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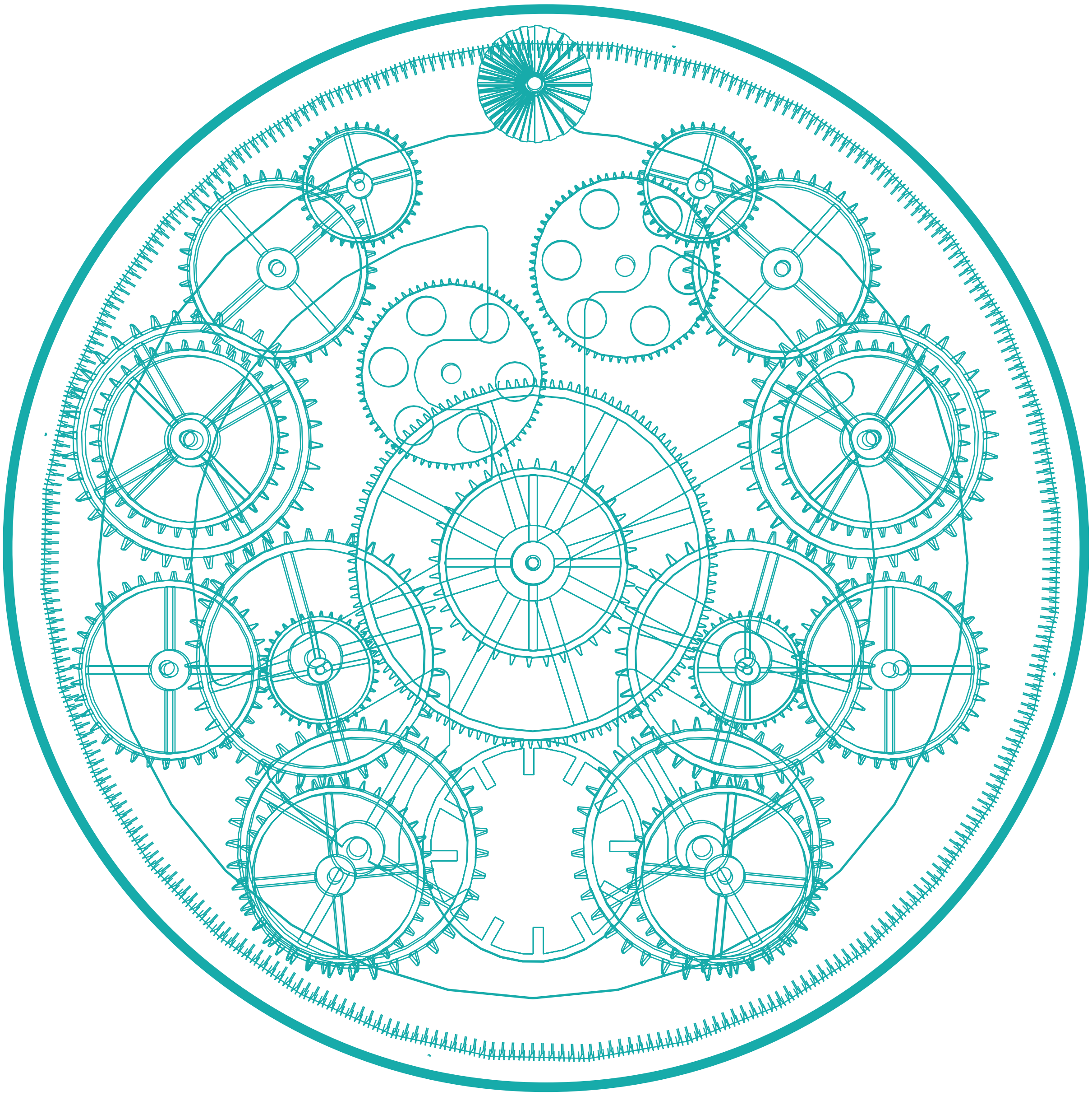

Predictive Maintenance

Taking pro-active measures based on advanced data analytics to predict and avoid machine failure

analytics INSTITUTE

"In the environment of Industry 4.0, maintenance should do much more than merely preventing downtimes of individual assets. Predicting failures via advanced analytics can increase equipment uptime by up to 20%."

