

Preventive Maintenance Strategy for Data Centers

White Paper 124

Revision 1

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> Executive summary

In the broadening data center cost-saving and energy efficiency discussion, data center physical infrastructure preventive maintenance (PM) is sometimes neglected as an important tool for controlling TCO and downtime. PM is performed specifically to prevent faults from occurring. IT and facilities managers can improve systems uptime through a better understanding of PM best practices. This white paper describes the types of PM services that can help safeguard the uptime of data centers and IT equipment rooms. Various PM methodologies and approaches are discussed. Recommended practices are suggested.

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Introduction

This paper highlights data center power and cooling systems preventive maintenance (PM) best practices. Hands-on PM methods (i.e., component replacement, recalibration) and non-invasive PM techniques (i.e., thermal scanning, software monitoring) are reviewed. The industry trend towards more holistic and less component-based PM is also discussed.

The term **preventive maintenance** (also known as *preventative maintenance*) implies the systematic inspection and detection of potential failures *before* they occur. PM is a broad term and involves varying approaches to problem avoidance and prevention depending upon the criticality of the data center. **Condition-based maintenance**, for example, is a type of PM that estimates and projects equipment condition over time, utilizing probability formulas to assess downtime risks.

PM should not be confused with **unplanned maintenance**, which is a response to an unanticipated problem or emergency. Most of the time, PM includes the replacement of parts, the thermal scanning of breaker panels, component / system adjustments, cleaning of air or water filters, lubrication, or the updating of physical infrastructure firmware.

At the basic level, PM can be deployed as a strategy to improve the availability performance of a particular data center component. At a more advanced level, PM can be leveraged as the primary approach to ensuring the availability of the entire data center power train (generators, transfer switches, transformers, breakers and switches, PDUs, UPSs) and cooling train (CRACs, CRAHs, humidifiers, condensers, chillers).

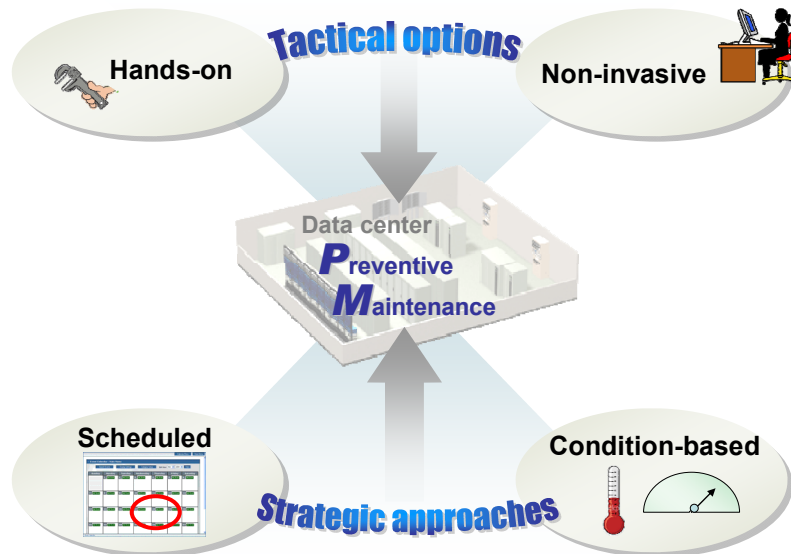


Figure 1

Today's PM landscape

A data center power and cooling systems preventive maintenance (PM) strategy ensures that procedures for calendar-based scheduled maintenance inspections are established and, if appropriate, that condition-based maintenance practices are considered. The PM strategy should provide protection against downtime risk and should avoid the problem of postponed or forgotten inspection and maintenance. The maintenance plan must also assure that fully trained and qualified maintenance experts observe the physical infrastructure equipment (i.e., look for changes in equipment appearance and performance and also listen for changes in the sounds produced by the equipment) and perform the necessary work.

PM outcomes

One of four results can be expected during a PM visit:

- A potential issue is identified and immediate actions are taken to prevent a future failure. This is the most prevalent outcome of a PM visit.
- A new, active issue is identified and an appropriate repair is scheduled. Such a visit should be precisely documented so that both service provider and data center owner can compare the most current incident with past PMs and perform trend analysis.
- No issue is identified during the visit and no downtime occurs through to the next PM visit. The equipment is manufacturer approved and certified to function within operating guidelines.
- A defect is identified and an attempted repair of this defect results in unanticipated downtime during the PM window or shortly thereafter (i.e., a new problem is introduced).

