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Case Study: Smart Maintenance Maturity Assessment As A Starting Point For Achieving Reliability And Safety In The Oil And Gas Industry

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Abstract

Industry 4.0 and Smart Maintenance represent a great opportunity to make manufacturing and maintenance more effective, safer, and reliable. However, they also represent massive change and corresponding challenges for industrial companies, as many different options and starting points have to be weighed and the individual right paths for achieving Smart Maintenance need to be identified. In our paper, we describe our approach to evaluating maintenance organizations in a case study for the oil and gas industry, developing a shared vision for the future, and deriving economical and effective measures. We will demonstrate our approach, by showcasing a specific example from the oil and gas industry, where a need for action on HSE-relevant critical flanges in the company's piping systems was identified. We describe the steps, that were taken to identify the need for action, the specifications of the project and the criticality analysis of the piping system. This resulted in the derivation of a digitalization measure for critical flanges, which was first commercially analyzed and then the flanges were equipped with a continuous monitoring solution. Finally, a conclusion is drawn on the performed procedure and the achieved improvements.

Keywords

Online Condition Monitoring; Reliability; Safety; Oil and Gas Industry; Smart Maintenance; Maturity Level Models

1. Introduction

For decades, the importance of maintenance has been increasing as the basis for competitive management of production facilities used in-house and beyond [2,1]. The demands placed on maintenance are manifold. These include ensuring high performance of the production facilities, ensuring safety, maintaining the plant inventory, and constant knowledge retention and information generation for the further development of the plants and the organization. In addition, it is (co-)responsible for the fulfillment of internal and external regulatory requirements. The diverse requirements and tasks are also reflected in the design and embedding of maintenance within the company and have led to an increasing number of scientists dealing with maintenance for 30 years and researching how the interaction of maintenance with other functions within and outside the company is to be designed [2,1]. Industry 4.0 and Smart Maintenance lead to new requirements, but also opportunities, in terms of collaboration, effectiveness, and efficiency in maintenance [3]. Industry 4.0 provides high data volumes in real-time for multilateral communication between machinery and people, for improved data-based decision processes and multi-stakeholder interchange [4]. As a service

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department providing technical services for the company, maintenance is characterized by numerous interdependencies with internal and external stakeholders. Therefore, maintenance can only be considered in the context of its stakeholders since mutual influence is a constituent feature of the department. The previous maintenance management concepts represent only partial aspects in their description of maintenance. For example, they focus on the process organization of the maintenance or service organization [5,2]. Other models or case studies have other reference points, focusing for example on stakeholders for the wind power industry, the machinery and equipment to be maintained in the context of Industry 4.0 [6], and other specific processes or viewpoints [7].

2. Smart Maintenance Assessment and Roadmap

FIR at RWTH Aachen developed the so-called "Maintenance Check" as early as 2001 to evaluate, compare and further develop maintenance organizations [11]. In recent years the approach was further augmented to make the assessment more and more comprehensive and complete through various research and industry projects. At the same time, the influence of digitization became more important for the industry. By combining the assessment approach with the *Industry 4.0 Maturity Index* the capabilities of industry 4.0 could be integrated into the maintenance assessment [4]. The result is a comprehensive assessment with over 500 questions, which provides a well-founded and detailed 360° view of the current status in just a few days and which can provide approaches for the further development of your organization. This is divided into 4 phases, which are iteratively run through at intervals of several months or years (shown in Figure 1).

