VERTIV WHITE PAPER

Condition-Based Maintenance Services address data center challenges

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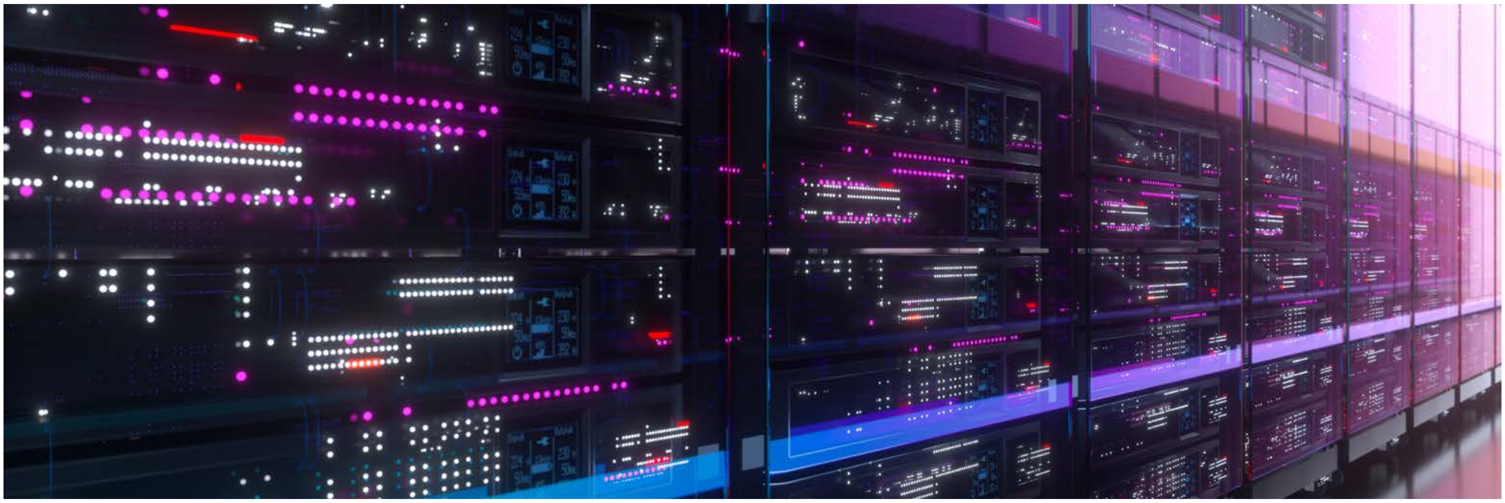

Abstract

The rapid expansion of the data center industry challenges operators in resource availability, capacity, and capability, exacerbated by the specific infrastructure demands in artificial intelligence (AI) computing. The scale and complexity of modern data centers threatens the efficiency and effectiveness of any maintenance program and requires increased data analytics to supplement current time-based maintenance delivery methodology.

The primary objective of any preventive maintenance strategy is to avoid catastrophic failures that result in expensive unplanned outages. A preventive maintenance strategy enhanced by data analytics—utilizing real-time or retrospective data analysis—enhances traditional time-based methods with condition-based maintenance, critical event monitoring, and advanced diagnostics. This enables activities to be prioritized and scheduled based on the criticality of actual operating conditions, leading to real-time insight into equipment health and enabling better planning and visibility of operating expenses. In this paper, we emphasize the points for considering Condition-Based Maintenance and Advanced Monitoring Services as part of the industry's overall preventive maintenance strategy:

- The scale and complexity of critical digital infrastructures for modern and AI data centers are surging. The industry has been working to develop a standard and repeatable system that balances their needs today with their business goals in the future and improves the resilience of the facility's equipment to optimize return on investment (ROI) and total cost of ownership (TCO).
- The traditional maintenance method will no longer meet future requirements. In addition to developing and upskilling the pertinent personnel on the ground, the changing maintenance strategies will include using technologies and algorithms capable of refining the data needed for real-time analytics integration, monitoring, and insights for actionable procedures.

