WHITEPAPER

Potentials and Opportunities for New Business Models in the Era of Industry 4.0

PREDICTIVE MAINTENANCE WITH DATA SCIENCE

eoda

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Introduction: What is Predictive Maintenance?

„The catchphrase „Industry 4.0“ also conceals the vision of networking machines, manufacturing processes and storage systems by using IT solutions.

Aspects such as international competition, shorter product life cycles and faster technological leaps increase the requirements for resource-saving and efficient handling of production means. Downtimes, reduced performances and quality losses in production have always represented a risk that must be minimized. The risk is growing in many markets because requirements are becoming more complex than ever. At the same time, competition is increasing while supply bottlenecks or poor quality can weaken the market position.

As part of the German government's „High-Tech Strategy 2020“, the „Industry 4.0“ concept aims at a cross-industry approach as a future project. The aim of the strategic initiative is to find solutions to economic and financial challenges of the 21st century. For the industry, this means that modern information technologies are integrated into classic industrial processes. The project requires an interdisciplinary approach and can be realized above all in close exchange between electrical engineering, mechanical engineering and IT.

The catchphrase „Industry 4.0“ also conceals the vision of networking machines, manufacturing processes and storage systems by using IT solutions. A central element here is the „Smart Factory“ (intelligent factory). This concept focuses on intelligent production systems and processes as well as on the realization of distributed and networked production facilities. Important goals here are the development of intelligent products, methods and processes that enable individual areas to exchange information independently.

Within this concept, predictive maintenance represents an important component of the smart factory, in which a high availability of production plants and minimizing failures is an important goal. High availability requires not only high-quality systems, but also prompt repair in the event of a breakdown. A prompt repair in turn requires the provision of the corresponding resources such as specialists, spare parts, logistics etc. Ideal would therefore be either a fail-safe operation, which is almost impossible to implement in practice, or the reliable prediction of damage events in order to stockpile the necessary means for maintenance in line with demand.

To achieve this goal, you need a maintenance strategy that detects possible faults before happening, and thus enables you to plan optimal maintenance. Predictive maintenance can be a decisive component in this.

The successful anticipation of future events is often an advantage. An important key to successfully predicting future events lies within the patterns of past events. This is the field of statistical methods, which are summarized under the generic terms Data Mining and Predictive Analytics.

The free statistical language R provides a powerful tool for this purpose, which has made its way from scientific institutions to companies in recent years. R is primarily a programming language for data analysis. Not least because of the worldwide scientific developer community, a software has been developed that offers many advantages. The almost infinite range of applications due to the more than 6,000 expansion packages is only one of many aspects.

Scope of functions, integration options or the possibilities for graphical processing of the results – especially in view of requirements that predictive maintenance places on a statistical solution, R is one of the best alternatives.

2

The Economic Importance of Service and Maintenance

Maintenance and repair belong to the industrial services sector. Industrial services cover a wide range of applications, as this sector is still quite young. Maintenance and repair is becoming increasingly important as an industrial service as well as in general and experiences a dynamic process of development.

Until the 1980s, however, industry in Germany was still dominated by labor-intensive production processes. As a result, maintenance was a rather reactive task within the company. Nevertheless, production processes and maintenance were usually viewed separately. Maintenance was thus not linked to products, quality and sales. The increasing cost and time pressure as well as the higher equipment intensities and more complex production lines led to a rethinking. Maintenance moved more into the economic focus.

Many companies have developed maintenance strategies that were integrated into the overall production strategy in order to ensure the highest possible availability of machines and systems. As a result, the division of labor in the provision of production-supporting services became increasingly self-evident.

This was followed by a trend towards outsourcing industrial services, as production companies wanted to concentrate on their core competencies in order to withstand increasing cost and competitive pressure. However, high demands are placed on external service providers, because their tasks are often closely linked to the actual core competencies of the companies and the high availability of the systems is a basic prerequisite for entrepreneurial success.

In summary, service and maintenance plays an important role in the market and thus also for the individual companies, which will gain in importance in the future. Especially in companies with high output volumes and high-quality requirements, where downtimes can cause horrendous costs such as in the automotive and food industries, service and maintenance will play a central role in determining whether a company can assert itself in the market or not.

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3

Predictive Maintenance

Maintenance is very important for ensuring almost all processes in the provision of services. The optimization of maintenance, especially with regard to the cost/benefit ratio, is a great opportunity to operate the entire process of service provision more efficiently. The use of automated recording of framework parameters and statistical evaluation of the data can make a major contribution.

3.1 Classification into the Maintenance Strategies

According to the German Institute for Standardization, maintenance includes:

a. care, cleaning, lubrication and readjustment of technical equipment of a system in the sense of monitoring the target condition.

b. inspection measures aimed at determining and assessing this condition by measuring and testing.

c. the repair, i.e. the restoration of the target condition by replacement or repair in case of permissible tolerance limits of the system or its components are exceeded.

In summary, maintenance includes everything that serves to maintain or restore the functionality of a system. Individual strategies coordinated with inspection, maintenance or repair are useful to consider special features of different systems types regarding fault events quality and availability requirements. In general, a distinction is made between three different maintenance strategies, which are also defined in ISO 9000 and differ mainly in the time of maintenance:

1. Fault-related maintenance

Fault-related maintenance, often called reactive maintenance or failure repair, usually takes place after faulty parts or the failure of the entire system has been discovered. Those systems are mostly operated until individual parts or the entire system fail due to the occurrence of damage. This type of maintenance requires spontaneous and fast work in order to keep production downtime as short as possible. Additionally, a high level of technical competence on the part of the maintenance engineer is required to quickly assess the system status and identify the cause of the fault.

