APPLICATION OF PERFORMANCE-BASED MAINTENANCE IN LEAN PRODUCTION SYSTEMS

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Abstract: *Over the past several decades maintenance became a critical contributor towards achieving the strategic objectives in a typical industrial company. Traditionally, outsourced maintenance services are delivered transactionally, meaning that company pays for services provided. Emerging trend is to change from cost of maintenance services to value and performance. Performance-based maintenance is a concept where the performance measures are defined related with structured monetary incentives rather than the process to achieve results. By this performance-based maintenance approach motivates service providers to implement effective maintenance practices to achieve results at lower cost. The paper clarifies the application of performance-based maintenance in performance-oriented companies such as lean production systems. Furthermore, paper outlines global industry trends enabling more widespread application of performance-based maintenance: servitization, industrial digitalization, and circular economy.*

Key words: performance-based maintenance, servitization, industrial digitalization, circular economy

1. INTRODUCTION

Industrial companies are facing increasing challenges in terms of operating costs optimization, innovative technologies implementation and more demanding environmental regulations. Together with product commoditization and the competition from low-cost economies it becomes very difficult to maintain competitive advantages.

Over the past several decades maintenance has become a critical factor to meet business objectives and maintain a competitive edge. To maximize productivity companies must achieve the right performance from their production equipment. At the same time, companies are focusing on their core business activities, increasingly requiring maintenance services suppliers to provide more comprehensive solutions rather than individual service offering.

Traditionally, outsourced maintenance services are delivered transactionally, meaning that company pays for services provided. While some companies are sensitive to maintenance services costs for others such as lean production systems achieving performance outcomes is the top priority. In these companies there is an understanding that the costs related with premature or unexpected failures, such as lost production, loss of reputation, and penalties for late deliveries, are usually much larger than the actual repair costs of the failure.

Performance-based maintenance emerged as a new maintenance concept and received much attention in performance-oriented companies. With this approach performance results are contracted instead of paying for the materials and labor consumed in a maintenance process. At the same time service providers are incentivized to achieve performance goals at lower cost by decreasing the equipment total cost of ownership.

The paper clarifies the application of performance-based maintenance in performance-oriented companies such as lean production systems. Furthermore, paper outlines global industry trends enabling more widespread application of performance-based maintenance: servitization, industrial digitalization, and circular economy.

2. MAINTENANCE IN LEAN PRODUCTION SYSTEMS

Lean principles and practices application including lean approach to maintenance are considered a necessity for success in today's competitive marketplace. Even companies focus more on the production

optimization by applying lean principles, lean approach to maintenance should be considered as a prerequisite for lean manufacturing.

Lean maintenance is defined as "*a proactive maintenance operation employing planned and scheduled maintenance activities through total productive maintenance (TPM) practices using maintenance strategies developed through application of reliability centered maintenance (RCM) decision logic and practiced by empowered (self-directed) action teams using the 5S process, weekly Kaizen improvement events, and autonomous maintenance together with multi-skilled, maintenance technician-performed maintenance through the committed use of their work order system and their computer managed maintenance system (CMMS) or enterprise asset management (EAM) system. They are supported by a distributed, lean maintenance/MRO storeroom that provides parts and materials on a just-in-time (JIT) basis and backed by a maintenance and reliability engineering group that performs root cause failure analysis (RCFA), failed part analysis, maintenance procedure effectiveness analysis, predictive maintenance (PdM) analysis, and trending and analysis of condition monitoring results*" (Smith, 2004).

Effectively operating total productive maintenance is identified as the foundation of lean maintenance (Smith and Hawkins, 2004). It is also noted that implementing lean maintenance without total productive maintenance as a foundation would be difficult. However, authors also identified foundation elements of successful maintenance which should be implemented to achieve lean maintenance including planning and scheduling, documentation, work order system, computerized maintenance management system, predictive maintenance, and the root cause failure analysis.

Total productive maintenance program is driven by the concept of overall equipment effectiveness, which requires strict attention to the measurement and quantification of the major losses. According to that in lean production systems there is a strong focus on performance measures.

During the years different roadmaps are proposed to apply lean thinking in a maintenance processes (Sherif et al., 2015), as well as industry case studies of the lean maintenance methodologies application (Clarke et al., 2010). Even competitive advantages gained from successful lean principles and practices application in maintenance processes are easily justified it still seem like a daunting task.

Successful lean maintenance implementation depends on a comprehensive set of knowledge and skills, such as maintenance strategy development, spare parts optimization, or maintenance procedure effectiveness analysis. Predictive maintenance and operator inspection programs requires right technologies, together with processes and trained employs.

Considering all the above mentioned it becomes obvious that lean production systems are suitable for performance-based maintenance application. They need support from maintenance services providers, equipped with right technologies, processes and people for successful lean maintenance implementation and on the other hand they have clear performance indicators aligned with the strategic objectives throughout the whole organization.