To achieve the benefits of a data-driven service routine, several factors have to be considered, not least the correct vendor with whom to work. This paper highlights the factors and benefits that need to be reviewed when embracing the data center maintenance paradigm change enabled by the availability and developments in data, machine learning (ML), and AI.

Introduction

Integrating high-performance computing (HPC) technologies in the data center has led to a reevaluation of traditional power and cooling design, implementation, and maintenance. New problems and technologies warrant modern and adaptable solutions. The increase in volume and the variations of solutions in the market today present challenges in establishing the ideal, repeatable AI data center design, including the enablement of effective and efficient maintenance routines to reduce the risk of increasingly expensive equipment outages. [1]

In recent years, consistent research, development, and collaboration among leading industry players have developed stable and standardized solutions. Data center designs have evolved to reduce the impact and cost of failure by controlling the hardware failure "blast radius." [2] However, with the increasing densification and complexities of computing and infrastructure demand, this growth needs to align with an enhanced maintenance strategy. In addition, new critical digital infrastructure architecture will have to coexist with legacy solutions, which further increases the complexity of maintenance planning.

As compute clusters increase and the terminology around AI factories becomes commonplace, the drive toward zero unplanned downtime for large learning models (LLMs) is inevitable. While IT hardware is designed to detect and remediate issues quickly any failure in IT or infrastructure clearly impacts the schedule. [3]

Moreover, the increased power demands and presence of liquid cooling systems — with significantly reduced thermal inertia and increased ratings of busbars and power distribution units (PDUs) — are additional critical technology shifts for data center operators already struggling to cope with the reduced availability and capability of experienced site operational staff. [4]

The traditional service model for data center assets typically involves performing preventive maintenance at set intervals to reduce potential failures while providing a fast-response reactive service to reduce mean time to repair (MTTR). However, with significant advancements in AI and ML, there is an opportunity to adopt a new paradigm for service delivery with Condition-Based Maintenance (CBM) services. This approach empowers data center operators to be well-informed about the health of assets, schedule preventive maintenance at optimal times, and proactively prevent failures.

The data analytics needs to be fully supported by the service provider and linked to the attending maintenance engineer to ensure effective maintenance. An extensive reporting capability, avoiding having condition-based alerts reported together with generic alarms in the site Building Management System (BMS), is required to provide validation that actions taken have resolved identified risks and issues.

The reactive support capabilities of data-driven services can also be enhanced with traditional "emergency call out" services empowered by Advanced Incident Management reporting, which uses collected data to produce conclusive root cause analysis (RCA) reports.