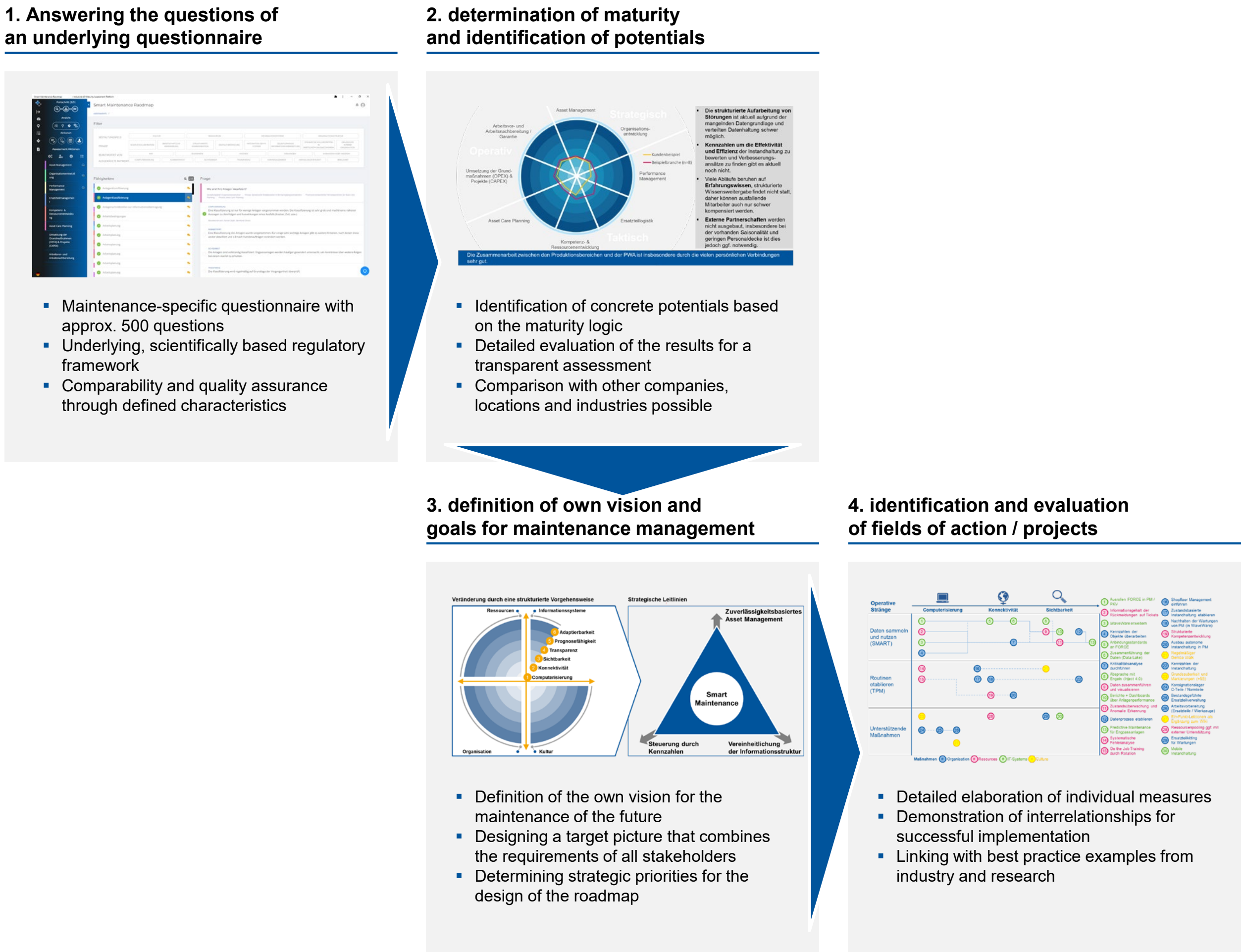

Figure 1: Assessment of maintenance and derivation of a roadmap

3. Research Design

Case Study Research enables the in-depth study of a lifelike phenomenon, taking into account its environmental influences, which, unlike an experiment, are not delimited or controlled [8]. The research methodology has been around since the beginning of historiography and is widely used in a variety of scientific disciplines [9]. The consideration of different research designs within the case study research makes it possible to increase the validity of the conducted investigation [8]. Yin's research design seems to be the most suitable to extend the existing approaches. It consists of the steps: plan, design, prepare, collect, analyze and share [10]. The planning phase has already been accomplished through the explanation of the research design in section 2. The design and preparation phase are completed by the explanations in section 3 about the applied method. The collection and analysis of the data, through the subsequent description of the procedure, as well as the explanations in section 4. Peer sharing and discussion is the motivation for this paper.

4. Case Study: Smart Maintenance in the oil and gas industry

To illustrate the approach, we chose a case study from the oil and gas industry, where we will focus on one specific challenge and use it to highlight the steps and link it to a specific outcome. The refinery operates around 500.000 flanges, 300 km of piping, and many other leak critical assets. Around 10 % of those assets can be defined as critical enough to justify a higher maintenance focus. In this instance critically is defined by the medium that is being processed within them, operating pressure, or due to other external factors like mechanical influences. Pipe joints like a flange have an increased risk. Flange leakage is dependent on the size, quality of inspection and preventive maintenance measures.