The risk of a negative outcome increases dramatically when an under-qualified person is performing the maintenance. Methods for mitigation of PM-related downtime risks will be discussed later in this paper.

Evolution of PM

In the data centers of the 1960s, data center equipment components were recognized as common building support systems and maintained as such. At that time, the data center was ancillary to the core business and most critical business processing tasks were performed manually by people. On the data center owner side, the attitude was “Why spend money on maintenance?” Manufacturers were interested in the installation of equipment but the “fix it” business was not something they cared about.

Over time, computers began performing numerous important business tasks. As more and more corporate data assets began to migrate to the data center, equipment breakage and associated downtime became a serious threat to business growth and profitability. Manufacturers of data center IT equipment began to recognize that an active maintenance program would maintain the operational quality of their products.

Annual maintenance contracts were introduced and many data center owners recognized the benefits of elevated service levels. As corporate data evolved into a critical asset for most companies, proper maintenance of the IT equipment became a necessity for supporting the availability of key business applications. The PM concept today represents an evolution from a reactive maintenance mentality (“fix it, it’s broken”) to a proactive approach (“check it and look for warning signs and fix it before it breaks”) in order to maximize 24x7x365 availability.

Impact of changes in physical infrastructure architecture

As with computer maintenance, data center physical infrastructure (i.e. power and cooling) equipment maintenance has also evolved over time. In the 1980s the internal architecture of a UPS, for example, consisted of 100% separate components that were not, from a maintenance repair perspective, physically integrated with other key components within the device. These UPSs required routine maintenance such as adjustment, torquing and cleaning in order to deliver the desired availability. A maintenance person would be required to spend 6-8 hours per visit, per UPS, inspecting and adjusting the individual internal components.

In the 1990’s the architecture of the UPS evolved (see **Figure 2**). Physical infrastructure equipment began featuring both individually maintainable components and integrated, computerized (digital) components. During this time period, a typical UPS consisted of only

50% manually maintainable parts with the remainder of the “guts” comprised of computerized components that did not require ongoing maintenance.

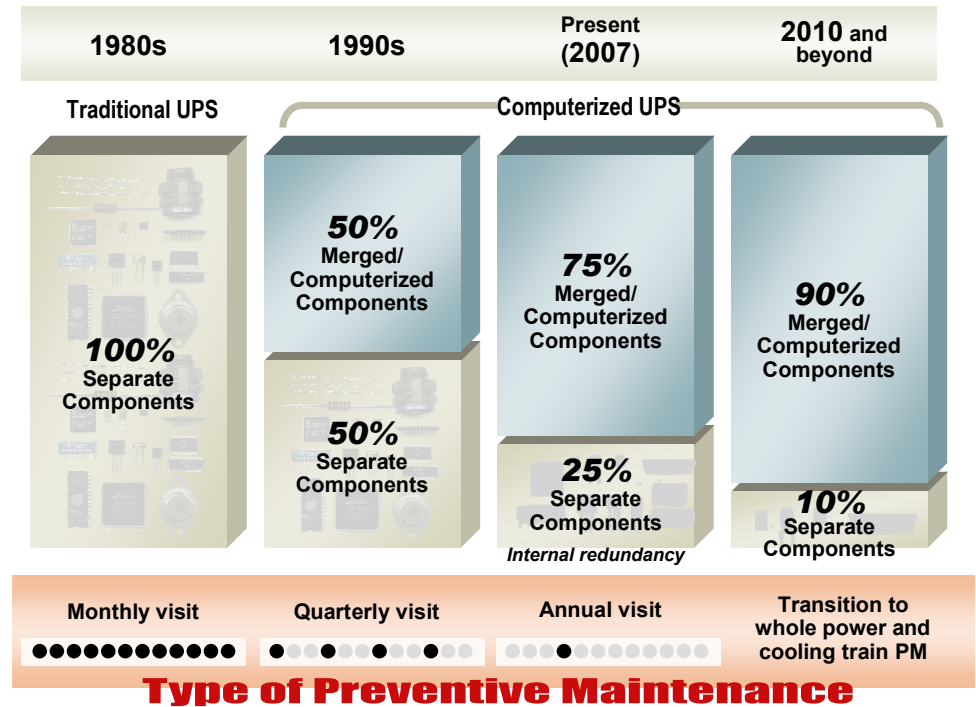


Figure 2

Evolution of UPS design and associated PM

By the mid-1990's the computerized components within the UPS began to communicate internal health status to operators in the form of output messages. Although PM visits were still required on a quarterly basis, the repairperson spent an average of 5 hours per visit per UPS. At present, the ratio of maintainable parts to computerized components has shifted further to 25% manually maintainable parts and 75% computerized parts (see **Figure 2**).

