Automated Predictive Monitoring and Diagnosis in the Energy and Natural Resources Sector

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ABSTRACT

This paper explores strategies for automated predictive monitoring and diagnosis (M&D) using advanced intelligent systems technologies within the Energy and Natural Resources (ENR) sector to address safety implications and costs associated with downtime and emergency breakdown repairs. Automated predictive M&D lends itself towards application within centralized M&D centers to allow monitoring across an entire fleet, to improve efficiency, reduce duplication of functions and allow for consistent, best practice operation and higher quality repairs across distributed assets. However, centralization is often accompanied by a reduction in the number of on-site personnel and loss of critical knowledge for the operation and maintenance of assets. Therefore, the selection of appropriate data, sensors, algorithms, a suitable platform, analytical tools, visualizations and Enterprise Resource Planning (ERP) / Computerized Maintenance Management System (CMMS) integration form the basis for automated predictive M&D of asset performance (intelligent Asset Performance Management (iAPM)) making it possible to detect and diagnose issues across geographically dispersed assets so that results are available in daily operational workflow for executive, analytical and operational personnel before they impact production, operations and safety.

1. INTRODUCTION

Integrated and remote monitoring and diagnosis (M&D) is not a new concept. However, due to the size and scale of operations, without an appropriate strategy, expert resources, a suitable technology platform, enabling technologies and support structure within an intelligent system framework it is difficult to implement and take advantage of the benefits of automated predictive M&D across the Energy and Natural Resources (ENR) sector.

The emergence of centralized M&D centers worldwide has resulted from manufacturers wishing to implement servitization strategies, to no longer just sell products, but to generate new revenue streams by selling maintenance contracts (Jennions, 2011). Companies such as Boeing, Rolls Royce and General Electric (GE) have been offering centralized M&D as a service focusing on aviation and power generation (Boeing, 2012; Rolls Royce, 2016; Stephenson, 2006). The automation of real-time and long-term monitoring of airplane data allows for proactive management of maintenance across the airplane fleet (Maggiore, 2007). When an airplane arrives at the gate, replacement parts and the maintenance crews are available to make repairs (Maggiore, 2007). Within utilities, GE offers centralized M&D as a service for customers operating GE's gas turbine and generator assets (GE, 2015).

It is important to note that in the examples from aerospace and power generation, it is the original equipment manufacturer (OEM), with detailed knowledge and domain expertise of the assets, who provides remote M&D as a service. Other sectors leveraging off centralized M&D include the automotive sector, autonomous or intelligent vehicles for the space sector, energy generation, precision agriculture, health and usage monitoring (HUMS) for military (helicopters) and healthcare.

Integrated and remote M&D is gaining increased attention within the Australian ENR sector with companies such as BHP, Rio Tinto, Woodside and Santos starting to incorporate centralized and remote M&D into their organizations (Hamm, 2016; Latimer, 2015; Crozier, 2015a; Crozier, 2015b; Crozier, 2016). However, the resources sector, with its large-scale machines, infrastructure such as bridges and rail, processing plants and many suppliers, involves a more comprehensive approach involving different types of assets.

2. THE BUSINESS CASE FOR AUTOMATED PREDICTIVE M&D ACROSS THE ENR SECTOR

The Australian ENR sector is characterized by disparate mines in remote locations often with ageing assets operating under harsh environmental conditions. Simultaneously, new equipment is becoming more complex with the development of autonomous trucks, automated drilling and driverless trains. There are also significant costs associated with loss of expertise from a transient workforce and training on-site personnel who may only remain in a role for a short time. Managers accountable for asset failure may have only been in position for a few years, whereas the failure of a critical asset or component may have taken several years to manifest due to poor operation, maintenance practices or as a result of environmental factors. Costs associated with an emergency breakdown repair on a large-scale critical asset operating at a remote site can reach tens of millions of dollars which includes downtime, parts, labor and transportation costs, impacting production, safety and license to operate. All of these factors contribute to a strong business case for automated predictive M&D of asset performance, that is, intelligent asset Performance Management (iAPM), which can be incorporated into a centralized M&D facility.

