MAINTENANCE MANAGEMENT, AI & BIG DATA: A Review (2005-2019)

Khairy A H Kobbacy*, Adolfo Crespo Marquez**

*Independent researcher, Manchester UK
kobbacyk@gmail.com

**University of Seville, Seville Spain
adolfo@us.es

Introduction

- This paper presents an up to date review of the recent development in the field of application of AI in maintenance management with identification of the major application areas and a view of the expected future developments.

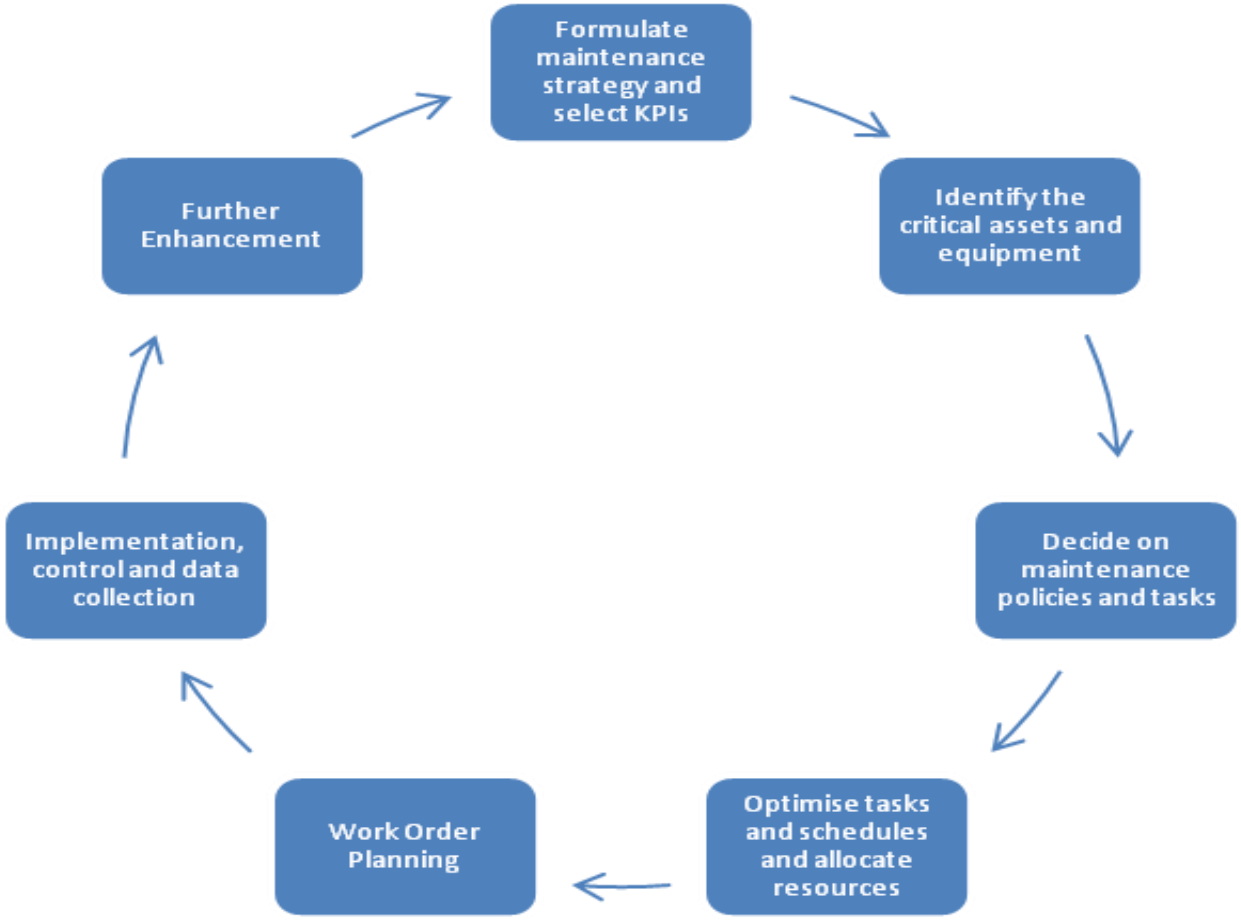
- The paper has particular emphases on handling big data in maintenance using AI techniques.

