Service Report

Predictive Maintenance for Medical Imaging Equipment

Context

Imaging equipment requires ongoing maintenance to ensure device reliability and seamless workflow.[1] Routine maintenance can influence the longevity of imaging equipment by extending projected life cycle expectancies.[2]

Delays in patient care due to imaging equipment failure may contribute to rising wait times.[3,4] Regular maintenance is intended to minimize disruptions to patient care by lessening unplanned downtime and the expenses associated with costly repairs.[1] An average of 50 hours per year of unplanned downtime per CT and MRI unit was reported by the Canadian Medical Imaging Inventory in 2019-2020.[3]

Maintenance service agreements used in imaging departments typically include preventive approaches for equipment servicing.[5] Indeed, preventive maintenance is the most commonly implemented equipment servicing model in health care.[6] Preventive approaches to maintenance aim to avoid equipment breakdown by continuously checking that equipment is working optimally based on fixed time interval visits, irrespective of performance and condition.[1,7] Corrective maintenance is performed when equipment is in poor condition or requires urgent repair.[7] Corrective action is likely the main cause of unplanned downtime and it can be costly given the complexity of medical imaging devices,[8] especially when significant repairs or part replacements are needed.[1]

Given rising health care costs, imaging departments are looking for solutions to maintenance beyond preventive approaches that are intended to extend equipment life while decreasing costs and delays in care.[5]

Other industries have looked to predictive maintenance (PdM) strategies for servicing equipment.[9] PdM involves the continuous monitoring and data collection of equipment conditions and performances, instead of the current time-based schedule.[1,7,10] With PdM, collected data are analyzed to predict equipment breakdowns to schedule downtime effectively, which is intended to minimize interruptions in operations while avoiding unnecessary repairs. In addition to optimizing maintenance, predictive approaches may prolong equipment lifetime and improve patient and staff safety.[11]

Objective

This report aims to provide a high-level summary of PdM models for servicing imaging modalities and considerations for its use in medical imaging departments.

Predictive Maintenance Tools

Effective PdM strategies require information on the condition of equipment and its previous maintenance activities. Historical data on equipment performance are inputted into statistical models to predict failures and breakdowns, and to inform maintenance planning (e.g., maintenance prioritization activities).[12-14] When potential problems are identified, alerts are sent to technicians in radiology departments who can conduct manual inspections of the equipment to determine next steps.[15]

PdM is based on the concept that problems can be anticipated and eliminated before they occur,[15] and shifts the concept of maintenance from a reactive service to a proactive one.[14] Current preventive maintenance approaches to equipment servicing are based on contractual agreements between the service provider and the health care facility that include regularly scheduled onsite and/or remote service calls. A PdM approach to servicing equipment focuses maintenance on need rather than a time interval approach.[16]

A variety of statistical models are available to inform PdM, each with its own strengths and weaknesses.[10,17] Some medical device manufacturers offer PdM tools as part of service agreements,[18,19] and medical imaging departments can develop custom PdM to meet specific needs, with help from data and imaging equipment experts.[10]

The main intended benefits of PdM are to:

- minimize unplanned downtime[20]
- improve reliability and productivity of equipment[20]
- reduce operational costs because maintenance is carried out when it is required, rather than to a schedule[21]
- improve the quality and safety of equipment[21]
- provide a real-time overview of the condition of equipment[22]
- lengthen the life cycle of equipment by servicing equipment before failures occur.[23]

Some common challenges associated with PdM are:

- the implementation costs associated with the monitoring of equipment and software required to perform PdM[22]
- that staff with specialized skills are required to understand and analyze data[22]
- that data can be misinterpreted, resulting in unnecessary maintenance requests[24]
- that it may discourage proactive onsite inspection of equipment[24]
- that contextual information, such as the age of equipment, may be excluded from data analysis.[24]

Artificial intelligence (AI) and the internet-of-things (IoT), when integrated with sensor data, have enabled the digitization and automation of maintenance programs beyond those available with advanced analytics.[25]

Sensors

PdM relies on data collected from sensors that alert maintenance staff when preventive maintenance is needed to ensure the optimal performance of equipment.[22] Sensors are devices that convert physical signals that are measured from the environment into electrical signals.[21] The use of sensors automizes data collection and eliminates the potential for human error.[26] Sensors also provide the means for continuous, remote, and real-time monitoring of imaging equipment when used with IoT.[27]

