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MAINTENANCE ANALYTICS FOR BUILDING DECISION-MAKING: A LITERATURE REVIEW

Ifeoluwa Adedoyin Adeyemi[1*], Mohd Shahril Abdul Rahman[2], Adegbenga Adeyemi[3]

[1] Department of Real Estate, Universiti Teknologi Malaysia, Malaysia
Email: Ifeoluwa.doyin@gmail.com
[2] Department of Real Estate, Universiti Teknologi Malaysia, Malaysia
Email: mshahril.ar@utm.my
[3] Department of Estate Management and Valuation, Abubakar Tafawa Balewa University, Nigeria
Email: aadegbenga@atbu.edu.ng
[*] Corresponding Author

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Abstract:

There is a prevalence of poor building maintenance practices in both the public and private sectors in Malaysia. To improve the current state of maintenance, effective decisions must be made by the building stakeholders. Unfortunately, the decision-making process for building maintenance in Malaysia is still traditional. The decisions are usually made based on the latest maintenance inspection without taking into consideration the trend of past data. This limits the building maintenance strategy to corrective (reactive) and preventive (expensive). Data-driven decisions improve building operations and create better predictive maintenance programs because the stakeholders can instantly identify problems and effectively act. Maintenance analytics is a structured and technological approach used to extract information from data and has proven to be an acceptable tool to improve building operation and maintenance. It is used to determine "what has happened?", "why it happened?", "what will happen?", and "what needs to be done?" to enable decision-makers to take appropriate actions. In a country like Malaysia where maintenance practice is not data-driven, there is a need to identify the techniques to improve the maintenance process (especially decision-making). Therefore, this study aims to identify the various analytical techniques applied in existing maintenance analytics studies and determine the current direction of maintenance analytics studies. A comprehensive literature review was done to understand maintenance analytics, types of data and its sources, and the analytical techniques applied. Findings from the literature review revealed that the major data sources are CMMS, BIM, IoT, BAS. It was also noticed that the type of data used influenced the choice of analytical technical techniques. In addition, it was noted that certain studies did not use the major data sources and analytical techniques, and other studies used more than one data source.

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Overall, the general direction of the maintenance analytics studies was building performance and operation, end-user complaints, and work orders. There is a gap in the application of maintenance analytics to cost-effective decision-making in building maintenance. Which is recommended as the direction for future studies.

Keywords:

Data Analytics, Maintenance Data, Data-Drive Decision-Making, Malaysia

Introduction

Building maintenance in Malaysia is of great concern because of the prevalence of poor maintenance practices in both the public and private sectors (Hauashdh *et al*., 2020). There is a lack of a proper maintenance culture which has plagued Malaysia to a level that maintenance is only implemented during an emergency, and no priority is given to maintenance issues (Adnan, Daud & Razali, 2012). To meet up with the current settings and standards, there is a need to change the understanding and approach to maintenance (Suffian, 2013).

In theory, every building should be assessed and a clear maintenance plan made for its management (Le *et al*., 2018). However, building maintenance in Malaysia is heavily regulated by available funds (Ali, Chua & Ali, 2016). This is a challenge because of the drastic increase in maintenance cost for public buildings as revenue is generated from federal government grants to support the maintenance budget (Mohd-Noor *et al*., 2011). Therefore, resulting in deferred maintenance because of insufficient budget to cover the entire maintenance cost (Chong *et al*., 2019). To effectively manage the funds and efficient decision-making process.

Decisions made by building stakeholders have a direct impact on the overall performance of a building. An important aspect of building maintenance is assessing strategic management options and alternative decisions (Au-Yong *et al*., 2019). Examples of the decisions to be made are reducing maintenance by addressing the cause of faults, identifying the consequences of the building failure, deciding if to repair or replace an item, determining when to undertake preventive or corrective maintenance (Che-Ghani, Myeda & Ali, 2016). This is in addition to decisions that will have to be made on tasks to be carried out, the priority of the tasks, and tasks to be deferred (Chong *et al*., 2019). Therefore, the better the decision-making process, the more optimal the maintenance outcome.

