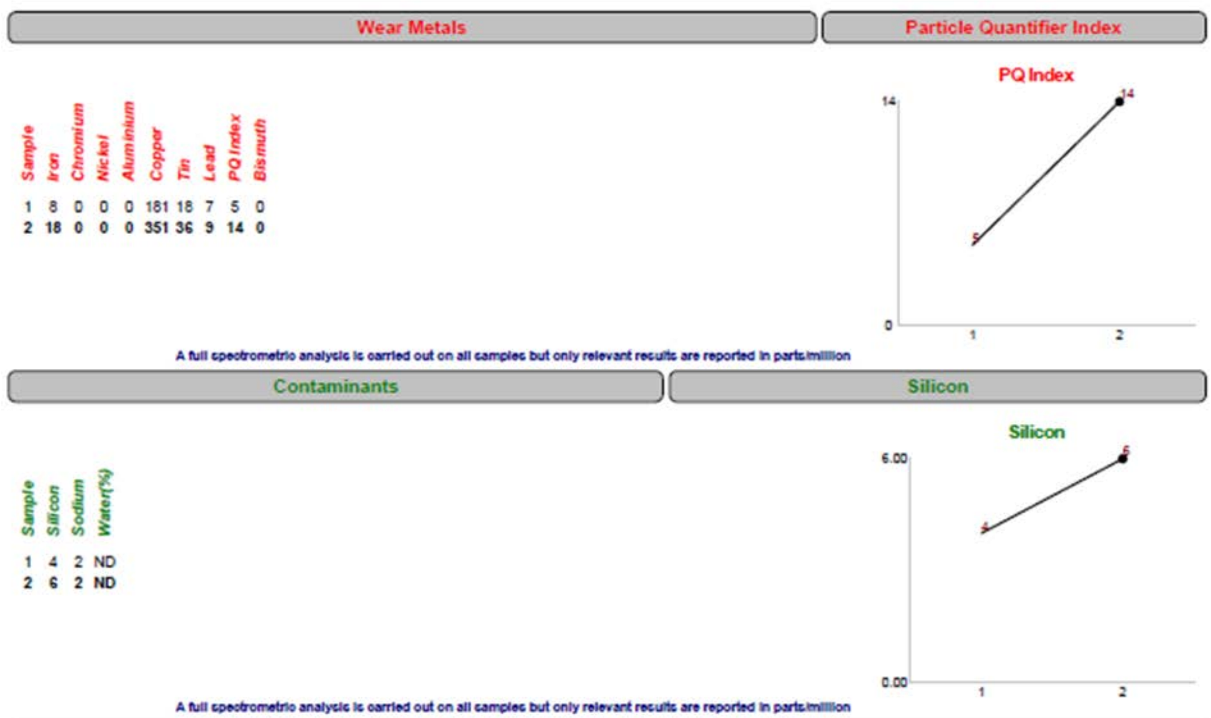
A practical review was made at a South African manufacturing company to ascertain the extent to which they applied surveillance and scheduled maintenance. The predominant surveillance or degradation condition monitoring that they applied in their processing plant was vibrations and oil state monitoring. Some of the components were continually monitored and while some had inspection intervals of one calendar month. The determination of the inspection intervals was not done according to any modelling or decision criteria, and these interims were arbitrarily derived.
The analysis of oil and vibrations showed that there were established thresholds and these thresholds were determined by the specialist oil analysis and vibration monitoring service providers. The methodology used to establish the threshold was firstly, carrying out baseline vibration analyses for various equipment before establishing the alarm levels; and analyzing oil contamination or deterioration according to percentage impurities or the oxidation of the oil shown by colour change. The figure below shows a sample oil analysis and maintenance decision making. This is for a gearbox unit with a sample which was assigned number 422639, which was analyzed as having a borderline severity when the oil sample was assessed. The analysis results for various factors such as viscosity, contamination and wear particles count were all shown in the figure below.



