The Use of Autonomous Maintenance in the Fertilizer Industry in Zimbabwe

Tawanda. Mushiri *Member, IAENG*, Kumbirayi. Mugwindiri, and Charles. Mbohwa

Abstract — The paper aims to give a guideline on the use and implementation of Autonomous Maintenance in a typical manufacturing facility. It details the chronic and perennial problems besetting typical developing countries maintenance regime scenarios. It then proffers a simple but concise paradigm shift toward the adoption and use of Autonomous Maintenance. A thorough literature exposé is articulated which it is hoped should cement the benefits of Autonomous Maintenance. Autonomous Maintenance is a dynamic, team-based methodology that involves all employees in identifying and eliminating equipment related losses such as equipment failure, inconsistent adjustment procedures, lengthy set-up time, idling and minor stoppages, processing defects and reduced production yields among others. The importance of teams in goal attainment is highlighted and finally the paper concludes by articulating the World famous 5's due to Nakajima and incorporates these in the implementation of Autonomous Maintenance.

Index Terms — autonomous maintenance; manufacturing; developing countries, maintenance, fertiliser, automation.

I. INTRODUCTION

The fertilizer industry in Zimbabwe is dogged with profitability problems. For example, in 2010, ZimFert made a loss of US$ 800 000 whilst in 2011 it made a marginal profit of $400 000 (Mutombozana, 2012). The ever-increasing costs of new equipment and spares, perennial foreign currency shortages and the need for improved competitiveness bring about the need for more effective maintenance systems, this results in maximum utilisation of plant-installed capacity through improved reliability, uptime, quality and asset life, all achieved at optimal levels of costs versus benefits (Endrenyi, 2001). Emphasis should be on ensuring that the correct maintenance is being done (doing the right job) rather than merely ensuring that maintenance is being done correctly (doing the job right). For the same company ZimFert, for example, process losses have traditionally been 1.5% of total losses but increased to 10% in 2011 (Mutombozana, 2012). This has raised concern and

hence the need to find new emerging maintenance management philosophies such as improving maintenance cost effectiveness as one sure way of increasing the overall profitability. Experience in other parts (Aicheson, 2003), of the world shows that maintenance costs may be reduced by between 40% and 60% by eliminating chronic failures. This is a typical example where elimination of the chronic failures is doing the right job, as opposed to just ensuring rapid return to operations whenever a failure occurs. As a result, maintenance is essential in the restoration of the machine to its functional state, for as long as possible (Gorelick, 1998). It is often forgotten that these failures are normally a result of human error or omission. Effective maintenance plays a role in cost effective manufacturing that has established a greater attention with the concepts such as asset management and life cycle costing of the productions asset which has recently gained importance. Maintenance has to ensure economical production (Hitomi, 1998), and hence profitability. Thus profitability has to do with both, maintenance cost effectiveness and economical production as well; and in turn profitability itself leads to overall company effectiveness (Horner, 1997).

Autonomous Maintenance is one of the latest plant management tools engaged to maximize equipment effectiveness resulting in increased productivity and cost reduction in any industrial establishment (Zhongwei, 2010). As a facet of maintenance, Autonomous Maintenance is necessary in the restoration of the machine to its functional state, preferably for a long time. (Gorelick, 1988).

II. AUTONOMOUS MAINTENANCE PRINCIPLES

Within autonomous maintenance, operators maintain their machines in highest standards. These operators are trained to do so through a structured approach of seven steps of Autonomous Maintenance (Nakajima, 1988). Autonomous Maintenance means activities of the operator that uses the machine to personally conduct maintenance activities. These maintenance activities include cleaning, retightening, oiling and inspection which levitate production efficiency to its limit and also prevent forced deterioration of equipment (Kelly 1991). This is because even after maintenance has been carried out, equipment can revert to systemic failure if due regard to maintenance instructions is not adhered to. The major reductions in routine operations and scheduling directly leads to reduced cost of operation (Kiinigsmann 1996).