3. A STRATEGY FOR AUTOMATED PREDICTIVE M&D ACROSS THE ENR SECTOR

Often organizations approach iAPM as an Information Technology (IT) initiative, uncertain where to start and not realizing that it involves the integration of different teams at various stages and appropriate technologies to meet the overall objective of automated predictive M&D. If implementation focuses on large teams, without specialist knowledge and expertise to setup a solution, one is moving away from iAPM. It has been the author's experience that by overcoming these challenges, significant progress can be made in improving operations, maintenance, safety and profitability.

A centralized M&D facility in the ENR sector incorporating iAPM must focus on (Power, 2014):

- High value assets, where the costs associated with downtime, including considerations into safety and license to operate, justifies the implementation costs.
- Standardized assessment of asset condition, making visible the risk associated with critical asset failure on a site by site and organization wide basis.
- Comparison of assets performance across similar assets to prioritize maintenance based on condition.
- Automated M&D, predicting and highlighting performance degradation and automatically providing recommended actions incorporating best practice operating responses to restore optimal operation.
- An estimate of Remaining Useful Life (RUL) to minimize the spares requirement and maximize the asset lifecycle.
- Providing information in simplified user displays for strategic, analytical and operational users to provide an opportunity to act on events before they impact operations.
- Integration of output results into the Enterprise Resource Planning (ERP) or Computerized Maintenance Management System (CMMS) to schedule work and facilitate budgetary planning.

Monitoring asset performance incorporating operational information and environmental conditions and providing this information to Original Equipment Manufacturers (OEMs) allows them to improve asset design based on actual operating conditions and usage.

To lay the foundation for fully integrated iAPM, it has to be initiated on a site by site basis with the following stakeholders involved at some stage during the implementation process:

- Strong leadership support at the executive level.
- An internal project champion who is a trusted authority on the asset.
- On-site operations and maintenance teams including engineers, metallurgists, on-site technicians, planners and external service providers, whose knowledge and skills are required to develop the M&D modules.
- iAPM subject matter expert with knowledge on tools, data modelling and technologies to guide implementation.
- The process control and information technology departments in supporting roles.

3.1. Automated M&D and iAPM

Automated M&D within the ENR sector needs to take full advantage of sensors, systems and data already existing within an operation when automating the role of the 'expert' engineer, operator or maintainer, traditionally responsible for monitoring and diagnosing asset performance issues. Currently, when an asset fails, experienced personnel with domain expertise assess the operating characteristics of the asset, using condition monitoring data and engineering knowledge to support the troubleshooting process. Automating the expert's role allows them to focus on optimizing asset performance across the entire supply chain.

However, M&D should go further than automating the process. To predict and prevent asset failure the M&D platform should continuously assess asset performance using data from disparate sources which includes the Supervisory Control and Data Acquisition (SCADA) system, with automatic activation of 'reasoning' algorithms when precursors to asset failure are detected. Because automated M&D is achieved through on-line algorithms, monitoring of asset performance can be done continuously, examining long term and current performance characteristics using large volumes of data ('big data') across the entire enterprise.

Accurately predicting the remaining useful life of a machine or component once an impending failure condition is detected, isolated and identified is also known as prognosis, which can be model-based, probability-based or data-driven and often entails a large degree of uncertainty (Vachtsevanos, 2006).

Capturing the troubleshooting process through automated application of engineering algorithms, asset management and engineering standards, means diagnosis is activated once a failure is detected, providing timely, consistent, standardized and best practice operating responses. Application of automated predictive M&D algorithms across an entire asset fleet provides for early intervention, mitigating the risk of asset failure and downtime losses. It is important to be aware that many existing frameworks do not fully automate the M&D process, hence the service or platform provider needs to be actively involved in setup and day to day use of the platform.

Using appropriate displays to visualize results means further analysis and optimization across the entire asset fleet or value chain can be performed, either within a centralized M&D collaboration facility or by centralized engineering and asset management teams. Site personnel have access to output results for use in their troubleshooting process. Integration of output results into the CMMS or ERP system, would bypass many of the manual steps in scheduling maintenance or ordering parts.

Initial application of the automated predictive M&D framework could be across an entire value chain, however, simpler application and quicker return on investment (ROI) can be demonstrated by focusing on a particular asset class repeated across an asset fleet.

