INDUSTRIAL ANALYTICS

/PRESCRIPTIVE MAINTENANCE IN REFINERIES

THIS WHITE PAPER DESCRIBES AN INNOVATIVE APPROACH TO BUILD A SCALABLE ANALYTICS SOLUTION FOR PETRO-CHEMICAL PLANTS. THE RESULTS ARE DOCUMENTED IN AN EXAMPLE IN A REFINERY.

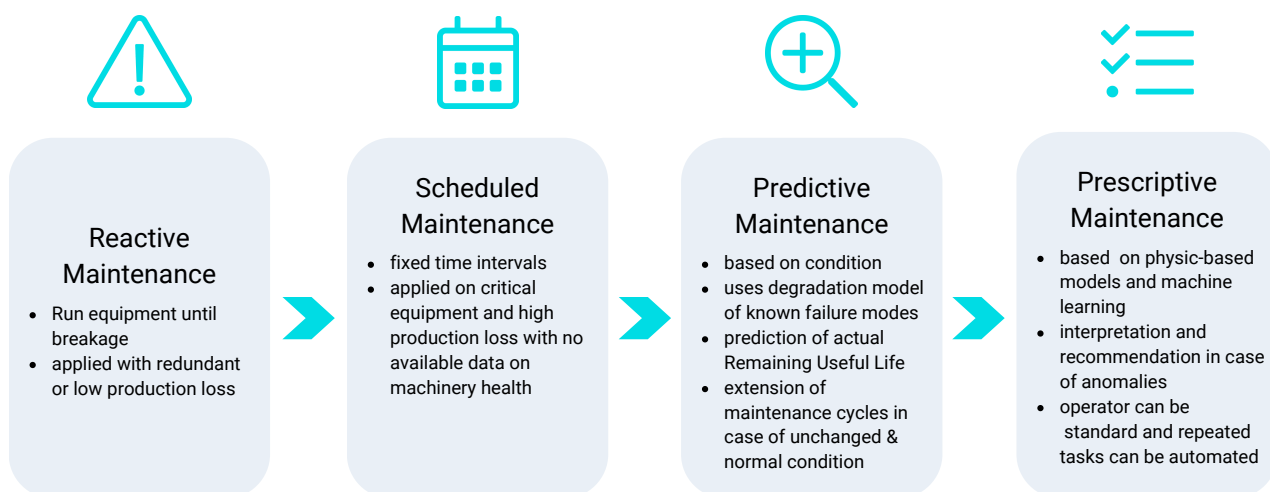# PRESCRIPTIVE MAINTENANCE IN REFINERIES

WHAT IS PRESCRIPTIVE MAINTENANCE? /

The general aim when operating a chemical plant is the actual usage of operational data for process and maintenance optimization by advanced analytics. Typically, this is realized by implementing a data-driven central oversight function that supports the operation and maintenance staff. A major lesson-learned is that the results of a rather simple statistical approach to detect anomalies fall behind the expectations and are too labor-intensive. Such analysis needs experts in order to interpret the detected anomalies which are defined as unusual operation points.

The next step on the digital transformation journey is to provide actionable insights into the data. This is often referred to as prescriptive maintenance. With such a solution the system does not tell the operator that "something happened" but "what to do".

First-principle- or physics-based models provide additional insights into the data, since the results are directly interpretable. However, such approaches are typically assumed to be expensive to build and not scalable.

/ EVOLUTION OF MAINTENANCE METHODS

Reactive Maintenance
- Run equipment until breakage
- applied with redundant or low production loss

Scheduled Maintenance
- fixed time intervals
- applied on critical equipment and high production loss with no available data on machinery health

Predictive Maintenance
- based on condition
- uses degradation model of known failure modes
- prediction of actual Remaining Useful Life
- extension of maintenance cycles in case of unchanged & normal condition

Prescriptive Maintenance
- based on physic-based models and machine learning
- interpretation and recommendation in case of anomalies
- operator can be standard and repeated tasks can be automated

/ WHAT ARE SUCCESSFUL STRATEGIES?