Introduction

Knowing well ahead of time when an asset will fail avoids unplanned downtimes and broken assets. On average, predictive maintenance increases productivity by 25%, reduces breakdowns by 70% and lowers maintenance costs by 25%. It is based on advanced analytics and marks a new way of organizing and implementing maintenance on an industrial scale. Deloitte has developed an approach to smoothly introduce predictive maintenance into business processes in a customized and structured manner.

The Deloitte Analytics Institute is a center of expertise operating at the intersection of business, science and technology. We develop and implement customized state-of-the-art analytics and big data solutions.

The Value of Maintenance for Production Processes

Industrial production has evolved enormously over the last centuries. It has come all the way from steam and hydro power via assembly lines to digitalization.

Industry 4.0 – the proclaimed fourth industrial revolution – is unfolding at the moment. It is characterized by interconnectedness and vast amounts of available information.

Productivity has risen continuously due to modern machines. They are highly complex and often represent substantial investments. In 2015, German automotive OEMs alone have invested over 14 billion Euros in tangible assets[1]. Despite all efforts to prolong lifecycles, wear, erosion and depletion will eventually lead to machine failure.

The Value of Predictive Maintenance
In the environment of Industry 4.0, maintenance does much more than merely preventing downtimes of individual assets. Machines are increasingly interconnected along the production chain. One failing machine might halt the whole production process. Today, poor maintenance strategies can reduce the overall productive capacity of a plant by 5 to 20 percent[2]. Long and continuous runtimes of capital-intensive, highly-integrated assets can represent a significant competitive advantage. So can efficient and well-orchestrated maintenance. Deloitte has identified six core dimensions of maintenance and failure to be managed.

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[1] "German Industrial Businesses' Investments in Tangible Assets per Industry Sector in 2015", Statistisches Bundesamt, destatis.de, November 2016

[2] "IoT Slashes Downtime with predictive maintenance", Gary Wollenhaupt, ptc.com, March 2016

Six Dimensions of Maintenance and Failure

REACHABILITY
There are more and less convenient times for maintaining an asset.

Maintaining a train in the depot overnight is easier than maintaining one that has broken down during business hours on a remote track.

CASCADED DAMAGE
The failure of a single part can cause damage to a wider system.

An electrical discharge due to a malfunctioning capacitor may render a whole circuit board broken beyond repair.

QUALITY
Assets progressing towards failure endanger production quality levels.

Gluing nozzles which are increasingly clogged may not dispense sufficient glue to ensure a long lasting connection.

EQUIPMENT LOGISTICS
Maintenance requires preparation such as ordering of parts or deployment of tools.

Broken gears can only be identified after opening the gearbox and need to be ordered from the manufacturer while the asset remains idle.

INTERDEPENDENCE
Unplanned maintenance can lead to substantial downtimes and jeopardize productivity.

Maintenance of a pipeline may render subsequent production idle.

SAFETY
Breakdown of an asset may directly or indirectly jeopardize the safety of the process.

Breaking of a food processing machine may introduce chards of debris into the food.

Maintenance Strategies on an Industrial Scale
Depending on assets, costs and technical sophistication, a broad spectrum of maintenance strategies can be applied. These strategies range from mere reaction to failures to highly evolved systems optimizing maintenance efforts for groups of assets. Figure 1 illustrates four maintenance strategies by level of sophistication. It highlights their characteristic traits, advantages and disadvantages.

Reactive Maintenance entails acting when a failure has already occurred. It is the classic form of maintenance, usually being applied when the object is of low value, easy to replace and does not have a severe impact on the business process. Examples include replacing a broken light bulb or gear as well as fixing a ruptured tube.

Preventive Maintenance attempts to prevent failure by maintaining machines at pre-scheduled time intervals. This approach is usually taken when the cost of maintenance is moderate and when it can be done outside of production hours. A typical example are the biannual checkups of wind turbines.

"Predictive maintenance increases equipment uptime by 10 to 20% while reducing overall maintenance costs by 5 to 10% and maintenance planning time by 20 to 50%"

Condition Based Maintenance is similar to preventive maintenance but rather considers the actual use of the object instead of relying on pre-scheduled intervals. As for Preventive Maintenance, this is usually done when maintenance costs are not very high and maintenance can be carried out at convenient times. An example for this approach are the checkups for airplanes that have travelled a certain distance or hours.

Sometimes, however, these approaches are not enough.

Predictive Maintenance utilizes a wealth of process data and advanced analytical methods to predict failures well before immediate action has to be taken. With the implementation of concepts like Industry 4.0 or Smart Factory additional process data becomes available. This allows for estimating the remaining runtime of assets with increasing accuracy. This maintenance approach is usually taken when high costs are incurred due to downtimes or maintenance. Also, it can ease scheduling when maintenance activities are complex.

