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RETROFITTING EQUIPMENT AND INTERFACING SYSTEMS FOR CONDITION BASED MAINTENANCE

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Abstract

A Gas Turbine Health Monitoring (GTHM) system has been installed to monitor a fleet of compression equipment on a natural gas pipeline in China. The fleet consists of 22 General Electric PGT25+, 15 Rolls-Royce Coberra 6562, and 4 Siemens Variable Speed Drive (VSD) packages. Using the China pipeline project as an example this paper describes the implementation of this unique Gas Turbine Health Management system.

The GTHM system is an aftermarket solution that allows operators employing different makes, models and vintages of equipment to implement a master data historian with customized analysis tools and a common user interface.

GTHM relies on an underlying expert system; the Gas Turbine Analysis Program (GTAP™) which uses the engine instrumentation to calculate engine performance degradation. Trending of the performance degradation can assist the operator in scheduling condition based maintenance (CBM) activities, such as, compressor washing and component repair or replacement.

CBM has become recognized as an advantageous strategy to prolonging equipment life but comprehensive CBM programs are still not widely implemented in industry. One of the factors is the perception that new CBM technologies are not easy to implement with legacy equipment and there is no straightforward, cost effective way to implement CBM without retiring older systems that are still working well. Retrofitting equipment with new instrumentation and creating data access software to communicate with older systems is both possible and worth the investment.

List of Acronyms and Glossary Terms

AB	Allen-Bradley
AF	PI System Analysis Framework
BN	Bentley-Nevada
CBM	Condition Based Maintenance
DCN	Data Collection Node
FINS	Factory Interface Network Service
GE	General Electric
GG	Gas Generator
GTAP™	Gas Turbine Analysis Program
GTHM	Gas Turbine Health Management
HP	High Pressure
LP	Low Pressure
Modbus/TCP	A standard industrial network communication protocol
NA	Not Available
ODBC	Open Database Connectivity
OEM	Original Equipment Manufacturer
OLE DB	Object Linking and Embedding Database
OPC	Object Linking and Embedding for Process Control
PC	Personal Computer
PCCC	Programmable Controller Communication Commands
PI	Plant Information
PLC	Programmable Logic Controller
PT	Power Turbine
RR	Rolls Royce
S7	Step 7
SRTP	Service Request Transfer Protocol
VSD	Variable Speed Drive

1 Introduction

Before embarking on a project to implement a gas turbine health management system, one has to embrace the idea of condition based maintenance by acknowledging the limitations of an OEM preventative maintenance schedule (e.g. hours and starts). The assumptions that are used to create an hours and starts based preventative maintenance schedule are not entirely valid when one considers the nature of a gas turbine. The fundamental principle of preventative maintenance is that equipment failure is a function of service time and one can make a linear correlation between age and wear. The components of a gas turbine are extremely sensitive to operational load and ambient conditions that are unlikely to remain constant over time in a pipeline fleet. A gas turbine can be old or young for its “age”. Wear is a complex function of many variables and does not accumulate uniformly in the components within the turbine.

The inefficiency of a simple preventative maintenance approach has given rise to a very active community of researchers who are developing diagnostic methods that use the variable operating parameters to determine actual component condition. The volume and sophistication of the work being done is very impressive and has evolved over decades. The motivation for all of this effort is tied to the value that can be realized when the methods are applied to a commercial operation. One source claims that as much as 80% of maintenance expenditures are attributed to chronic problems and an effective maintenance program can see these expenditures reduced by 40-60% [1]. This can be correlated to the maintenance programs of gas turbine operators. Over the course of a gas turbine life cycle an operator can needlessly incur costs several times over when actual component condition is ignored as a factor in maintenance scheduling. For those operators that are convinced that CBM is a valuable tool but the task of implementing a system appears to be daunting, this paper discusses how the latest technologies can make the job a little easier.

2 Planning GTHM

The case study presented in this paper centres around a project undertaken in China. A natural gas pipeline is in operation and the operator had come to the conclusion that a health management system for the fleet of gas turbines would be a valuable long-term investment. Since their fleet consisted of equipment from several different manufacturers, the operator decided to use a customized aftermarket solution for their CBM system rather than purchasing individual systems from each OEM. The experience gained during this project is the basis for the discussion.