Some common sensor measurements include vibration, pressure, oil, and noise.[22] A CT unit has sensors for monitoring tube temperature, water temperature, fan speed, air temperature, water flow, and other variables.[8] An MRI unit has sensors for monitoring the magnetic field, temperature, pressure, sounds, and image quality.[10,17,28,29]

Internet-of-Things

IoT refers to the network interconnectivity of devices that capture information. IoT provides a communication interface between different networks that are integrated to exchange data using the internet.[30,31] IoT relies on sensors to monitor equipment, collect data on performance metrics, and communicate this information in real-time via the internet to a central system.[29] Information collected in a central repository can be compared to predefined optimal thresholds and an alert system can be implemented to signal an anomaly.[13,14,27]

Machine Learning

Machine learning (ML) is a subfield of AI that involves algorithms learning from input data.[21] Increasingly, maintenance service providers are integrating ML into servicing models to more effectively predict malfunctions and breakdowns compared to basic analytic models.[27,28] Using anomaly detection techniques, ML is automatically able to identify anomaly data and events, find correlations, and make precautionary recommendations.[8]

Historical data are used to train a model or algorithm to detect anomalous sensor values and identify critical trends.[6,32] The performance of ML is highly dependent on the quality and quantity of data available.[33] ML techniques require a great amount of data to develop, train, evaluate, and validate the model.[33] Furthermore, certain failures or breakdowns may be overrepresented in historical data, affecting the predictive capabilities of the model for underrepresented machine issues. There are techniques to reduce the impact of imbalanced datasets but these may require further testing to determine their accuracy.[33,34]

Implementation Considerations

Data Requirements

Large amounts of data are required to inform PdM models, and it is important to ensure that the data are sufficient, in terms of both quantity and quality.[33] This type of data may be available from imaging departments depending on previous and current maintenance policies and/or contractual agreements. Integrating data from multiple sources into a single algorithm may present challenges, particularly if the data are not recorded consistently between data sources.[35] As well, because logged data may not have been collected for the purposes of PdM, it may be challenging to use for this purpose. [35,9,36] Manually entered data are also prone to error and inconsistencies, and may require expertise to clean and manipulate for analysis.[9,10,33]

Maintenance Service Agreements

There are a variety of tools offered by manufacturers through maintenance service agreements. Some tools may only be available for certain imaging equipment, sometimes limited to those manufactured by the vendor.[18,37] Hence, a one size fits all approach for predictive tools may not be suitable in a facility with a variety of imaging modalities from different manufacturers. Furthermore, variations exists between PdM programs on the type of monitored physical parameters, as well as the number and location of sensors,[18,27,28,37] as optimal sensor placement can depend on the particular make and model of an imaging modality and the features of interest.[6,32,38]

There are different types of PdM models that can be incorporated into service agreements. Increasingly, maintenance service providers are incorporating emerging technologies, such as ML and IoT, into their PdM models, and others may used advanced analytics. Most providers will include remote monitoring, remote intervention, or proactive monitoring services as part of their PdM agreements.[18,19,37]

Interoperability

Interoperability is the backbone of IoT approaches, allowing communication and data sharing between devices. IoT technologies can be proprietary and may only operate in predefined hardware or software.[15] An anecdotal account of a health facility's experience with software from a maintenance service provider revealed poor integration with the facilities' current systems. Multiple IoT systems may also not work seamlessly together,[38] and a lack of interoperability may limit IoT expansion opportunities in the health care setting.[38]

Aging Equipment

Older equipment may require retrofitting to install sensors.[33,39,40] The Canadian Medical Imaging Inventory observed that around 40% of CT and MRI units in Canada are older than 10 years, which is an indicator as to the number of units that would require retrofitting.[3] As well, imaging departments will require the infrastructure to ensure sensors in older equipment are well integrated into the network and can communicate data to central repository systems.[29]