In the last decade, data analytics has helped organizations to change from the traditional operation modes by generating information that can be used to create innovation (Gartner, 2017). Organizations today are working towards generating value from data by applying analytical techniques to convert raw data to workable information (Baijens & Helms, 2019). Similarly, the analytics of maintenance data (coined maintenance analytics by Karim *et al*., 2016) has proven to be an acceptable tool to improve the operation and maintenance of public buildings (Razali *et al*., 2020). This is because it offers insight into the overall operational performance of the building as well as occupant satisfaction (Gunay, Shen & Yang, 2019). Maintenance analytics can be used as a tool to make data-driven decisions that will enhance the maintenance process (Yang & Bayapu, 2020). Data-driven decisions improve building operations and create better predictive maintenance programs (Razali *et al*., 2020). It saves

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time, cost, labour, and energy as effective and immediate access to information aid in making an informed decision (Ergen *et al*., 2007). Therefore, it is important to have a database for ease of information access of access to information.

Karim *et al*. (2016) observed that although organizations are looking to imbibe the practice of maintenance analytics, they are still overwhelmed by the management and transfer of data. However, since 2016 to date there have been great strides by authors in applying maintenance analytics to generate information that can be used to make informed building maintenance decisions. Maintenance analytics has been applied to a variety of activities like regulating and prioritizing work orders (Bortolini & Forcada, 2019), establishing performance metrics for work orders (Dutta, Gunay & Bucking, 2020), and improving staff assignment (Mo *et al*., 2020).

Since building maintenance in Malaysia is still traditional and not data-driven, many challenges come with this form of maintenance. Olanrewaju *et al*. (2019) stated that traditional building maintenance restricts the maintenance strategy to corrective (reacting only to building failure) and preventive which costs a lot in the long run, forcing a resort to unplanned maintenance. Bortolini & Forcada (2019) noted that with traditional maintenance, surveys are usually carried out to benchmark building performance and occupant satisfaction. Post-occupancy evaluation is the common survey method to make decisions. However, it is stressful to carry out, time-consuming, and the facility managers may not be equipped to analyse the results. Finally, the absence of data-driven maintenance forces the building stakeholders to make decisions based on the latest maintenance inspection without taking into consideration the trend of past data.

Razali *et al*. (2020) stated that the implementation of maintenance analytics to building maintenance in Malaysia is faced with the challenge of insufficient and disintegrated data. Thus, hindering the maintenance decision-making process. This lack/inaccuracy of data will shorten the building life as it will impede maintenance proactiveness (Sullivan *et al*., 2010). In addition, the availability of data does not guarantee the use of maintenance analytics for decision-making (Macchi, Roda & Fumagalli, 2017). Therefore, is a need to review the current maintenance analytics studies to ascertain what is needed for its effective implementation in Malaysia.

Methodology

To achieve the purpose of this study, a comprehensive literature review was carried out to understand maintenance analytics, its application, data source, and the various analytical techniques. Articles for this study were sourced from Web of Science, Springer Link, Elsevier, Emerald, Scopus databases, and Science Direct.

Keywords used in the search were ‘maintenance analytics’ OR ‘data analytics’ OR ‘machine learning’ AND ‘big data’ OR ‘maintenance data’; AND ‘maintenance’, OR ‘facility management’ OR ‘building maintenance’. A total of 1647 papers were generated from the search, but after reviewing the abstracts and keywords, articles that did not fit the study were eliminated. Fifty-seven (57) articles were then selected for the review.

The content analysis was applied for the literature review. Each article was reviewed based on the research problem, aim, methodology, analytical technique, case study, and size of data. The results and findings from the analysis and the recommendation for future research are provided.