2. Time-based maintenance

In contrast to fault-related maintenance, time-based maintenance attempts to avoid the failure of a system. The repair or replacement of parts is here completely independent of the actual condition of the components. Based on past analyses and experiences of failures, defined intervals are determined in which maintenance work will be carried out.

3. Condition-based maintenance

Condition-based maintenance aims to make the best possible use of the parts and systems while simultaneously preventing a breakdown of the system. Like time-based maintenance, this strategy is one of the prophylactically oriented maintenance strategies. However, when determining maintenance intervals, it is not based on time but on the condition of parts or systems. The wear margin is determined by inspection and maintenance is planned if it is exhausted.

Predictive maintenance is an extension of condition-based maintenance that can predict system failures and thus also have a prophylactic character. Like the condition-based maintenance, the aim is to make the best possible use of the components and at the same time eliminating any faults or failures before they occur.

To make this possible, a sophisticated monitoring system of plant states is required. Many sensors collect as much relevant data as possible. These are promptly available in a central database and analysed with extensive statistical procedures to forecast faults, failures or other critical events.

The present text understands predictive maintenance as the extension of condition-based maintenance by the most automated possible condition recording of the plant, supplemented by the statistical evaluation of the recorded data and the forecast of future malfunctions.

	Fault-related maintenance	*Time-based maintenance*	*Condition-based maintenance*
Characteristic	Occurs after a fault	Attempts to avoid a malfunction by interval-based replacement and inspection	Wear is detected and maintenance is planned accordingly
Requirements	Spontaneous and fast work, professional competence of the maintenance engineer, spare parts on site	Planning of maintenance personnel and spare parts	Costly inspection often by sensor technology
Suitable for	Systems with low failure probability or redundancy, small units, simple and non-critical systems	Systems in which the time between two faults is known	Systems that can be well monitored and inspected
Advantages	No costs if no malfunction occurs	Maintenance can be planned, availability will most likely be increased	Ensuring high availability
Risks, Disadvantages	Production downtime	Usage stocks of parts and systems which are usually not used up, no guaranteed availability, faults outside the intervals	High costs for monitoring

3.2 A Loop System in Four Stages

According to the above definition predictive maintenance can also be understood as a control loop of four phases.

Four stages of Predictive Maintenance

1. Collection of data

There are various, most of them sensor-based, technologies and processes that monitor the status of plants and plant components as well as important environmental parameters. Used among others are the following:

- Vibration monitoring/analysis
- Lubricating oil and fuel analysis
- Wear particle analysis
- Storage and temperature analysis
- Performance monitoring
- Ultrasonic noise detection/ ultrasonic flow measurement
- Infrared Thermography
- Non-destructive testing
- Visual inspection
- Insulation resistance
- Motor current signature analysis
- Polarisations- index
- Electrical monitoring

2. Storage of data

Continuously recorded data mostly leads to enormous amounts of data, which are often distributed worldwide. Relevant data should be stored in a central data warehouse. Thus, data from distributed plants can be processed and compared with each other.

3. Analysis and evaluation of data

Statistical analysis methods are used to analyse data as it is known from Chapter 3. More precisely, patterns are identified in data and models are formed that enable the prediction of certain future developments.

It is therefore important that a sufficiently large database is available. At the same time, data quality is also of great importance. Detailed and reliable analyses can only be carried out with an appropriately large and meaningful data basis.

4. Determination of maintenance by statistical models

Depending on the objectives, models can make different statements. For example, the results when or under which conditions which disturbance with which probabilities occurs. The results allow a more precise determination and planning of future interventions regarding type and time. The quality of those models can be continuously improved within the framework of an iterative process. All four steps offer potential for improvement:

a. Data acquisition can be optimized in quality and quantity.

b. Data storage can be improved through faster access times to more extensive data.

c. Statistical analysis and modelling can be improved and extended.

d. Inspection or maintenance can provide new insights that help to improve the whole process.

4

Statistical Procedures as a Basis for Predictive Maintenance

> Through modelling, reality becomes abstracted in such a way that essential influencing factors can be easily identified.

The targeted utilization of high-quality statistical methods is besides the actual data the basis for predictive maintenance. Only data mining and predictive analytics models can determine meaningful findings for reliable forecasts and derive concrete instructions for action.

Through modelling, reality becomes abstracted in such a way that essential influencing factors, which are important for the process, can be easily identified. In this context, a distinction is made between structural and pragmatic modelling. When structural modelling (white-box model), the internal structures are known in the system, but abstracted, modified and reduced to such an extent that they are useful for the model. In contrast, the internal structures of pragmatic modelling (black box model) are not known, only the behaviour or interaction of the system can be observed. Combinations of both methods are available in many variants. The best known is called the grey-box model. Processes that can be identified by modelling include demarcation, reduction, decomposition, aggregation and abstraction.

The best possible model match to reality provides the right combination of sufficient and relevant data as well as the right procedure. Often this combination has to be worked out through an iterative procedure and adapted over time.

Some of the possible procedures are briefly outlined below.

4.1 Anomaly or Outer Detection

The anomaly or outlier detection defines the search for data that does not correspond to the given pattern or the expected behaviour. Anomalies are also called exceptions, deviations or outliers, often offer critical but partly comprehensible information. An outlier is an object that differs significantly from the average of the dataset or the combination of data. Its numerical value is far from the values of other data and thus indicates that something lies outside the normal range and should be examined more closely.