4.1 Step 1: Site visit and structured expert interviews

The assessment includes a structured questionnaire to analyze the characteristics of the maintenance department. The questionnaire follows 8 main categories, which are based on the processes of maintenance: *Asset Management, Organizational Development, Performance Management, Spare Parts Management, Competence & Resource Management, Asset Care Planning, OPEX & CAPEX Process, Work Order / Warranty Management*. Each question is linked to a maturity level and is described which requirements maintenance has to fulfill to reach the corresponding maturity level (shown in Figure 2).

In the conducted interviews, Gemba walks and data analysis for the oil and gas plant it was shown, that one major safety and production issue were leakages of flanges. Leakages are a maintenance-relevant issue because they can lead to serious consequences that affect the safety of employees, the environment, and the plant itself. This is especially true for flammable liquids and gases that can form explosive mixtures with air. Besides the safety-related consequences, leakages come with directly accountable costs like loss of medium, pressure energy, or heat energy. Leakages on the other hand that can be repaired during planned downtime for regular maintenance do usually not create additional costs. Planned downtimes are usually factored into the operational costs of a plant. Leaks can be classified in different severity grades which increase over time if no counteractions are taken. Every hour a leak goes unnoticed, environmental issues like water contamination and respective consequences become more probable. Also required repair efforts and probability of unplanned downtimes increase over time.

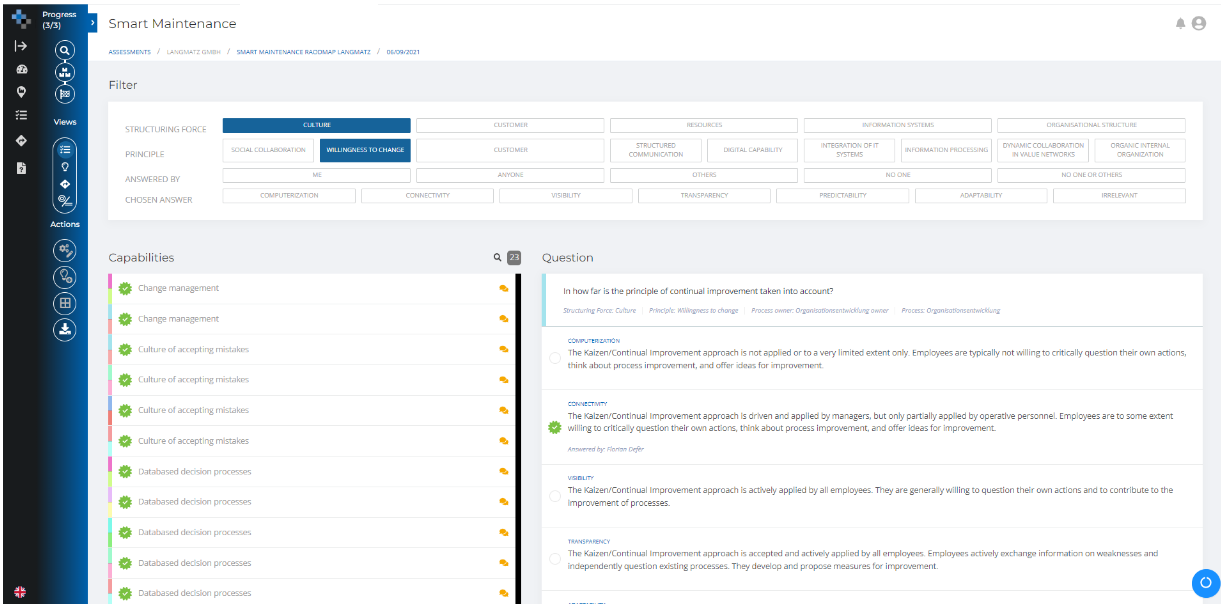

Figure 2: An analysis tool for maintenance assessment (example)

4.2 Step 2: Determination of the maturity level and identification of potentials

Determining the degree of maturity results in focal points that should be addressed first. Our experience shows that also in maintenance, the weakest link in the chain disrupts the other processes and prevents an optimum. For example, the organization can have the most advanced maintenance planning, but if the spare parts management cannot provide the parts at the right time and in the right quality, the plan will fail (s. Figure 3).