3. PERFORMANCE-BASED MAINTENANCE

Maintenance is defined as "*combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function*" (BS EN 13306, 2018). Based on the definition maintenance can be performed in two major types: corrective maintenance undertaken after a breakdown, and preventive maintenance which is further divided on periodic time-based maintenance and condition-based maintenance. All traditional maintenance types are widely used in practically all industrial companies.

Performance-based maintenance emerged as new maintenance concept and received much attention in performance-oriented companies. Despite the examples of successful performance-based maintenance implementation in defense and aerospace industries (Kim et al., 2007), and in some manufacturing industries (Hypko et al., 2010) its widespread application remains in an early stage.

In general, maintenance service contracts could be divided in two main categories: resource-based contracts and performance-based contracts. Traditionally maintenance services are performed transactionally under the resource-based contracts. In this approach service providers are paid each time maintenance service is performed. Three types of resources-based contracts are commonly used in practice: fixed-price contract under which the maintenance service providers are paid with a fixed fee for labor and materials consumed, cost plus fixed fee under which customers pay for all resources consumed with a negotiated fixed fee added and cost-plus incentive under which customers are willing to provide some gain sharing. Maintenance service providers are often not well motivated to improve their services

under resource-based contracts, and instead they usually focus on how to minimize the costs and to increase the profits.
Emerging trend is to change from cost of maintenance services to value and performance provided. Performance-based maintenance is a concept where the performance measures are defined related with structured monetary incentives rather than the process to achieve results.
The goal of performance-based maintenance is to design and implement effective maintenance service program to incentivize the supplier to achieve predefined performance results and decrease the total cost of ownership while ensuring the reliability and availability of the equipment (Jin, 2018). With this approach equipment user define the performance measures related with company's strategic objectives. Service provider is focused to achieve predefined performance measures at lower cost, and motivated to even exceed performance goals as this relates with increased revenue.
Together with increased focus on total cost of ownership under the performance-based maintenance the responsibilities between service supplier and the equipment user are changing, with transferring more responsibilities to service supplier (Jin et al., 2022).
Performance-based maintenance service program can have different starting points and goals (Figure 1):

- product performance including product selection, application engineering services, root cause failure analysis or technical upgrades,
- asset performance including technical assessments, application or design reviews, maintenance and lubrication products, condition monitoring products, remote monitoring, remanufacturing services, and trainings or
- plant performance including assessment and benchmarking, plant reliability improvement, programs, maintenance best practices implementation, spares and inventory management and optimization.

Figure 1: Contracting performance starting points and goals

Performance-based maintenance provides benefits compared to traditional transactional approach to maintenance services contracting. The concept motivates maintenance service providers to implement effective maintenance policies to attain performance goals at lower cost by bringing their extensive experience and latest technologies.
Nevertheless, it can be challenging to develop and implement performance-based maintenance since both contracting sides should adapt to this significant shift compared to traditional maintenance services contracting. Developing effective maintenance program capable to achieve performance results could take time. In practice, it can take years of traditional cooperation before the relationship such as performance-based maintenance is mutually acceptable.

4. ENABLING GLOBAL INDUSTRY TRENDS

Ongoing global industrial trends fundamentally changes the conditions for maintenance service providers when developing and delivering innovative maintenance services. Following section will outline recent global industry trends which are having profound effect on increasingly widespread application of

performance-based maintenance: servitization, industrial digitalization, and shift towards circular economy.

4.1 Servitization

Servitization can be defined as the process of creating value by adding services to product offerings (Vandermerwe and Rada, 1988). The concept can be explained as a movement towards integrated systems of products and services to become more competitive.
Over the last decades across manufacturing industries there is a growing interest to integrate products and services (Annarelli et al., 2021). This can be explained with increased customer focus on the function of the products rather than the products itself.
Many manufacturing companies have been focusing on adding services to their products to gain competitive advantage. Those newly developed integrated product-service solutions are creating additional value and make it more difficult for low-cost competitors to compete due to the lack of additional knowledge.
Between a pure product manufacturer and a pure service provider, various business model options exist, in which products and services are combined to varying degree. Between the pure product and pure service integrated product-service offering could be product focused, use oriented or result oriented (Tukker, 2004).
The type and scope of products and services packages are limited only by the ingenuity and technological capabilities. SKF integrates the products, the technologies, and various services into an integrated Rotating Equipment Performance business model (Figure 2).

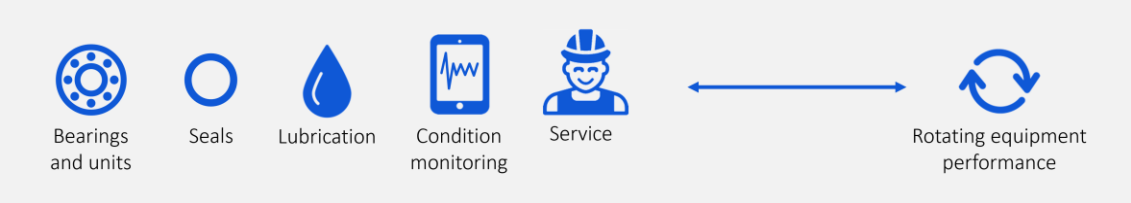

Figure 2: SKF product-service integration model

The objective of Rotating Equipment Performance business model is to maximize the reliability, performance of the machinery, and the production process tracked thru clearly defined key performance indicators. With access to application information, along with the integrated knowledge, technology products and service capability, this results-oriented approach purpose is to prolong the useful life of equipment while reducing the total cost of ownership.