Anomaly detection is used to detect adulterations and risks within critical systems and filter out all characteristics that may show what could have caused this deviation in further analysis. Please note that a small number of outliers can occur with large amounts of data. Causes for anomalies can be poorly maintained data, random variation or relevant events.

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In order to evaluate the relevant data for predictive maintenance, further procedures are used in parallel. Each of these procedures represents a small model of reality.

4.2 Cluster Analysis

The aim of cluster analysis is to identify homogeneous groups of objects that stand out from other groups. These are often accumulations in the data room where the term cluster comes from. High homogeneity within the clusters enables precise characterization of the individual elements as well as heterogeneity between the groups ensures selectivity and clear demarcations. This form of segmentation offers decisive advantages when carried out correctly, for example in a targeted and individualized customer approach in marketing. A cluster analysis implemented in advance increases the probability that entrepreneurial measures will achieve the desired success.

4.3 Factor Analysis

Like cluster analysis, factor analysis is a method of multivariate statistics. It is a tool for extrapolating from many different variables to partially unobserved underlying latent variables. The purpose of this data-reducing or dimension-reducing method is the discovery of independent variables or characteristics. A factor analysis has three objectives:

- **Reducing the number of variables**
  All variables with similar information are recorded in variable groups. This summary in homogeneous groups results in an economic presentation of the overall information
- **Determination of reliable measured variables**
  The variables combined to a factor have more favourable metrological properties than the individual variables.
- **Analytical objectives**
  Enables you to extrapolate from manifest variables (indicator variables) to superordinate latent variables. Latent variables have an influence on each indicator to different degrees and thus have different effects on each indicator.

A distinction is made between explorative factor analysis (used to explore hidden structures of a sample or to reduce dimensions) and confirmatory factor analysis (used to test previously established hypotheses about the existing data structures).

4.4 Classification Analysis

Classification is similar to a cluster analysis as it involves assigning individual objects to groups. However, classes are here usually predefined and methods from machine learning are used to assign objects not previously assigned to these classes. These assignments are based on class properties and reference characteristics that are compared with each other. The classification structures the existing data and prepares it for efficient further use.

For example, spam filters work based on classification analysis. Email providers classify spam using specific words or attachments that may indicate spam.

In industry, algorithms can be used to classify the condition of plant or machine parts. Using the collected data from the production process, such as pressure curves, vibrations or temperature changes, the system and machine parts are classified as "OK", i.e. in running order, or "faulty".

4.5 Regression Analysis

The aim of regression analyses is to establish connections between dependent variables and independent variables. They are used to describe connections quantitatively or to forecast values of the dependent variables. Regression analyses are for instance used to determine different levels of customer satisfaction, to analyse how these levels affect customer loyalty or how service levels are affected by weather conditions.

Salzgitter Mannesmann also uses regression analysis to determine the temperature of processed steel at the various production stages. Furthermore, it is used to investigate how temperature is influenced by transport and production.

4.6 Event History Analysis

Event history analysis is a field of statistical analysis in which the time of an event between data groups is compared to estimate the effect of prognostic factors or harmful influences. The method is applied to all objects that are successively excreted, i.e. have a mortality rate, as soon as the event time can be defined. Mechanical reliability is a challenge here because gradual failure (for example, a machine failure that has been repaired) is difficult to determine in terms of time. Usually, only events that can occur at most once per subject are investigated, but meanwhile an extension to repeated events is a promising and feasible task.

Example analyses for this method are the Kaplan-Maier estimator or the Cox regression.

5

Examples for the Success of Predictive Maintenance

Used correctly, predictive maintenance is promising and cost-saving. To show this, Barber and Goldbeck have listed various studies and case studies in their text, which are described below. In the US, for example, the Electric Power Research Institute (EPRI) carried out detailed case studies in the electricity supply industry on the costs of plant maintenance and was thus able to draw up an interesting maintenance cost comparison.

The comparison shows that Predictive Maintenance (PdM) has a savings potential of almost 50% compared to Reactive Maintenance in the entire power supply industry. PdM also has a clear advantage over preventive maintenance with a savings potential of 30.8%.

In addition, Pat March, a senior mechanical engineer at the Engineering Laboratory of the Tennessee Valley Authority (one of the largest power plant operators in the US), compiled an overview of the successes of predictive maintenance based on a 1988 cross-industry survey of companies that used predictive maintenance:

- Maintenance costs reduced by 50 to 80%
- Machine damage reduced by 50 to 60%
- Spare parts stock reduced by 20 to 30%
- Total machine downtimes reduced by 50 to 80%
- Overtime expenditure reduced by 20 to 50%
- Machine service life increased by 20 to 40%
- Total productivity increased by 20 to 30%
- Profits increased by 25 to 60%

But predictive maintenance is far from being applied to all parts of energy production. Especially in the wind energy industry, where the turbines are often difficult to reach and exposed to extreme climatic fluctuations, reactive maintenance is still largely used. A report by the National Wind Coordinating Committee (NWWC) concluded that unscheduled maintenance times account for about 75% of the total maintenance costs of wind turbines and that it may be possible to reduce the total maintenance costs to 50% on average with predictive maintenance.