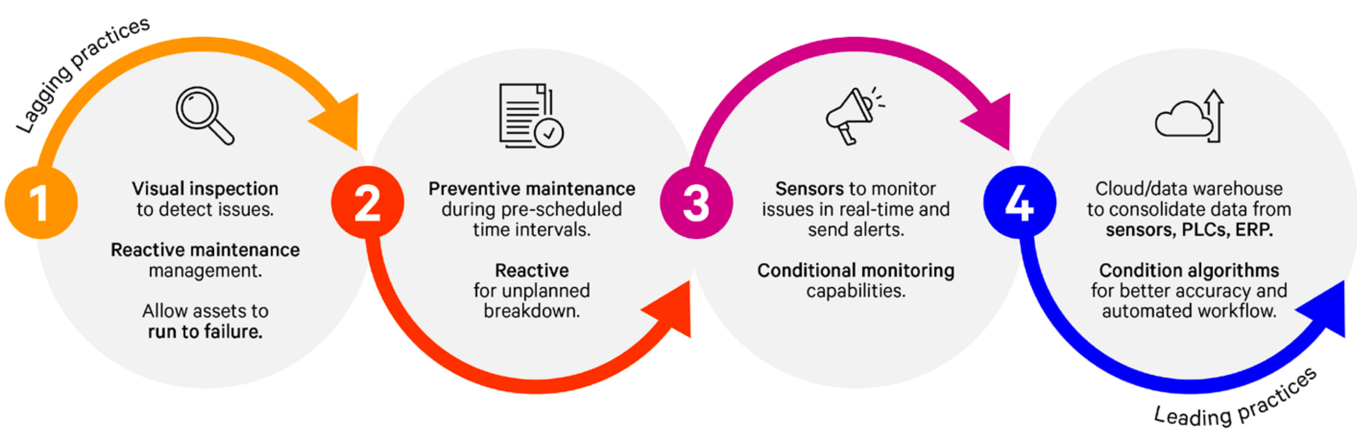

Figure 1. *The evolution of maintenance shows that the changes and subsequent combination of lagging, traditional practices and leading ones allow companies to create a maintenance model that optimizes their asset continuous runtime, efficiency, and lifecycles.*

Data acquisition, management, and analysis

Critical infrastructure systems generate a significant amount of data during normal operations. However, not all data are equally significant when making decisions on maintenance activities that could add risk to site operations. Hardwired or IP-connected generic alarms collected via BMS offer limited equipment condition information other than system output anomalies, which require a more detailed investigation to understand where the problem is located.

Experiential data collected on fleets of assets over prolonged periods, together with theoretical mean time between failure (MTBF) data, has been used for many years to make time-based lifecycle replacement decisions, such as capacitor, fan, and filter replacements. While this can prevent significant issues in equipment output during the full lifecycle, it cannot prevent early-life failures from being identified. It can also lead to unnecessary costs due to components being changed earlier than necessary.

Third-party sensors can be added to equipment after installation to collect condition and operating environment data. However, this is less effective and fail to provide historical trending data from factory and site-testing stages. Additionally, individual equipment does not store the necessary information to provide Condition-Based Maintenance services, and ML algorithms will only start collecting data from the sensors' installation date. The variety of third-party sensors also makes it difficult to make a comprehensive database for comparative purposes.

Where data output requirements can be specified during the design stages of equipment, together with the opportunity to either factory-fit additional sensors or derive specific measures, the quality of the data provided can be confidently relied upon to make decisions on the appropriate preventive or reactive maintenance measures.

Manufacturers' specified data enables preventive maintenance to evolve from a time-based intervention to a more condition-based regime, ensuring optimized activity. When equipment manufacturers work actively with the suppliers of critical components such as compressors, fans, insulated gate bipolar transistors (IGBT), and pumps, the condition algorithms can be further validated. Having access to the data from hundreds or thousands of units allows manufacturers' algorithms to be trained not only for the specific units or site installation, but also using the benchmarking analysis information from the whole population of units.

Data management

Comprehensive, integrated, high-quality data—refined with specific algorithms and ML/AI—provides high-level analytics and actionable information from a single platform.

Once the Condition-Based Maintenance service platform captures data from the equipment and associated sensors, the system centralizes and transfers this information into a private and secure global data lake. The data is curated and transformed for advanced analysis using the extract, transform, load (ETL) process. Leveraging AI and ML tools, algorithms process the relevant information and generate outputs by:

- Defining clear problem statements from subject matter experts (SMEs) and component manufacturers to guide analysis.
- Using equipment behavior and feedback from operating conditions to refine algorithms continually.
- Benchmarking devices with the same design, installation, and configuration to identify potential anomalies.

Additional data analysis throughout the equipment lifecycle is required to continuously refine these AI/ML algorithms, incorporating insights gathered from service visits, evaluating user interactions, and considering operator preferences.

The service provider's commitment extends beyond delivering real-time analytics and includes providing advanced tools to seamlessly integrate these insights into various dashboards for monitoring, servicing, quality control, and asset management.

