Intelligent Predictive Maintenance of Electric Trains in South Africa

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Abstract **- This paper presents a review on techniques used to monitor rolling stock equipment in order to predict the maintenance needs and activities before failure could actually occur. There is limited number of research on this study which has focused majorly on the infrastructure, and very little has covered the topic on maintenance or the rolling stock maintenance. This paper explores the available current source and findings about three maintenance strategies, two which are currently the most commonly practiced in South Africa and one which is taking the focus on this research. The review also revealed that artificial intelligence techniques are rarely used in monitoring of railway equipment. Part of the discussion in this paper is about the use of these AI techniques in maintenance. A discussion of a proposed maintenance strategy that uses the application of AI techniques is included and the whole review is closed off by outlining the possible challenges and future considerations relating to the predictive maintenance of Electric Trains.**

Keywords - predictive maintenance, electric trains, intelligent techniques, AI

I. INTRODUCTION

There are two main subsystems that make up the railway network which are: Rolling stock (which for the rest of this paper will be referred to as 'Electric Trains [ETs]) and the rail infrastructure, basically referring to the rail track and the overhead equipment. In order to meet the demands of the railway large numbers commuters and provide a reliable service, both of these subsystems need to be well sustained and managed to ensure availability and reliability of the network. The link between sustaining provision of acceptable services from assets in any kind of industry and the reliability of those assets while in service has been proven by many researchers to be maintenance. In the railway, the railway infrastructure system can be considered stable and motionless. There are not many factors unanticipated from design stage that can possibly affect the system. However, looking at the ETs they are the most maintenance complex subsystem in the railway as they consist of subsystems and they are the moving parts. This then makes it safe to conclude/assume that, ETs requires the most intense and accurate maintenance if it is made a goal to sustain the availability and reliability of the system. Asekun (2014) mentioned in his research paper that a train fails in service, it immediately closes the railway track line and this would result in delays and cancellations on the timetable schedule for that track until the train either goes back on service or is removed from the track. This was to emphasize the importance of reliability of ETs to the railway in providing services meets its demands from the customers. Whenever reliability is a key factor, adequate maintenance becomes of even much higher importance also.

With the current state of transport needs and economy status, many South Africans are turning to the use of rail transport in larger numbers causing a high demand on reliability and availability of the rolling stock fleet in service. With such a high demand of reliability and availability, maintenance becomes a crucial tool in ensuring that the trains are supplied to meet the demand needs. The main purpose of this research is to review the state of predictive maintenance of ETs generally but more specifically in South africa.

II. GENERAL MAINTENANCE OF ETS

When a system is designed and given life, its life span gets determined. In an ideal situation, it would be expected that the system would perform its perfect function for its estimated life span and in the end it would fail and maintenance would be done in order to extend the life of the product. However, in real practice maintenance is what it is required to restore systems or equipment performance to its desired function as well as to sustain its expected life (Ahmad & Kamaruddin, 2012). This means whenever a product is put in service, there has to be a maintenance strategy or function put in place already to ensure sustainability of that product. Maintenance being a tool is integration of specific methods, personnel of certain skills and availability of defined resources. If any of the above mentioned is compromised, the whole maintenance operation is most likely to be compromised. Accuracy in maintenance is an important matter, which should be the main drive in maintenance planning. This study has discovered that inadequate maintenance strategies can result in poorly performed maintenance activities which would lead the vulnerability and failure of the product or system (Akesun, 2014). Maintenance does no only ensure the availability of equipment and on-time deliveries, as part of reliability it also ensures that the product remains of good quality and is also safe to be in-service (Niu, Yang and Pecht, 2010).

A. Maintenance Objectives

In all history, from all maintenance discussions, the main goal of maintenance is described as a way to ensure the maximum efficiency and availability of production equipment and related facilities at the lowest possible cost and with no compromise to quality and environmental health and safety. Umiliacchi, Lane & Romano (2011) described today's ETs as complex, real-time, distributed and reconfigurable systems, incorporating many embedded subsystems, which are integrated together to perform a high quality transportation service. When such systems are not properly maintained or none maintenance is perform, failures which would have heavy impact on system operations, with undoubtable deterioration of performance, reduction of initial accepted quality and increment of costs occur (Umiliacchi, Lane & Romano, 2011). Countless maintenance discussions have become prove that in any operation maintenance should never be underrated or treated as sub-function, which is not necessary or just a waste of money; nor be considered just an optional standard function which can be featured with production; maintenance is a basic requirement for producing and providing acceptable services, which stems from the time of product design and grows its need until the moment of product end of life.