As most wind farms, one wind farm in Canada with wind turbines of the megawatt class did not yet apply predictive maintenance but waited until a damage had happened. In January 2004, for example, a bearing failure occurred at this wind farm, which made a complete overhaul of the entire transmission necessary. The required spare part and a suitable crane were ordered immediately. Then, however, a period of bad weather set in, making maintenance impossible for the following 3 weeks in which the crane was standing still.
This caused total costs of $426,000:

- Costs for the crane of more than $150,000
- Energy generation costs of about $26,000
- Costs for the replacement transmission of more than $250,000.

With predictive maintenance these costs could have been reduced by $319,000.

By using acceleration sensors, oil particle counters and a weather forecast module in combination with a reliable evaluation of the data, the damage to the transmission bearing could have been detected early without the entire transmission failing (cost savings of $220,000), according to Barber and Goldbeck. With an early detection, maintenance could have been planned in advanced and could then have taken place in a period of low production with good weather conditions. This would have not only significantly reduced production revenue losses (cost savings of $24,000), but also avoided unnecessary crane costs (cost savings of $75,000).

Maintaining the wind turbine with predictive maintenance would have cost only $107,000. That is a saving of almost 75%.

In another case described in Barber and Goldbeck, predictive maintenance is used for a vibration analysis to detect defective cogs in a cooling tower fan transmission.

The early detection of the error saved repair costs of about $9,000. If a serious fault had occurred, the secondary damage could easily have been many times this sum, since the damage potential of rotor blades and superstructures is high. (In the case of a wind turbine transmission, the secondary damage caused by a similar error could, for example, lead to a total failure of the entire transmission with costs of about $200,000).

Damaged teeth of a transmission cog

6

Benefits and Advantages of Predictive Maintenance

> Optimized maintenance helps to increase customer satisfaction.

Predictive maintenance offers the opportunity to predict faults, errors and failures before they occur and thus avoid them. This minimizes cost-intensive downtimes so that the potential of the plants can be optimally exploited. Maintenance can thus be planned more cost-effectively and foresighted.

Especially where a wide variety of data is already being collected, predictive maintenance can be introduced quickly. However, a subsequent upgrade of monitoring systems can also be worthwhile, as predictive maintenance offers further potential benefits and advantages such as:

- Avoidance of downtimes
- Higher exploitation of the potential benefits
- Increase in productivity
- Reduction of storage costs
- Improvement of product quality
- Conservation of resources

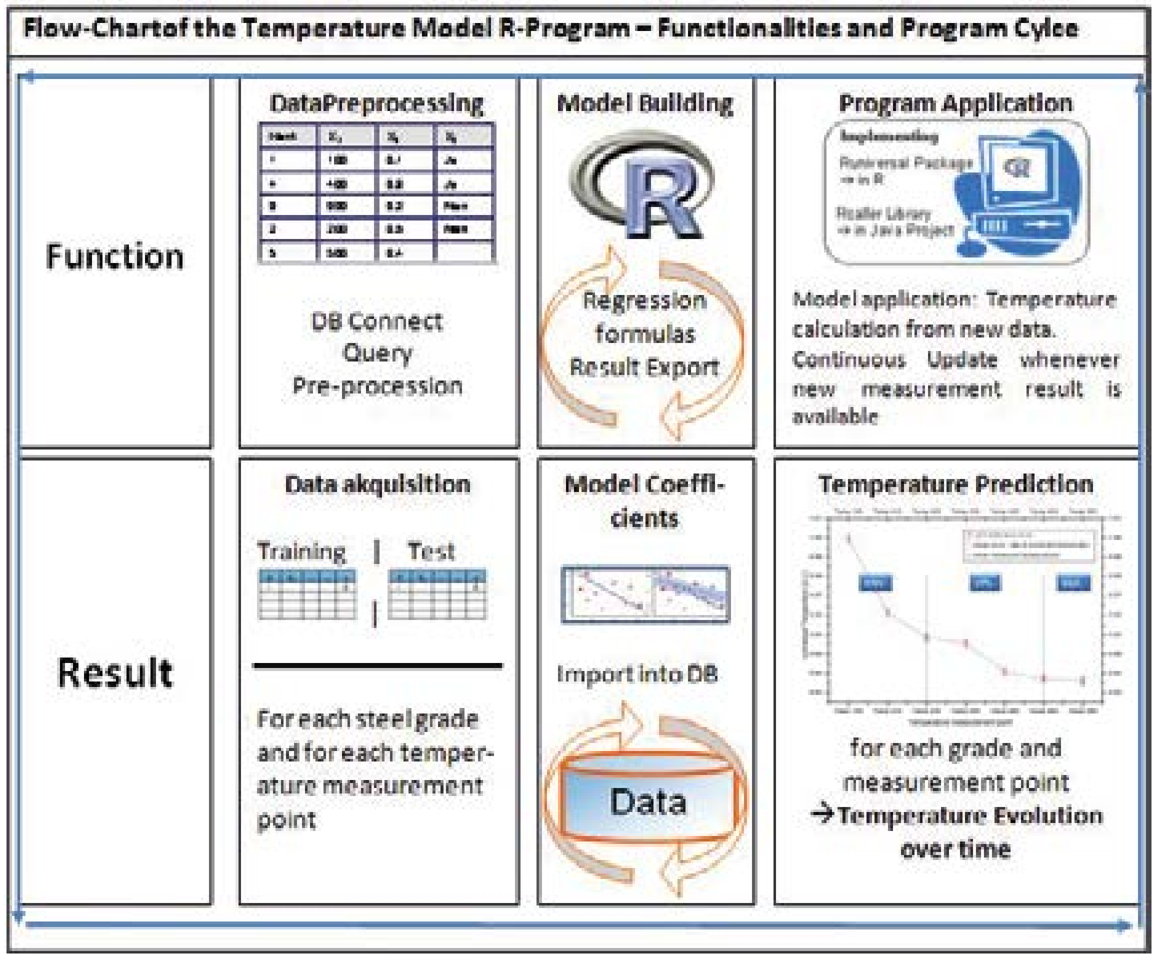
Improved maintenance options help to increase customer satisfaction and provide the opportunity of developing new service concepts.

