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Dynamic criticality assessment as a supporting tool for knowledge retention to increase the efficiency and effectiveness of maintenance

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Abstract

Digitalisation offers industrial companies a multitude of opportunities and new technologies (e.g. Big Data Analytics, Cloud Computing, Internet of Things), but it still poses a great challenge for them. Especially the choice of the maintenance strategy, the increasing complexity and level of automation of assets and asset components have a decisive influence. Due to technological progress and the new possibilities offered by industry 4.0, the interaction of different systems and assets is essential to increase the efficiency of the maintenance processes within the value-added chain and to guarantee flexibility permanently.

These factors lead to an increased importance of a process methodology for a dynamic evaluation of the asset's condition over the entire life cycle and under changing framework and production conditions. Therefore, legal and environmentally relevant requirements are considered, based on the procedure of HAZOP (IEC 61882), and ensure the traceability of the results and systematically record the asset's knowledge gained this way so that it is not tied to individual employees, as it is currently the case.

The criticality assessment as a basic component of Lean Smart Maintenance, the dynamic learning, and knowledge-oriented maintenance, offers such a holistic, value-added oriented approach. A targeted optimization of the maintenance strategy is possible through automated evaluation of the assets and identification of the most critical ones based on company-specific criteria derived from the success factors of the company and considering all three management levels normative, strategic and operational. By considering the resource knowledge in the maintenance-strategy optimization process and using suitable methodologies of knowledge management based on the prevailing data quality for it, the efficiency and effectiveness are permanently guaranteed in the sense of continuous improvement.

Keywords

Criticality assessment; Knowledge Management; Lean Smart Maintenance; Digitalisation

1. Introduction

Today, digitalisation and industry 4.0 are propagated everywhere and these topics have a significant influence on industrial companies. A multitude of opportunities and new technologies of the digital transformation exists and offers new challenges, advantages and disadvantages for the asset management itself. Because of these reasons also the requirements for maintenance have changed considerably in recent years.
To be able to assert oneself in the automated production economy also in the future, a dynamical adaption of the maintenance strategy due to the changing environmental as well as production conditions is necessary [1].

Therefore, it's very important to include the life-cycle-aspect in the strategy adaption process, which is already anchored in international and national standards such as ISO 55000, DIN EN 13306 and DIN EN 16646 [1]-[4]. The overall goal is to increase the asset's availability and to minimize maintenance costs over the entire life of an asset; to start with the investment phase up to the disposal phase [5].

A suitable tool for this purpose is the criticality assessment. It is based on the idea of the Lean Smart Maintenance (LSM) concept, which is a process and value-orientated model with the focus on the Lean part (cost-efficient and continuous adaption of the maintenance strategy to changing environmental conditions) and the Smart part (learning and knowledge-orientated approach). Especially the knowledge retention plays an essential part in the strategy adaption process. The fact that the criticality assessment is carried out as automatically as possible, based on the data quality of a company, and has a uniform and standardized documentation involved, makes decision making and strategy adaptation as easy and comprehensible as possible [1].

This systematic approach makes it possible to ensure the required objectivity of a qualified risk assessment. Various tools are available for the quantitative consolidation of risk factors. Some of the best-known approaches are HAZOP (Hazard and Operability Analysis), FTA (Fault Tree Analysis), ETA (Event Tree Analysis) and FMEA (Failure Modes and Effects Analysis) [6], [7].

In this article, the HAZOP method is presented in combination with the criticality analysis based on the LSM philosophy. The first step of this criticality analysis, the uniform plant evaluation, lays the foundation for an asset-specific dynamic strategy optimization based on a targeted risk analysis. The standardized and, if possible, automated asset valuation identifies cost- and risk-critical assets without much effort by using a standardized procedure. This uniform documentation, which is part of the HAZOP methodology also lays the foundation for long-term knowledge assurance and prevents loss of knowledge. Once the cost-critical and risky assets have been identified, they are analysed in detail using the HAZOP approach, which is defined in the standards IEC 61882, ISO 31010 [8]. Measures for improving the asset are derived and evaluated in terms of cost and risk reduction, and the most profitable measures are implemented with the best cost/benefit ratio and the maintenance strategy is simulated and subsequently adopted based on the previous validation [9].