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Findings

Maintenance Analytics

Karim *et al*. (2016) described maintenance analytics as a structured approach for extracting valuable information from a methodological and technological perspective. Maintenance analytics can be applied to align maintenance needs with projected growth or reduction, using data obtained from field works and inspections (Razali *et al*., 2020). This decreases maintenance frequency to ensure corrective maintenance is as low as possible, thereby reducing the overall maintenance cost. Yang & Bayapu (2020) highlighted the following action plan for the implementation of maintenance analytics:

i. Assessing and defining assets.
ii. Provide tests and tools to train employees.
iii. Establish data owner.
iv. Assign codes
v. Collect data requirements in a manageable manner.
vi. Develop a master list.
vii. Prioritize task.
viii. Evaluate current asset data.

Analytics cannot be carried out without the availability of big data (extremely large datasets). Karim *et al*. (2016) suggested the storage of a large amount of data using the cloud, this will lead to results that are structured and of value to the organisation. Data being 'big' does not always make it useful, it is the analysis that generates insights (Thirathon *et al*., 2017). Asides from capturing, storing, managing, and analysing data, it is important to plan for its implementation (Ranjan & Foropon, 2021). Organisations constantly search for deeper and clearer ways to understand data. To ensure the data is appropriately utilised in maintenance, there is a need for infrastructure, data management, analytical tools, and applications (Razali *et al*., 2020). It is important to note that data does not replace intuition, it is simply a tool to be used by managers to make informed decisions.

Ahmed *et al*. (2017) identified technical factors that can affect the implementation of data analytics to be:

i. data redundancy,
ii. data presentation,
iii. data life cycle management,
iv. data security,
v. interdisciplinary cooperation,
vi. staff lacking expertise,
vii. maintenance cost,
viii. lack of adequate management,
ix. difficulties in designing analytical systems, and
x. lack of existing database software in analytics.

Other factors that may be of concern are:

i. the accuracy of data resources,
ii. the misconception that the bigger the datasets the better it is, without taking methodological issues and quality of data,
iii. the ethical concerns of data application,

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iv. data analytical context-dependent nature, and
v. access to large data volume is limited to small societal groups, this results in different concessions on knowledge and information.

McAfee *et al*. (2012) identified listed several managerial challenges for data analytics in organisations. They are:

i. Creating leadership teams to set clear goals, define success, and ask the right questions.
ii. Ensuring personnel are competent in capturing, analysing, making inferences, and presenting big datasets.
iii. Technology management and enhancing the skill sets of the IT departments.
iv. Effective decision-making through a flexible organisational structure.
v. Sustaining a data-driven culture in the organisation.

Maintenance Data

Maintenance activities generate data in large quantities. The data can be used to identify patterns in building use, maintenance expense, preventive maintenance, and energy use from sourced maintenance data (Ahmed *et al*., 2017). This makes it important to have an effective system to manage maintenance data (McCarthy & O'Sullivan, 2014). It helps with the organization of the database for efficient classification and easy access.

Computerised Maintenance Management System (CMMS)

The CMMS was designed to assist in planning, management, and administrative functions needed for effective maintenance and repairs (Jamkhaneh *et al*., 2018). The software assesses a building to reduce maintenance problems (O’Donoghue & Prendergast, 2004). Lopes *et al*. (2016) listed the functions of CMMS to be facility management, work order management, inventory control, preventive maintenance, and report management. It covers a wide range of activities related to maintenance work order, work location, material, equipment needed, and intended date of completion (Hassanain, Froese & Vanier, 2003). Also, it supports the maintenance budget and financial management. The CMMS tool is not exclusively designed to control maintenance but to ensure high output by carrying out appropriate activities over time (Kumar *et al*., 2014).

Of the various maintenance systems, CMMS is the most practical for the facilitation of maintenance decision-making because it contains information on maintenance operations (Yousefli, Nasiri & Moselhi, 2020). Although it is impossible to be proactive in maintenance without computer-based support, the successful implementation of CMMS is still low (Wienker, Henderson & Volkerts, 2016). This is because organisations are reluctant to adopt the accompanying process for its implementation, their view of CMMS as a strategy rather than a maintenance tool, the lack of adequate IT infrastructure, failure to promote its importance to senior management, and insufficient resources for its implementation (Wienker *et al*., 2016).