Successful strategies concentrate on specific equipment with a clear use case. For example a model with a proven capability of reliably detecting irregularities in the temperature control valve flow characteristics and actuator can be applied to all temperature control valves within the plant.

Another successful strategy is to concentrate on assets that actually have high criticality and have a significant history of issues.

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HOW CAN *INDUSTRIAL ANALYTICS* HELP THE PLANT OPERATORS TO REALIZE THEIR DIGITAL STRATEGY? **/**

Industrial Analytics uses hybrid models for monitoring of the industrial process and the machinery. These hybrid models use first principle- or physics-based models together with machine learning. The models can be thermodynamic process models of the plant which are fitted with historic data. These models can be used in order to perform dynamic simulations of the plant behavior or to calculate expected values when used for monitoring.

Compared to other software solutions for industrial process simulation these models are designed to be fitted based on historical data with a minimum of information necessary provided in data sheets or drawings on the actual equipment. The whole model is built for high performance since it is necessary to realize a live stream processing AI-service. A key functionality of such thermodynamic models is the correct representation of thermodynamic properties like heat capacity.

Industrial Analytics uses different approaches to do a high-performant and accurate representation of all technical fluids. One option is the usage of a high performance version of <u>NIST REFPROP</u>.

A prerequisite for application of machine learning algorithms in such critical applications is the assessment of the model uncertainty. Most machine learning applications are restricted to provide a best guess. A much better approach for this kind of application is the expression of uncertainty of this result in effect of size and significance. Only then one is able to draw conclusions.

Industrial Analytics uses special algorithms, sometimes referred to as **Explainable AI** which are able to generate such results. The ability of these models is being improved continuously in collaborative research projects with different university partners.

/ FIRST PRINCIPLE MODEL: COMPRESSOR STAGE

The development of the model goes back to experience of working for a turbomachinery manufacturer where the task was to rebuild the design software and to develop a new compressor impeller family including planning and realization of test campaigns.

The model is built upon the general features of a compressor performance map, including variable inlet and outlet guide vanes. It is based on many years of experience on how to describe the compressor characteristics in a universal way.

In contrast to the model used for compressor design, it does not start with geometric parameters of the impeller which are modified to find an optimal solution for the operation points specified by the operator. The definition starts with historic data of the compressor stage. The geometric data is then fitted to best rebuild the historic data.

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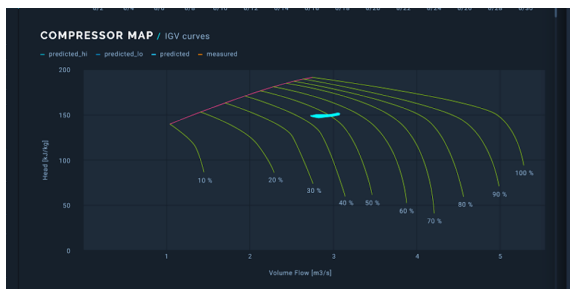
This approach has - compared to pure machine learning - model two advantages:

1. The results are directly interpretable (e.g. the head is lower than expected).
2. The model does not tend to be overfitted to the data features' much better extrapolation capabilities.

/ DATA MODEL

A main differentiation between first principle and statistical models is the necessary data modelling. Working with first principle models in a scalable way means that the software needs to be aware of the properties of a data stream and the relations. For a statistical model everything can be simply data without the need of additional knowledge. The first principle model of, for example, a compressor stage needs to work with inlet and outlet conditions. It is mandatory to represent by the data model that the data stream is, for example, a temperature measurement in degree C and that it is located at the outlet of the compressor stage and at the inlet of the intercooler. The representation of the *compressor stage* with the relations of the data stream as *outlet temperature* of *compressor stage* and *inlet temperature* of the *intercooler* is in the AI context often referred to as an ontology.