Today, most data center sites require one or two PM visits per year. However, more PM visits may be required if the physical infrastructure equipment resides in a hostile environment (i.e., high heat, dust, contaminants, vibration). The frequency of visits depends upon the physical environment and the business requirements of the data center owner. The system design of the component may also impact the frequency of PM visits. Often the number of visits is based upon the manufacturer's recommendation.

Evidence of PM progress

Today's physical infrastructure is much more reliable and maintenance-friendly than in the past. Manufacturers compete to design components that are as mistake-proof as possible. Examples of improved hardware design include the following:

- Computer room air conditioners (CRACs) with side and front access to internal components (in addition to traditional rear access)
- Variable frequency drives (VFDs) in cooling devices to control speed of internal cooling fans. VFDs eliminate the need to service moving belts (which are traditionally high-maintenance items)
- Wrap-around bypass functionality in UPS that can eliminate IT downtime during PM

In addition to hardware improvements, infrastructure design and architecture has evolved in ways that support the PM goals of easier planning, fewer visits, and greater safety. For example:

- Redundant cooling or power designs that allow for concurrent maintenance – the critical IT load is protected even while maintenance is being performed
- Proper design of crimp connections (which provide an electrical and mechanical connection) can reduce or eliminate the need for “re-torquing”, which, if performed in excess, can increase exposure to potential arc flash
- Recent attention to the dangers of arc flash are now influencing system design, in order to protect PM personnel from the risk of electrical injury during maintenance

Software design as a critical success factor

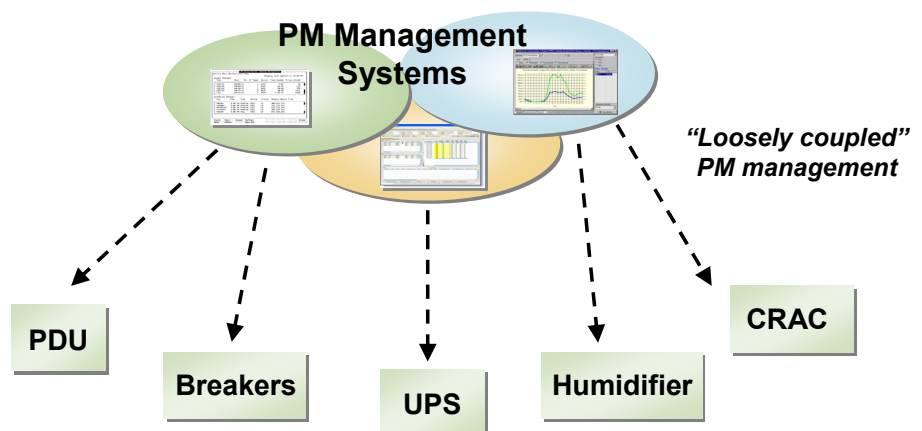
The design of the physical infrastructure hardware is one way reduce PM cost and complexity. Efficient physical infrastructure management software design is being vaulted to the forefront as *the* critical success factor for maintaining high availability. Best in class data centers leverage physical infrastructure management software.

Through self-diagnosis, infrastructure components can communicate usage hours, broadcast warnings when individual components are straying from normal operating temperatures, and can indicate when sensors are picking up abnormal readings. Although PM support personnel will still be required to process the communications output of the maintenance management system, the future direction is moving towards complete self-healing physical infrastructure systems.

*Multiple management systems, each addressing its own type of component(s)
Little or no communication among management systems*

Figure 3

Traditional approach: component-by-component PM management



Forward thinking data center owners contemplate a holistic PM strategy for the entire data center power train. While traditional PM support for existing equipment continues to play an important role, a strategy for maintaining future equipment should look to embrace a PM approach that views the data center as an integrated whole as opposed to as assembly of individual components (see **Figure 3** and **Figure 4**).

A further analysis will help to clarify the evolution from component-based PM to whole-power-train or whole-refrigeration-cycle cooling PM. Consider the UPS (uninterruptible power supply) physical infrastructure component as an example. When a power problem manifests itself, the problem is not always with the UPS. The problem instead may be with a breaker, switch, or faulty circuit. A monitoring system that ties together all of these critical components

and communicates data back to an individual who understands the integrated power train and who can properly interpret the system messages represents a great value.