Despite the benefits to be gained, the CMMS has certain weaknesses and limitations. Yousefli *et al*. (2020) noted that the CMMS cannot ascertain data integrity, and this impacts scheduling and resource plans. The CMMS is also not object-based (Irizarry *et al*., 2014) and lacks 2D/3D visualisation (Becerik-Gerber *et al*., 2012). It is a database that contains large, unstructured, and amorphous data (Gunay *et al*., 2019). Jamkhaneh *et al*. (2018) added that CMMS lacks the

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capability for condition monitoring analysis and equipment failure diagnosis, it is also limited in its support resource allocation and decision support analysis.

Building Information Modelling (BIM)

BIM is an exact virtual model of a building constructed digitally in 3D (Ismail, Rahim & Ghazaly, 2020). BIM is beneficial for all stages of the building development process because of its capacity to store large data related to 3D representation, assess building information via the platform, and receive an automated update of the model (Goedert & Meadati, 2008). It facilitates the sharing of life cycle data (Gao *et al.*, 2017), and facilitates the interaction and collaboration between the various stakeholders at the various stages of the building development (Costa & Madrazo, 2015). BIM is used to enhance the maintenance management performance of facilities (Kameli *et al*., 2020). This is because it provides an integration of building data from the construction and design stage to the operational stage of the building (Gao *et al*., 2019). The 3D building representation makes it possible for the facility managers to circumnavigate buildings and use their reasoning and perception for problem solving and response to emergencies (Motamedi, Hammad & Asen, 2014).

Although BIM is beneficial to the maintenance process, there are still shortcomings that need to be remedied. Past studies have also noted that BIM application in maintenance is still in its infancy (Rowland, 2015). Mohamed, Abdallah & Marzouk (2020) opine that BIM dominates more in the Architectural, Engineering, and Construction (AEC) industry because it was primarily designed to be used in new building development. Its application to existing buildings is limited. Despite its automation, precise data generation, and easy accessibility of data, there is still a problem of interoperability between FM and BIM technologies as well as diverse system management even in the same building (Kassem *et al*., 2014). Yousefli *et al*. (2020) stated that BIM cannot track workflow and resource allocation. Thus, the facility managers are unable to apply BIM to test various workflows and resource allocations situations to identify the best scenario. Additionally, there is still a resistance to adopting BIM as facility managers believe will increase their workload (Lin *et al*., 2016). Overall, the major challenge to the integration of BIM is it does not align people, processes, and systems the same way FM does.

Internet of Things (IoT)

ISO/IEC 20924:2018 defines IoT as “an infrastructure of interconnected entities, people, systems, and information resources with services which processes and reacts to information from the physical world and the virtual world”. This implies that it is a network of connected devices like fixed, wearable, and mobile sensors (Cheng *et al*., 2020). IoT is a key component in building automation systems because buildings can be controlled and linked through modern digital technologies like sensors and actuators, as information about the state of the building is provided by wireless technologies (Puķīte & Geipele, 2017). Efficiently carrying out maintenance in the absence of real-time data is challenging. IoT has gradually changed by bringing about digital transformation in maintenance by connecting buildings, end-users, components, and services while merging the physical and virtual world and allowing communication via digital interfaces (Atta & Talamo, 2020). Also, with the real-time sensors and cloud storage capability of IoT, facility managers can update knowledge bases when needed (Tang *et al*., 2019). This facilitates effective resource monitoring and prompt response to emergencies.

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Building Automated System (BAS)

BAS is mostly utilized in modern buildings to monitor and control the various installations in real-time (Fan, Xiao & Yan, 2015). It is comprised of data that is both categorical and numerical (Bouabdallaoui *et al*., 2021). Numerical data refers to measurements like temperature, air, and water flow rate, energy consumption, etc. While categorical data consists of time, alerts, and binary state (ON/OFF) (Fan *et al*., 2018).