The first problem one encounters when planning any CBM system is the question of how to assess the condition of components in operation. Enough information about the components has to be acquired to permit a satisfactory analysis. Understanding how components will change as they degrade from the new condition and what resulting behaviours can be observed in the system defines the type of information needed. As discussed in the introduction, this is a mature field in gas turbine maintenance. There are several diagnostic methods being practiced based on performance analysis relying on gas path parameter data and expert systems that use knowledge bases to assess component condition. A useful review of many of these methods is discussed in [2].

2.1 Diagnostic Method

The diagnostic method employed on the China pipeline project is a systems approach to hot section component life management as described in [3]. This approach has three main engineering functions; metallurgical, mechanical and performance. All three functions contribute to a robust and comprehensive assessment of component condition. The performance engineering function utilizes a physics based model of the gas turbine and the Liburdi Gas Turbine Analysis Program; GTAP^{TM}. GTAP^{TM} combines the gas turbine model with actual operating data to calculate component degradations and can be used to evaluate inter-stage gas path conditions like pressure, temperature and flow. These inter-stage evaluations are vital inputs to the lifing module that is used to calculate the accumulated damage to the individual gas turbine components. The accuracy of the analysis program outputs is dependent on the availability and accuracy of the operating data and hence the availability and accuracy of the instruments that provide the data.

Working backwards from the selection of diagnostic methods the maintenance engineer can determine what input data must be supplied.

2.2 Gap Analysis

In order to proceed with a GTAP^{TM} implementation on the China pipeline, a gap analysis was performed to determine which data points were missing from the list of required inputs for the performance calculations. The China pipeline uses several different equipment packages at its compressor stations. Eight of the stations house Rolls-Royce Coberra 6562 power generators. A gap analysis of the GTAP^{TM} performance analyser and the instrumentation of the Rolls-Royce package are summarized in Table 1.

Table 1: GTAP^{TM} Inputs and Instrument Tags

	GTAP^{TM} Input Parameter	**RR Instrument Tag**
1	ambient temperature	26am
2	ambient pressure	NA
3	relative humidity	NA
4	low pressure axial compressor inlet temperature	26gg10.1a
5	gas generator inlet pressure loss	63gg20j0
6	low pressure axial compressor discharge temperature	NA
7	low pressure axial compressor discharge pressure	NA
8	high pressure axial compressor discharge temperature	NA
9	high pressure axial compressor discharge pressure	a63gg30
10	gas generator exhaust average temperature	a26gg455b

11	gas generator exhaust pressure	P2Ti
12	power turbine exhaust temperature	26gg05a 26gg05b 26gg05c
13	power turbine exhaust pressure	NA
14	low pressure shaft speed	a99ggnl1 a99ggnl2
15	high pressure shaft speed	a99ggnh1 a99ggnh2
16	power turbine speed	a99pt1 a99pt2
17	fuel gas flow	fueldmd
18	axial compressor inlet bell mouth differential pressure	NA
19	centrifugal compressor suction temperature	26pgs
20	centrifugal compressor discharge temperature	26pgd
21	centrifugal compressor suction pressure	63pgs
22	centrifugal compressor discharge pressure	63pgd

The gap analysis revealed a number of data points, shown as NA (not available), that were not being measured. This indicated the need for additional instrumentation and some of this instrumentation would have to be installed on-engine. This is one of the issues an operator can encounter that at first may seem like a prohibitive problem but in fact it can be solved without too much difficulty. Performance analysis is not essential to gas turbine operation but it is an integral step in commissioning a new turbine. The OEM must demonstrate the performance level of the turbine when it is delivered new and clean. As a result, performance analysis can require instruments that were only installed during the initial commissioning. The OEM may offer a performance package as an add-on item and this can include the additional instrumentation but this tends to be expensive. As a result of the increase in purchase price, these extra instruments are often left out. Regardless of whether or not the instrumentation is installed, the ports are manufactured on the engine so the capability to add it without making modifications exists and this is what is important.