Industrial Analytics uses a graph-based data model for the semantic description of the item and representation of the relationships as links. The flexibility of the approach allows to model different functional relationships. For example, the bearing temperature sensor is located in the bearing which is part of shaft x which is part of the compressor. The bearing temperature will depend on the load of the connected compressor stage, the speed of the shaft and of the oil supply. The function of the oil in the bearing is to lubricate and to cool the bearing. The knowledge of the different relationships can be modelled by different networks for example oil system or process. In general, the data model is used for several purposes.
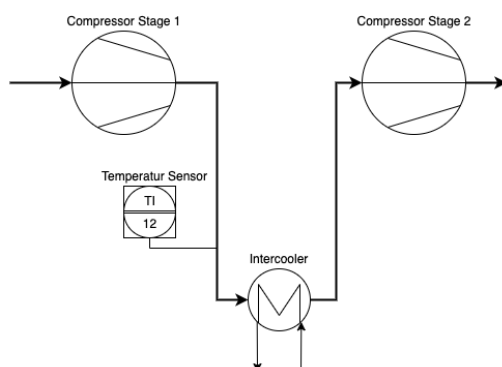
The main features are

- mapping of data streams,
- configuration of signal processing tasks,
- definition of visualization dashboards,
- automation of fitting, training and running of AI-services.

The result is a data structure that represents the knowledge of the relationships and parts of the industrial process and configures all processing steps.

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/ AI-ASSISTED EVENT MANAGEMENT

The event management assists with information aggregation, classification and learns to support operators. With the UI user annotations are gathered in a way to train AI models. The trained AI is able to give advice to the operator on what to do in the actual event. With the models and the event management it is possible to retain knowledge on machinery and process.
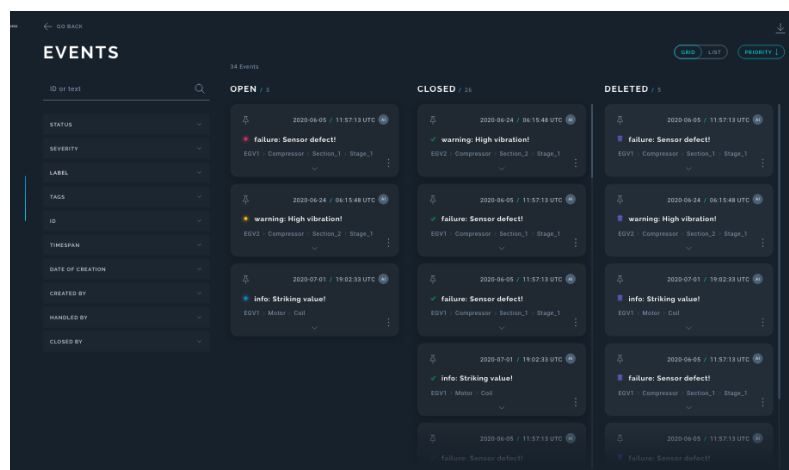
Example Temperature Control Valve

The actuator of a temperature control valve with the oil system is not working properly. The team in the control room gets a series of event notifications from the control system as the bearing temperatures are above the specified warning level. When using the Industrial Analytics Prescriptive Maintenance the workflow is as follows:

The functional system *shaft vibration* defined in the network within the data model shows that the bearing temperatures are within the expectation range due to the higher inlet temperature of the oil.

The *oil system* also includes the bearing temperatures and reports the anomaly of the temperature control valve. The events that are within a typical cause and effect time period are aggregated. The user is not being confronted with a multitude of individual events, but already receives the information that these are connected. This decreases the reaction time and might lead to timely response and prevention of damage.

The dashboard gives the possibility to label the combined event with hashtags (#ActuatorTCVdefect, #OilTemperatureTooHigh) and provides instructions on what to do. The expert information is now learned by the system and is shown as a recommendation on similar occasions. The similarity here is being obtained by the system using the semantics of the data model. A similar event needs to be connected to an *oil system* and the events need to be *bearing temperature too high*.