Organizing for “holistic” PM

To optimize efficient PM, the data center owner’s internal organizational structure should also be aligned to support a robust implementation of holistic, integrated PM practices. Traditionally, IT and facilities groups have not been harmonized to work closely together. IT has relegated itself to supporting IT systems in the data center while the facilities department has been relied upon to oversee the installation and maintenance of the physical infrastructure components. Since these systems are now closely coupled in the data center, an alternative organizational approach that tightly integrates key members of both teams needs to be considered.

One management system, addressing all components as a system

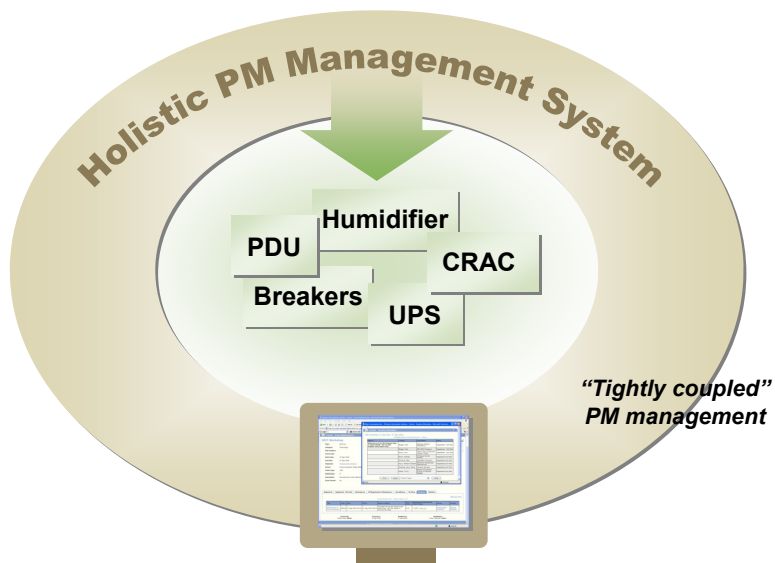


Figure 4

Strategic approach: integrate holistic PM management

Why physical infrastructure components fail

Older UPSs (those installed in the ‘80s and ‘90s) need to be manually adjusted on a regular basis to prevent voltage drift and “out-of-tolerance” conditions. For example, UPS control cards required that the calibration of potentiometers be adjusted manually by a technician utilizing an oscilloscope on a quarterly basis. Today this same function is executed by an onboard microprocessor. Periodic recalibration helps to minimize the possibility that the UPS will fail.

More modern UPSs are controlled with digital signal processor controls. These do not “drift” and do not require recalibration unless major components are replaced. In addition to out-of-tolerance conditions, harmonics and power surges also have a negative impact on physical infrastructure power components.

Temperature fluctuation is another common cause of electronic component failure. Electronics are designed to support specific temperature ranges. If temperatures remain within the design range of the equipment, failures rarely occur. If, however, temperatures stray beyond the supported range, failure rates increase significantly. In fact, according to studies con-

ducted by high-performance computing researchers at Los Alamos National Laboratory, the failure rate doubles for every rise of 10° C (18° F)¹ (see **Figure 5**).

The recommended operating temperature range for IT equipment, according to the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) TC 9.9, is 68-77°F (20-25°C). Proper airflow can help maintain consistent and safe temperatures and can help to sustain environmental conditions that translate to longer component life and increased time between failures. Excessive current is another source of damage to internal components. Mechanical systems also require the inspection of normal and abnormal bearing wear and the periodic replacement of oils and lubricants.