Legal Issues and Regulation

Contracts for maintenance service agreements should detail data ownership, liability, and any potential governing laws.[41] With a lack of standards of care and regulation for AI and IoT technologies, liability can be difficult to establish, especially with multiple stakeholders involved (e.g., equipment providers, algorithm developers, manufacturers, equipment users, cloud services, internet provider).[41] Additionally, there is uncertainty around data ownership and how collected data can be used beyond the agreed-upon services.[26,41]

Cybersecurity

Devices that use IoT to communicate are a potential target for cyberattacks and data breaches,[42] and health organizations are reported to be at high risk for cyberattacks.[43] Enhanced security measures and assessments are important to limit access and help prevent unauthorized access.[29,42] The Canadian Information Office has proposed cybersecurity standards covering IoT devices and systems to meet requirements for security, safety, confidentiality, and integrity. These standards are intended to provide a consolidated overview of security features and best practices to meet industry recommendations.[44]

Shortage of Medical Physicists

In maintenance agreements, onsite visits are still needed for planned maintenance or unanticipated breakdown or failure. Outside of service agreements, medical physicists may be needed to use the information from predictive strategies as insights to make decisions around equipment maintenance. Three provinces and all of the territories operate without designated certified medical physicists, meaning there may be a shortage of medical physicists to make decisions around equipment maintenance based on information from predictive analytics.[3] As well, PdM strategies can inform and facilitate effective maintenance, but that does not eliminate the need for physical maintenance when breakdown is predicted, or the need for medical physicists expertise when intervention or replacements are needed.[20]

Staff Training

Operational changes will likely follow the adoption of predictive strategies and use of associated technologies. To maximize the value of PdM, new policies and devices must be well integrated into current processes.[20] Staff should also be trained and educated on new technologies and have some knowledge of IoT and AI. For example, medical physicists may be required to understand how to handle alerts from new systems, and IT personnel may need some knowledge on IoT to handle potential connectivity or infrastructure issues.[23] Additionally, training staff on proper security practices can help prevent cyberattacks.[45]

Cost

Proper planning and cost analysis should be exercised before implementing predictive strategies. Given the various approaches available for PdM, there are a variety of factors that can impact the cost. For example, IoT strategies will have costs associated with any equipment and infrastructure needed to support data communication,[22,29] which, as noted previously, can be expensive. At the same time, it is reported that PdM in health care is expected to reduce overall maintenance costs by 12%.[6]

Environmental Impact

The development of PdM systems requires hardware components (sensors and communication devices that use multiple semiconductors), and the manufacturing of these components uses earth metals and other toxic substances that may be damaging to the environment.[31] The semiconductor manufacturing process requires large amounts of purified water that can contaminate ground water with heavy metals and toxic solvents. As well, the electricity consumption of semiconductor plants may be higher than those of car manufacturing plants and refineries.[46] Nonetheless, electricity consumption may be considered within the context of extending the life of equipment by approximately 20%.[6]

Conclusion

PdM is an emerging maintenance model in health care. PdM uses advanced analytics deliver through IoT to alert technicians to potential problems before they occur. Minimizing unplanned downtime, reducing costs, and prolonging equipment lifecycles are the main goals of PdM. Large amounts of good quality data are required for PdM that uses ML, as well as collaboration from data and imaging equipment experts.

Predictive tools do not eliminate the need for physical maintenance or repairs of imaging equipment. Furthermore, the extent to which aging imaging equipment in Canada may accommodate sensor and network integration is unclear. Some tools offered by manufacturers are also limited to specific modalities or models of imaging equipment, and may not support all modalities used in a department. Other considerations include cybersecurity, legal and regulatory issues, interoperability with current systems, staff training, and a lack of information on the costs of PdM in the context of imaging departments.

References

01. Corciovă C, Andrițoi D, Luca C. A Modern Approach for Maintenance Prioritization of Medical Equipment. 2020.

02. Lifecycle guidance for medical imaging equipment in Canada. Ottawa (ON): Canadian Association of Radiologists (CAR); 2013: https://car.ca/wp-content/uploads/car-lifecycleguidance-mainreport.pdf. Accessed 2021 Sep 29.

03. Chao YS, Sinclair A, Morrison A, Hafizi D, Pyke L. The Canadian Medical Imaging Inventory 2019-2020. (CADTH health technology review). Ottawa (ON): CADTH; 2021: https://cadth.ca/sites/default/files/ou-tr/op0546-cmii3-final-report.pdf. Accessed 2022 Jan 10.

