Data-driven prognostics

M von Plate and M Zvyagina

Condition monitoring and predictive analytics are well established in the field of industrial asset management. Diagnostic solutions, however, are naturally limited in their prognostic horizon: they provide thorough technical insights, but do not claim explicit, objective foresight. For prognostic purposes, most operators still rely on a subjective expert gut feeling. New prognostic technologies that simultaneously utilise continuous and periodic data streams work with different sets of data analysis methodologies. Based on unique stochastic algorithms, prognostics solutions address this ‘when’ question (when will the anomaly turn into a malfunction?) and in doing so enable the shift from time-based to condition-based maintenance. In contrast to established methods, prognostics is non-parametric and not based on physical modelling; also it does not rely on fleet averages. No failure history is required, such that malfunctions that have never occurred in an asset can also be prognosticated. Utilising condition and process data histories, including vibration, temperature, pressure, flow, etc, prognostics solutions generate and periodically update prognostic reports, forecasting malfunction risk and remaining useful life. These prognostic reports support equipment operators with their decisions on optimal asset deployment, maintenance planning and lifecycle management. To illustrate the benefits of prognostics, detailed examples of cases in which prognostics is used in different industries will be presented.

1. Introduction

With progressing digitisation, operators of industrial equipment are able to explore new possibilities in asset management. Such opportunities range from lifecycle management (LCM) with minimised total cost of ownership (TCO) to intelligent maintenance strategies, maturing from a traditional time-based to a cost-efficient condition-based paradigm.

However, the asset management strategy rarely incorporates data analytics on the future condition of the assets into the risk assessment and, hence, maintenance decisions. The decisions about operating and maintaining infrastructure assets are commonly made based on subjective expert judgements combined with quite costly preventative measures, such as a time-based, inflexible maintenance plan. In other words, important maintenance decisions are principally based on an assumption about future events. Thus, the initial purpose of an advanced asset management tool is to support decision-makers with prognostic information, rather than to solely focus on the technical performance of the equipment.

Today, the spectrum of intelligent maintenance methods is wider and more diverse than ever before. The new technologies bring nothing less than a paradigm shift in asset management, away from a focus on the past and towards the future. With smart maintenance methods and tools, companies can incorporate future equipment condition into maintenance decisions; therefore, they can determine future maintenance needs on an explicit time horizon.

The aim of this paper is to show how to utilise all available condition and process data to obtain valuable foresight regarding the state of assets and to assist asset managers in their maintenance and planning decisions.

2. Intelligent maintenance practices

2.1 Data analytics

Data analytics is closely tied to the term ‘big data’. This term is used in varying contexts and with differing definitions. Typically, it is characterised by the increasing volume, variety and velocity of data gathering and analysis. The increasing level of data acquisition and storage is also prevalent in the energy sector and most of the industrial asset operators have recognised the value of data utilisation for maintenance and operational purposes.

However, in order to succeed in this world, even the most advanced solution needs to be able to cope with the reality of industrial applications, which is not uncommonly driven by legacy systems and restrictive original equipment manufacturer (OEM) service agreements. Hence, it is paramount to combine state-of-the-art algorithms and software with tried-and-true IT features, thereby linking new solutions into the reality of the world of industrial asset operators.

At the same time, equipment condition data has been explored and exploited for decades. Internal data networks, repositories and historians, along with condition monitoring, predictive diagnostics and performance optimisation applications, show a long tradition of utilising data to gain useful insight. As a result, predictive analytics methods are known to the industry. They can detect anomalies before they turn into an actual malfunction. Based on sophisticated pattern recognition, similarity-based models and statistical inference, predictive analytics solutions can detect the earliest anomalies presently impacting critical assets. However, even the most advanced predictive diagnostic solutions are naturally limited in their prognostic horizon: they provide thorough technical insights into the asset’s current condition and data anomalies, but do not claim explicit objective foresight. For prognostic purposes, most operators still rely on subjective expert judgements.

2.2 Smart data tools

With intelligent maintenance, companies permanently reduce overall operation and maintenance costs, minimise downtime risks, allow better planning of maintenance to be performed and make asset management more efficient. New prognostic technologies simultaneously utilise continuous and periodic data streams and work with different sets of data analysis methodologies. Based on unique stochastic algorithms, prognostic solutions address the ‘when’ question (when will the anomaly turn into a malfunction and, subsequently, into a failure?) and in doing so enable the shift from time-based to condition-based maintenance.