Maintenance strategies in an industrial context

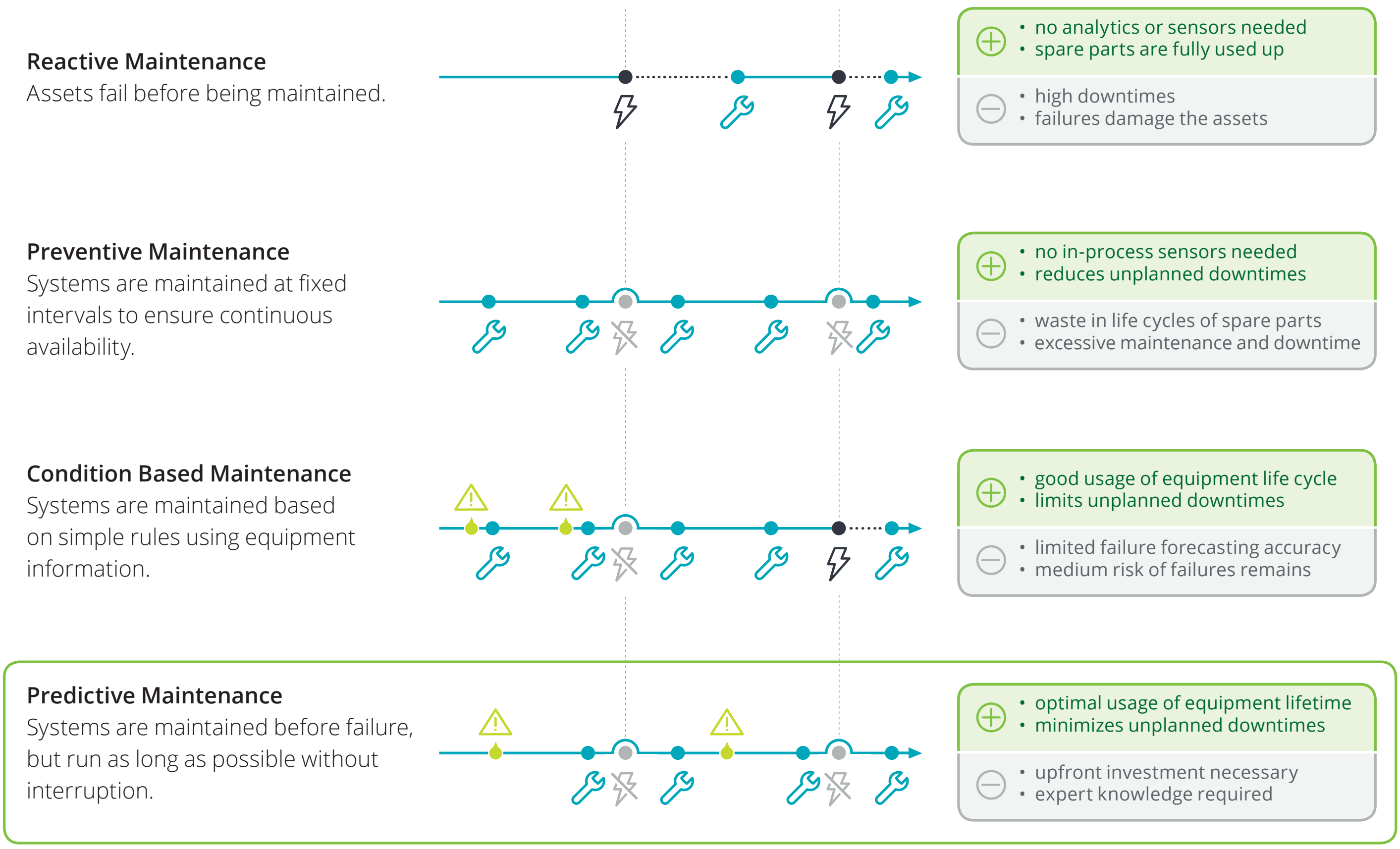

Figure 1. Maintenance strategies in an industrial context

A Closer Look at Predictive Maintenance

Each maintenance strategy comes with certain upsides and challenges.

In the context of Industry 4.0 – increased interconnectedness and new opportunities to collect, process and analyze information – predictive maintenance can be a very powerful strategy. In this section, we will discuss its benefits and challenges before outlining how it can be implemented into production processes.