Akesun (2014) outlined the importance of maintenance in few objectives listed below, amongst many:

- Increasing reliability of the operating systems.
- Reducing breakdowns and emergency shutdowns
- Optimizing the use of maintenance resources
- Optimizing the utilization of resources to reduce downtime
- Improving spares parts stock control.
- Maximizing production at lower cost, highest quality and within optimum safety standards.
- Improving equipment efficiency which reduces scrap rate.
- Optimizing capital equipment life.
- Identifying and implementing cost reductions.
- Minimising energy usage.
- Optimizing the useful life period of the equipment.

Akesun (2014) also outlined how Dekker (1996:230) further summarised and grouped maintenance objectives into four main objectives:

- Functionality assurance
- System life elongation
- System Safety
- Ensuring mankind well-being

Maintenance is a critical function which helps companies makes profit in a manner that guarantees their assets' life span and function. When maintenance is done right, it can build trust between service providers and consumer as the services provided would be reliably available when required with only minor setbacks.

B. Maintenance strategies

Maintenance strategies have widely been discussed in many platforms and different researchers in many sources have grouped or defined maintenance strategies according their findings. Many sources have classified maintenance strategies into two main functions: Corrective (Run-To-Failure (RTF)) and Preventive Maintenance. Bengtsson, 2004, classified maintenance activities into two main classes. Corrective maintenance, which can either be performed immediately or deferred to a more convenient time for production capacity (Bengtsson, 2004), and Preventive maintenance which is further broken into two, Condition based which can be a scheduled, continuous or requested maintenance activity, and Time-based schedule maintenance. Figure 1, Ahmad & Kamaruddin (2012) classification diagram of maintenance strategies outlining two basic functions: Corrective and Preventive, of which preventive is divided into Predictive Maintenance (PdM), also referred to as Condition-Based (CBM) and Periodic Maintenance, and commonly known as Time-Based Maintenance (TBM).

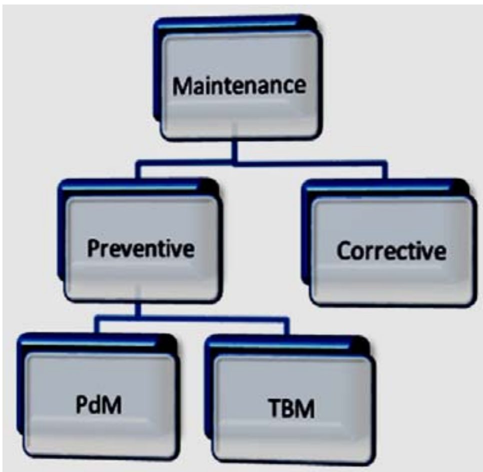

Figure 1: Maintenance strategies by Ahmad & Kamaruddin (2012)

B1. Corrective Maintenance

Corrective Maintenance (CM) which is failure-triggered kind of maintenance, and is performed after a failure has occurred. This maintenance function aims restoring a failed product back to its operational form. This kind of maintenance uses troubleshooting as its key tool to isolate and remove failure from a system. CM is found to be associated with in-service failures, emergency remedial and repairs, and in often cases equipment is badly damaged and completely dead that it would need to be rebuilt (Akesun, 2014). Niu, Yang (2010) referred to CM as maintenance that should be utilized only in non-critical areas where capital costs are small, consequences of failure are slight, no safety risks are immediate and quick failure identification and rapid failure repair are possible. Though it is the easiest type of maintenance strategy to implement compared to Preventive, this strategy can not necessarily be considered cost-effective. It has been associated, (Akesun, 2014), with high expenses in spare parts inventory, machine down time, overtime labour costs and low production availability.