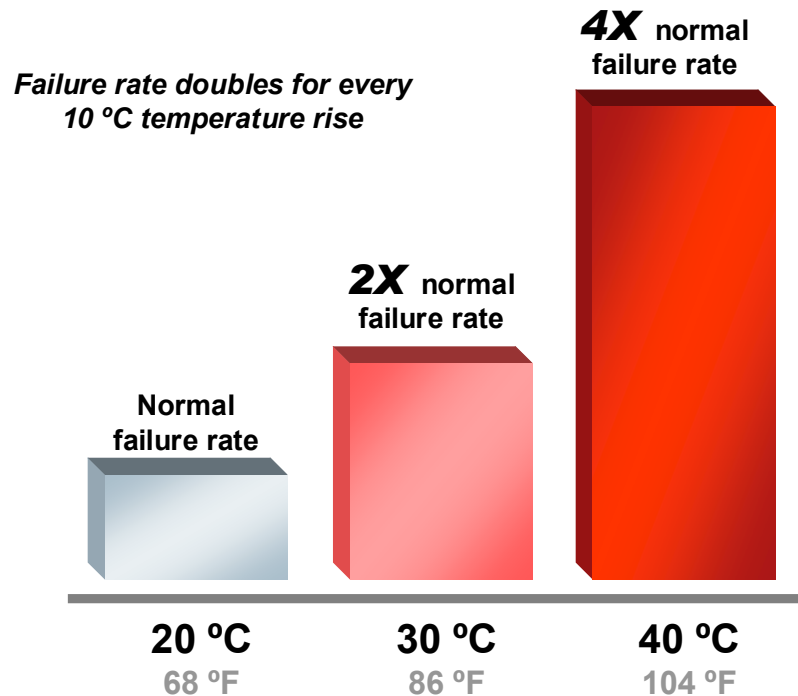


Figure 5


Los Alamos National Laboratory
heat-to-failure study

Recommended practices

Visits by qualified maintenance personnel serve as a validation that the physical infrastructure equipment is on track to support the data center owner's system uptime goals. Physical infrastructure professionals with data center expertise can identify the aging of various internal components and identify how much the component influences the overall reliability of the system.

The PM professional should observe the data center environment (circuit breakers, installation practices, cabling techniques, mechanical connections, load types) and alert the owner to the possible premature wear and tear of components and to factors that may have a negative impact on system availability (i.e., possible human error handling equipment, higher than normal temperatures, high acidity levels, corrosion, and fluctuations in power being supplied to servers).

A PM visit should also include an evaluation of outside environmental factors that can impact performance (see **Table 1**). The depth and breadth of the PM visit will depend upon the criticality level of the data center (see White Paper 122, *Guidelines for Specification of Data Center Criticality / Tier Levels*) and should result in the formulation of an action plan.

 Related resource
White Paper 122
Guidelines for Specification of Data Center Criticality / Tier Levels

¹ Los Alamos National Laboratory: "The Importance of Being Low Power in High Performance Computing", Feng, W., August 2005

Table 1*Sample PM environment checklist*

Internal environment	External environment
<p>Hands-on</p> <ul style="list-style-type: none"> • Appearance of circuit boards • Appearance of sub-assemblies • Appearance of cable harnesses • Connectors • Filters • Windings • Batteries • Capacitors • Insulation • Ventilation <p>Non-invasive</p> <ul style="list-style-type: none"> • General appearance • Thermal scanning readouts • Predictive failure reports • Internal temperature readings 	<ul style="list-style-type: none"> • Overall cleanliness • Temperature levels • Acidity levels • Presence of corrosion • Frequency of disruptions • Presence of dripping water • Dust content of area • Hot spots • Ventilation obstruction • Access hindrance • Open windows and doors • Nearby construction • Radio usage • Roof penetrations • Noise quality of equipment • Connections of equipment to earthing cables

Thermal scanning and predictive failure

Thermal scanning of racks and breaker panels is recommended during a PM visit. Abnormal temperature readings can prompt a required intervention. Infrared readings can be compared over time to identify trends and potential problems. In this way, an electrical connection, for example, can be retightened based on scientific data instead of a guess.

The thermal scanning approach can also be applied to switchgear, transformers, disconnects, UPS, distribution panel boards, power distribution units, and air conditioner unit disconnect switchers.

Computational Fluid Dynamics (CFD) can also be utilized to analyze the temperature and airflow patterns within the data center and to determine the effect of cooling equipment failure.

By utilizing a predictive failure approach, capacitors, for example, are replaced only when continuous onboard diagnostics make a recommendation for replacement. This is in stark contrast to the traditional “it’s been 6 months and its time to replace them” approach. Adhering to predictive failure practices avoids unnecessary execution of invasive procedures which injects the risk of human error leading to downtime.

Table 2 presents a sample list of physical infrastructure devices that require PM. These systems interact with each other and need to be maintained as a whole system.