AI/ML algorithms typically generate analytics on health scores, remaining useful life, anomaly detection, and quality assessment, highlighting deviations that signal potential performance deterioration. Each alert is tailored to the specific component and technology, considering unique working conditions and degradation patterns. When an anomaly is detected, an alert is sent to operators at the Network Operating Centers, who manage the output and direct the required service response:

- Trend performance
- Investigate at the next planned maintenance visit
- Immediate intervention

Connectivity

Enabling data to be collected for CBM and advanced monitoring requires a secure connection method.

Data quality is fundamental in AI/ ML algorithms as it directly impacts the performance, accuracy, and reliability of the model. Challenges in ensuring the data quality include inaccurate or incomplete data, inconsistent and outdated data, and a lack of data integrity. These challenges can all be managed with the correct level of standardization and governance. If data is not secure and breaches occur, the quality of data can also be compromised.

Various connectivity options allow real-time data collection, providing flexibility based on network architecture and security requirements. Data center operators can access the most advanced and secure internet of things (IoT) and device connectivity technologies. Additionally, offline data-gathering capabilities are available for facilities without connectivity options. Over time, data from thousands of devices and billions of data points will be accumulated for algorithm development.

Operational implementation

Generating health scores for assets and their components alone is insufficient to initiate service actions. Devices can have hundreds of health scores and pertinent data that provide various unique insights. To make sense of the numerous outputs of the algorithms, advanced monitoring tools make operators aware when an asset or one of its components shows behavior warranting service intervention. These tools provide context about the health trends of the assets and the necessary corrective actions.

Since AI-generated alerts are provided before any immediate need for service occurs, decisions can be made in a non-urgent manner, enabling a new method of service delivery. Operators can create a service request for tracking in the service management system or—if necessary—dispatch an engineer with all the relevant information to the site to address the issue. With unprecedented insight into asset condition and performance, operators can significantly reduce incidents requiring emergency service responses.

Condition-Based Maintenance and Advanced Monitoring services give operators more information about the condition and behavior of assets within the system, including insights into how environmental factors, controls, and usage drive service needs. The ability to recommend actions to prevent downtime and extend asset life enables a focus on high-tariff items like lifecycle parts replacement, optimizing preventive maintenance schedules, managing parts inventories, and optimizing control logic rather than completing tasks that do not immediately impact reliability or efficient operation. The effectiveness of a service visit can be subsequently validated as the actions taken are reflected in asset health analyses.

Reporting

Condition-based algorithms can provide highly accurate system status updates and enable improved service workflows.

The Condition-Based Maintenance and Advanced Monitoring platform reinforces operational practices by capturing and reporting data with a detailed dashboard for efficient equipment health monitoring. This helps data center staff make quick, informed decisions based on data and severity insights. Condition-based systems can integrate seamlessly into various platforms for monitoring, servicing, quality control, and procurement, enabling customers to manage asset health comprehensively.

Typical views of the platform include:

- **Health score:** Overview of the overall data center campus current state, including the component, equipment, and site condition.
- **Health score per site:** Health scores by site, highlighting healthy and potentially problematic locations.
- **Health score trendlines:** Graphical representations of the rapid or gradual declines in health scores.
- **Number of critical events by site:** Display of sites with frequent critical events.
- **Critical alarms:** List of alarms needing immediate attention by operational teams.
- **Critical events:** Types of frequent critical events for better preparation and prevention (i.e. stock parts).

Benefits

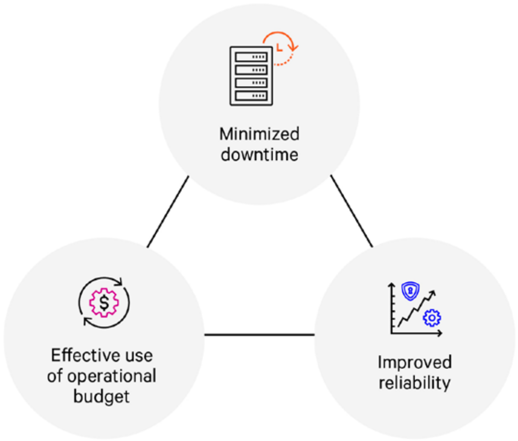

***Figure 2.** The Condition-Based Maintenance model allows for a data-driven maintenance system that responds to the actual needs of the equipment via analyses of logged historical and real-time telemetry and events. The service enables the ability to automatically monitor and report asset health scores and service events while maximizing uptime and integrated relational system insights.*