In summary, predictive maintenance reduces overall costs, boosts overall plant efficiency and the cost-benefit ratio for the operator. Additionally, the efficiency of the entire maintenance processes increases which leads to the improvement of competitiveness.

An important component of the entire predictive maintenance process is the software which processes data and makes results available. The requirements for such a software can be divided into three areas:

1. A good opportunity for integrating existing software
2. Comprehensive and high-performance tools and libraries for data mining and predictive analytics
3. Various possibilities for individual, interactive and high-quality presentation of results

Keeping the requirements in mind, the statistical environment R is one of the best software solutions for predictive maintenance.



The use of R in steel production at Salzgitter Mannesmann

> The R-project has proved to be most useful for the implementation of the calculated results, the same as the external control of its functionalities in a process automation environment.

Bengt Maas, Hakan Koç
Salzgitter Mannesmann

7

R – the Most Powerful Language for Statistical Tasks

> It's the most powerful and flexible statistical computing language on the planet."
>
> Norman Nie

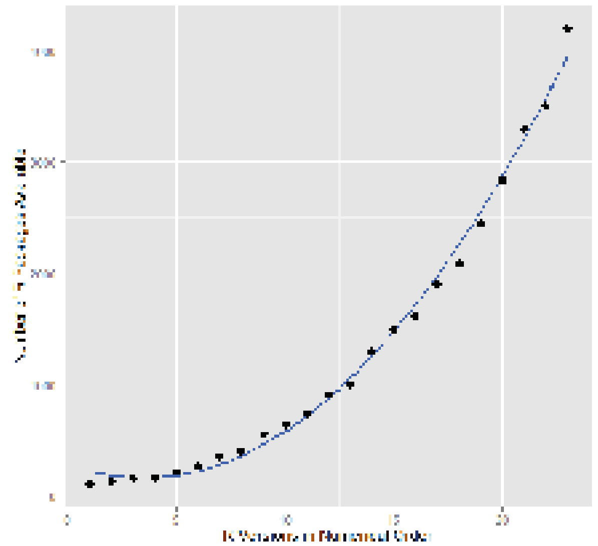
R is an open source programming language for statistical data analysis and visualisation. Developed in 1992 by Ross Ihaka and Robert Gentleman at the University of Auckland, R gained popularity and established itself in both science and business. Today, R is considered the "lingua franca" of data analysis .
Since 1995, R has been under the GNU General Public License, so everyone can use, explore, distribute and modify R, similar to Linux.

The reason why R fascinates so many people will be explained more detailed below.

7.1 The Packages

R is not only a programming language, but also a software environment with a lean core system that can be extended to any topic with optional packages. These packages contain different "tools" for specific methods and procedures, depending on the subject area. There are currently more than 12,000 packages available.

The application possibilities that can be exploit with such packages are limitless. Starting with the standard statistics, there are no upper limits. R-packages are available for portfolio optimization in the financial sector as well as for gene data analysis in biology, or image data recognition, which is used in the form of X-ray image analysis.



Number of R packages plotted for each major release of R. The last value on the x-axis represents version 2.15.2, the final release in 2012

7.2 The Community

The packages are developed by leading international experts from various disciplines who constantly work on additional features and improvements. That is the reasons why established packages are of the highest quality. Another point is the freely accessible code, which is open for examination and discussed among the experts.

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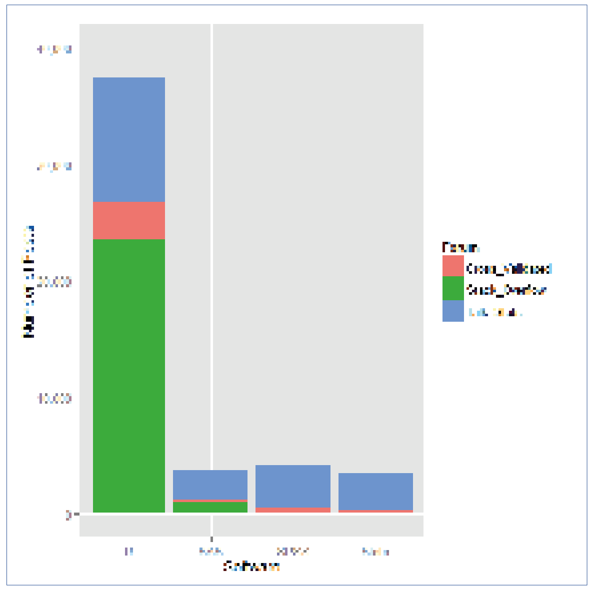
R is an open source movement and the support of the community as well as the exchange within the community on specific topics, procedures or R problems is exceptionally good and high quality.
Communication is an essential part of the data analysis process, which can be divided into "peer" and "management communication". Both types of communication are very well supported by R. When data analyses have been performed, it is often necessary to discuss details of the procedure with colleagues. R is an excellent programming language for this step. A single aspect can be well described with exemplary data without undermining the confidentiality of a project, as all R functions are available to everyone.