B2. Preventive Maintenance

Preventive Maintenance (PM) strategy is the about the concept of performing maintenance activities before the time failure is estimated to most likely occur. This type of maintenance mainly focuses on reducing failures that the equipment is most likely to have over a period of time. Unlike RTF, PM is a planned type of maintenance which is scheduled either periodically, TBM, depending on the assumptions made at design stage or scheduled base on the condition (CBM) of the system or predictions. The disadvantage of TBM is that its nature is mostly dependent on either the experience of engineers and technicians working on the equipment or original equipment manufacturer's recommendations (Shin & Jun, 2015) thus limiting realistic interaction with the equipment.

B3. Condition-Based Maintenance

CBM model as mentioned above, as at preventing the failures from occurring before they can actually cause system errors and damages. Shin & Jun (2015), explained CBM to be focusing on the prediction of the degradation process of equipment, based on the assumption that most abnormalities do not occur instantaneously, but rather follows a degradation process from normal states to failures. Bousdekis & Magoutas (2015) defined this degradation process as an opportunity window for maintenance actions to be planned and executed before break down and refer to it as the P-F Curve. The strategy uses the idea that in real-life machine failures are never sudden death and is a process which takes time getting influenced by different parameters which if monitored can be detected at early stages and machines can be saved from unexpected break-downs and damages that permanently takes the life of a machine.

Since the degradation process takes time, failures are able to be detected at early stages, maintenance actions can be planned in time and adequate maintenance procedures can be implemented and right resources can be prepared in time, but in TBM the maintenance needs are always the same for all similar systems and spares are replaced solely on grounds of assumptions made when life span was being estimated. Corrective activities can be carried out before the failure occurs. However comparing the cost of implementation of this strategy to other strategies, it is relatively high. Implementing this strategy may require the use of extra smart devices, which might be expensive, on the system for monitoring. Niu, Yang (2010) mentioned that it is very important to decide whether the equipment is importantenough to justify the investment.

B4. Analysis of Predictive Maintenance Application

PdM uses the principle of collecting data/information on a system in real-time performance by means of condition monitoring. According to Ahmad & Kamaruddin (2012), CBM was introduced in 1975 in order to maximise the effectiveness of PM decision making, and has since evolve to become the most modern and popular maintenance technique discussed in the literature. The application of PdM is thereby achieved by monitoring the equipment life through its operating condition, which can be measured based on various monitoring parameters, such as vibration, temperature, lubricating oil, contaminants, and noise levels; the motivation of CBM (PdM) is that 99 per cent of equipment failures are preceded by certain signs, conditions, or indications that a failure is going to occur (Ahmad & Kamaruddin, 2012). These monitoring techniques observe the operation of equipment and hold the actual state of the system. The condition monitoring process can be applied by setting up data collection systems which include different sensor for different parameters and then setting a system, Artificial Neuron Network (ANN) that analysis the collect data and make decisions of the state of the system by comparing the data to the equipment original state data. It is also important to note all the necessary changes that need to be applied to equipment design in order suit the real-life operations. These can be achieved by two patterns concurrently that are mentioned by (Ahmad & Kamaruddin, 2012): First, collection of the condition data (information) of the equipment and Secondly, increasing knowledge of the failure causes and effects and the deterioration patterns of equipment.

Ahmad & Kamaruddin (2012) also mentioned that these processes can either be done online, meaning monitoring while the equipment is running and in operation state, or offline while the equipment is out of service. In shin & Jun (2015), three major techniques for to be applied in data processing, diagnostics, and prognostics for implementing for implementing PdM are outlined as :

- **Data-driven**, discussed to be the model that collects equipment or system historical data and learns the actual behaviour of the equipment. This technique is dependent on the quality of the operational data.
- **Model-base –** collect data and has a physical interaction with the physical equipment. This approach makes use of analytical model to represent the system behaviour including that of degradation.
- **Hybrid –** a combination the two techniques.

Figure 2 below shows the condition based process according to Shin & Jun (2015). The process describes condition monitoring as process that start by gathering systems status data and monitoring by making use of sensors; then it moves to making a diagnosis of a product status in a real-time way; then an estimation of the deterioration level of the product can be made, the equipment repairing or replacement cost depends on the deterioration level; the time of equipment or machine abnormality can be predicted; and appropriate and required maintenance activities can be performed. There are many other approaches to system monitoring, only to mention a few above.