The aim of this criticality assessment, the combination of the HAZOP approach with the criticality analysis, is to optimize the efficiency and effectiveness of the assets over the entire life cycle in the long term by dynamically adapting the maintenance strategy [10].

2. Dynamic criticality assessment

The dynamic criticality assessment (Figure 1) is a standardized methodology, split into 4 phases (planning, preparatory-, implementation phase, and result evaluation) to identify critical assets and dynamically adapt their maintenance strategy. With this method information can be generated out of the data used for the identification of most critical assets and subsequently generate knowledge out of it because of the standardized documentation of the results. This knowledge can be secured in long-term basis to fulfil the company's and maintenance goals permanently [11].

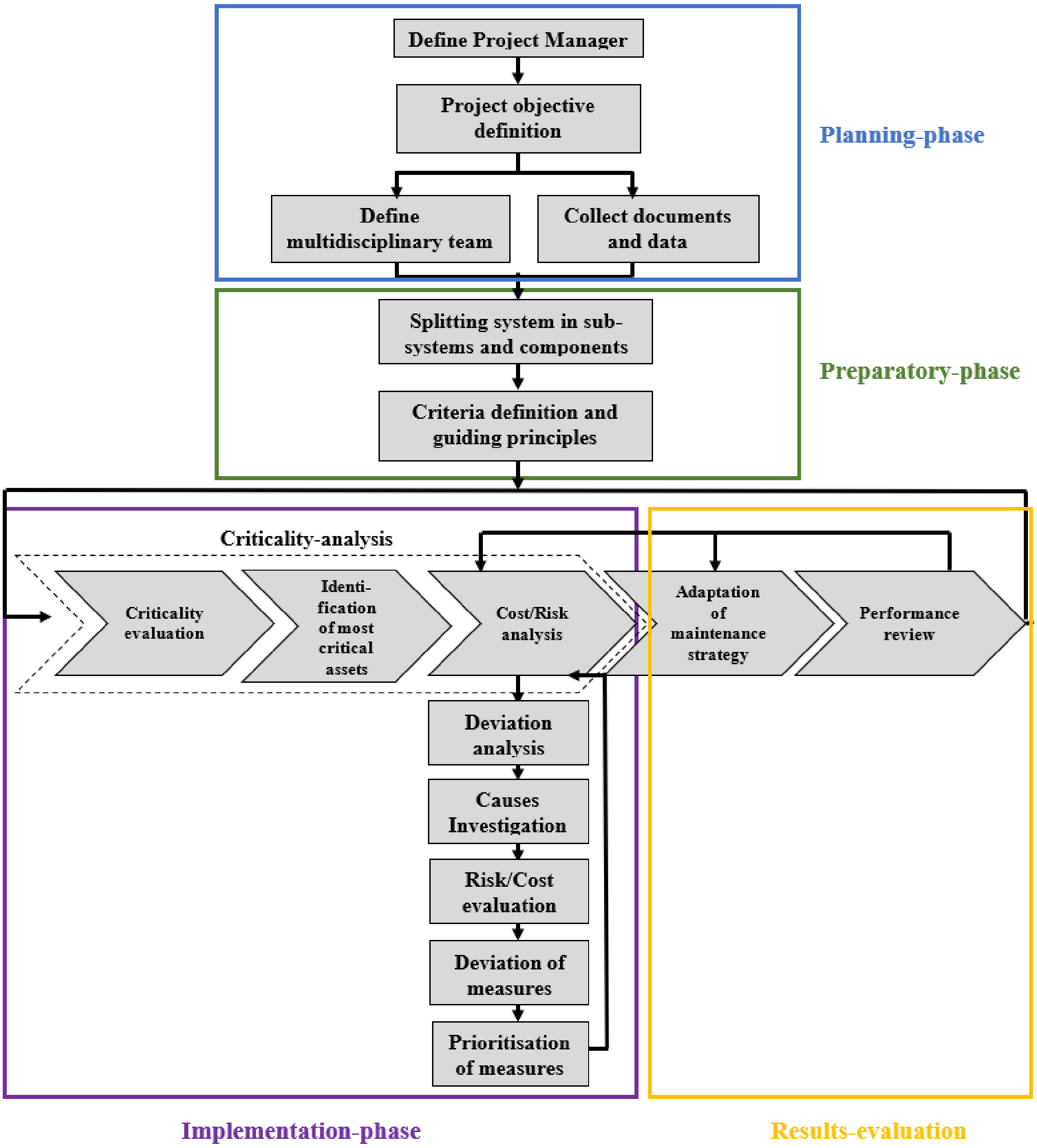

Figure 1: Criticality assessment - Criticality Analysis embedded in the HAZOP-approach