Condition-Based Maintenance and Advanced Monitoring services provide operators with actionable information to make decisions driving optimized operations and to tailor maintenance schedules on the actual infrastructure status, improving the overall lifecycle service effectiveness and efficiency. By leveraging the correct service partners, technologies, insights, and data accumulated over decades, these services can provide many benefits such as:

Operational efficiency

The real-time data and alerts from Condition-Based Maintenance support site personnel and enable the delivery of a better-planned maintenance schedule, avoiding over- or under-servicing. As a result, there are fewer manual equipment interventions reducing the associated risk. Condition-Based Maintenance can support data centers in improving task delegation to their site staff, even at limited capacity. Health analytics and advanced monitoring systems provide insights that allow staff to focus on high-impact tasks rather than routine checks. This efficient use of human resources can boost productivity and enhance job satisfaction.

Enhanced risk management

Status updates help data centers continuously monitor equipment health by identifying anomalies and potential issues before they occur. By benchmarking performance locally and globally, data center operators can make more informed decisions on load management and environmental condition adjustments, reducing the risk of unplanned failures.

The data analysis capabilities of Condition-Based Maintenance Service help identify the root causes of equipment degradation or failures. Addressing these root causes through targeted maintenance further reduces the risk of repeated failures.

The continuous monitoring feature inherent in Condition-Based Maintenance acts as an early warning system, detecting anomalies, trends, and potential issues that could lead to equipment failures or hazardous situations if left unaddressed. This can enable potential safety risks like electrical overheating, battery deterioration, or equipment malfunctions to be managed in a controlled environment, further avoiding secondary damage.

Asset management

Data centers can use proactive alerts and health analytics to replace and repair equipment, avoid unexpected costs, and optimize budgets. By monitoring environmental factors like temperature, humidity, and abnormal vibrations, Condition-Based Maintenance services can identify suboptimal operating conditions that accelerate equipment degradation.

Optimized maintenance timing ensures components are not over-stressed or run to failure, maximizing their respective lifecycles. This proactive approach prevents secondary damage and extends the lifespan of surrounding equipment and systems.

With detailed performance data and proactive maintenance insights, field engineers can execute lifecycle replacements efficiently and make informed maintenance decisions, setting the stage for boosting overall data center maintenance effectiveness. The advanced analytics and alerts generated can be fed into asset management planning software to plan, and budget for asset replacements at regular and expected timelines.

Sustainability

Monitoring equipment conditions and performance parameters enables data center operators to identify inefficiencies and energy consumption trends while taking corrective actions to optimize equipment performance. The collected information can be used to maximize airflow, adjust temperature set points, implement targeted energy-saving measures in specific hotspots, replace worn components, and recalibrate equipment to operate at peak efficiency. The information can also be used for proactive capacity planning, allowing data centers to right-size their infrastructure and avoid over-provisioning, which can lead to energy waste.

Conclusion

Condition-Based Maintenance services represent a significant advancement in the maintenance strategies employed for data center assets, moving beyond traditional preventive maintenance. Leveraging real-time data collected from sensors and advanced AI and ML algorithms enables proactive maintenance decisions based on the current and actual condition of the equipment.

Identifying inefficiencies and optimizing energy use contributes to more environmentally responsible and cost-effective operations. Continuously monitoring and analyzing equipment conditions allows for targeted maintenance actions, thereby preventing catastrophic failures, reducing safety risks, and ensuring the optimal performance of critical infrastructure.

When working with the correct vendor, data center operators are provided with the information and tools to manage dynamic environments and changing workloads effectively through sophisticated monitoring and condition-based analytics.

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