3 GTHM Infrastructure

To rectify the problem of missing instrumentation on the China pipeline, a team was assembled to install a retrofit package at each compressor station. Designing the package required a thorough inspection of the existing installation. To acquire the pressure measurements, the team needed to identify the ports that would be used to connect to the engine body and then fabricate fittings to create taps for the ports. Tubing runs were designed within the turbine enclosure to connect the taps to pressure transducers that would be mounted near the electrical junction boxes. Spare terminals and wiring were available in the junction boxes to bring the signals across the station yard from the compressor building to the control room. The temperature measurements could be acquired from thermocouples installed on-engine but the thermocouple wiring was not extended back to the turbine controller PLC. Thermocouple cable and connectors were added to complete the temperature circuits. The new signals were routed through their own PLC to keep the health monitoring system separate from the turbine controller. The last piece of equipment needed to complete the GTHM infrastructure was the data collection node.

3.1 Data Collection Network

The data collection node (DCN) is a personal computer (PC) that interfaces each of the PLCs collecting sensor sourced information and the operations centre to create a data collection network. The PLCs at the compressor stations included the turbine controller, vibration monitor and the newly installed health monitor. The PLCs were all connected to the station's local area network making Ethernet a natural choice for network interface. The data collection node would also be connected to the pipeline's wide area network using Ethernet. The pipeline network consists of a fibre optic cable that connects all of the stations with the operations centre where the data is ultimately stored. The physical layout of the GTHM system at a Rolls Royce compressor station is shown in Figure 1.