Operator based maintenance seeks to empower operators to being full partners with engineering. It is basically the

blending of traditional preventive maintenance with quality management (Khanna, 2009). Preventive Maintenance involves the policy of upkeep; replacement and modification rather than repair and incorporates periodical inspection of the plant in order to diagnose the imminent failure (Levitt, 1988). However Autonomous Maintenance seeks to create that operator ownership of the plant hence developing that sense in the operators that they are responsible for plant reliability as well as its availability (Khanna, 2009). Secondly, it has the appreciation that the operator has more of the machine and plant inter-phase therefore the operator has more appreciation of the faults and defects that are common and usually encountered during the running of the plant hence is more likely to give a more practical and immediate solution to those problems (Mckone, 2001). Autonomous Maintenance incorporates Condition Based Maintenance which is centred on monitoring a parameter or parameters that will indicate the condition of the equipment (Myers, 1988). Thirdly, since the birth of world class manufacturing, it has been noted that there is a competitive advantage in preventing maintenance than to repair broken down equipment; as a result the involvement of all concerned in production, engineering and management is important, and this is well addressed by Autonomous Maintenance (Wheeler, 2007. In addition, Autonomous Maintenance also has an essential role in overall system safety management (Rausand, 2008). Overall Equipment Effectiveness (OEE), which is the result of availability, utilisation and quality rate, is increased with the implementation of Autonomous Maintenance (Nakajima, 1988).

III. IMPLEMENTING AUTONOMOUS MAINTENANCE

Autonomous Maintenance aims to minimize maintenance costs and downtime costs at a particular quality of production whilst fulfilling the safety requirements (Rausand, 2008). The maintenance problems that are currently in Zimbabwe fertiliser manufacturing sector include:

1. General deterioration of infrastructure
2. Malfunctioning equipment
3. Frequent breakdown of equipment
4. Process not conforming to quality control standards

Consequences as a result of the above problems are:

- Reduced plant availability
- Failure to meet production targets
- Low overall equipment effectiveness
- Reduced plant utilization
- Deterioration of process capability index
- Loss of revenue (Mutombozana, 2012).

The current economic environment in Zimbabwe and shortage of foreign currency, makes it costly to buy new equipment or make drastic process changes. This challenge could be abated by using multi-currency instead of heavily depending on a single currency. The situation calls for a cost effective and optimal maintenance strategy. Historical data and records of companies show that the above listed consequences can be addressed by adopting Autonomous Maintenance. However implementing this strategy can be labour intensive when fully carried out. Autonomous Maintenance is an important solution in obtaining a committed and sufficiently motivated maintenance workforce. (Kelly, 1998). Some of the typical challenges that are likely to be faced in the implementation of Autonomous Maintenance include operator resistance and management inertia (Nakajima, 1988). This has also compelled the need for this paper to analyse the likely challenges and give a possible smooth implementation of Autonomous Maintenance that is acceptable to all stakeholders.

The fertiliser sector considered the implementation of Autonomous Maintenance since it is a pivotal component in the agro based economy of the country (Mutombozana, 2012). Implementation of Autonomous Maintenance has similarities for any plant with minor variations needed to the method that will be considered is applicable to any plant (Nakajima, 1988).

Autonomous Maintenance is targeted at failure root causes unlike preventive/predictive maintenance that is aimed at only symptoms of a problem. Its main objective is to extend the life of mechanical machinery as opposed to:

- pre-empting crisis failure maintenance in favour of scheduled failure maintenance
- making repairs when often nothing is broken (Hackman, 2002).

Autonomous Maintenance aims to prevent failures as the key to reduction of the Maintenance, Repair and Operation (MRO) costs, and increasing the return on assets. The optimal reliability threshold, within Autonomous Maintenance, is determined by reducing the cumulative maintenance cost per unit time in the residual life of the system (Xiaojun. 2007). Hence regular Autonomous Maintenance helps keep machines running efficiently and elimination of potential breakdowns (Zhongwei, 2010).