Table 2

Devices requiring data center PM (partial listing)

Device	Internal elements requiring PM	Overall maintenance level required
Transformer	Tightness, torque of connections	low
PDU	Tightness, torque of connections	low
Data center air and water distribution systems	Piping internal densities, valves, seats and seals	low
In-Row CRAC	Filter, coil, firmware, piping connections, fan motors	medium
New Generation UPS	Fans, capacitors, batteries	medium
Raised floor	Physical tiles, tile position, removal of zinc whiskers	high
Traditional UPS	Fans, capacitors, electronic boards, batteries	high
Traditional CRAC	Belts, air filters, piping connections, compressor, fan motors, pumps, coils	high
Humidifier	Drain, filter, plugs, water processor	high
Transfer switch	Switch components, firmware, torque	high
External Batteries (wet cell and VRLA)	Torque, connections, electrolyte / acid levels, temperature levels	high
Fire Alarm System	Valves, flow switches	high
Chillers	Oil pressure levels, gas levels, temperature settings	high
Generator	Fuel filter, oil filter, hoses, belts, coolant, crankcase breather element, fan hub, water pump, connections torque, alternator bearings, main breaker	high

Scheduling practices

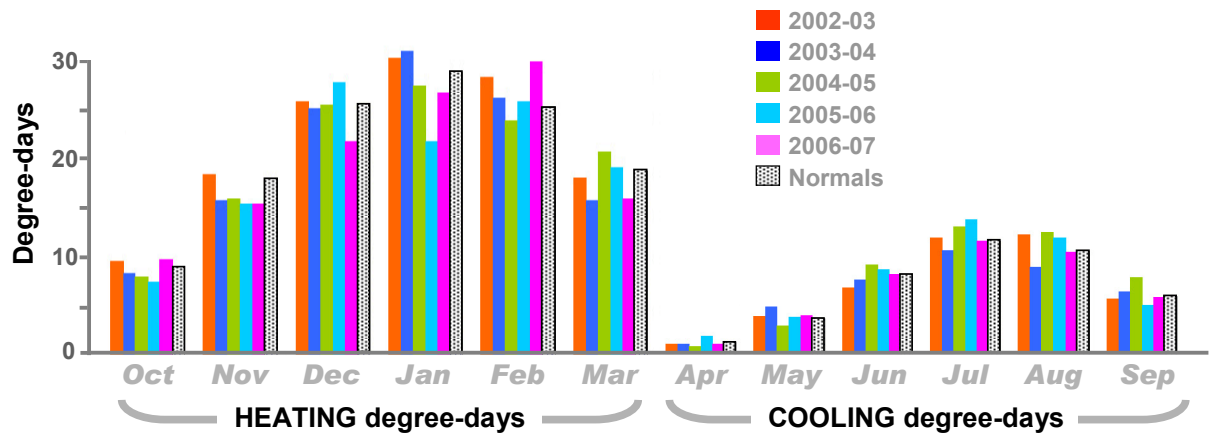
Traditional maintenance scheduling practices were established in the days before system availability became a significant concern for data center owners. Nights, weekends and three-day holiday weekends were, and are still, considered common scheduling times. However, the rise of the global economy and the requirement for 24x7x365 availability has shifted the maintenance scheduling paradigm.

In many cases, the justification for scheduling PM only on nights and weekends no longer exists. In fact, a traditional scheduling approach can add significant cost and additional risk to the PM process. From a simple hourly wage perspective, after-hours maintenance is more expensive. More importantly, services and support personnel are likely to be physically tired and less alert when working overtime or when performing work at odd hours. This increases the possibility of errors or, in some cases, can increase the risk of personal injury.

A PM provider / partner can add value by helping the data center owner to properly plan for scheduling PM windows. In situations where new data centers are being built, the PM provider / partner can advise the owner on how to organize the data center floor plan in order to enable easier, less intrusive PM. In addition, information gathered by governmental bodies such as the National Oceanic and Atmospheric Administration (NOAA) provide climate trend data that can guide data center owners on optimum maintenance windows (see **Figure 6**).

Figure 6

Research data (heating and cooling degree-days) as a guide to scheduling PM visits



Source: National Oceanic and Atmospheric Administration, National Weather Service
http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/cdus/degree_days/
 Short-Term Energy Outlook, June 2007



Note: A degree-day compares the outdoor temperature to a standard of 65° F (18.3°C); the more extreme the temperature, the higher the degree-day number. **Hot days** are measured in **cooling degree-days**. On a day with a mean temperature of 80° F, for example, 15 cooling degree-days would be recorded (80 – 65 base = 15 CDD). **Cold days** are measured in heating degree-days. For a day with a mean temperature of 40° F, 25 **heating degree-days** would be recorded (65 base – 40 = 25 HDD). By studying degree-day patterns in your area, increases or decreases in outdoor temperatures from year to year can be evaluated and trends can be established.