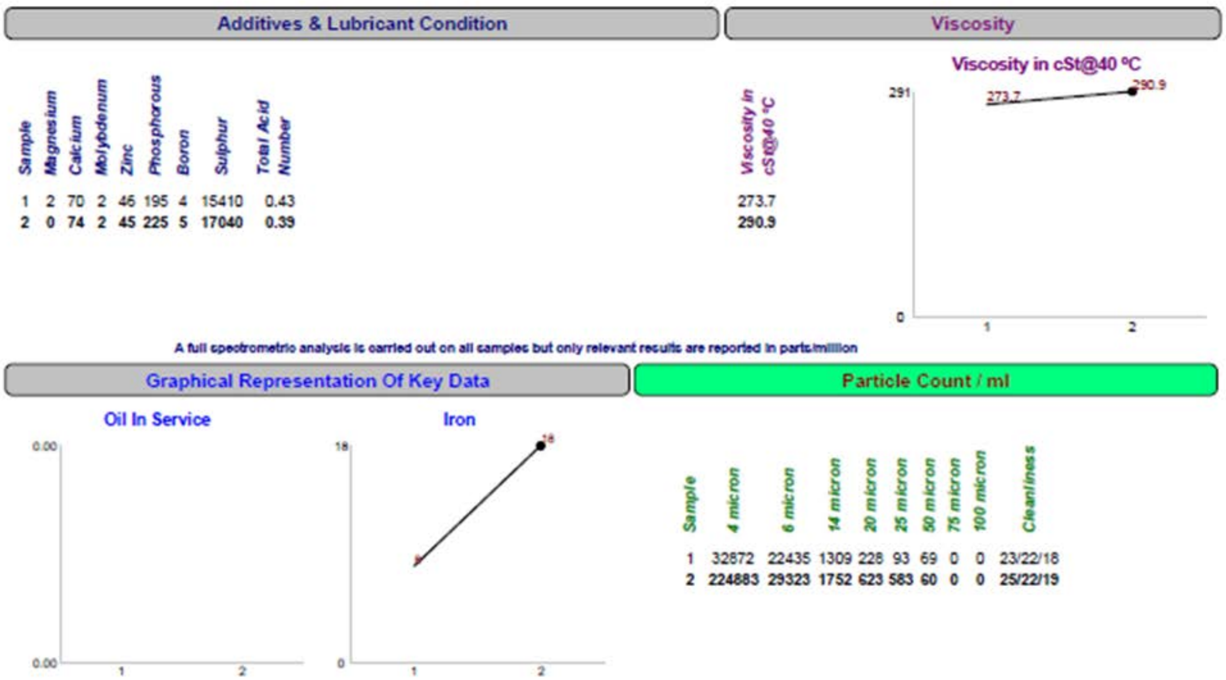
(a)


Description:
Component : GEARBOX
Model :
Oil :
Queries : Please Contact The Diagnostic Department
Diagnosis
Current Sample
2.) s/n:4226329 on 10/10/2017 SMR:0HRS
The oil in use appears to be an ISO 320. Gear wear rates have increased.
A microscopic particle examination of particles filtered from the oil revealed no abnormal contamination.
As a precaution check for abnormal noise and vibration. Check correct oil level is being maintained. The sample provided appears free from unacceptable contamination or degradation. Please return feedback.
4226329
0 25mm
0 1mm
Diagnoses
Previous History
Feedback

(b)


Wear Metals
Particle Quantifier Index
Sample Iron Chromium Nickel Aluminium Copper Tin Lead PQ Index Bismuth
1 8 0 0 0 181 18 7 5 0
2 18 0 0 0 351 36 9 14 0
PQ Index
14
0
1
2
5
A full spectrometric analysis is carried out on all samples but only relevant results are reported in parts/million
Contaminants
Silicon
Sample Silicon Sodium Water(%)
1 4 2 ND
2 6 2 ND
6.00
0.00
4
A full spectrometric analysis is carried out on all samples but only relevant results are reported in parts/million

(c)



(d)

Fig. 7: Oil sample analysis report (a) severity rating, (b) diagnosis and actions (c) wear particles and contaminants, (d) viscosity and particle count

Of particular note, is that the recommended maintenance actions were specified within the severity categories of critical, urgent, borderline and normal, but no timeline was specified for instance, on the maximum number of hours or days before a critical maintenance action is closed out. Thus the scheduling of the maintenance tasks was left at the mercy of the maintenance planning officer or the production planner to determine when the tasks should be scheduled. A further inspection of the scheduled tasks on the CMMS did not reveal whether the task actions were to be perfect or imperfect actions and that left room for reliability deficiencies allied to the scheduled actions.

6. Conclusion

CBM culminated due to the existing pressure on decreasing needless inspections and/or repair actions and their accompanying costs pertaining to added data gathering, recordings and assessments (Alaswad and Xiang, 2017:55). This has been attained through optimization modelling of CBM strategies. CBM defines a maintenance program that optimizes system's performance according to the costs, availability and reliability criteria, and the endgame is inspection schedules or paradigms like continuous monitoring, and scheduled repair actions thresholds (Alaswad and Xiang, 2017:55).

The practical application of the CBM strategy in industries is still not fully developed, and it is a far cry from what is covered in most literature findings. The crucial aspects of motivating for the migration to a combination of surveillance and scheduled maintenance from a conventional TBM strategy are mostly not considered when it comes to the adaptation of surveillance and scheduled maintenance. The choice of embarking on surveillance maintenance is usually taken on the basis of technical aspects without consideration of costs involved in a time horizon. Industrial users of surveillance maintenance mostly do not apply a cost modelling for them to motivate the adoption of such a strategy. There is also a blatant lack of scheduling and maintenance actions degree decision criteria within the industrial set-up as the case study review showed that arbitrary scheduling and work scoping was done on actions emanating from the inspections without any due consideration to components reliability. The driving focus of having surveillance maintenance and scheduling maintenance actions is attaining high equipment reliability, but there are still gaps within the industrial application.

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Biographies

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Professor Charles Mbohwa is the Vice-Dean Postgraduate Studies, Research and Innovation at the University of Johannesburg's (UJ) Faculty of Engineering and the Built Environment (FEBE). As an established researcher and professor in the field of sustainability engineering and energy, his specializations include sustainable engineering, energy systems, life cycle assessment and bio-energy/fuel feasibility and sustainability with general research interests in renewable energies and sustainability issues.