- Since the mid 1980s many attempts have been made to use AI techniques in maintenance modeling and management and the use of AI in order to replace human intelligence with machine intelligence in solving maintenance problems of complex systems.
- The ultimate objective is to achieve more effective maintenance management and in some cases to make achieving this goal a viable option
- The AI techniques used are numerous

Presentation Structure

- The maintenance management area is introduced through the maintenance planning cycle
- The area of "Big Data" is then discussed briefly.
- The relevant AI techniques are introduced and outline review of each technique application in maintenance are presented.
- The conclusion identify trends in the application of the various AI techniques in maintenance management since 2005.
- As with previous reviews, the **Science Direct database** was used to carry out the literature search

Maintenance Management and Planning Cycle



Maintenance Management and Planning Cycle

- *1.Formulate maintenance strategy and select KPIs*
- *2. Identify the critical assets and equipment*
- *3.Decide on maintenance policies and tasks*
- 4.Optimise tasks and schedules and allocate resources
- *5.Work Order Planning*
- *6. Implementation, control and data collection*
- *7. Further enhancement*

Big Data Definition and Structure

- Big Data is becoming a major issue in all aspects of Operations Management and particularly in maintenance due to its nature.
- Big data analytics is the use of advanced analytic techniques against very large, diverse data sets with different structures and sources.
- The analysis of these data is beyond the ability of traditional software e.g. relational databases.
- The features of Big data are broadly recognised as "4Vs" volume, velocity, variety and value.
- Kobbacy has argued since 1986 that the nature of large and changeable maintenance data lends itself to the application of AI in its analysis.

AI In Maintenance Management

- There are many AI techniques that have been developed since the middle of the past century with the fast development of computers and software.
- In what follows the main AI techniques that are used in maintenance management area are briefly introduced.
- This paper presents an overview of the published research in the area of AI in maintenance management.
- The focus will be on papers published since 2010 but interested reader can refer to other relevant papers that cover previous periods.

Case-Based Reasoning (CBR)

- CBR utilises past experience to solve new problems.
- It uses case index schemes, similarity functions and adaptation and provide intelligence through updating the case base.
- CBR provides **learning capabilities** to AI systems which is a main dimension of intelligence and when combined with other AI techniques such as KBS it produces powerful tools.
- CBR has moderately employed in maintenance management applications since 2005.
- CBR is particularly useful in hybrid systems and can provide "learning" capabilities that utilize past experience in supporting decision making.

- Wan et al [2019] presents a knowledge based maintenance planning system to facilitate information and knowledge sharing between all stakeholders including machine tool manufacturers, users, maintenance service providers and part suppliers in "product Service" business model. CBR is used to improve efficiency of maintenance planing.
- Almarshad [2013] developed a knowledge-based Building Information Model (BIM) system for building maintenance which utilises the functions of information modelling techniques and knowledge systems to facilitate retrieval of information and knowledge for maintenance work.
- Cheng et al [2008] presents an Intelligent Reliability Centred Maintenance Analysis (IRCMA) with CBR is used to utilise historical records of RCM analysis on similar items to analyse a new item.

Data Mining (DM)

- DM detects data patterns for data bases using machine learning techniques. It helps developing predictive models to support decision making.
- DM has experienced significant increase in use in maintenance management in the past few years.
- Lee et al [2015] proposes the use of intelligent factory agents with predictive analytics for asset management.
- Uz-Zaman et al [2017] proposes a text mining approach to extract accurate failure time data from work orders and downtime data. A keyword dictionary is constructed using work orders text descriptions.