At the beginning of an asset criticality assessment in the planning phase, the project framework must be defined, which is also part of the HAZOP approach. In the first steps, a project or study manager is nominated, who is responsible for the execution of the study and subsequently controls the implementation of the defined measures based on the criticality evaluation. Besides, the project objective must be defined which, in the case of the asset evaluation, is the identification of cost-critical or risky assets. Building on this, a multidisciplinary team composed of experts from different departments such as maintenance, production, IT, finance, etc. is created to fulfil the requirements of the assessment. At the same time, the consistency of the plant master data, as well as the data quality should be analysed in detail, as this forms the basis for an automated asset valuation. [12].

During the preparatory-phase for the criticality analysis, facilitated workshops must be held to determine the evaluation level and to select and define criteria used for the asset evaluation, based on the success factors of a company. Part of the workshops is the splitting of the systems, the process or the procedure into smaller elements or sub-systems [8]. In the special case of an asset, the sub-elements are defined as asset, sub-asset, assembly and components [13]. In the best way, the asset structure is defined correctly in an ERP (Enterprise Resource Planning) system, where the data can be transferred in another system or a data file. Depending on a company's data quality the asset evaluation can be either dynamic or static [1]. If the master data for the assets are formulated and checked, a criteria catalogue for the asset evaluation is generated in the next step [1].

2.1 Criteria-definition

One of the most important steps in the criticality assessment is the criteria definition. In this step, qualitative and/or quantitative criteria are chosen based on a company's data quality. For the criteria selection, it is important not only to focus on the area of maintenance and its key figures but also to try to derive criteria from all three management levels (normative, operational and strategic) to obtain an overall picture of the company and the most important influencing factors [2], [14].

To identify the most important success factors of a company or an industry, a morphological box is used, which forms the basis for the criteria selection. For this catalogue, categories have been defined which have a direct influence on maintenance, e.g. the production, the asset, the digitalisation, the company's characteristics as well as maintenance itself (Figure 2). Gradations were defined for each category, consisting of individual elements [15]. For each element, characteristics were specified, based on benchmark surveys, project acquisition and extensive literature research. Based on these fundamentals, a profile was created for each industry branch, which should already give the company a direction for the criteria definition workshop. Figure 2 represents an example of such a morphological box for the steel industry. Especially the degree of digitalisation must be queried on a company-specific basis, as it is fundamental for the asset evaluation as well as for the criteria used for it.

Category	Charactaristic	Markedness				
Company	**Industry branch**	Automotive	Steel industry		Energy	Paperindustry
	Company size	>500 employees	50-500 employees		<50 employees	
Production	**production type**	one-of-a-kind production	Single-/Small manufacturing		Series production	mass production
	Degree of automation	no	medium		high	
Maintenance	**Budgeting**	static	dynamic		past orientated	risk-tolerant
	Maintenenace strategy	reactive	preventive		predictive	perfective
Asset	**Average asset age**	>5 Years	5-20 Years		>20 Years	
	Asset availability	>98%	98-95%	95-90%	90-80%	<80%
	Degree of utilization	> 95%	95-90%	90-70%	70-50%	<50%
Digitalisation	**Degree of digitalisation**	high	medium		low	
	Data quality	very good	good		sufficient	insufficient

Figure 2: Example of the morphological box for criteria definition

If the data quality is very good, a dynamic asset evaluation can be used. If the data quality is barely sufficient or bad or if no data exists, only a static asset evaluation must be applied. The consequence of this is that only qualitative criteria can be used for the evaluation, whereby the human influence and the assessment's effort are higher and therefore a stricter approach for the evaluation must be used to reduce human failures to a minimum. Qualitative criteria can be described subjectively, because these are undetermined numerical values and can only be measured to a limited extent [16]. Quantitative criteria are numerical values and additional data from measurements are used, which in turn contribute to the production of information. In the best case, these criteria are drawn from the ERP system by real-time interfaces, which are used to dynamically adapt the maintenance strategy and to reduce the human influence and the related faults (Figure 3) [2].