The use of small group activities is an effective way of implementing Autonomous Maintenance. These are achievable through using three main Task Groups which are;
1. A management task group 1.
2. An engineering task group 2.
3. A production task group 3.

The Responsibilities of management task group:

- Formulating the Autonomous Maintenance policy and objectives
- Promoting the Autonomous Maintenance philosophy to all personnel in the whole plant. The information should describe clearly the maintenance policy, Autonomous Maintenance concept and the reason for implementation in the factory.
- Training staff.
- Executives and the Managing Director should show enthusiasm in the implementation of the Autonomous Maintenance. Conducting introductory seminars to eradicate resistance to change.
- Formulation of master plan is imperative.
- Commencement of Autonomous Maintenance programme, usually in the factory greens, and to be

attended by sister companies, suppliers etc. Responsibilities of the other Task Groups, 2 and 3:
- Defining current problems in their areas.
- Analysis of the problem areas and bottleneck operations.
- Identification of every potential problem root cause.
- Evaluation of the equipment, materials and malfunction.
- Planning and investigation of functions and malfunctions.
- Improving plant availability for tasks groups 2 and 3.
- Implementing autonomous maintenance for operators for task group 2.
- through continuous improvements, reducing spare part consumption, maintenance for quality and reliability.

I. CONDITION BASED MAINTENANCE

Condition Based Maintenance (CBM) is a management philosophy that postulates the repair or replacement decisions established on the current or future condition of assets (Raheja et al, 2006); CBM recognizes that change in asset condition and/or performance is the major cause for implementing maintenance (Horner et al, 1997). CBM is a modern procedure that determines what, if any, testing and maintenance procedures to be executed using the condition of equipment. (DiLeo et al., 1999). It is similar to preventive maintenance (PM) program with an extensive collection of predictive maintenance (PdM) procedures, that necessarily means CBM is not PdM but, a PdM is a subset of CBM.

$PdM + CBM = Holistic\ maintenance$ (This can have intelligence applied in it). The Intelligency can be applied through fuzzy controller. In this research a fuzzy controller has been used. As shown in Fig 1, the CBM approach has proactive and a predictive maintenance. All the problems and failures are analysed and solved systematically. Condition based is a holistic approach to maintenance and is a powerful tool for autonomous maintenance.

Condition Based Maintenance on the other hand is to monitor and assess the condition or health of a machinery unit while it is running and stop it for maintenance only (Okah-Avae, 1981). On-load monitoring is done without interruption of the operating unit and off - load monitoring, which would require the unit to be shut down or at least removed from its prime duties. Figure 2 shows the available prognostic methods and its groups. Maintenance strategies have evolved from breakdown maintenance (**fix after failure**) to preventive maintenance as driven by the need to reduce maintenance costs, maintain high equipment availability and shorten repair time (Lee, Ni, Djurdjanovic, Qiu and Liao, 2006), then further proceeding to condition-based maintenance (CBM), and intelligent predictive maintenance (**predict and prevent**) (Heng, Zhang, Tan and Matthew, 2008), (Tao, Chen, Chan and Wang, 2013). In actual fact the breakdown maintenance and preventive maintenance are labor intensive and also expensive to keep on doing them. For rotating machinery it will be very difficult however to apply PM and breakdown maintenance

- Increasing plant utilisation for task group 2.
- Autonomous maintenance is achievable through using the five S's or 7 Nakajima steps of stage 8 in the 12 step Autonomous Maintenance implementation plan.
- 5S's stand for Seiri (Organisation), Seiton (Tidiness), Seiso (Cleaning) and Seiketsu (Discipline), Shitsuke (Training). The engineering task group handles education and training.
- Preventive maintenance, reducing breakdowns