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/ SCALABILITY

The key to build scalable AI solutions is a data model that is flexible, standardized and holistic. The configuration should be at a single place and there should not be any individual solutions. Scalability for a software company often means giving the user a tool to do the work'. Industrial Analytics wants to provide a solution that actually solves the problem and goes beyond Templating possibilities that can be found in SAP Asset Central or OSIsoft PI Asset Framework but follow a flexible easy to configure approach.

With the usage of tools that support the analysis of P&ID together with a productive data model, it is very easy, fast and flexible to build such solutions.

/ DATA FLOW IOT VIBRATION ANALYSIS
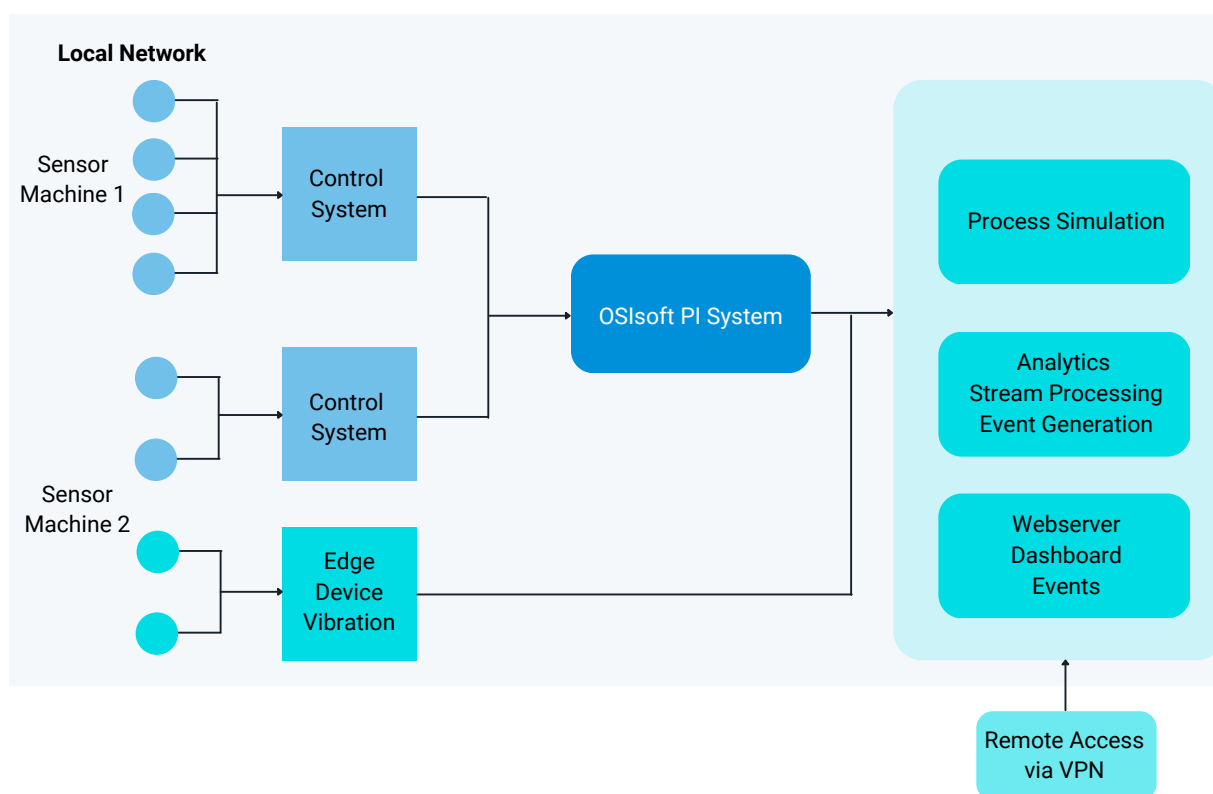
REALISATION IN PCK REFINERY /

The realization of AI-service in the refinery started in different steps. The start was to build a virtual plant model based on historical data of the compressor together with the directly attached equipment like vessels, heat exchanger and valves. With this model of the industrial process it is possible to simulate the plant's behaviour. This model was, in a next step, extended to cover larger parts of the process in order to generate more meaningful results. This building of a model was done in a two-week project based on provided P&ID drawings and data snapshots. Industrial Analytics uses tools to quickly build a graph-based data model including mapping of measurement tags.