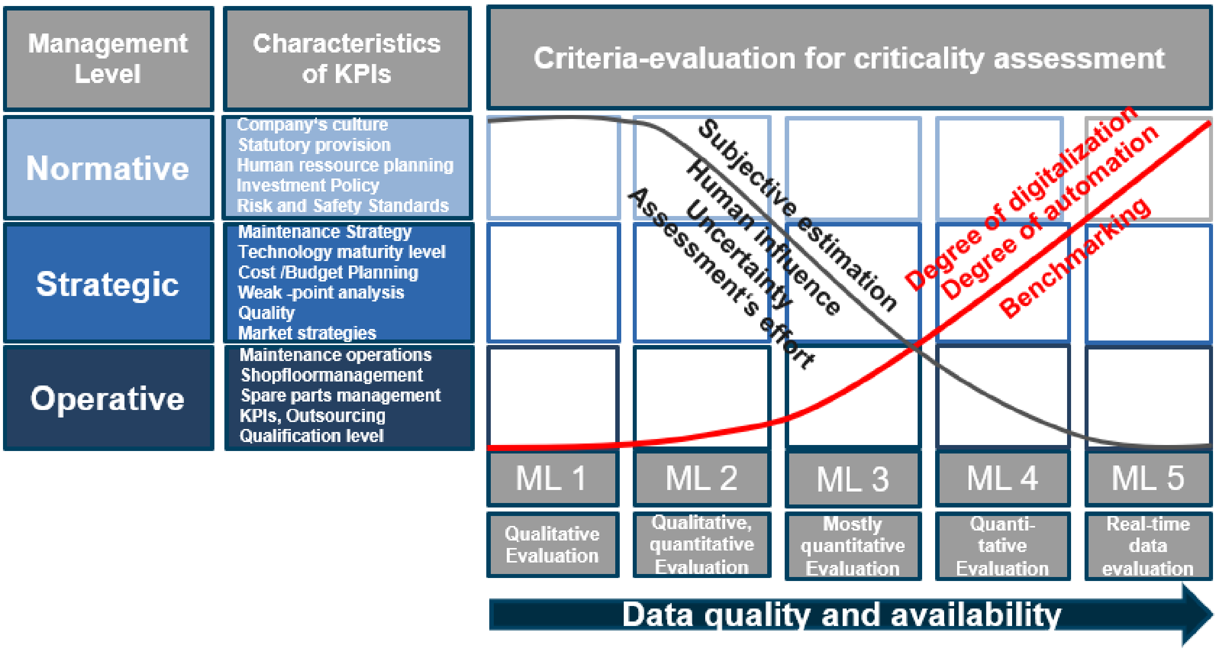

Figure 3: Maturity Assessment Model for criticality analysis

For the criteria selection a maturity assessment, based on a questionnaire is used. As a result of it, a company gets its maturity level for the criticality analysis as well as a list of criteria that are suitable for the asset evaluation. The higher a company's data quality is, the less qualitative criteria are used. In this case, the assessment helps to replace necessary qualitative criteria by quantitative ones. As a result of the questionnaire response, a list of criteria that represent the success factors of a company as well as the biggest influencing factors on the asset's availability is generated.

In the next step, a definition for each criterion as well as respective gradations (low, medium, high) to provide a uniform understanding of the criteria and the weighting of the criteria to complete the preparatory phase for the criticality analysis must be set during a workshop. For a better understanding, if one criterion is the availability of the asset, a definition of high, medium and low availability in terms of moderate numbers have to be considered. A numerical value is then stored for each of these states of expression, which, after a successful evaluation, delivers the asset index, the evaluation's result [17]. Once the assessment preparations have been completed, the assets can be rated based on the previously defined criteria. In the best case, if the data quality is high, this step is carried out automatically [2].