Figure 3: Assessment of the maintenance organization

Several aggregation levels of the assessment in combination with concrete examples provide a comprehensive overview of the current status quo and illustrate the results for all levels and stakeholders of the organization. In the next step, this enables a comprehensive starting point for building a vision and concrete goals for the maintenance organization in the coming years.

Based on the evaluation and in the interplay of the other challenges, the flanges were judged to be sufficiently critical to conduct a detailed analysis. The influence is thereby divided into three categories, which also depends on the intensity of the leakage and spilling:

- **HSE:** Health, Safety, and Environmental issues arise due to the spilling of hydrocarbons into the environment. For the safety of the operators and maintenance personnel, there is an increased hazard of slipping of personnel if there is spilling of the liquid medium of the piping system. With the leakage, there is also an increased risk of fire, depending on its substance properties. Due to the contamination of the soil, air, or surrounding health and environmental issues can arise by the leakage as well. A refinery can emit more than 600.000 tons of volatile organic compounds per year from leaking equipment and in more than 90% of these cases, the connecting flanges are accountable for this.
- **Operations:** The operational impact of leakage impacts the yield and maintenance of the plant. Depending on the production location of the critical flange there could be a loss in product or material. Impacts on the OEE (overall equipment effectiveness) could also arise from the maintenance task to repair the leakage if the piping system needs to be shut down and there is no opportunity for a quick fix. Direct costs arise from the maintenance task, including the costs for labor and spare parts, and clean-up of the spill.
- **Asset Management:** Long-term effects of the leakage could negatively affect the object substance. The fluid contamination of the outside of the piping and flange could lead to an increase in chemical corrosion, which would decrease the rest of the useful lifetime (RUL) of the impacted asset.

There are a lot of factors that could have an impact on the effectiveness and efficiency of the plant, but not all of them are very likely or relevant. Additional matters of HSE and object substance are usually hard to link to certain objects or events and therefore hard to quantify. Since there are already measures in place to improve the reliability of flanges and piping the calculation will focus on the cost of the unmitigated risk and include the maintenance service, which is already in place in step 4.

The estimation of the unmitigated risk of leakages for production loss and maintenance cost was calculated as shown in Table 1.

Table 1: Calculation of the unmitigated costs per year

Description	Calculation	Remarks
Number of flanges per year	4 flanges p.a.	Selected critical flanges leak on average once in 25 years this means each year 4 out of 100 critical flanges leak
	*	
Production cost	(48,000 $	A leak causes 12 hours of unplanned downtime to repair the flange. One hour of unplanned shutdown costs ~$ 4,000/h.
	+	
Maintenance cost	2,600 $)	Repair takes 8 person-hours at personnel costs of ~$ 75/h and causes material costs of ~$ 2,000 for emergency repair and spillage cleanup.
	=	
Summary p.a.	**202,400 $**	

4.3 Step 3: Definition of own vision and goals for maintenance management

The analysis can be used to set priorities and define which points should be given the greatest attention by maintenance and its stakeholders. In particular, the consolidation of information and processes in maintenance represents a large untapped potential that is underestimated by most companies. By defining the strategic guidelines, concrete measures can be developed and combined in a roadmap.

In the case of the oil & gas company, besides production cost and yield, there are two main drivers for the future of the maintenance organization that all other goals must be subordinated.

- **HSE excellence:** Especially in the oil & gas industry the environmental impact due to spillage and leaks is beyond the actual damage to the environment, but linked to bad publicity, increase in regulation, and so on. In recent years there were also major safety incidents, that were so severe that they hurt the industry in terms of the perception by society and the immediate neighborhood.
- **Skilled labor shortage:** Another big driver is the decrease in the skilled labor force due to an aging society, which leads to a decrease in the working-age cohorts. Also, technical labor is increasingly out of fashion and younger generations focus more on office jobs, which leads to a decrease in trade apprenticeships.