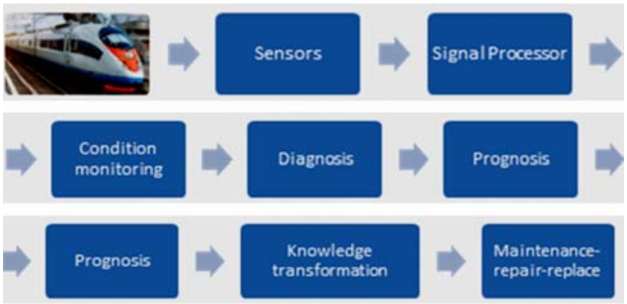

Figure 2. PdM process (adapted from Shin & Jun, 2015).

III. MAINTENANCE OF ETS

From the findings of many discussions, maintenance functions and strategies seems to have been evolving and improving from decades to decades with

more and more companies increasingly adopting its use as an activity that adds value to assets (Akesun, 2014). Su, Jamshidi, Núñez, 2017, emphasized maintenance to be a crucial requirement for an appropriate functioning and lifetime extension of all different functions of railway network infrastructures. Alkali, Dinmohammadi & Ramani, 2018, mentioned to CBM as having the advantage to reduce the risks of in service failures, and to improve the reliability of railway rolling stock train. Dinmohammadi & Ramani, 2018, further referred to CBM on rolling stock as a strategy which can determine the state of critical systems prior to failure and improved service delivery to customers. However, whether it is practicable to fully implement of ETs remains a mystery as many discussions also argued factually that it is expensive implement CBM and that data collection is not always accurate due to factors such as environmental complexity (Niu, Yang & Pecht, 2010). According to Niu, Yang & Pecht, 2010 to implement CBM requires confidence in Knowledge of basic principles on subject matter, insight to real time performance/behaviour of equipment (System training with accuracy), relevant data handling skills and experience, and reliable information system. Combining these requirements increases the complexity of CBM implementation.

IV. MONITORING TECHNIQUES IN ET

Following the principle that most equipment failures that occur have prior signs, conditions or indications which can be picked up when a system is monitored, presented below are monitoring techniques that can be applied by railway operations on ETs:

- Vibration Monitoring – vibrations in the system can be used to predict the degradation level of system
- Oil-analysis or lubricant monitoring – lubrication is very important factor when it comes to mechanical equipment.
- Electrical Monitoring – which monitors changes in electrical parameters such as resistivity, conductivity, dielectric strength, and potential
- Temperature monitoring is very crucial in every operation as it plays a very influential role.

A. The use of Artificial Intelligence Techniques

AI systems are generally known to be systems that have the ability to simulate human-like decision-making executions. However, AI systems are considered more accurate and precise. AI networks or techniques have highly been recommended to be a useful tool in dealing with complex system which today's railway ETs have become. Raza, Khosravi (2015), described ANN to be getting much attention by researchers and considered as a powerful computational tool for complex problems. Raza, Khosravi (2015) also mentioned ANN as also having a mimic ability like a human brain's to make decision and shows adaptive behaviour for complex, noisy set information.

When PdM is achieved by means of application of AI techniques, it maximises the effectiveness of the model. In this research, it is intended to develop a PdM model that also uses the collection of data technique to develop artificial neuron network.

V. PREDICTIVE MAINTENANCE VS CORRECTIVE/TIME-BASED

From the finding, many researchers have elaborated CBM/PdM to be more advantageous compared to TBM and CM. PdM is most cost effective type of maintenance, especially for important and expensive equipment that cannot be easily repair and would not be favourable to loose. PdM is found to sustain maintenance resources as it is associated with little overtime work as corrective actions can always be planned before time and maintenance activities hours can be accurately estimated. Shin & Jun, 2015 mentioned PdM to be associated with very less amounts of corrective spares as it minimizes failures or damages to equipment by giving warning prior the impending failure and increase precision in failure prediction. Shin & Jun (2015) discussed the role PdM can play on the importance of product safety. They mentioned