V. CONDITION MONITORING

Condition monitoring (CM) is the process of monitoring a parameter of condition in machinery, using statics in a way that a significant change indicates a developing failure (Okah-Avae, 1981). CM is a major constituent of predictive maintenance. Conditional monitoring allows maintenance to be scheduled, or act in prevention of consequences of failure, before the failure occurs. Nevertheless, to identify impending damages a deviation from a reference value (for instance temperature or vibration behaviour) must occur (Jardine, Daming and Dragan, 2006). Predictive Maintenance does not predict failure. Machines with defects are at a higher risk of failure compared to defect free machines. The failure process commences once a defect has been identified and CM systems can only measure the deterioration of the condition. It is much more cost effective to intervene in the early stages of deterioration instead of waiting till failure of machinery. Condition monitoring is highly beneficial as it allows conditions that shorten lifespan of machinery to be addressed before occurrence of repeated failures. It benefits in that the actual load, and subsequent heat dissipation representing normal service can be noticed and be addressed. Machinery that could be serviced includes rotating equipment and stationary plant for example boilers and heat exchangers (Liu, Jie, Wang and Golnaraghi, 2008).

hence the need to come up with intelligent CBM. Generally this section of literature highlights the other work and case studies that have been carried out in doing maintenance to move away from the general maintenance that is found now to be expensive and time consuming.
The idea underlying conditional maintenance is that a component is not replaced unless it is showing signs of ageing or wear likely to impair its performance (Blanchard and Fabrycky, 1990). The decision is based on physical measurements which are usually:
- Noise and vibration
- Temperatures (thermal monitoring)
- Analysis of oil debris
- Corrosion monitoring
- Acoustic emission monitoring
- Motor and transformer current analysis

The more specialized methods which tend to be associated with particular plant or industry include ultrasonics, shock

pulse monitoring, crack detection and some more advancement (Okah-Avae, 1981).

VI. FUZZY LOGIC IN MONITORING PLANT

Most companies are using what is termed smart technologies in reducing machinery breakdown (Innovolt, 2014). Control is a term generally defined as a mechanism used to guide or regulates the operation of a machine, and/or apparatus. The notion of control is often intimately linked with feedback which is a process of returning a fraction of the output signal to the input of a device. There is negative feedback, whereby feedback opposes the input and therefore reducing the input, and there is also positive feedback whereby it reinforces the input signal (Passino K and Yurkovich S, 1998).
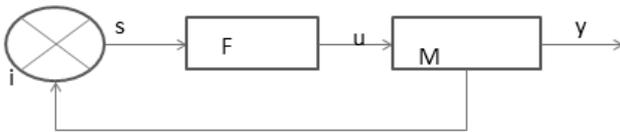
Fig 3: Feedback conventional control mechanism

Where;

M- Machinery, F- Feedback, s- Signal of the error, i- Input, u-control signal or non-linear function, y-output

Fig 3 shows a typical feedback conventional control mechanism and it controls the error if it arises.

The control signal (u) can either be; proportional to the error with a proportional constant (K_P), proportional to both the magnitude of the error and the duration of the error with a feedback constant called derivative constant (K_D) or lastly can also be proportional to the relative changes in the error values over time that has a feedback integral constant (K_I).

According to (Babuska and Mamdani, 2008); these constants can be linked as follows;

$$u(t) = K_p s(t) + K_I \int_0^t s(\tau) d\tau + K_D \frac{ds(t)}{dt}$$

Equation 1

With equation 1 deductions of the following is carried out and concluded.

TABLE I: WHAT THE PID MEANS

Value (PID)	Determines reaction to the
Proportional (K_P)	Current error
Integral (K_I)	Sum of recent errors
Derivative (K_D)	Rate at which the error has been changing