04. Germano D. Radiologists warn of growing backlog in medical imaging due to COVID-19 pandemic. The Globe and Mail 2022 Jan 12; https://www.theglobeandmail.com/canada/article-radiologists-warn-of-growing-backlog-in-medical-imaging-due-to-covid/. Accessed 2022 Jun 29.

05. General Electric. Medical equipment predictive maintenance method and apparatus. Justia Patents 2003; https://patents.justia.com/patent/6912481. Accessed 2022 Jun 29.

06. Shamayleh A, Awad M, Jumana F. IoT Based Predictive Maintenance Management of Medical Equipment. Journal of Medical Systems. 2020;44(72).

07. World Bank. Procurement guidance: medical diagnostic imaging equipment: understanding how to procure medical diagnostic imaging equipment. Washington (DC): The World Bank; 2019.

08. Guller M. Machine Learning Based Anomaly Detection: Driving Proactive Machine Maintenance. 2018; https://www.glassbeam.com/blogs/machine-learning-based-anomaly-detection-driving-proactive-machine-maintenance/. Accessed 2022 Jun 29.

09. Tyagi V, Chourasia U, Dixit P, Pandey A, Arjaria A. A Survey: Predictive Maintenance Modeling using Machine Techniques. 1st International Conference on Intelligent Communication and Computational Research 2020; https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3564964. Accessed 2022 Jun 29.

10. Man YSI. Condition-based maintenance resonance imaging systems. Department of Mathematics and Computer Science. Netherlands: Tenchnische Universiteit; 2015: https://www.semanticscholar.org/paper/Condition-based-maintenance-of-magnetic-resonance-Man/d19b2d8ecfb8d7012456b86d2cfa462a21928f3e. Accessed 2022 Jun 29.

11. Goyen M. Preditive maintenance in healthcare - if you can predict it, you can prevent it. 2018; https://healthmanagement.org/c/it/post/predictive-maintenance-in-healthcare-if-you-can-predict-it-you-can-prevent-it. Accessed 2022 Jun 29.

12. Taghipur S, Banjevic D, Jardine AK. Prioritization of medical equipment for maintenance decisions. J Oper Res Soc. 2011;62(9):1666-1687.

13. Zam Zam A, Ibrahim, Al-Ani, A.Y., Abdul Wahab, A.K., Lai, K.W., Satapathy, S.C., Khalil, A., Azizan, M.M., Hasikan, K. Prioritisation Assessment and Robust Predictive System for Medical Equipment: A Comprehensive Strategic Maintenance Management. Frontier Public Health. 2021.

14. Sakib N, Wuest, T. Challenges and Opportunities of Condition-Based Predictive Maintenance: A Review. Procedia CIRP. 2018;78:267-272. https://reader.elsevier.com/reader/sd/pii/S2212827118312344?token=62C46F8B783F7CB1E25CBED24A0AAAEA1AA0294E34D511E70ADE792DC0CDF4F66396DCA0249A6129AE53D80BCA039D7B&originRegion=us-east-1&originCreation=20220511190320. Accessed 2022 Jun 29.

15. Hasegawa M, Hanada K, Idei H, Kawasaki S, et al. Predictive maintenance and safety operation by device integration on the QUEST large experimental device. Heliyon. 2020;6(6):e04214. https://www.sciencedirect.com/science/article/pii/S2405844020310586. Accessed 2022 Jun 29.

16. General Electric. Medical equipment predictive maintenance method and apparatus. 2003; https://patents.justia.com/patent/6912481. Accessed 2022 Jun 29.

17. Rucker N, Pfluger L, Maier A. Hardware failure prediction on imbalanced times series data. J Digit Imaging. 2021;34:182-189.

18. Hitachi. Predictive maintenance of medical devices based on years of experience and advanced analytics. 2017; https://social-innovation.hitachi/en/case_studies/mri_predictive_maintenance/#section2. Accessed 2022 Jun 29.

19. Philips. Philips Maintenance Optimization Service Agreements. 2022; https://www.philips.com.au/healthcare/services/maintenance-services/customized-service-agreements/maintenance-optimization-service-agreements. Accessed 2022 Jun 29.