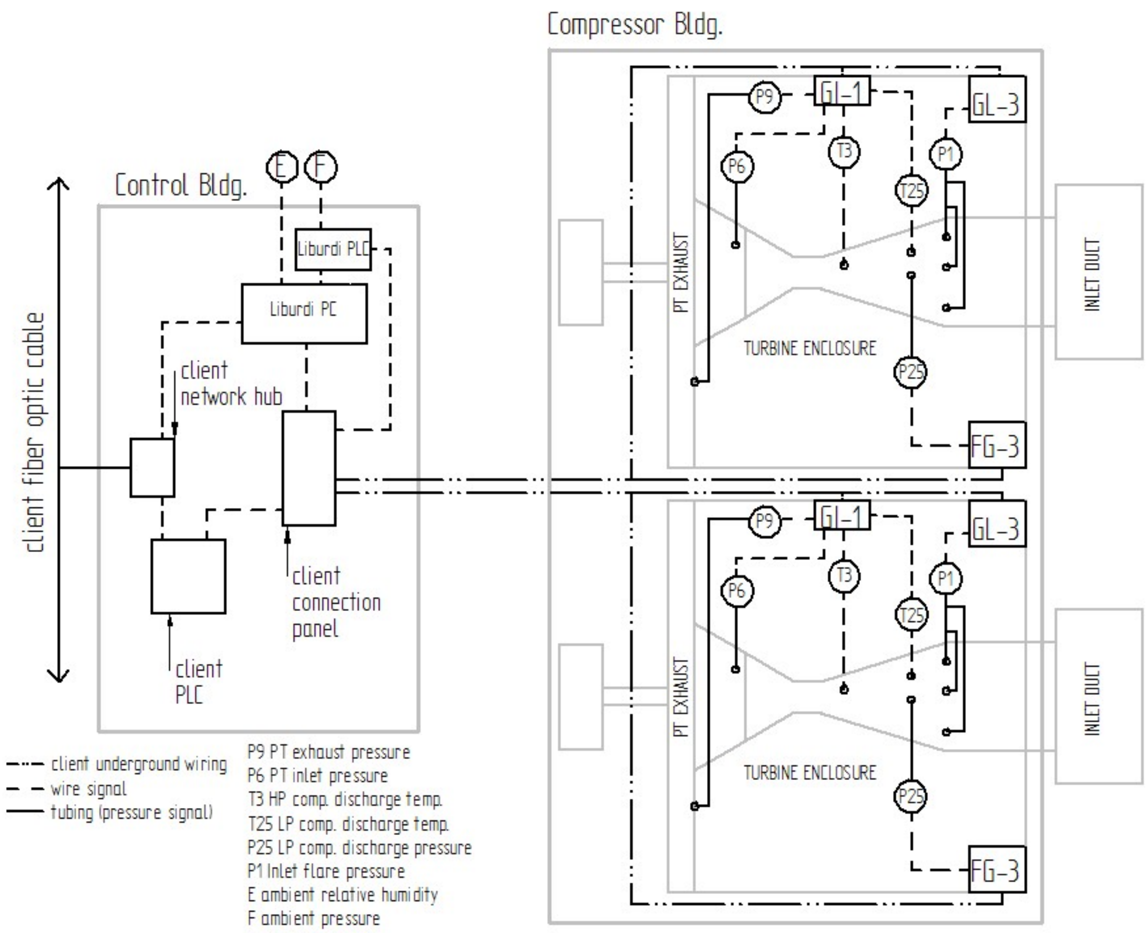

Figure 1: Rolls Royce Station Installation

3.2 Infrastructure Considerations

The existence of extra capacity to accommodate all of the new analog and digital signal transmission was a fortunate circumstance on the China pipeline project. The station and pipeline network had sufficient bandwidth and surplus ports on the switching equipment for the DCN and health monitor PLC. The cables running under the station yard between the compressor building and control building had a sufficient number of spare conductors and terminal blocks for the instruments. Verifying the signal capacity should be part of the station inspection during the planning stage. Depending on the station design and layout adding additional capacity could be difficult and expensive. In this scenario, there are wireless technologies that might prove to be a practical solution, potentially offsetting much of the cost. On the positive side, it is possible a gap analysis would reveal all required measurements are available. In a best case scenario, the data collection node is the only real hardware setup required to enable a compressor station for health monitoring.

Each of the data collection nodes is responsible for transmitting its data to the central data server. This server is known as the data historian and it is the foundation on which the GTHM system is built.

4 GTHM Data Historian

The data historian is a sophisticated database server optimized to the task of capturing, storing and retrieving time-series data. A great deal of the information being transmitted to the historian is in the form of continuous analog signals representing temperatures, pressures, flows and other dynamic process parameters. Filtering and compression techniques allow the historian to record a highly accurate representation of these signals for very long periods of time. This allows the precise parameter value from any instant in time to be retrieved over the duration of several years. The ability to analyze actual historical data and not summarized, averaged or otherwise interpolated data is a powerful feature for the data consumer and specifically the expert system.

4.1 Features

The market place offers many options for the data historian and careful consideration should be given to how a historian product will fit into a health management system. The following are some features to consider.

- Capacity to store all data points of interest
- Scalability to accommodate growth
- Buffering at the collection node to prevent data loss during network outages
- Easy and reliable back up mechanism
- Automatic failover to a standby server depending on availability requirements
- Security and authentication framework
- Support for connectivity

Capacity is obviously critical but the amount of data that can be stored in a modern historian is incredibly large and is not likely to become a deciding factor. Connectivity is the criteria that most affects the implementation of a GTHM system. Data entering the system is sourced from devices from various manufacturers. There are numerous standard and proprietary communication protocols that may have to be used to enable the flow of information. A data historian should have a full library of data adapters to create the device interfaces and features that allow the development of custom interfaces.

4.2 Tools

To further reduce the workload of building a GTHM system, data historian vendors or third parties can provide complimentary tools, modules and application interfaces that integrate seamlessly to create the upper layers of the system. Some of these are listed below.

- Object modelling tools
- Computation engines to perform calculations and develop algorithms for analysis rules
- Notification sub systems to generate emails, texts or pages in response to events
- Front end visualization and presentation tools

Object modelling is indispensible when creating a GTHM system. The data stored in the historian is essentially time stamped name-value pairs. It can be viewed as a single table with random data entries listed one after another in roughly chronological order. The name of an entry corresponding to a particular sensor or measurement is referred to as the tag. To make the data easily accessible it should be structured so that tags can be associated with the physical elements of the system. An object modelling tool allows the developer to group tags according to component class (i.e. station tags, compressor tags, turbine tags) and organize the component classes into a relational hierarchy (i.e. a compressor is part of a unit which is part of a station). It is much easier to navigate the data when it can be accessed through a component object model instead of a flat listing.

A GTHM system must have a user interface and a complement of visualization and presentation tools will go a long way towards creating a positive user experience. These tools include screen designers with graphical content like status indicators and trending charts, web portals for mobile and remote access, and export capabilities to easily transfer data to productivity applications like spreadsheets.

A full featured GTHM system requires a lot of software but not necessarily a lot of programming. The majority of the effort can be put towards configuring software modules already built by the data historian vendor or industry partners instead of developing software from scratch.