In the case of classical operations of process control one has to solve the non-linear function u. Furthermore, it is very important that one also finds the proportionality constants (PID). In the case of fuzzy controller, the non-linear function is represented by a fuzzy mapping, typically acquired from human beings (Babuska and Mamdani, 2008). The conventional controller used to work as for the general PID but it will face some challenges in case of robotics section. This is where rules and laws are generated, the IF THEN ELSE rules and put in the fuzzy logic software. Figure 4 shows the arrangement of components in fuzzy logic controller.
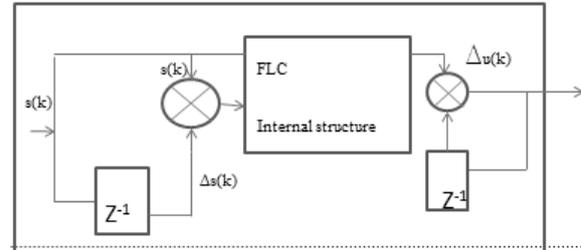
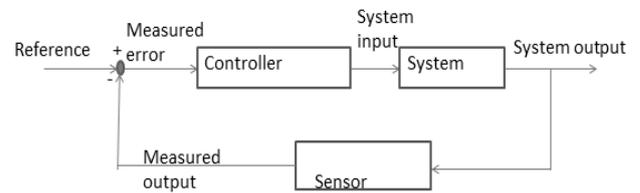Fig. 4: A fuzzy logic based controller (FLC)

Fig. 5: Fuzzy controller

The fuzzy controller uses intelligent sensors that react faster if any error or fault occurs. Fig 5 shows the fuzzy controller with a sensor and the controller. A fuzzy controller is a device intends to model a vaguely described or vaguely known processes (Babuska and Mamdani, 2008). Fuzzy logic has basically two types of controllers which are the Mamdani and Takagi-Sugeno (Yager R R and Filev D P, 1994). In this manner the researcher will focus on the Takagi-Sugeno-Kang method which uses (Supervisory Control and Data Acquisition) SCADA for online monitoring.

TABLE II: CONTROLLERS UNDER FUZZY LOGIC

Controller type	Typical operation
Mamdani (linguistic) controller with either fuzzy or singleton consequents.	Direct close-loop controller
Takagi-Sugeno (TS) or Takagi-Sugeno-Kang controller	Supervisory controller – as a self-tuning device

There are two modes in which a controller can be used with the process these are: Feedback mode whereby the fuzzy controller acts as a control device; and feed forward mode whereby the controller will be acting as a prediction device (Yager R R and Filev D P, 1994). A controller is implemented using an algorithm. This controller is to be used in this research for maintenance duties in CBM.

VII. Conclusion

Implementation groups of Autonomous Maintenance are not mutually exclusive however they have to interact. This is very important to consider especially during implementation of Autonomous Maintenance and reviewing its performance. The benefits accomplished result the basis of a Kaizen path which is the continuous improvement cycle. Implementing Autonomous Maintenance is usually carried out in tandem with the structural change of an organisation such that the new proposed policy has a deliberate bias towards Autonomous Maintenance to achieve its implementation. The implementation of this policy will certainly improve the performance efficiency and effectiveness. The centrality of Autonomous Maintenance together with its overarching importance in maintenance systems has evidently been brought out.

Acknowledgment

References

[1.] Aicheson, K. Lecture Notes, MSc in Engineering Management and Manufacturing Systems, Maintenance Engineering and Management, Cranfield Univesity, England, Bedford. 1993.

[2]. Endrenyi, J. The present status of maintenance strategies and the impact of maintenance on reliability, power Systems, IEEE Transactions, Volume 16, Issue 4. 2001.

[3]. Gorelick, B. Getting the most from maintenance, Enercheck Systems, UE Systems Inc., TWI Press Inc., Charlotte NC, 1998.

[4]. Hitomi K. Manufacturing Systems Engineering, A Unified approach to manufacturing technology, production management, and industrial economics, Second Edition, Standard Publishers Distributors, 1998.

[5]. Horner, R.M.W., El-Haram, M.A., and Munns, A. K., Building maintenance strategy: a new management approach, Journal of Quality in Maintenance Engineering, Vol. 3 No. 4, pp. 273-280. 1997.

[6]. Kelly, A. Maintenance Planning and Control, New Delhi, East West Press Private Ltd, 1991.