Number of posts per software on each forum on 2/10/2013

7.4 Advantages of R

As a software solution for predictive maintenance, R offers numerous advantages that make it a decisive and trend-setting solution approach:

1. *Range of functions:* The range of features R already offers are incomparable (without additional investments). For the future it seems unlikely that companies will find viable business models with which they can generate innovative power comparable to that of the R-community.

2. *R in analytic stack:* R can be integrated with all layers of an analysis or reporting architecture such as data storage, data analysis or the layer for presenting the results. Almost all well-known manufacturers offer interfaces and integration options.

3. *Security of investment:* R has asserted itself among data analysts in recent years as the involvement of the scientific community in connection with the increasing commitment of large companies to combine R with its products confirms its vehemence. This gives reason to expect a very positive development for market acceptance.

4. *Flexibility:* R experts can use the same language and toolset to analyse data mining on big data on a Hadoop cluster as well as smaller data sets and perform text mining, image data analysis or regression analyses.

5. *Quality:* The essential advancement of R takes place in the field of science. Two thirds of the core developers are professors which are professionally active in the field of data analysis at universities or in companies. Since the publication of an R-package equals a scientific publication, the packages usually offer highest reliability and use statistical methods at the pulse of time.

6. *Specialist:* International and German universities increase the training in R. Open source initiatives- like Linux- are very popular in the academic environment. Thus, the universities produce a steady stream of analysis experts for R.

7. *Data visualisation:* R is one of the most powerful alternatives for creating presentable graphics. From data preparation and analysis to visualization, the entire workflow in R can be implemented.

8. *License costs:* R is Open Source, there are no license costs.

9. *Platform-independent:* R is universally applicable due to its platform independence.

R is a very suitable software solution for predictive maintenance and offers all possibilities for beginners as well as analysis experts.

Predictive maintenance is a very complex and dynamic process which will become increasingly extensive in the future. From data acquisition and analysis to the creation of forecasts and the clearest possible presentation of results, the entire process needs an integrated software in order to respond to this challenge in the future. The integrated software solution requires the potential to collect and analyse data from all interfaces, such as system sensors and environmental conditions.

8

Advantages of R for Predictive Maintenance

> The data science language R is ideally suited for Predictive Maintenance.

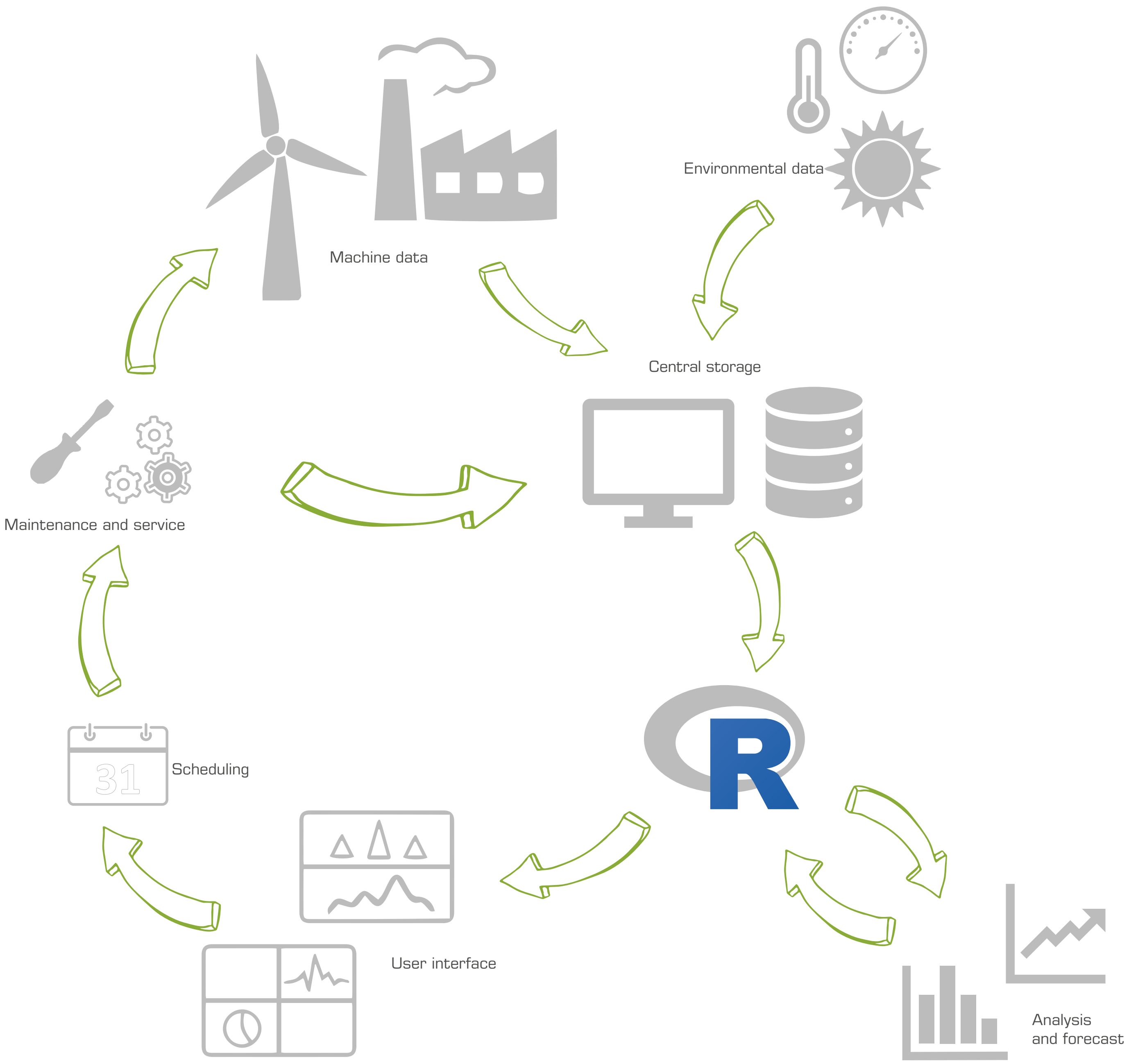
Data analysis software used in predictive maintenance environments must meet many requirements, such as:

- Statistical functions enabling specific analyses and evaluations
- The widest possible range of statistical methods and functions to extend flexibility and benefit
- A wide range of further processing of the results and comprehensive possibilities of visual representation
- Seamless integration of the software into the existing application landscape (background: Industry 4.0, smart factories and Big Data)

The statistical language R is particularly suitable for evaluation, analysis, forecasting and visualization in predictive maintenance due to its openness and range of functions.

The following graphic illustrates the applications of R in the predictive maintenance context:

Possible application of R in Predictive Maintenance



8.1 Annealing Wires and Random Forest - the Concrete Use Case

An example from the Austrian Journal of Statistics shows how R can be used to predict machine failures in the semiconductor industry using regression trees and random forests, and how maintenance dates can be optimized based on these results.

The authors have chosen ion implantation as an example, in which charged atoms or molecules are shot at a wafer in order to systematically change its electrical properties. The ion implanter is a very complex device and is used several times in the production process of semiconductors. A glow wire in the device generates these ions and emits them in the form of an ion beam. This glow wire is subjected to massive stress during use and fails in very irregular periods, every few days. These failures cause machine downtimes and thus an undesirably high loss of productivity. To prevent this, an attempt is made to determine the optimum time at which the glow wire should be replaced.

This production step contains many, often non-linear, related parameters, which is why a non-linear multivariate method is required for model-based defect detection to capture these complex interactions.
In order to uncover such relationship structures, decision and regression trees were used in this example from the semiconductor industry. In addition, the Random Forest method, a special form of decision trees, was used. The calculations were performed exclusively in the programming language and statistical environment R. The packages rpart, partykit and randomForest were used for the random forest algorithm.

The basis for the forecasting model was the information collected from previous production processes. In total, the raw data comprise 6,781 observations with 20 characteristics. The variables are listed below in Fig. 13 with a brief explanation. The original data was first cleaned up. Cases that do not correspond to the natural life cycle of a annealing wire were removed from the work data set. A premature replacement of the annealing wire or times in which the annealing wire was not used could therefore not falsify the forecast. What remained were 1,812 observations as seven annealing wire life cycles that were used for modelling. The preparatory data management also included the creation of the variable NextPM, which was the target variable in the following analyses. NextPM describes the time until the annealing wire breaks. Data management was also carried out in R.
A success factor for a reliable forecast are variables that are valid indicators for the status of the target variables. Scheibelhofer et. al. used two different methods to filter out the most reliable forecast characteristics from the range of possible influences.

On the one hand, the central influence variables were calculated with the help of a regression tree and rules for the duration until the next break of an annealing wire were determined. Subsequently, a random forest model was created, which forms a forecast model and additionally secures the results of the regression tree.

9

Success Factors for the Implementation of Predictive Maintenance

The implementation of a predictive maintenance project is a challenge full of complicated tasks and great complexity. The following aspects should be considered in order to successfully implement a predictive maintenance use case.

Testing a comprehensive vision on a prototype

Moving from a different maintenance strategy to predictive maintenance also means noticeably changing the culture, philosophy and workflows of the areas involved. A well-thought-out plan that is tested on a prototype is always a valid way of making the challenges manageable.

Support the holistic character of a predictive maintenance use case

Predictive maintenance has a holistic character, which should be reflected in everyday business life and should be conveyed right from the start through coaching. For example, it may be helpful for the correct use of the Vibration Data Collector to understand which goal is pursued with predictive maintenance. High quality data, a comprehensive data collection and smooth-running processes in order to collect data are the most important conditions for predictive maintenance.

Documentation and transparency: the be-all and end-all

Success of predictive maintenance and the challenges which goes along with it should be transparent for all stakeholders involved. Above all, corporate management should be able to understand the value added by the new maintenance programme so that it can continue to be promoted.

Maintain continuity and consistency in implementation

Consistency in implementation is important and necessary to create structure and clarity for all parties involved to trust the new maintenance programme. In order to maintain consistency within the company, there are several possibilities, such as the adequate instruction of personnel, targeted training of employees, the commitment of qualified personnel to the company, continuity in the program and technology direction, a clear definition of the programme from the outset and/or transparent and detailed documentation of the programme's efficiency over time. If you do this, you will quickly notice the improvements that predictive maintenance can provide.

10

Predictive Maintenance at Trumpf Laser

Challenge

TRUMPF is world market and technology leader in the field of industrial lasers and laser systems. The TRUMPF laser technology offers CO2 lasers, solid-state lasers, marking lasers as well as laser systems. To keep performance and quality high and prevent sudden machine failures, the company wants to implement predictive maintenance via data analyses and thereby increase the quality and availability of the machine.

Goal

The main goals of applying predictive maintenance to the laser machines were as follows:

- Introduction of data science for using data
- Analysis of lasers with sensors producing countless machine data everyday
- Transparent and descriptive visualization of machine data
- Overarching workflows for supporting business processes between development, service, after sales and external as well as internal data scientists
- Introduction of algorithms for the recognition of error patterns and the prediction of future failures

Basically, the goal was to increase the analytics maturity – based on data and algorithms.