Fuzzy Logic (FL)

- In 1965 Zadeh introduced the concept of fuzzy sets to allow dealing with vague and imprecise concepts. Later he introduced FL which allows the representation of information of uncertain nature.
- FL lost some interest by researcher in modelling maintenance though due to its convenience in dealing with uncertainty it maintained interest in hybrid systems.

- Erozan [2019] presents a fuzzy decision support system for managing maintenance activities of critical components in manufacturing systems. This aims at managing components with very low reliability. The proposed method uses the duty cycle, utilization rate of capacity, safety stock and redundancy effect.
- Alamaniotis et al [2014] introduces a methodology called regression to fuzziness that estimates the remaining useful life (RUL) of power plant components.
- Sriramdas et al [2014] proposes Fuzzy arithmetic based reliability allocation approach during early design and development stages when every system has to meet its specific reliability goals.

- Risk based maintenance/ inspection continue to be a popular approach to ensure safe as well as economically viable operations.
- Gallab et al [2019] present a model to quantify the risk associated with maintenance activities by coupling the risk analysis method with FL in order to calculate the qualitative value of the risk level.
- Sa'idi et al [2014] argues that the risk based maintenance (RBM) as a proper risk assessment methodology minimizes the risk resulting from asset failures but a main engineering problems in risk modelling of the complex industries is uncertainty due to the lack of information. This paper proposes a model for the risk of the process operations in the oil and gas refineries. A fuzzy logic system (FLS) was proposed for risk modelling as it overcomes the uncertainty of the RBM components.

Genetic Algorithms (GAs)

- GA is an optimisation technique based on the principles of genetics and natural selection i.e. solutions can be evolved through mutation and weaker solutions become extinct.
- GAs have superior and versatile features compared with the classic optimisation and search techniques. For this reason GAs are a most popular technique for solving complex maintenance management problems.
- GAs are the most popular AI technique used in maintenance management.
- GAs is a powerful optimisation methods which explains why the GAs papers addresses operational rather than strategic issues.

- Preventive maintenance planning is arguably the most complex problems in maintenance due to its nature and its typical lack of data.
- There are many examples of applying GA in this area. For example:
- Zhiqiang et al [2015] addresses the problem of finding a robust and stable schedule for a single machine with availability constraints.
- Chen et al [2013] deals with the preventive maintenance (PM) scheduling problem of reusable rocket engine using GA.

- There are several attempts to use GAs on optimising maintenance of parallel/ series systems
- Gao et al [2015] proposes an optimal dynamic interval preventive maintenance scheduling for series systems.
- Xiao and Peng [2014] considers the optimal allocation and maintenance of multi-state elements in series–parallel systems with common bus performance sharing.
- Nourelfath et al [2013] studies the joint redundancy and imperfect PM optimisation for a series-parallel multistate degraded system.

- The application areas of GA in maintenance are numerous. Examples include:
- Maintenance in underground pipelines,Tee et al [2014],
- Bridge maintenance, Motawa et al [2013],
- Nuclear Power system Jiejuan et al [2004]
- Building maintenance planning, Paulo et al [2016] presents a software which uses GAs applied to Markov Chains to estimate best building maintenance plan.
- Manufacturing and flow-shop; Xanthopoulos et al [2015] addresses the problem of single-stage Kanban system with deterioration failures and condition based PM.

Knowledge Based Systems (KBS)

- KBSs use domain specific rules of thumb or production rules to identify a potential outcome or suitable course of action.
- Initial interest in applying AI techniques in maintenance started with KBS/ expert Systems. Kobbacy [1992] proposed an information oriented KBS to maintenance and Kobbacy et al [1995] presents "IMOS", an Intelligent Maintenance Optimisation system that uses KBS.
- Over the years the interest in KBSs in maintenance declined to a relatively low number of publications in the past few years
- Ruiz et al [2014] suggests an original Experience Feedback process dedicated to maintenance.
- Guo et el [2019] proposes a fault diagnosis strategy of the variable refrigerant flow system based on an expert rule base. The system contained 22 rules identified by experts and system characterisation.