For the applicable solutions, the main drivers should be automation and continuous measurement, to provide a maximum of reliability with a minimum of bound personnel.

4.4 Step 4: Identification and evaluation of fields of action and projects

Specific measures can be derived and weighted from the goals of the individual organization. In this context, many measures are closely technical related to each other and should therefore be addressed in a specific order regardless of their direct added value. For example, one basis for efforts towards condition data analysis is that a criticality analysis has been performed so that the right asset can be focused on and the basis in terms of infrastructure can be provided with reasonable cost (s. Figure 4).

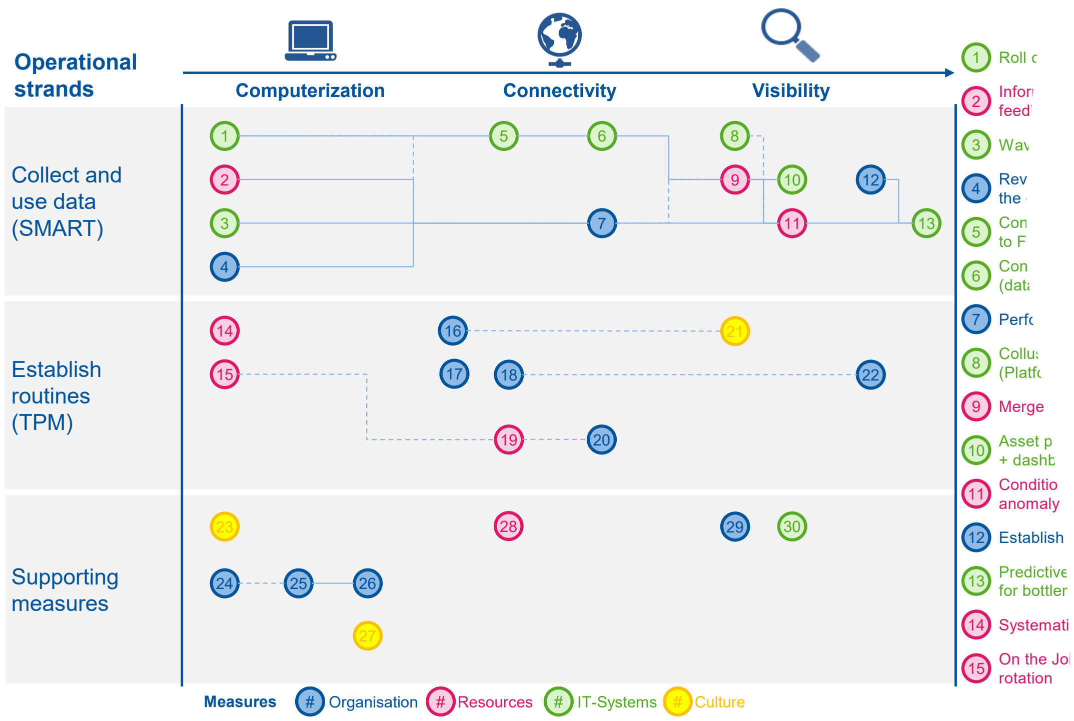

Figure 4: Roadmap for customer companies (example)

The different colors in the future categorize the focus of the measures, i.e. whether the focus of the measure is more organizational, technological, etc., although there is of course always overlap in complex measures. In our research and conducted assessment, we observed the trend, that usually organizational and cultural measures lay the basis for sustainable change, before being supported by technological measures. By weighting and structuring the measures, a long-term program can be set up to optimize maintenance. Often, a separate project or program structure with regular deadlines, resources, budget, etc. must be set up for this purpose.

The goals and the initial situation of the oil & gas company have shown that there is an imperative need for inspections. The current solution and routine use a visual inspection of the critical flanges every week. This technique has some merits and drawbacks, especially with a focus on continuous and reliable hydrocarbon leak detection. Real-time leak localization and estimation of the leakage rate are important as they will facilitate spillage containment and allow predictive maintenance strategies at an early stage to avoid serious damage to the environment. One pragmatic way to achieve this goal is through the implementation of a certain number of leak detection sensors in a sensor network between the upstream and downstream of the piping system. By doing so, it will be easy to identify the position of leakage and thus improve the ability to see and track information when a sensor acquires anomalous data.