5 GTHM System

The data historian being used for the China pipeline project is the PI Historian from OSIsoft. The selection criteria included the points discussed above as well as other factors related to this particular customer and the project location. The most beneficial aspect of using PI and products like it is that PI is an entire system and not just a historian. The best way to conceptualize the system is with the data historian at the centre between a back-end and front-end system. The back-end system is mainly focussed on the data collection network and the data entering the system. The front-end system is focussed on delivering data to other systems and providing functionality and content to the user. These systems will be discussed separately.

5.1 Back-End System

The major technical hurdle faced in the back-end system is interfacing the historian database to the numerous devices that hold the data. On the China pipeline the list of devices included Allen-Bradley (AB), GE-Fanuc, Siemens, Omron PLCs and Bentley-Nevada (BN) vibration monitors. Each PLC uses its own proprietary protocol developed by the manufacturer and the Bentley-Nevada monitor uses the industry standard Modbus/TCP.

The solution to managing all the different communication protocols was to select a single protocol to communicate with the historian and convert all other protocols. Object Linking and Embedding for Process Control (OPC) is a communication standard created specifically to facilitate real time data exchange between devices from different manufacturers. The PI system can act as an OPC client so transferring data into the historian archive is straightforward if all the data sources are OPC servers. If a device does not directly support OPC, a data adapter is likely to exist for converting a supported protocol to OPC. There are suitable products from CimQuest Ingear and OPCtechs amongst others that provide all the necessary conversions. It is also possible to create custom OPC servers if one cannot be sourced. This requires programming and a specification for the protocol being converted. Proprietary protocols are not always published making them difficult to obtain.

None of the devices on the station network natively supports OPC but adapters exist for all of them. The China pipeline has five different OPC servers, one for each type of device, set up on the data collection node to convert protocols. The wide spread support for OPC solves the issue of transferring data into the historian. A back-end system is diagrammed in Figure 2.

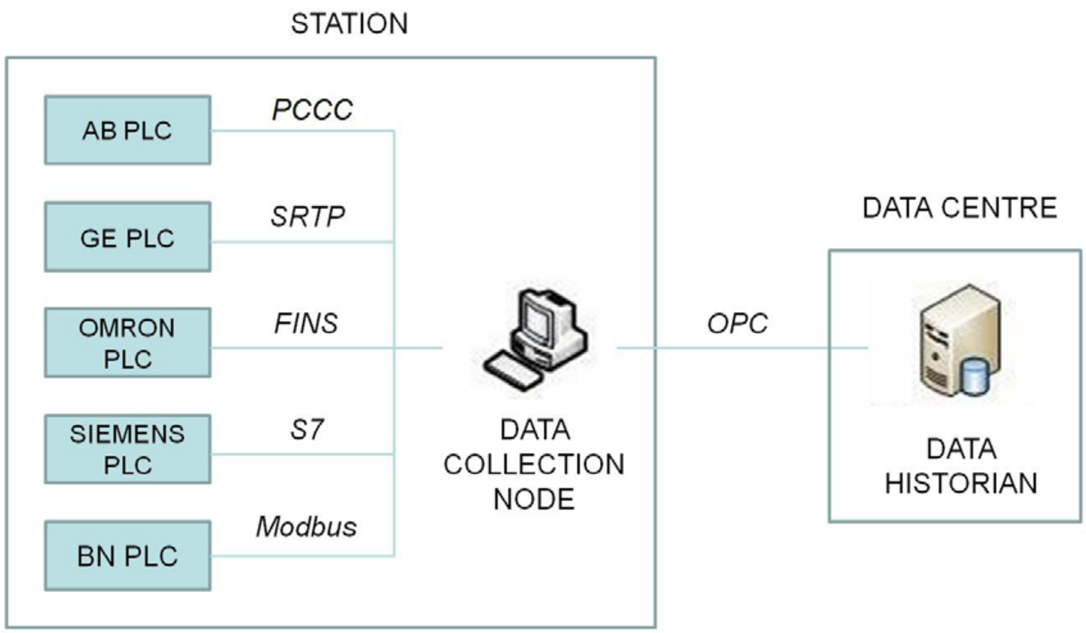

Figure 2: A GTHM Back-end System

5.2 Front-End System

The major technical hurdle faced in the front-end system is providing access to the data in the historian in an intuitive and responsive manner. Diagnostic tools and expert modules require a systems interface to the data. Open Database Connectivity (ODBC) is a widely supported interface for providing database connectivity and Object Linking and Embedding Database (OLE DB) is another useful interface for Microsoft based applications. The GTAP diagnostic modules interact with the PI historian using ODBC. ODBC makes it possible to read the input data for the analysis directly from the historian and write the results back.