[7]. Khanna, V. K, 5 "S" and TQM status in Indian organizations, The TQM Journal, Vol. 21 Issue: 5, pp.486 – 501. 2009.

[8]. Kiinigsmann, H., Collins, J., Dawson, S. and Wertz, J., Autonomous orbit maintenance System, Arm Astronautica, Vol. 39, No. 9-12, pp. 977-985, Pergamon, California.1996.

[9]. Khobbacy A.H Khairy and Murthy Prabhakar. D.N, 2007; Complex system maintenance handbook (Springer series in reliability engineering), United States of America, 2007, Published by Springer London.

[10]. Levitt, J. Making Preventive Maintenance Really Work For You, Charlotte NC, TWI Press Inc., 1998.

[11]. McKone, K. E., Schroeder, R. G., and Cua, K. O. The impact of total productive maintenance practices on manufacturing performance, Journal of Operations Management, Volume 19, Issue 1, Pages 39–58, 2001.

[12]. Mutombozana T, Optimizing fertilizer manufacturing plant by way of preventive maintenance using process based work study techniques, MSc Dissertation, University of Zimbabwe, Harare, 2012.

[13]. Myers C., Transformers- Condition Monitoring by Oil Analysis Large or Small; Contentment or Catastrophe. International Conference, Edinburgh, 1998

[14]. Nakajima S, TPM Development Program, Productivity Press, Cambridge, UK, 1988.

[15]. Raheja D, Llinas J, Nagi R and Romanowski C, 2006; Data fusion/data mining based on architecture for condition based maintenance: International Journal of Production Research, 2006 Volume 44, Issue 14.

[16]. Rausand, M. and Vatn, J. Reliability Centred Maintenance, Springer Series in Reliability Engineering, Part B, p79-108. 2008.

[17]. Wheeler, P. Reliability Centred Maintenance, Buildings. Vol. 101, no. 11, pp. 38-40. Nov. 2007.

[18]. Xiaojun, Z., Lifeng, X. and Jay, L. Reliability-Centred Predictive Maintenance scheduling, Elsevier, Reliability Engineering & System Safety, Volume 92, Issue 4, Pages 530–534. April 2007.

[19]. Zhongwei, W. and Qixin, C. Development of an autonomous in-pipe robot for offshore pipeline maintenance. International Journal of Robotics and Automation, Emerald Group Publishing Limited [ISSN 0143-991X] Volume 37, Number2, p177–184, 2010. http://www.ct@consulting.com.au/MaintEng.htm

[20].Babuska and Mamdani. (2008, November 2). Fuzzy control scholarpedia. Retrieved September 27, 2013, from Fuzzy control: http://www.scholarpedia.org/article/Fuzzy_control

[21]. Blanchard and Fabrycky. (1990). Systems engineering and analysis. New Jersey: Prentice Hall, Englewood Cliffs.

[22].Heng, Zhang, Tan and Matthew. (2008). Rotating machinery prognostics: state of the art, challenges and opportunities. Mechanical Systems Signal Processing, 724-739.

[23]. Innovolt. (2014, August 18). Innovolt. Retrieved March 11, 2015, from Powering performance: http://innovolt.com/

[24]. Jardine, Daming and Dragan. (2006, October). A review on machinery diagnostics and prognostics implementing condition-basedmaintenance. Mechanical Systems and Signal Processing(7), 206-217.

[25]. Lee, Ni, Djurdjanovic, Qiu and Liao. (2006, February 9). Intelligent prognostics tools and e-maintenance. (Elsevier, Ed.) Computers in industry, Elsevier, 57(1), 476-489.

[26]. Liu, Jie, Wang and Golnaraghi. (2008). An extended wavelet spectrum for bearing fault diagnostics. IEEE Transactions on Instrumentation and Measurement, 57(12), 2801-2812.

[27]. Okah-Avae. (1981). Condition monitoring – A maintenance management strategy for industrial machinery. Benin: University of Benin-City.