Moritz von Plate is with Cassantec AG, Switzerland. Email: moritz.von.plate@cassantec.com
Marina Zvyagina is with Cassantec GmbH, Germany. Email: marina.zvyagina@cassantec.com
In contrast to established methods, prognostics is non-parametric and not based on physical modelling; also it does not rely on fleet averages. No failure history is required, such that malfunctions that have never occurred in a particular asset can also be prognosticated. Utilising condition and process data histories, including vibration, temperature, pressure, flow and speed, prognostics generates and periodically updates prognostic reports forecasting malfunction risk and remaining useful life. These prognostic reports support industrial asset operators with their decisions on optimal asset deployment, maintenance planning and lifecycle management. This enables companies to use forecasts across all critical assets and utilise all types of available data for forecasting. Moreover, the innovative prognostic solutions provide insight into the future state of assets with an explicit time horizon of typically weeks or months, sometimes even years.

The forecasting of asset conditions may address different levels of detail, including:
- Wear at the technical level;
- Malfunctions at an aggregate level;
- Remaining useful life of assets at the level of individual components; and
- Plant and fleet availability at the top level.

3. Benefits of prognostic technologies

3.1 Use cases of prognostics

Prognostic data analytics can bring significant benefits for maintenance, reliability and operations professionals, given the high cost of preventative and reactive maintenance and given the loss of revenue from downtime. Overall, prognostics allows for the minimising of maintenance and downtime costs via:
- Suitable long-term scheduling and scoping of maintenance;
- Maximisation of remaining useful life through informed operations decisions; and
- Optimal deployment considering future asset risk profiles.

3.2 Retention of critical knowledge through prognostics

According to a number of academic research papers, for example a study published by the Hudson Institute, most industries are facing a knowledge retention problem. At 50% of utilities, more than 50% of professionals are going to retire in the next five years. Therefore, the question of how to avoid the loss of critical knowledge is gaining importance.

Knowledge management, combining the three elements of intellectual capital, organisational culture and information technologies, represents an essential source of innovation and is therefore crucial for the economic success of any company. According to its complexity, knowledge can be categorised in a continuum from explicit to tacit. Unlike explicit maintenance knowledge, tacit maintenance knowledge should be of great concern to an industrial asset operator. It encompasses the intelligence, know-how and experience of its experts and affects how decisions are made. Therefore, this intellectual capital must be captured and shared in order to promote continuous development and ensure operational advantages.

Figure 1. Exemplary prognostic report
The configuration of prognostics includes the structured documentation of asset operators’ implicit experience and know-how, which forms the basis for the forecasting process. The result is a well-documented catalogue of malfunctions, their possible identification through data parameters and possible mitigation action. This can be used for HSE reporting, management reporting, benchmarking and standardisation across assets and plants, knowledge management and training.

Thereby, the utilisation of intelligent maintenance tools in industry incorporates critical expert knowledge into the asset management processes and thereby builds a unique instrument, which helps to retain the critical knowledge and at the same time enables easier access to the knowledge created inside an organisation.

### 4. Case studies

#### 4.1 Case Study I: Hydropower

Recent applications of prognostics in the hydropower industry have been especially encouraging and will spread further as reliance on hydropower increases globally. Hydropower initially faced multiple challenges in the adoption of prognostics. Slow rotating equipment can be more challenging due to specific vibration patterns and data types. Additionally, changing flow conditions create highly variable data. Lastly, hydropower often uses equipment that has been in operation for decades, making it difficult to ascertain the remaining useful life of the equipment from operator experience.

Nonetheless, during the recent introduction of prognostics in a European hydropower plant, the plant harnessed prognostics to identify a generator with a particularly bad prognosis, which had been deteriorating steadily over a number of years. Further investigation showed that bearing vibration data was linked to the active power driven at the generator. Using the capability of prognostics to perform scenario analyses on remaining useful life, analysts realised that a power level past a certain limit would result in a steady increase in vibration, whereas below this level the vibration would not worsen.

Using this information, the plant operators revisited their operation plan and reduced the load on the generator to extend its remaining useful life. Additionally, they were able to optimise maintenance scheduling based on upcoming replacement needs. Overall, the insight that prognostics brought served as a proof-of-concept for managers, who rolled out prognostic technologies to more plants in the fleet.