For object modeling, the China pipeline project has an Application Server running the PI System Analysis Framework (AF) module. AF maps historian tags to objects for the user interface. The goal of the user interface is to give the user an intuitive search path for finding information. This was achieved by creating displays that are navigated from the top down moving from overview to detail. This classic drill down technique starting from the pipeline, then to the station, the unit, and finally the component of interest is easy to implement when the data is organized in AF.

The look and functionality of the user interface can be sophisticated or clean and simple. The first incarnation of the GTHM interface was created using PI Processbook. Processbook is a tool with a suite of screen elements like labels, boxes, simple graphics and charts that can be arranged on screen and connected to AF by setting a few properties. The PI Software development kit (PI SDK) is a tool that lets developers use a high level programming language to build a custom windows application on top of AF. These tools make it possible to put together an interface quickly but have the flexibility to build more complex and custom interfaces over time.

The China pipeline project required users to have access while mobile or otherwise not connected directly to the pipeline network making a web portal a necessity. A Microsoft Sharepoint site was deployed on the Application Server and PI Web Parts were used to create web pages that can display live data. These tools remove almost all of the programming from creating a web portal.

Reporting is a core function of health management. The best reporting system utilizes the productivity applications already available. The China pipeline project uses Microsoft Excel and PI DataLink to embed raw and calculated data into templated spreadsheets for automatic reports. Spreadsheets are also great tools for casual analysis and ad-hoc reporting.

A front-end system is diagrammed in Figure 3.

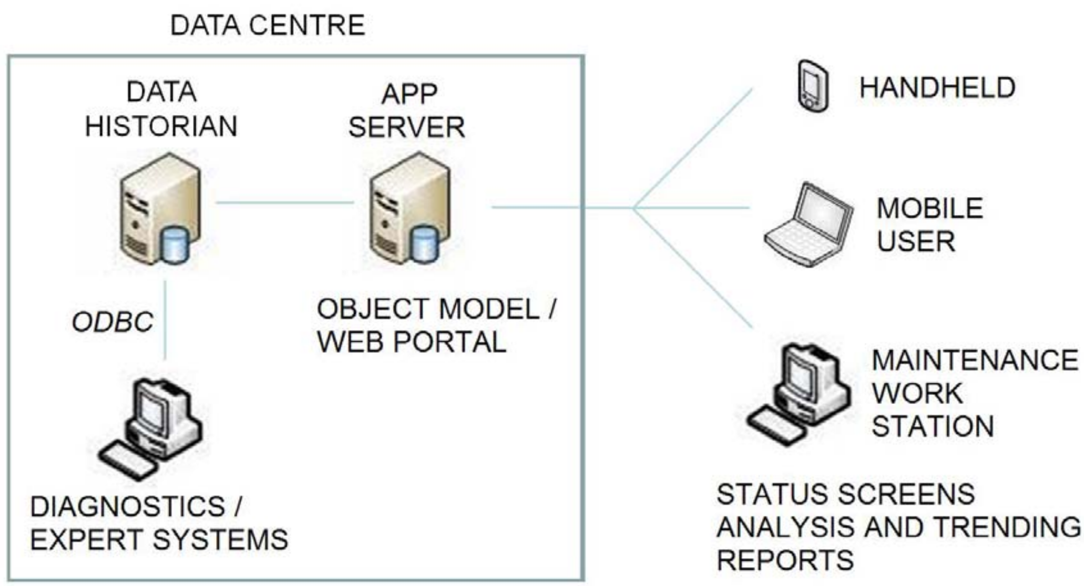

Figure 3: A GTHM Front-end System

6 Conclusion

This paper may serve as a blue print, a relevant example or a motivational story for anyone interested in implementing CBM for gas turbines. Technology continues to move forward at a steady pace and the effective use of technology often separates successful operations from poorly performing ones. GTHM is a system that is feasible to implement and provides great value because it takes advantage of emerging diagnostic and systems technology.

7 References

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