Other E-Sources

Other sources of maintenance data are computer-aided facility management (CAFM), building energy management (BEMS), and integrated workplace management systems (IWMS). However, they are limited to some specific facilities (Bouabdallaoui *et al*., 2021).

Manual Sources

In traditional maintenance, manual tools like paper were used to record and update the operation and maintenance activities (Kameli *et al*., 2020). This made it difficult to track repair history, it was error-prone, time-consuming, and led to costly replacements (Jiang, Wang & Wu, 2018). Problems like incomplete and incorrect information are frequent with manual recording and paper-based inspections (Lu & Lee, 2017). The major challenges faced with this approach are the lack of interoperability between various software programs, lack of an integrated view, and distorted understanding of building problems (Shen, Hao & Xue, 2012).

Discussion

Table 1 is a representation of the various maintenance analytics methods and data sources that were used in the articles that were reviewed. Findings from the review revealed that text analytics is the most common analytics method in studies that used CMMS as a data source (Bortolini & Forcada, 2019; Dutta *et al*., 2020). What differentiated the application of text analytics was the tools that were used with it. Programming languages like Python and R and algorithms like MapReduce and association rule mining are tools that can be applied for text analytics. Since BIM is a 3D representation of the building, it is not surprising that visual analytics was the method applied to the data source (Motamedi *et al*., 2014). Asides from the identified maintenance data source from the literature, some organizations choose to establish their maintenance database (Mo *et al*., 2020; Razali *et al*., 2020). The analytics method that was carried out differed from others. Finally, the review revealed that in studies where IoT and sensors were used as their source of maintenance data, machine learning (not maintenance analytics) was carried out (Bouabdallaoui *et al*., 2021).

The review also revealed that the general direction of maintenance analytics in building maintenance was building performance, maintenance work order, building operation, and end-users' complaints. There is a gap in the application of maintenance analytics for cost-effectiveness. For a country like Malaysia where available funds regulate maintenance, there is a need for more studies to determine how maintenance analytics can be applied to achieve cost-effective decision-making.

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Table 1: Application of Maintenance Analytics

Study	Purpose	Source of Data	Analytics Methods
Motamedi, Hammad & Asen (2014)	To investigate the possibility of knowledge-assisted BIM-based visual analytics to visualize.	CMMS & BIM	Visual analytics
Gunay, Shen & Yang (2018)	To develop a text-mining method using CMMS to extract information on failure patterns in building systems and components.	CMMS	Text-mining method (using document-term matrix and association rule mining)
Bertolini & Forcada (2019)	To analyse and obtain information from end-users' complaints in the CMMS dataset.	CMMS	Text analytics (using Python programming language and MapReduce algorithm)
Dutta, Gunay & Scott (2020)	Presents a text analytics-based method to extract performance metrics from CMMS.	CMMS	Text analytics (using Association rule mining and R programming language)
Razali *et al*. (2020)	To assess the significance of big data applications in the maintenance management of government buildings.	Web queries	Econometrics
Mo *et al*. (2020)	To create a prediction model to automatically assign tasks request documented in unstructured texts.	Centralized database (IBM Maximo) that is manually processed.	Natural Language Processing (NLP)
Bouabdallaoui *et al*. (2021)	Design a framework to provide guidelines to implement predictive maintenance for building installations.	IoT & BAS	Machine learning techniques like autoencoders

Conclusion

To improve the overall building maintenance process, there is a need for data-driven decision-making which is made possible through maintenance analytics. This study looked to identify the various maintenance analytics methods for data-driven decision-making. It revealed the different maintenance data sources and the analytics methods that were applied to it. From the study findings, it is suggested that maintenance analytics methods should be determined according to the available data. It is recommended that future studies be carried out to primarily ascertain how maintenance analytics can be implemented for cost-effectiveness.

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