Solution

In a first step, eoda helped TRUMPF to train their own data science team. This team combined domain and statistics know-how and thus was soon able to successfully identify and implement their first use cases. The open source scripting language R was used for performing complex analyses of the machine data. It features an unparalleled range of functions for analyses, forecasts and visualizations and was employed by TRUMPF engineers after a short time. The use cases were supposed to evaluate existing machine data sets, analyse them for anomalies and failures as well as display the results and forecast future problems.

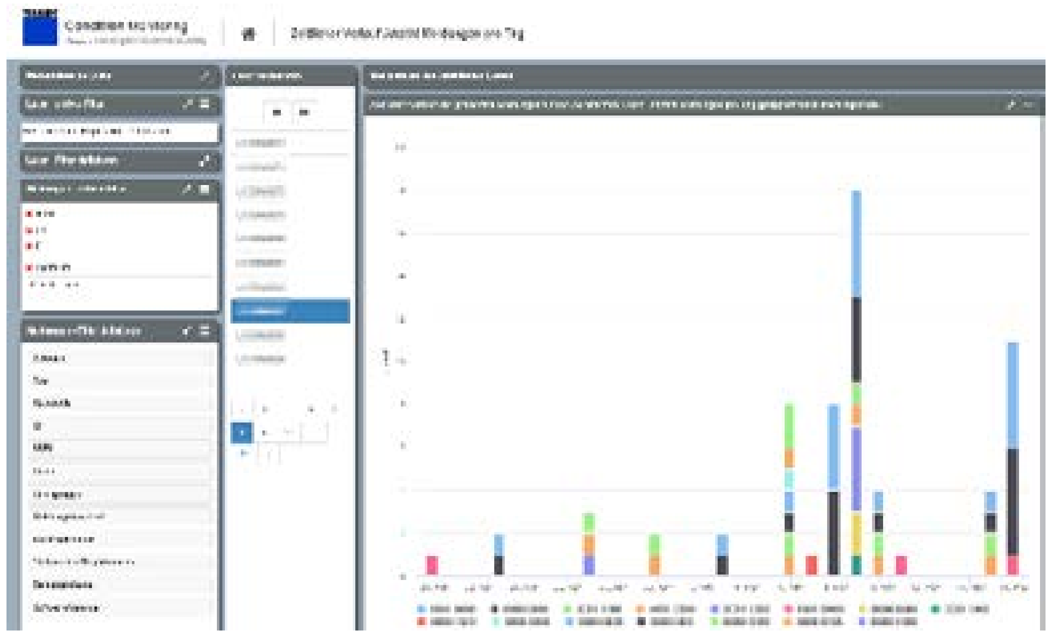
The results of the analyses have lastingly convinced the technical departments involved as well as the management. During the further procedure, the focus was on the integration of data science into existing business processes. A condition monitoring portal was therefore developed based on the eoda | data science environment

This condition monitoring portal enables our client to check the condition of the machines and optimize maintenance efforts and costs within the framework of predictive maintenance. The portal is an on-premise solution: TRUMPF keeps full control of the data and algorithms.

Results

Thanks to the condition monitoring portal, machine data and trends can be visualized and analysed in the form of dashboards, flexibly combinable widgets and graphics. Different departments, e.g. development, service or after sales, in different roles work together on different use cases – connected by workflows.

As a result, a maintenance strategy is implemented which detects errors in advance and thus prevents sudden machine failures. This enables the planning of optimal maintenance as well as the creation of new value-added services based on data and algorithms.



Condition Monitoring Portal

More information about our solution:

[More information.]

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Conclusion

Nowadays, the question of the right maintenance strategy is already playing an important role in companies. It is becoming apparent that the issue of maintenance will continue to grow in the future. Predictive maintenance gives companies the opportunity to ensure continuous production and repair plant wear and damage when it is most advantageous in terms of time, costs and production. Not only can the costs of repair and downtime be reduced, but also the quality of the products and the market position of the company improved.

Predictive maintenance is the optimal maintenance strategy of the future that will be indispensable in the era of industry 4.0. In linking central offices, systems and the internet, enormous amounts of data will be processed and evaluated. What is indispensable here is a flexible analysis software that copes with rapid change and constantly growing requirements, offering individual solutions that can be integrated.

R is the appropriate solution and will play an increasingly important role in statistical evaluations in the future. Many different analysis and visualization options that R already offers today are ideally suited to individually integrate or introduce predictive maintenance into the most diverse companies, no matter which system software and structures already exist. With the current development speed, R will also meet the challenges of future requirements.

We also realize your data science project. Please do not hesitate to contact us.

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The perfect time to start your successful analysis project.

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Take your data-driven processes to the next level.

More information

eoda is an IT company specialized in data science. Its portfolio comprises consulting, analytic services, software and training. The services cover the entire workflow from data acquisition to analysis to the interpretation of results and the integration of analysis workflows into existing processes and applications. The interdisciplinary team of eoda combines a profound knowledge of business processes with a competent usage of suitable methods for statistical analysis.

As a pioneer in Germany for the open source statistical language R, eoda provides a comprehensive portfolio for the productive application of R. The use of spark, AI frameworks like tensorflow or MxNet and other data science languages like Python and Julia complete our toolkit and help us master the daily challenges of data science.

We are looking forward to your request:
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