[28]. Passino K and Yurkovich S. (1998). Fuzzy control. Sand Hill Road, Menlo Park, California: Addison Wesley Longman, Inc.

[29]. Tao, Chen, Chan and Wang. (2013). An approach to performance assessment and fault diagnosis for rotating machinery equipment. EURASIP Journal on Advances in Signal Processing, Springer, 738-746.

[30]. Yager R R and Filev D P. (1994). Essentials of Fuzzy Modeling and Control. USA: John Wiley & Sons Ltd.
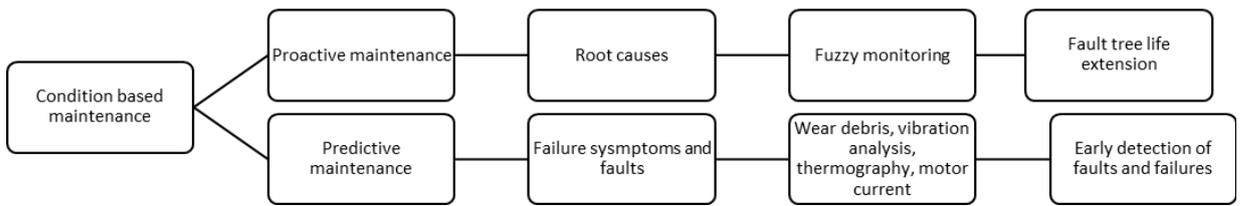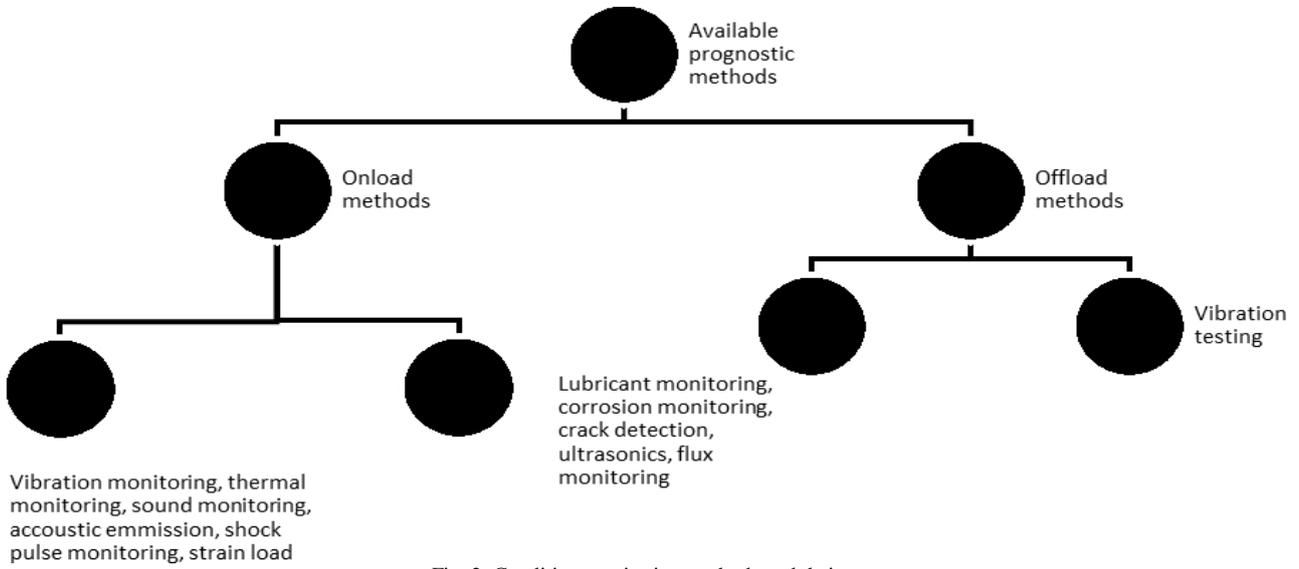
Fig 1: CBM approach has a proactive and predictive maintenance approach.

Fig. 2: Condition monitoring methods and their groups