Benefits of Predictive Maintenance
The obvious benefit of predictive maintenance is that it maximizes runtime. Repairs can be carried out just before a breakdown. That represents a major advantage – studies show that unplanned downtime is costing industrial manufacturers an estimated $50 billion each year[3]. Also, necessary maintenance efforts can be orchestrated to minimize system-wide downtimes. Predictive maintenance can further be used to ease logistics by maintaining machines at convenient times – for example outside of production hours or while the needed personnel is close by. Lastly, it can assist purchase departments by predicting which spare parts will be needed at which point in time.

Predictive Maintenance. An Investment That Pays Off

Predictive maintenance programs create the following benefits:

5-10% cost savings in operations and MRO material spen

10-20% increased equipment uptime and availability

5-10% reduced overall maintenance costs

20-50% reduced efforts on maintenance planning time

[3] "How Manufacturers Achieve Top Quartile Performance", Industry Week & Emerson, Partners.wsj.com, accessed May 2017

The benefits of predictive maintenance are dependent on the industry or even the specific processes that it is applied to. However, internal Deloitte analyses have concluded that material cost savings amount to 5 to 10% on average. Equipment uptime increases by 10 to 20%. Overall maintenance costs are reduced by 5 to 10% and maintenance planning time is even reduced by 20 to 50%[4].

The profit of predictive maintenance increases with the underlying maintenance costs. The higher the expenses caused by failure the bigger the benefits.

Challenges of Predictive Maintenance

Data is the fuel of any predictive maintenance engine. Its quality and quantity is the limiting factor for analyzing root causes and predicting failures well ahead of time. Therefore, a major challenge inherent to any predictive maintenance program is increasing data quality and coverage. The more information is available on events to be predicted the better predictions become.

We distinguish between required data – without which predictive maintenance cannot be applied – and additional data, which improves the quality of predictions.

Predictive maintenance is an investment, which reveals implicitly the second key challenge: Establishing the needed processes initially creates costs. Businesses need to add sensors to their machines and set up a wide array of IT infrastructure, processes and trained personnel.

Data from various sources must be integrated and transformed so that it can be made available on a suitable platform. Dashboards, email or SMS warning systems must be put in place to coordinate the necessary maintenance efforts. Process experts' and data scientists' knowledge is needed to build and maintain a functioning predictive model. Also, personnel needs to be trained to handle the information inflow and interpret alerts correctly.

"The more information is available on events to be predicted the better predictions become."

Required data	Additional data
Process failures with exact date and time are the very basic requirement.	**Indirect process parameters** like raw materials, supplier details, assigned employees can help the analysis.
Process/Component variables like temperature, pressures, voltages and other physical measurements are needed to identify root causes of failures.	**Additional sensors** like cameras or laser sensors can be integrated and connected to track important process parameters such as shape or speed of rotation.

[4] Deloitte internal research

How to Implement Predictive Maintenance

After evaluating the different maintenance strategies and having decided to implement predictive maintenance, businesses begin a journey with new learnings and insights waiting along the way. Initially, there is no certainty as to which level of failure prediction can be reached. In our experience, an incremental approach as illustrated in Figure 2 has proven to be valuable for mitigating project risk. Each step yields better results leading to reduced downtimes and increased productivity.

Before implementing a predictive maintenance program, we aggregate expert knowledge from our far-reaching network of global industry experts. Workshops with the client help lay a foundation for trusting collaboration – a crucial prerequisite for overall success.

Once this non-technical framework is set up, the journey is initiated at the individual maturity level. When starting at stage 0, creating an understanding of the process through data is the primary objective.

For step 1, we need a constant stream of sensor data into an integrated platform. With the help of powerful visualization, experts can identify which parameters indicate imminent failure.

For step 2, expert insights about the process and its parameters are vital. With their help we can deduct simple rules. Applying these may prevent a large proportion of failures from occurring already.

Anomaly detection requires sufficient accumulated sensor data with a minimum frequency of measurements per time unit and sensor. This data allows us to define the norm for any given process. Aberrations from the norm can then trigger alerts to the operators – who will have to decide if an actual failure has occurred.

To be reactive and preventive, we need a significant amount of failures with detailed log data. Applying advanced analytics, failures can then be detected immediately and reliably.