4. CHALLENGES AND CONSIDERATIONS OF AUTOMATED PREDICTIVE M&D

There are a number of technical, structural and behavioral considerations to address in setting up an automated predictive M&D framework; these include regulatory, interoperability, privacy, confidentiality, security and intellectual property considerations (McKinsey Global Institute, June 2015). However, one of the most important considerations is the operating model, to provide a strategy for OEMs, dealers, service providers and the asset operator to work together, so that the new way of operating can benefit all stakeholders.

Significant challenges include the asset operator not wanting to release operating data to the OEMs or dealers, because visibility into operating characteristics may void warranties. OEMs may not want to make asset data accessible to other service providers to enable them to maintain their competitive advantage. It is important to consider location of cloud-based infrastructure for future security and access issues. There is also the significant challenge of addressing culture change within the asset operator’s organization, including visibility into poor asset condition or maintenance practices which would otherwise remain hidden within the site or by the team until the time the asset fails and detailed investigations begin.

The greatest challenge is developing scalable, sustainable and supportable M&D algorithms to reap benefits not just in the short term, but over the long term across the life of the asset. This is where application of machine learning needs to be considered carefully. Many of the platforms appearing on the market today focus on machine learning. Machine learning relies on training models (such as neural networks) with large amounts of historical data. It’s a relatively straight forward exercise to establish a profile of normal operation using machine learning which will work in the short term. However, it’s more difficult to establish profiles for different operating characteristics, including transition periods such as start-ups and shutdowns (when a large amount of failures occur), operation under transient loads, varying operating environments (temperatures, weather conditions) and classifying the failure pattern of every single fault encountered based on historical data. This is where domain expertise and physics based or engineering models are important. Automated predictive M&D involves a knowledge centric approach for optimizing assets and processes as opposed to a data centric approach. Knowledge management is achieved through replication of intelligent ‘reasoning’ algorithms deployed within the platform.

It is important to emphasize that since the ENR sector relies on assets designed, operated and maintained using domain expertise, physics-based principles and engineering knowledge. A partnership agreement would need to be established between the platform provider and the asset operator to periodically update the models for changing operating conditions or new failure scenarios. In addition, an automated mechanism would need to be setup within the framework for a domain expert to periodically tune and update the machine learning model when a new failure scenario or operating state is encountered.

Many machine learning platforms read data from a ‘data lake’, a storage repository that holds vast amounts of raw data in its native format until needed (Rouse, 2015). Data lakes are typically setup by IT personnel, focusing on data volumes, protocols and the IT architecture in the hope that data scientists may be able to ‘mine’ the data to come across operating insights. What is overlooked is data quality, particularly the quality of data coming from the Supervisory Control and Data Acquisition (SCADA) system (which resides in the Operations Technology (OT) domain) via the process historian and domain expertise. Data from poorly tuned controllers in the regulatory control layer, failed sensors or actuators can arrive in the ‘data lake’ and may be used to incorrectly train a machine learning model monitoring asset performance.

5. COSTS

Digital data collection and automation of industrial processes has created new issues which can lead to failure and increased costs. Before installing new sensors, full advantage should be taken from the sensors and data already existing within the operation.

In the ENR sector, one of the major sources of 'big data' is the SCADA system providing measurements such as flows, temperature, pressures, speeds, currents and voltage draw to characterize asset performance and operating conditions. The SCADA system resides in the OT domain and this data is generally made available to the IT domain via a plant historian. However often this data needs to be reconciled to ensure readings are correct and controllers are optimized (Power & Bahri, 2003). Reconciliation should take place before data is made available to the IT domain. Other data sources include on and off-line condition monitoring technologies (vibration, oil analysis) and CMMS/ERP data for maintenance information. As technology develops, new sensors can be added at a relatively low cost. However, new sensors should only be added as required following engineering (e.g., FMECA) analysis.

It is interesting to note that over the past thirty years the number and frequency of alarms in processing operations has increased with technology. The use of computer-based control systems means that configuring new alarms is at minimal cost resulting in a significant increase in the number and frequency of alarms (Beebe et al., 2012) ('big data'). Most of the incident investigation performed by the US Chemical Safety Board (CSB) cite alarm floods as being a significant contributing cause to industrial incidents including those that occurred at Three Mile Island, Bhopal and Texaco Milford Haven (Beebe et al., 2012). So, unless a data management strategy is in place and data is assessed for its relevance (from an engineering and asset management perspective) and used appropriately, 'big data' can cause significant issues and increased costs.