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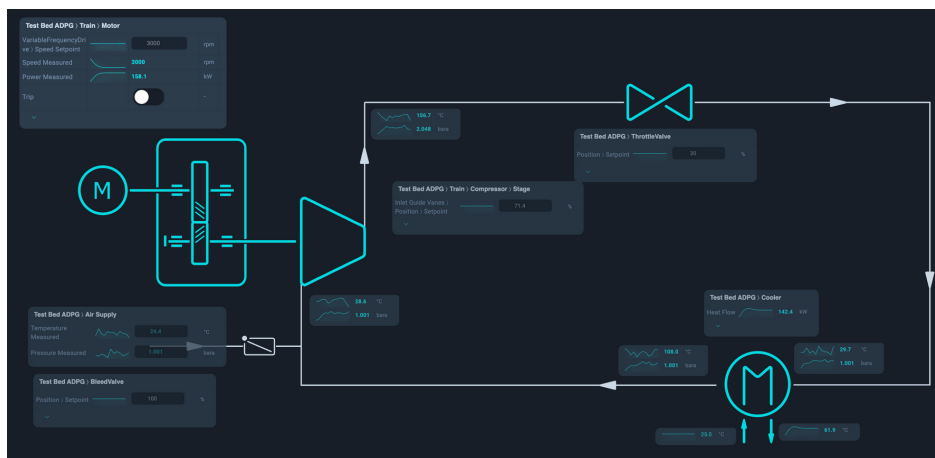
In a next step, a running monitoring service has been built that checks if the process data is within expectation range and configures an event if there is a significant change within the data.

The general expectation of the prescriptive maintenance solution

- reduction of workload for maintenance & reliability and
- knowledge retention by AI service

were fulfilled and the solution was applied stepwise to several plants within the refinery. The extension has been scaled up to more than 12 assets with several hundreds of measurement tags.

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The overall data flow architecture is shown below. The installation is done using docker on a virtual machine (VMware ESXi server) supplied by the refinery's data center. The dashboard is accessible from the intranet and via VPN for support and maintenance. Additionally to the monitoring dashboard each asset is provided with a *virtual plant* process simulation where the model can be used in order to run experiments with the virtual plant.

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/ SUCCESS STORIES

With the application of the AI-services a series of data-driven optimization and troubleshooting were realized which result, additionally to the strategic outcomes, to short term benefits:

1. Detection of operation points that most likely led to droplets that destroyed a compressor impeller. The results were recommendations on how to operate the plant without taking the risk of droplet generation.
2. Pumps with repeated failures by deposits in gaskets. A study analyzed the process data draw recommendations on minimal instrumentation to increase the reliability.
3. Increase of plant throughput by analysis of compressor performance. The compressor model was fitted to historical data and recommendations were derived on how to modify the machine to reach higher throughput of the plant with minimal cost.

OUTLOOK /

A further extension in order to boost the scalability is the usage of naming and data model standards. The IEC/ISO 81346 defines helpful rules for reference designation systems, which are commonly used, especially within power plants. The IEC/ISO 81346 rules out the necessity to build a labeling depending on the context. There are strong initiatives like OPC UA, Mimosa, DEXPI that help to ease data exchange and provide contextual information. Engineering design tools like Aveva P&ID and Siemens Comos already allow P&ID import and export using ISO 15926.

ABOUT THE AUTHOR /

Richard Büssow did his PhD in Acoustics at TU Berlin. He used to work at MAN Energy Solution in different roles including Innovation Management and collaboration with startups and universities.
2017 he funded together with other former colleagues Industrial Analytics and is one of the managing directors.

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