Conducting root cause analysis requires recordings about successful as well as unsuccessful approaches are needed to resolve failures. Causes for occurring failures can be narrowed down and appropriate actions proposed.

"Applying advanced analytics, failures can be detected immediately and reliably."

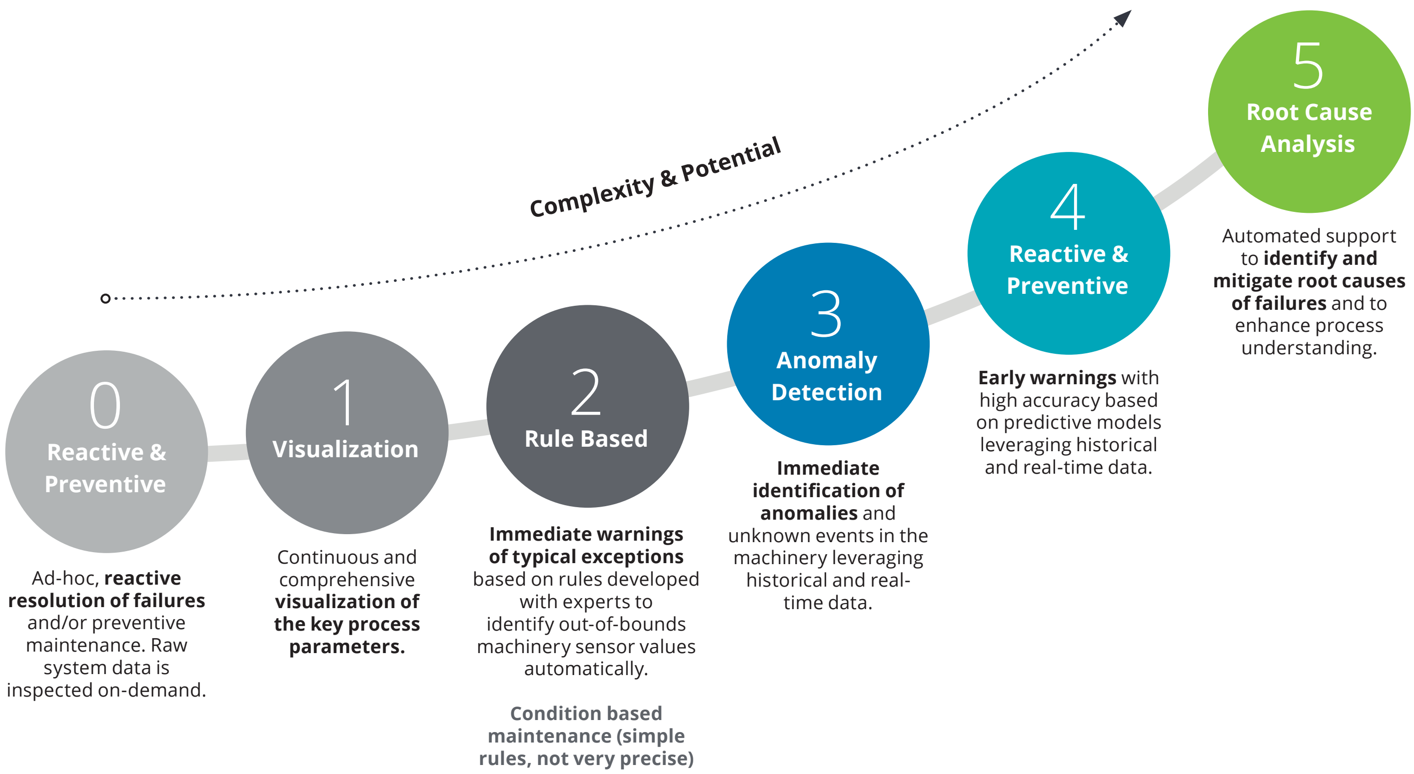

Figure 2. Journey towards higher levels of predictive maintenance

Deloitte Analytics Approach
Each of the five steps described above follows our proven analytics approach. Firstly, we define success criteria in close cooperation with our client. Subsequently, we have a look at the available data and aim to understand, model and validate it. To do so, we apply a well-tried approach for datamining – the CRISP-DM process. This process results in an offline prototype for testing purposes and illustrating functionality and business value. As the next step, the resulting models are deployed on productive systems.

Enabling business users, intuitive dashboards and user interfaces as well as alert systems are designed for maintenance crews. As a crucial element project finalization includes a long-term strategy for model upgrades.