#### 4.2 Case Study II: Fossil power – full risk transparency with prognostics

An established power plant in the USA seeks full transparency of both market and generation risk, which is largely driven by the

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**Table 1. Cases in which prognostics is used**

<table>
<thead>
<tr>
<th>Category</th>
<th>Use cases</th>
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<tbody>
<tr>
<td>Maintenance and repair</td>
<td>■ Long-term scheduling of maintenance</td>
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<td></td>
<td>■ Short-term preparation of reactive maintenance</td>
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<td>■ Maintenance staff planning and allocation</td>
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<tr>
<td>Operations</td>
<td>■ Production planning according to the future availability profile</td>
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<td></td>
<td>■ Increased asset availability and minimised downtime risk</td>
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<tr>
<td>Finance</td>
<td>■ Saved profit opportunities from downtime reduction</td>
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<td></td>
<td>■ Decreased annual maintenance costs</td>
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<td></td>
<td>■ Increased profit generation capabilities for industrial asset operators</td>
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<td></td>
<td>■ Optimised insurance policy and costs</td>
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<tr>
<td>Lifecycle management</td>
<td>■ Replacement and retrofit planning</td>
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<td></td>
<td>■ RUL-optimal exploitation</td>
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<td></td>
<td>■ Active management of the remaining useful life by adjusting operating capacity</td>
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**Figure 2. Example report for an FD fan**
risk of unscheduled generating unit downtime. In order to better understand and manage risk on the basis of its assets’ actual conditions, the operator has introduced a prognostic solution across its entire fleet of generating assets, including such crucial asset components as gas and steam turbines, power generators and transformers and induced and forced draft fans.

Based on condition and process data of the generating assets, the prognostic solution provides a daily update of unscheduled future downtime risk for all critical asset components. The risk of unscheduled downtime is computed at the component level, then aggregated to the unit and fleet level and explicitly compared to power-zone-specific market prices.

The operator’s objective to actively manage the future availability of its power-generating assets, in line with its ongoing commercial commitments, was reached through the introduction of the prognostic solution. Malfunction forecasts allowed targeted decision-making to be carried out as to which maintenance actions to take and when. The aggregated availability forecasts, coupled with market information on power pricing, enabled calculations of MW at risk and margin at risk over a significant future time horizon, thereby helping the operator’s trading department make better commercial decisions.

4.3 Case Study III: Fossil power – ensuring the reliability of critical assets

A leading European utility saw the need to increase the reliability and efficiency of a 1600 MW coal-fired power plant without putting an additional burden on its personnel. One type of component with a history of issues that is critical for the reliability of this coal-fired plant is the boiler feed pump. The operator did not only want to monitor the redundant pump’s condition and use the data for diagnostic insight, but also to take a future-oriented view by using prognostics.

An initial retrospective analysis revealed that all critical malfunctions in the last six years could have been prognosticated with a prognostic horizon of up to several years. As an example, high pressure and high rotational speed were detected; based on the data patterns, the prognosis identified a significantly shortened remaining useful life, caused by a defect in the sealing and casing. Furthermore, the risk of future malfunction was increased through a defect of the coupling. Soon after these findings, the damage, especially to the sealing and casing, was fixed. This way, the low factor of efficiency that had been recognised for a while was also improved.

This retrospective analysis helped to identify value levers on three levels. In the short term, the aggregated and complete analysis, as well as the built-in machine learning mechanism, directly simplifies day-to-day operations. In the mid-term, prognostics helps to turn unplanned outages into controlled and scheduled maintenance interventions. In the long-term, prognostics helps to optimise the overall maintenance economics, while delivering higher reliability and efficiency. What is more, the operator concluded that its personnel would not be burdened but rather released from previously manually executed time-consuming tasks.

5. Conclusions

Advanced maintenance tools provide foresight about the future state of assets and in so doing provide a basis of essential information for asset management decision-making. Plant operators can improve the overall equipment performance, secure their assets’ availability and extend the assets’ lifecycles by avoiding excessive maintenance action and costly redundancies.

However, a prudent application of prognostic solutions requires an extended skill set of reliability and maintenance professionals within industry: the ability to think in terms of risk, to explicate forecasts and to consider both in asset management decisions. Prognostics complements and requires operator experience and manufacturer know-how, but it also necessitates a shift in thinking and language towards a risk management approach.