20. Sam Solutions. Predictive Maintenance with IoT: Comprehensive Guide. 2022; https://www.sam-solutions.com/blog/iot-predictive-maintenance/. Accessed 2022 Jun 29.

21. Sohaib M, Mushtaq S, Uddin J. Deep Learning for Data-driven Predictive Maintenance. Vision, Sensing and Analytics: Integrative Approaches. Berlin (DE): Springer Nature; 2021.

22. Limble CMMS. A complete guide to predictive maintenance. 2022; https://limblecmms.com/predictive-maintenance/#:~:text=The%20goal%20of%20predictive%20maintenance,and%20preventing%20unexpected%20equipment%20breakdown. Accessed 2022 Jun 29.

23. Deloitte Consulting. Predictive Maintenance: Taking pro-acive measured based on advanced data analytics to predict and avoid machine failure. 2017: https://www2.deloitte.com/content/dam/Deloitte/de/Documents/deloitte-analytics/Deloitte_Predictive-Maintenance_PositionPaper.pdf.

24. EC-MSP. Pros and Cons of Predictive Maintenance in the Cloud. [date unknown]; https://www.ecmsp.co.uk/it-blog/pros-cons-predictive-maintenance-cloud/. Accessed 2022 Jun 29.

25. Resende C, Folgado D, Oliveira J, et al. TIP4.0: Industrial Internet of Things Platform for Predictive Maintenance. Sensors (Basel). 2021;21(14):4676.

26. Druetta C. Legal Perspectives on Predictive Maintenance: a case study. International In-house Counsel Journal. 2018;11(44). https://www.iicj.net/subscribersonly/18september/iicj1sept-IT-corradodruetta-comau-italy.pdf. Accessed 2022 Jun 29.

27. Philips. MRI e-Alert Customer Story. 2016; https://www.documents.philips.com/assets/20170523/b0b994940ed44f0da941a77c014f3a39.pdf?_gl=1*32y2or*_ga*MTgwNDAzMDMzMS4xNjUzNDg3NTA2*_ga_2NMXNNS6LE*MTY1MzU3NzA4NS40LjAuMTY1MzU3NzA5My41Mg..*_fplc*WXhYM3hacExWaE9RY1dZNnFFOE5tTyUyRkh6akxSY2pBT1BUcU5MOHd4WmVmSlk4cHFaRWtBSzBGM1RpT09FalltRG93RUpIdXYycn-piaERyJTJCeXBOVWV6QjFyTiUyQjN3RnZVYllqbmYyRFo1c0ZOQ1ZWVTVkVlR6emFZenJJS0tRJTNEJTNE*_ga_Q243QQ1P76*MTY1MzU3NzA-3Ny41LjEuMTY1MzU3NzA5My40NA..&_ga=2.41352033.291203316.1653487507-1804030331.1653487506. Accessed 2022 Jun 29.

28. Hitachi. Advanced malfunction diagnosis/prediction for diagnostic imaging equipment through collection of abnormal sounds. 2019; https://www.hitachi.com/products/it/lumada/global/en/usecase/case/pdf/lumada_uc_00941.pdf. Accessed 2022 Jun 29.

29. Advanced Technology Services Inc. Top Considerations When Evolving to Predictive Maintenance. 2022; https://www.advancedtech.com/blog/predictive-maintenance-benefits-challenges/#:~:text=Predictive%20Maintenance%20Challenges,-Implementing%20a%20modern&text=By%20collecting%20and%20monitoring%20data,well%20before%20the%20equipment%20fails. Accessed 2022 Jun 29.

30. Dwivedi R, Mehrotra D, Chandra S. Potential of Internet of Medical Things (IoMT) applications in building a smart healthcare system: A systematic review. J Oral Biol Craniofac Res. 2022;12(2):302-318.

31. Pradhan B, Bhattacharyya S, Pal K. IoT-Based Applications in Healthcare Devices. J Healthc Eng. 2021;2021:6632599-6632599.

32. Pandit P. The Power Of Predictive Analytics. 2022; https://www.glassbeam.com/blogs/the-power-of-predictive-analytics/. Accessed 2022 Jun 29.