"A long-term strategy for adequate model updates on failure prediction is crucial."

Case Studies

We helped several clients implement predictive maintenance programs. In each of the four cases outlined below, the depth and sophistication of implemented predictive maintenance measures was tailored to the available data quality.

01. For a large construction company we have evaluated the possibilities of predictive maintenance for **facility management**. Through explorative analysis and comprehensive visualization of repair protocols, we have made maintenance efforts transparent and have laid out paths towards higher levels of predictive maintenance.

02. For a major **telecommunications provider** we have developed a prediction model for customer trouble tickets related to DSL connection problems. The model was based on network performance counters and allows prediction with high precision. It enables pro-active repair and thus improves network quality and customer satisfaction.

03. We have provided an **automotive manufacturer** with a harmonized maintenance solution for its welding robots producing vehicle bodies. The solution comprises visualization and several predictive models to detect failure onset in process data.

04. For another **automotive OEM** we have installed a state-of-the-art Big Data platform allowing for failure prediction in real time. Ingesting process data from various sources and running it through an anomaly detection engine enables continuous monitoring of the machines in use.

Can Predictive Maintenance Help Your Company?

Predictive maintenance can help you manage maintenance more efficiently. However, keep in mind that not all enterprises require the same level of reliability from their assets. A good place to start the assessment for your enterprise is to look at mission critical requirements and maintenance program maturity.

Ask yourself the following questions:

- How reliable do our assets need to be ?
- What are our availability targets?
- What is our machines' current failure-rate?
- How high are our current maintenance costs?
- Do we have the right spare parts in the right place at the right time?
- How do we determine when it is time to replace an asset rather than to maintain it?
- What data do we already have that is not being used effectively?
- Have we identified the critical assets in our production system?
- Are there some critical assets that would benefit from a predictive maintenance program?
- Do we have the needed technological expertise in house to develop a predictive maintenance program?
- Do I have advanced analytics experts in house?

A Glimpse into the Engine Room

Predictive models are one of two key components that any predictive maintenance program relies on. Their **algorithms** are the "machines" turning raw process data into targeted failure prediction insights. Predictive maintenance typically makes use of two well-established techniques from machine learning.

Classification algorithms learn to distinguish between normal and erroneous operations. These learnings must be based on a wealth of historic data providing sufficient examples for the failures to be detected. These methods are very powerful. They can differentiate even subtle variations from normal operations but require at least 20 to 30 recorded failure occurrences of each type. The algorithms are mostly insensitive to unseen failure conditions. Classical examples in this area are Random Forrest, Nearest Neighbours or Support Vector Machines (SVM). The methodic spectrum also includes more advanced methods such as hidden markov chain models.

Anomaly detection describes a class of methods that specialize in finding outliers against the backdrop of normal operations. While these methods require a sound data basis representing "normal operations" they detect previously unseen error patterns as a mere aberration from normal behavior. Typical methods in this area range from simple one class SVM to nonlinear neural networks such as autoencoders.

The other key component for successful predictive maintenance is an **architecture** that enables fast and scalable detection algorithms.

Parallelization is crucial to predict different assets simultaneously. This is important to ensure timely predictions of an array of assets but is especially crucial during the computationally intensive model retraining. In this phase, the predictive models are updated with the latest Data. Therefore, algorithms used for predictive maintenance are parallelized and make heavy use of Distributed Computing and GPUs wherever possible.

Streaming architectures for Big Data ensure real-time processing of the incoming data. Architectures like Apache Kafka, Apache Spark or Flink ensure extremely fast data processing in the below seconds regime to ensure maximally long reaction times before an asset failure occurs. Additionally, these frameworks provide a redundant and highly available configuration.

"Predictive maintenance could help you manage maintenance more efficiently. However, keep in mind that not all enterprises require the same level of reliability from their assets."

Meet the team

Olaf Peter Schleichert
Partner, Analytics Leader Germany
Head of Analytics Institute

oschleichert@deloitte.de

More information
http://www.analytics-institute.de

Dr. Björn Bringmann
Director
Deloitte Analytics Institute

bbringmann@deloitte.de

Dr. Hardy Kremer
Manager
Deloitte Analytics Institute

hkremer@deloitte.de

Dr. Sergey Zablotskiy
Senior Consultant
Deloitte Analytics Institute

szablotskiy@deloitte.de

Dr. David Köpfer
Senior Consultant
Deloitte Analytics Institute

dkoepfer@deloitte.de

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