5.1. Platform Development Costs

In the 1990's, companies such as Matrikon[1] and CSense[2] started to introduce performance monitoring technologies into industry, incorporating statistical techniques and advance modelling to monitor asset performance at industrial plants to optimize operations. At the time, the use of cloud-based solutions was not yet adopted, so solutions were setup by vendors or resellers working together with the customer to deploy on premise applications.

Organizations can now choose to develop data architectures in-house leveraging off open source or proprietary software, hosting solutions in the cloud. However, it is interesting to note that even large technology providers such as Honeywell and GE recognized that it is often better to acquire existing advanced monitoring technologies rather than to commence the development path which can become time consuming and expensive. This is a lesson that other owner-operators have discovered at a significant cost to their organization.

6. EXAMPLES

Industrial applications of iAPM across the ENR sector can be found in the reference Power, 2014, the most advanced being the application of iAPM to monitor a highly complex minerals processing operation. The AHEAD (Asset Health Effectiveness and Diagnosis) toolkit, developed within G2[3] (platform), had distinctive automatic root cause analysis capabilities, applied to automatically detect, diagnose and notify deviations from desired performance across the business, process, control and equipment levels of an operation (Narozny et.al, 2009). AHEAD was successfully piloted within a central control room, monitoring asset performance across minerals processing operation. AHEAD eliminated the need for an experience operator and metallurgist to manually monitor and troubleshoot issues across the highly complex uranium solvent extraction circuit. AHEAD performed this activity continuously, on-line in near real time making results available via simplified displays accessible across the organization. Rather than having data scientists 'mine' data to come across operating insights, AHEAD used fully automated Causal Directed Graph (CDG) theory to provide control room operators with targeted and specific actions to restore asset performance, including access to the full reasoning path to describe how AHEAD came to the conclusion. A feedback mechanism was incorporated into AHEAD so that the operator could indicate that they agreed with the diagnosis or could improve on any corrective actions. The application is outlined in Power et.al. (2009).

7. CONCLUSION

Implementation and adoption of automated predictive M&D across an organization relies on sponsorship at the executive level to provide strong leadership support and to articulate a clear vision. Successful implementation requires guidance and support by a subject matter expert with a theoretical and practical knowledge of automated predictive M&D (iAPM), that is, platforms, algorithms and technologies that will or will not work, and an understanding of the operation, that is, assets, roles and responsibilities. This expert, engaged by the senior sponsor, provides a strategy and works across the business, coordinating the different disciplines including external service providers, equipment specialists, asset management, maintenance, operations, engineering,

1 Matrikon was acquired by Honeywell in 2010 (Honeywell, 2010).
2 CSense Systems was acquired by GE in 2011 and incorporated into the Predix Platform (Business Wire, 2011).
3 G2 Platform by Gensym Corporation.

planning, IT and process control, collates and addresses feedback during implementation and deployment. When implemented correctly, automated predictive M&D transforms the way resource sectors operate, unlocking efficiencies, decreasing downtime, increasing safety.

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BIOGRAPHIES

Yvonne Power is the founder and principal of IMPOWER TECHNOLOGIES® (September 2009), with a background in Electrical Engineering (First Class Honours, 2000) and a PhD (Engineering, 2004) in Integrated Process Operations Management. Yvonne has worked nationally and internationally on intelligent Asset Performance Management (iAPM) including software development, guiding technology developments within a technical steering committee and has successfully introduced award winning asset health and integrity management initiatives into operations such as iron ore, uranium, gold, alumina, coal, hydroelectric power generation and rail. As Principal of IMPOWER™, Yvonne has consulted to some of the world's largest resources organizations, developing iAPM strategies and working closely with different operational teams of across a combination disciplines and organizational levels to successfully introduce Asset Health and Integrity Management solutions into organizations. Solutions developed by IMPOWER™ are being used to monitor rail, civil (process and non-process) infrastructure and balanced machines (stackers, reclaimers and ship loaders) within some of the world's largest resource organizations.