A market study on automated solutions was conducted to explore and evaluate options. The market study showed that Henkel AG & Co. KGaA has one solution that is specified for online condition monitoring for hydrocarbon leak detection. The LOCTITE® Pulse Smart Flange solution is based on innovative carbon nanotube-based hydrocarbon sensors. The retrofit sensors are placed non-intrusively within the flange gap in combination with secondary containment (see Figure 1). The secondary containment helps to prevent the medium from leaking into the environment for a certain period. The sensor can detect leakages in almost real-time and can be leveraged to monitor critical sections of pipes notifying the operator through an app and email notifications. Continuous digital documentation of the asset status and its accessibility increase transparency and reveal the potential for improvement. Therefore, the integrity of every leak critical asset can be monitored continuously. Leakages can be repaired when they have not yet developed into more severe leakages. This helps operators to prevent costly unplanned downtimes and risky consequences that might develop from a leak. On the other hand, the solution may reduce the required efforts for manual inspection, while increasing the inspection quality.

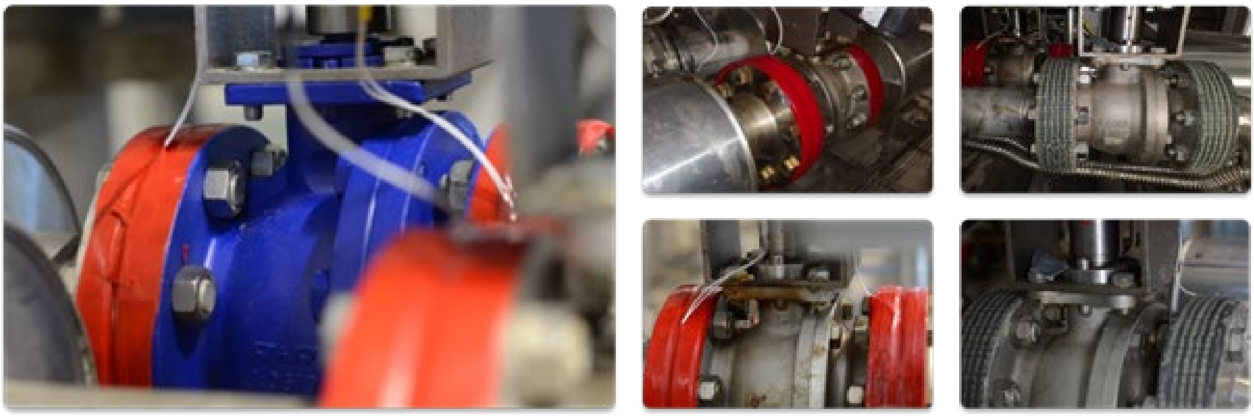

Figure 5: LOCTITE® Pulse Smart Flange installation examples

4.5 Phase 5: Implementation and performance review

The advantages of online condition monitoring may be immense from a cost-savings perspective and include minimizing planned and unplanned downtime, maximizing the lifetime of a piping system, optimizing maintenance strategies including the productivity of employees and increasing asset productivity. With the help of online condition monitoring, it is possible, to find the optimum between early leak detection on the one hand and costly repairs, production losses and unplanned downtime on the other hand. New sensor systems can now be retrofitted without the need to stop the plant or integration into legacy control systems. Thus, enabling data-based maintenance approaches to apply for assets, in this case, piping systems and here, especially flanges, that have been offline in the past. This technological shift allows to deviate from the reactive (run-to-failure) strategy in favor of data-based predictive maintenance which affects five key value drivers for plant operators described in the following.

1) Contribution to increased safety:

The greatest added value of continuous monitoring of critical flanges is certainly the contribution to increasing plant safety. Continuous monitoring in real-time enables early detection of leaks even before they can progress significantly and thus pose a considerable safety risk. It thus provides an additional level of safety in addition to existing systems and processes. In addition to the obvious added value in terms of health and safety risks, this can also result in an economic advantage, as the cost of insuring against safety-related incidents may be reduced.

2) Contribution to the reduction of environmental risks:

In addition to health and safety risks, another key added value of continuous and real-time monitoring of critical flanges is its contribution to reducing environmental risks. By preventing major leaks, damage caused by the release of critical substances into the environment can be reduced. This helps the environment and reduces the risk of reputational damage.