Coordination of PM

Extreme hot and cold outside temperatures and stormy “seasons” can pose significant risks. If climate data points to April and September as the optimum months for PM to take place, then both pros and cons still need to be considered. For example, is any nearby construction project planned during any of the proposed PM “windows”? If so, a higher likelihood of outages due to the construction accidents (i.e. power and water lines accidentally cut by construction equipment) could be an important factor to consider. Would cooler weather help provide free cooling to the data center, if data center cooling system downtime occurs? If September is deemed an optimal month to perform PM based on outside temperature data, is it wise to schedule during an end of quarter month, when financial systems are operating at full capacity?

One approach is to schedule PM at different times. Mobilizing all key staff members simultaneously could pose a risk by compromising the coverage/ support expected by both business users and customers. If lack of personnel human resources is an issue, a phased PM schedule will spread PM responsibilities more evenly and allow the data center to maintain its target service levels.

If access to human resources is not an issue, another approach would be to perform the PM all at once on the same day or group of days and not at different time periods. Rather than scheduling multiple PM visits with multiple organizations, one partner is called in to provide, schedule, and perform key infrastructure PM. This “solution-oriented PM” (as opposed to traditional component-oriented PM) with a qualified partner can save time and money and will improve overall data center performance. The overriding priority is to schedule PM with a qualified service provider when disruption to the data center is at a minimum and when recovery options are maximized.

PM statements of work

The PM process should be well defined to both the PM provider and the data center owner. A detailed PM statement of work (SOW) should be issued by the PM provider to the owner which clearly describes the scope of the PM. Listed below are some of the elements that should be included in the SOW:

- Dispatch provisions – Most manufacturers recommend a PM visit one year after the installation and commissioning of equipment although certain high usage components (i.e., humidifiers) may require earlier analysis and constant monitoring. Proper protocols should be followed in order to assure easy access to the equipment at the data center site. The owner’s operational constraints should also be accounted for. A plan should be formulated so that the equipment can be tuned for optimal performance.
- Parts replacement provisions – The SOW should include recommendations regarding which parts need to be “preventatively” replaced or upgraded. Issues such as availability of stock, supply of tested and certified parts, contingency planning in the event of defective parts, and the removal and disposal of old parts should all be addressed in the SOW.
- Documentation – The SOW should specify a PM output report that documents the actions taken during the PM visit. The output report should also be automatically reviewed by the vendor for technical follow-up.

PM options

PM maintenance services can either be purchased directly from the manufacturer or from third party maintenance providers. The selection of a maintenance organization capable of supporting the PM vision for the data center is an important decision. Such organizations can be global in scope or they can offer regional or local support. **Table 3** compares two categories of mainstream PM providers.

Table 3

Meeting service challenges: manufacturer vs. unauthorized third party

	Manufacturer / authorized 3 rd party	Unauthorized 3 rd party
Spare parts	<ul style="list-style-type: none"> Stock of spares available to data center owner locally Parts built and tested in an ISO certified factory Parts are most recent revision / compatible with product being serviced Original factory parts are used for replacement 	<ul style="list-style-type: none"> Replacement parts may be procured from the “salvage market” or from used equipment provider Replacement parts may be repaired locally by unqualified technicians Replacement parts may be purchased from manufacturer with third party as intermediary, adding delays
Product knowledge	<ul style="list-style-type: none"> Service specialized on specific products Experience linked to the high numbers of installations worked on 	<ul style="list-style-type: none"> Service personnel are more “generalists” and are expected to service a wide variety of products from multiple manufacturers May not have access to or knowledge of critical upgrades
Local support	<ul style="list-style-type: none"> Can offer standard 4 hour response 	<ul style="list-style-type: none"> Local firms may be able to provide 2 hour response May cover localities that manufacturer cannot
Knowledge of data center environment	<ul style="list-style-type: none"> Beyond individual components, manufacturer often is knowledgeable of power and cooling issues impacting overall data center operations 	<ul style="list-style-type: none"> Data center knowledge beyond the repair of individual components may be limited
Training	<ul style="list-style-type: none"> Personnel are service factory trained and certified to meet national safety standards Personnel receive regular evaluation and training updates 	<ul style="list-style-type: none"> Personnel may not be factory trained. If factory trained may no longer receive training updates
Cost	<ul style="list-style-type: none"> Typically more expensive but less time needed to diagnose and problem solve 	<ul style="list-style-type: none"> Typically less expensive than manufacturer
Product updates	<ul style="list-style-type: none"> Service has access to all product hardware and firmware revisions 	<ul style="list-style-type: none"> Access to product updates and firmware revisions may be limited
Documentation	<ul style="list-style-type: none"> Service documentation is most recent revision and includes service update information Issuance of technical reports and documentation to data center owner after PM is completed 	<ul style="list-style-type: none"> Service personnel may not have access to updated service documentation
Tools	<ul style="list-style-type: none"> Service has all required tools, test equipment and software and conforms to ISO calibration regulations 	<ul style="list-style-type: none"> May not have as quick an access to the latest tools