2.2 Criticality-analysis

The criticality analysis includes three steps: the criteria evaluation, the creation of an asset portfolio for the identification of cost-critical or risky assets and the detailed asset analysis of critical ones [2]. In the first step of the asset evaluation, the plants are evaluated based on the criteria defined in the previous steps, cost and critical ones are identified and measures to reduce cost or/and risks are deduced [14].

Asset-evaluation

In the step of the asset evaluation, an integral part of the implementation phase of the HAZOP approach, the assets are rated based on the predefined criteria. In the best case, this step is carried out automatically. The result of the asset valuation is the asset index for each of the assets valued. The higher the asset index, the more critical an asset is classified [18].

Identification of most critical assets

For the visualisation of the most critical assets an asset priority portfolio is used, in which the asset index is compared to the direct maintenance costs (Figure 4) [2], [16]. The portfolio is divided into 4 quadrants. Depending on the situation of the assets in the portfolio detailed cost or/and risk analysis must be performed. Assets above the cost line are classified as cost critical. For these assets, cost reduction should be achieved with little to no risk increase. Assets to the right of the index line are classified as risky. The most critical assets are placed at the top right, as they are classified as critical in terms of both costs and risk. In contrast, the assets on the top left or bottom right have only one critical influencing factor, either cost or the risk. The aim should be to shift all critical assets to the left bottom, the uncritical quadrant, by deriving the appropriate maintenance measures and adjusting the maintenance strategy [11], [18].

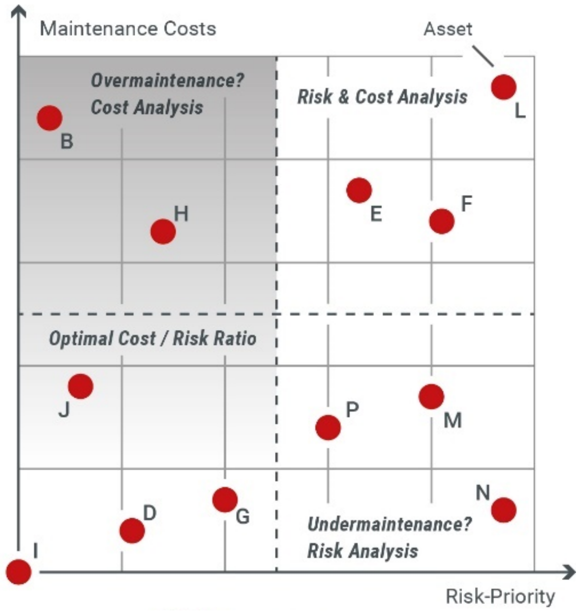

Figure 4: Example of an asset priority portfolio [modified 13]

The next step is to examine the assets identified as critical in detail and try to adjust the maintenance strategy by taking the defined measures into account for the risk and cost reduction, starting with those that have two critical influencing factors [18].

Cost- and risk analysis

In this step either cost or critical assets are analysed in detail by looking at each criterion and its deviation from the target value. Afterwards, the reasons for this deviation are analysed in detail and the consequences of such a deviation are considered. Therefore, all deviations, as well as current and potential risks of the critical assets, are assessed based on three dimensions and their predefined gradations: the extent of damage, the occurrence frequency and the probability of detection (Table 1).

Table 1: Example of definition of keywords

Extend of damage	Occurrence frequency	probability of detection
low	unlikely	very high
noticeable	rare	high
high	occasionally	low
critical	Several times	unlikely
catastrophic	frequently	highly unlikely

For the gradation of each dimension, a qualitative description has to be created and concrete examples are used to show its plausibility (Table 2).

Table 2: Example of a qualitative description of keywords

Probability of detection			
Appraisal	**Qualitative description**	**Example**	**weight**
very high	Errors are almost always detected in time	Sensor technology detects errors in the system/asset	1
low	Errors are rarely detected in time	Errors detected by a machine operator	3

In the next, the Risk Mode and Effect Analysis (RMEA) is used for the risk evaluation. As a result, the Risk Priority Number (RPN) is formed as a product of the previously defined three dimensions (extend of damage, occurrence frequency, probability of detection), which represents the degree of risk of the asset [18]-[20]. The aim is to reduce the risk per asset to a minimum and to increase the value-added contribution of the company by defining measures for its reduction [2], [16].