3) Contribution to the reduction of production losses:

In addition to the positive contribution to plant safety, the greatest economic added value of continuous monitoring of critical flanges for most plant operators is the contribution to reducing production losses. By detecting leaks in progress at an early stage, repairs can be planned, thus reducing downtime and/or quality losses in production. With hourly opportunity costs in the four- to the five-figure range, significant costs can be reduced by shrinking downtime in general and converting unplanned downtime to planned downtime. For a mid-size refinery, this can mean cost savings up to high six to mid-seven figures per annum.

4) Contribution to the reduction of inspection, documentation and repair efforts:

Another positive economic added value of continuous monitoring is the contribution to the reduction of inspection, documentation and repair efforts. Even though existing processes and systems for monitoring critical flanges should not be completely replaced by a continuous monitoring solution such as the Smart Flange, the solution offers the possibility of reducing previous efforts. For example, inspection intervals can be extended. In addition, the costs for repairs may be significantly reduced by early detection. Last but not least, efforts for manual documentation can be reduced by digital and automated data collection. For a medium-sized refinery, this, in turn, can result in cost savings of up to a mid-six to low seven-figure amount per annum.

5) Contribution to increased transparency:

An often overlooked and underestimated added value of continuous monitoring of critical flanges and other assets lies in their contribution to increased transparency. The continuous collection and analysis of data makes it easier to identify weak points and uncover possible correlations. This makes it easier to learn from failures and to contribute conclusions for avoiding future errors – in this case, especially leakages. The use of the solution investigated will be rolled out further, with suitable processes being developed together with the FIR to be able to use the information in the best possible way for the maintenance of the plants. The use of the solution proves to be simple and appropriate to the challenge so that the implementation should not pose any major challenges.

5. Conclusion

The open-solution survey of the individual challenges of the various stakeholders and the derivation of a common problem definition proved to be the best way to achieve the greatest added value for the organization. Our holistic maintenance assessment approach is a valuable tool for the manufacturing industry to leverage the efforts of data and technology. The focus is always on maximizing the effectiveness and maintenance in the context of the other stakeholders and their specific objectives (e.g. safety, product quality). A variety of technical and methodological approaches are available for this purpose and need to be considered without jumping to conclusions.

Digital solutions represent a significant lever for the industry to proactively respond to rising costs and labor shortages. In the asset-intensive industries, in particular, it is important to offer solutions that can be integrated into existing production environments in a user-friendly manner and with little effort. The ability to offer scalable solutions so that plant operators can gain their own experience and employees can be appropriately involved along the implementation journey is a great tool for the efficient and sustainable digitization of the industry.

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Biography

Prof. Dr. Günther Schuh holds the Chair of Production Systems at the Machine Tool Laboratory (WZL), is a member of the Board of Directors at the Fraunhofer Institute for Production Technology (IPT), Director of the Research Institute for Rationalization e. V. (FIR) at RWTH Aachen University and head of the Production Technology Cluster. He is the founder of the Schuh & Co. group of companies based in Aachen, St. Gallen and Atlanta.

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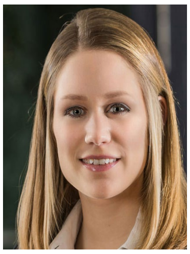

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Prof. Dr. Volker Stich has been head of the Institute for Industrial Management (FIR) at the RWTH Aachen University since 1997. Prof. Dr.-Ing. Volker Stich worked for 10 years for the St. Gobain-Automotive Group and lead the management of European plant logistics. In addition, he was responsible for the worldwide coordination of future vehicle development projects.

Dr. Kourosh Bahrami is Global SBU Head for General Manufacturing, MRO and Vehicle Aftermarket at Henkel Adhesive Technologies. He joined Henkel more than 20 years ago and had several P&L accountabilities in B2B business as well as in Supply Chain B2C-Business.

Dr. Michael Honné is building up, as Head of MRO 4.0, a new digital business within Henkel Adhesives Technologies. Before joining Henkel in 2020, he worked for the plant manufacturer thyssenkrupp Industrial Solutions, where he was responsible for the Global Service.