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on their discussion that PdM can increase safety by detecting problems in advance before serious problems occur, which leads to the improvement of customer satisfactions due to the high quality assurance. Monitoring real-time performance gives a clear view of the equipment safety status as opposed to relying on safety predictions made at design level. In many railway operations in South Africa, TBM and CM are the most commonly used maintenance strategies. The rail technology has been evolving over time and monitoring of systems techniques has also improved over decades. However, the monitoring (information/data recorders) technologies are mostly used to keep records of real-time performance in order for use in failure investigation after failure has occurred. CM is mostly an everyday practice in many South African Rail operations. Considering the complexity of today's ETs, when a failure occurs and it was never anticipated and its cause is unknown, maintenance becomes a long process as at times as identifying the cause in order to isolate it from the system becomes difficult as the cause might have happened over a period of time starting with a minor issue and ending with a major. Most failures in practices of CM are most likely to reoccur over and over without being isolated as the main cause is sometime never detected. In many rail operations, particularly in RSA, evolution of maintenance strategies has been very minimal over the rail industry decades. This has resulted in very less optimized and less cost-effective maintenance activities which become very costly to rail companies.

VI. CONCLUSION

This paper has reviewed the state of maintenance of ETs in general with specific focus to South Africa. Based on the literature studied, the findings show that the use of artificial intelligence for predictive maintenance is still not popular in South Africa. This is obviously a gap and a future research direction. The study also outlined three strategies used for maintenbance of ETs in South Africa. More so, CBM/PdM is found to have more advantages compared to TBM and CM. Though it may be associated with high implementation expenses, when implemented it is the most cost effective type of maintenance, more especially for important and expensive equipment that cannot be easily repaired.

REFERENCES

[1] Asekun, O.O., 2014. *A decision support model to improve rolling stock maintenance scheduling based on reliability and cost* (Doctoral dissertation, Stellenbosch: Stellenbosch University).

[2] Ahmad, R. and Kamaruddin, S., 2012. An overview of time-based and condition-based maintenance in industrial application. *Computers & Industrial Engineering*, *63*(1), pp.135-149.

[3] Su, Z., Jamshidi, A., Núñez, A., Baldi, S. and De Schutter, B., 2017. Multi-level condition-based maintenance planning for railway infrastructures–a scenario-based chance-constrained approach. *Transportation Research Part C: Emerging Technologies*, *84*, pp.92-123.

[4] Bengtsson, M., 2004. Condition based maintenance system technology–Where is development heading. *Condition Based Maintenance Systems–An Investigation of Technical Constituents and Organizational Aspects*, *55*.

[5] Umiliacchi, P., Lane, D., Romano, F. and SpA, A., 2011. Predictive maintenance of railway subsystems using an 'Ontology based' modelling approach. In *Proceedings of 9th world conference on railway research, May* (pp. 22-26).

[6] Dekker, R. 1996, "Applications of maintenance optimization models: a review and analysis", *Reliability Engineering & System Safety,* vol. 51, no. 3, pp. 229-240

[7] Shin, J.H. and Jun, H.B., 2015. On condition based maintenance policy. *Journal of Computational Design and Engineering*, *2*(2), pp.119-127.

[8] Niu, G., Yang, B.S. and Pecht, M., 2010. Development of an optimized condition-based maintenance system by data fusion and reliability-centered maintenance. *Reliability Engineering & System Safety*, *95*(7), pp.786-796.

[9] Raza, M.Q. and Khosravi, A., 2015. A review on artificial intelligence based load demand forecasting techniques for smart grid and buildings. *Renewable and Sustainable Energy Reviews*, *50*, pp.1352-1372.

[10] Bousdekis, A., Magoutas, B., Apostolou, D. and Mentzas, G., 2015. A proactive decision making framework for condition-based maintenance. *Industrial Management & Data Systems*, *115*(7), pp.1225-1250.

[11] Alkali, B.M., Dinmohammadi, F. and Ramani, A., 2018. Towards implementing condition based maintenance policy for rolling stock critical system. In *Towards implementing condition based maintenance policy for rolling stock critical system*. Institute of Mechanical Engineers (IMechE).