Neural Networks (NN)

- NNs are based on the idea of emulating human brain and use back propagation algorithm. They are often used in modelling and statistical analysis and in classification and optimisation.
- There has been a steep increase in number of papers on applications of NN in maintenance in the past decade.
- Sbarufatti [2015] studies the application of sequential Monte-Carlo sampling to estimate the probabilistic residual life of a structural component subjected to fatigue crack propagation
- Wang and Gao [2012] carries out a research on Risk and Condition Based Maintenance (RCBM) task optimization technology.
- Zhao et al [2019] propose an effective method based on the recurrent neural networks and statistical process control chart to predict the condition of gas turbines exhaust system.

Hybrid Systems

- Hybrid Systems are those which employ two or more AI techniques.
- In maintenance management applications the most frequently used AI technique in hybrid systems is FL particularly when coupled with NN. Other combinations in maintenance include KBS, GA and DM.
- Maatouk et al [2016] presents a hybridization FL control genetic algorithm and local search to solve the preventive maintenance optimisation problem in multi-state series-parallel system.
- Trappey et al [2015] developed intelligent engineering system for asset management.
- Ben Ali et al [2017] presents a method for accurate bearing remaining useful life prediction based on Weibull distribution and ANN.
- Kobbacy and Jion [2001] developed a Hybrid Intelligent Maintenance Optimisation System (HIMOS). The rule based KBS selects suitable model for evaluating and suggesting PM interval. The Case Based Reasoning provides learning capability to the system and selects a suitable model based on previous cases when the rule base failed to recommend a model. HIMOS will be continuously changing with use as expert users add new cases to the case base.

Findings

- Table (1) below demonstrates the number of papers published on use of AI in maintenance management during the period 2005-19.
- The 3 periods are not identical but sufficiently close in length.
- They show a drop in number of publication during 2015-2019 following a sharp increase between the 2005-09 and 2010-15.
- The number of publications remained at a high level. The technique with the largest overall number of papers is GAs though it witness significant drop in paper numbers in the last period (2015-19). The interest in GAs can be explained by its nature as a powerful optimisation technique.

Findings

Number of Published papers during 2005-09, 2010-July 2015 and 2015=2019

AI Tech	2005-09	2010-July15	2015-July19
CBR	**4**	**4**	3
DM	0	1	7
FL	7	13	4
GAs	7	34	10
KBS	4	1	1
NNs	0	6	12
Hybrid	5	12	12
Total	27	71	49

- FL remains second in overall number of publications despite a significant drop in numbers in the last period.
- FL is quite useful in dealing with uncertainty which suits the nature of maintenance management problems. FL is also the most popular technique used in hybrid approaches.
- NNs shows large increase in publications in the most recent period. They are particularly useful in dealing with modelling, statistical analysis and in classification and optimisation and hence justify the increasing interest in its application.
- The interest in CBR remains healthy though as a percentage of the total number of publication has halved to around 6% .
- NNs and FL are the typical combination in building hybrid systems.
- Hybrid techniques increased as a percentage of the total number of publications. This is a positive indication for interest in developing combinations to tackle complex maintenance management problems.
- Data mining has shown large increase in number of publications due to the surge in interest in Big Data and AI as a whole to tackle large scale and complex maintenance problems.

Summary Conclusions

- In conclusion this study shows continuous interest in the area of AI in maintenance management.
- GAs remains the most used technique due to its optimisation features.
- There is also a strong interest in applying FL, NNs and hybrid systems.
- Expert systems/ KBS are diminishing in this area.
- It is the author believe that these trends will continue in the future with Data Mining becoming more explicitly used and referred to.