PM by manufacturer

Manufacturers package maintenance contracts that offer hotlines, support, and guaranteed response times. Manufacturers also maintain thousands of pieces of equipment across all geographies and are able to leverage tens of thousands of hours of field education to further improve their maintenance practices and enhance the expertise of their staffs. Data gathered by the factory-trained field personnel is channeled to the R&D organizations so they can analyze the root cause of breakdowns.

The manufacturer’s R&D groups analyze the data and build needed hardware and software improvements into product upgrades that then form the basis for the next PM. This global exposure also allows for manufacturer-based service personnel to maintain a deeper understanding of integrated power and cooling issues, a knowledge that they can apply to both troubleshooting and predictive analysis.

PM by unauthorized third party

Most third party maintenance companies are local or regional in scope; they tend to work on fewer equipment installations. As a result, their learning curve may be longer regarding technology changes. Since they have few direct links to the manufacturer and manufacturing sites, most unauthorized third-party maintenance providers cannot provide an escalated level of support. Many problems they encounter are “new” because they don’t have the benefit of leveraging the global continuous improvement PM data gathered from manufacturer installations all over the world.

User maintenance

Whether or not data center owners decide to maintain their own physical infrastructure equipment depends on a number of factors:

- Architecture / complexity of equipment
- Criticality level of related applications
- Data center owner’s business model

Some manufacturers facilitate the user-maintenance approach by designing physical infrastructure components that require far less maintenance (i.e., a UPS with modular, user-replaceable battery cartridges). Factors in favor of user-maintenance include the ability to pay for maintenance service through an internal budget as opposed to an external budget and the ability of data center staff, if they are properly trained, to quickly diagnose potential errors.

Factors that discourage user-maintenance include limited internal staff experience (not a business core competency of the data center owner) and diminishing knowledge base of staff over time as a result of turnover. Delays in securing parts from an outside source and quick resolution to a problem may also be difficult if no maintenance contract is in place. Without properly structuring an organization for user maintenance, expected efficiency gains and financial gains may not be realized.

Condition-based maintenance

Estimating and projecting equipment condition over time will help to identify particular units that are most likely to have defects requiring repairs. Such an exercise will also identify units whose unique stresses (i.e., a UPS that often switches to battery power because of poor utility power quality) have an increased probability of future failure. A condition-based maintenance method also identifies, through statistics and data, which equipment components most likely will remain in acceptable condition without the need for maintenance. Maintenance can therefore be targeted where it will do the most good and the least harm.

Condition-based maintenance data that is useful and available to help estimate the condition of the equipment includes the following:

- Age
- History of operating experience
- Environmental history (temperature, voltage, run-time, abnormal events)
- Operating characteristics (vibration, noise, temperature)

Conclusion

PM is a key lifeline for a fully functioning data center. Maintenance contracts should include a clause for PM coverage so that the data center owner can rest assured that comprehensive support is available when required. The current PM process must expand to incorporate a “holistic” approach. The value add that PM services provide to common components today (such as a UPS) should be expanded to the entire data center power train (generators, transfer switches, transformers, breakers and switches, PDUs, UPSs) and cooling train (CRACs, CRAHs, humidifiers, condensers, chillers).

As of today, the PM provider in the strongest position to provide such a level of support is the global manufacturer of data center physical infrastructure. An integrated approach to PM allows the data center owner to hold one partner accountable for scheduling, execution, documentation, risk management, and follow up. This simplifies the process, cuts costs, and enhances overall systems availability levels.



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Guidelines for Specification of Data Center Criticality / Tier Levels

White Paper 122



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