33. Welte R, Estlet M, Lucke D. A Method for Implementation of Machine Learning Solutions for Predictive Maintenance in Small and Medium Sized Enterprises. Procedia CIRP. 2020;93:909-914. https://reader.elsevier.com/reader/sd/pii/S2212827120306223?token=E4033F917E9032E941C9020140461F4F6695A67E827E618190D7C9BDD4D4F2010F68C07D2167E1F26563F2EE2D310078&originRegion=us-east-1&o-riginCreation=20220513143630. Accessed 2022 Jun 29.

34. Sowjanya AM, Mrudula O. Effective treatment of imbalanced datasets in health care using modified SMOTE coupled with stacked deep learning algorithms. Appl Nanosci. 2022:1-12.

35. Barbieri M. Towards Zero Unplanned Downtime of Medical Imaging Systems Using Big Data. 2020; https://www.vertica.com/wp-content/uploads/2020/04/PHILIPS-Towards-Zero-Unplanned-Downtime-of-Medical-Imaging-Systems-Using-Big-Data_BDC.pdf. Accessed 2022 Jun 29.

36. Sundblad W. Why Predictive Maintenance is Not a Silver bullet Solution for Manufactureres. Forbes 2019 Aug 6; https://www.forbes.com/sites/willemsundbladeurope/2019/08/06/why-predictive-maintenance-is-not-a-silver-bullet-solution-for-manufacturers/?sh=3a13823d7d27. Accessed 2022 Jun 29.

37. GE Healthcare. Tube Watch. 2022; https://www.gehealthcare.com/products/tube-watch. Accessed 2022 Jun 29.

38. Ahmed M. The internet of things and interoperability. 2021; https://medium.datadriveninvestor.com/the-internet-of-things-and-interoperability-d85311b9d99d. Accessed 2022 Jun 29.

39. Gokalp S, Gokalp MO, Gokalp E. Predictive Maintenance in Healthcare Services with Big Data Technologies. 2018 IEEE 11th Conference on Service-Oriented Computing and Applications (SOCA); 2018.

40. Eurotech. Remote and Predictive maintenance of medical equipment in the era of connected healthcare. 2021; https://blog.eurotech.com/en/remote-and-predictive-maintenance-of-medical-equipment/. Accessed 2022 Jun 29.

41. Lifshitz LR. Brave new world: some legal considerations in using AI and IoT Systems. Canadian Lawyer 2018; https://www.canadianlawyermag.com/news/opinion/brave-new-world-some-legal-considerations-in-using-ai-and-iot-systems/275162. Accessed 2022 Jun 29.

42. Wasser L, Koczerginski M, Hill R. Cybersecurity and the Internet of Things. Canadian Privacy Law Review. 2016;13(6). http://mcmillan.ca/wp-content/uploads/2020/12/189631_Internet-of-Things-article-reprinted-from-Canadian-Privacy-Law-Review-May26.pdf. Accessed 2022 Jun 29.

43. Burke D. Hospitals 'overwhelmed' by cyberattacks fuelled by booming black market. CBC 2020 Jun 2; https://www.cbc.ca/news/canada/nova-scotia/hospitals-health-care-cybersecurity-federal-government-funding-1.5493422.

44. CIO Strategy Council. National Standard of Canada. Standards Proposal: Consolidated cybersecurity standard covering Industrial Internet of Things (IIoT) devices and systems. 2020; https://ciostrategycouncil.com/wp-content/uploads/2020/03/CIOSC_Standards-Proposal_IIoT-Devices_2020_03_24.pdf. Accessed 2022 Jun 29.

45. Kaelin MW. A well-trained staff may be your best defense against IoT cyberattacks. 2018; https://www.techrepublic.com/article/a-well-trained-staff-may-be-your-best-defense-against-iot-cyberattacks/. Accessed 2022 Jun 29.

46. Electronics Watch. The climate crisis and the electronics industry: labour Rrghts, environmental sustainability and the role of public procurement. 2020; https://electronicswatch.org/electronics-watch-policy-brief-3-the-climate-crisis-and-the-electronics-industry-labour-rights-environmental-sustainability-and-the-role-of-public-procurement_2574400.pdf. Accessed 2022 Jun 29.

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