For the detailed cost analysis, the costs are divided into their cost types and the largest cost drivers are identified. For both analysis-types, cost or risk-reduction measures are derived and the savings potential is considered. This regular automated system evaluation as the basis for detailed analysis enables companies to react more quickly to deviations, derive measures and thus permanently reduce costs and increase the availability of the systems. [17].

The derived tasks form the basis for the maintenance strategy adjustment, which in the best case should be carried out dynamically in the same way as the criticality analysis.

2.3 Adaption of the maintenance strategy

Based on the detailed analysis, the asset-specific maintenance strategy mix can be adapted [1]. By combining different maintenance strategies, it is possible to obtain a balanced mix that determines the optimum for the company concerned.

The following maintenance strategies are used to create the optimum strategy mix: reactive (failure-oriented), preventive, predictive (condition-based) and perfective (asset improving) [1], [2], [18]. By optimizing the maintenance strategy mix, both technical and cost-intensive weak points as well as organisational ones, which have been identified in the analysis phase, are eliminated. By adapting the maintenance strategy, changes can occur in the areas of maintenance resources, which can be differentiated into personal, structural and relational capital [18]. These changes can include the elimination of inefficiencies through adaptation of the maintenance process, the introduction or expansion of autonomous maintenance, the introduction of new technologies like Big Data Analytics, Simulation, etc. Furthermore, the qualification of the employees is very important and is essential to invest in facilities or to replace some of the old ones. An optimization of the spare part management is also part of the changes, as well as changes in the allocation of external services and also in the structural and/or process organisation [1], [18].

A cost/benefit analysis checks whether the costs incurred by the affected asset are justified in relation to the benefit. If unfounded, highly preventive and/or reactive costs become apparent, either the underlying activities or the biggest cost drivers must be identified. Afterwards, organisational measures can be derived like e.g. adjustment of the maintenance and inspection intervals, outsourcing of activities, employee trainings [1], [2].

In the sense of digitalisation and industry 4.0 the qualification of employees will become more important. The complexity of the assets will increase and the automation, as well as the heterogeneity of the asset park will rise. As a result, the working environment and requirement profiles of maintenance personnel will change in the future. To prevent loss of knowledge and to live a learning and knowledge-oriented maintenance, which is part of the LSM aspect, early competence development is indispensable as well as standardized approaches.

In order to see how the strategy optimization affects the cost- and risk level a simulation by optimizing the asset data used for the evaluation can be done and the shift in the portfolio due to it can be made visible. The simulation is used for trend analysis and as a decision support tool for several adjustment possibilities and helps to identify the best asset specific strategy.

2.4 Performance review

In order to check whether the strategy adjustment has been successful and whether the simulation has made the correct prediction, it is important to perform the asset valuation continuously and check the shift of the assets in the portfolio. If there has been no improvement in the risk or cost-level of a critical asset, the assessment should be carried out one more time and the derived measures must be questioned and further measures derived in order to permanently improve the state of indictment [18], [17].

The fact that many of the steps in the criticality assessment can be carried out automatically based on good data quality means that the resources required for this are minimal. Furthermore, this standardized procedure and standardized documentation ensure traceability throughout the entire assessment.

3. Conclusion

The more complex and diverse assets are, the more important it is to have a standard to dynamically adapt the maintenance strategy, due to the changing environmental and production conditions and to secure knowledge by using a standardized approach and documentation. Therefore, the criticality analysis can on the one hand help to significantly reduce the effort and create a standard independent of the data quality and, on the other hand, reduce the human factors influencing such maintenance decisions and to create a more objective and comparable evaluation by automating the evaluation step of the assessment. The good thing about this approach is, that the higher the data quality the more automated it can be carried out and the fewer human failures will occur. Another advantage of good data quality is that the optimization of the strategy can be simulated and thus forms the basis for trend analysis.

Therefore, the criticality assessment, which is based on the LSM concept, offers a good opportunity to optimize the efficiency and effectiveness over the entire life cycle of an asset through targeted plant-specific cost- and risk-reduction and, accordingly to lower the cost duration and increase availability through continuous improvement.

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Biography

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