4.2 Industrial digitalization

The ongoing “digital transformation” of manufacturing industries is influencing nearly every aspect of business. The maintenance function needs to take advantage of new developments in digital technology and the opportunities brought by industrial digitalization. Even though industrial digitalization is growing, most condition monitoring data is still collected manually for multiple reasons. This important fact indicates that there is still a lot of possibilities for further digital technologies adaptation.
SKF concept of digitalization in industrial maintenance applications can be broken down into four steps:

- connect: measuring or acquiring the right production equipment condition data, at the right rate, and then connecting to a host software,
- detect: establish a trend of data that describes normality and identify anomalies or alarms and its severity using automated algorithms and/or human expertise,
- inform: insights presented in dashboards or reports on the possible consequences of the diagnosis and when the failure may occur,
- improve: working together with the equipment user to act on resolving the issue, and avoid repeating, through a range of mechanical engineering technologies and services.

Condition monitoring is all about measuring physical parameters on an asset, that provide information about its physical condition. We need to have a range of data-acquisition devices: portables, wired and wireless installed systems, capturing condition data that indicates rotating asset health. Then establishing what is normal for that asset and detecting deviations from normal. The machine health alerts that are

the output of this process are then combined with other data and information. The data then needs to be managed, analyzed, and actionable information produced. That information then is shared, reported, and visualized, often in a key performance indicator (KPI's) dashboard (Figure 3).

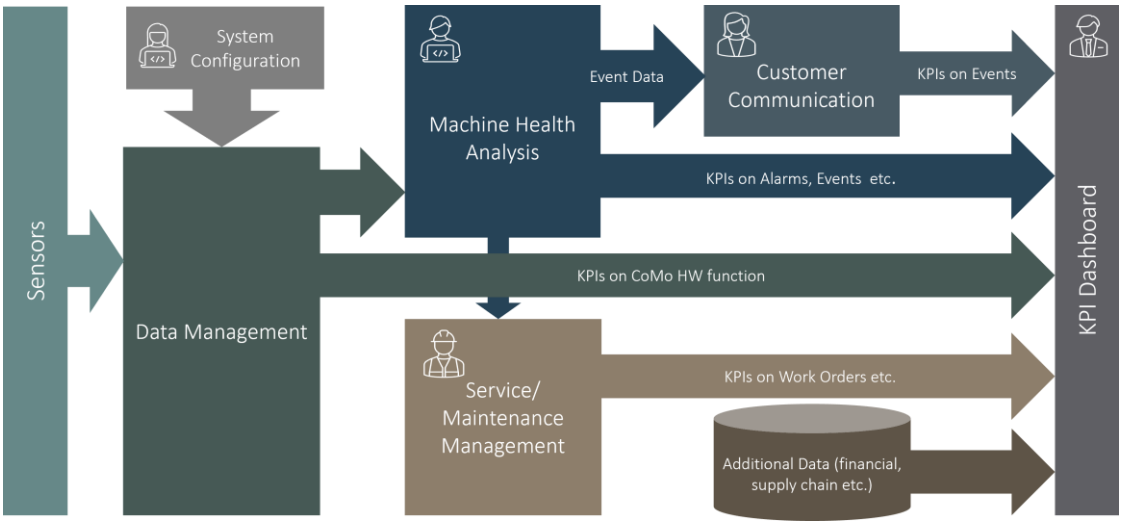

Figure 3: From sensors to dashboards

Ability to corelate equipment condition parameters measured by sensors with the company's key performance indicators will support more widespread application of performance-based maintenance in practice. Accordingly, ongoing industrial digitization should be considered as one of key enablers for performance-based maintenance.

4.3 Circular economy

Economy today has the major problems with that increased revenue also implies increased sales of products and use of resources. In a circular economy, there is no conflict between economic growth and environmental protection. The circular economy is gaining interest due to potential to align business and societal goals as it offers the opportunity to focus simultaneously on economic value creation and on the mitigation of impact on the environment.

All newly developed maintenance program should include maintenance services that recover resources, avoid generating waste, and provide the best quality and reliability to the customer.

SKF conduct two types of reconditioning services that help customers meet their climate goals and reduce their negative impact on the environment:

- remanufacturing of bearings which manages to reduce the carbon footprint compared to manufacturing a new one, consumes less energy and at the same time it is often the fastest way to replace a bearing due to failure and guarantees the same quality as the manufacturing process for new products,
- reconditioning of industrial lubrication oils offering reusing the same lubricating oil repeatedly while maintaining its essential additives, reducing the need for new oil, and by that reducing both costs and environmental impact, and generating emissions savings compared to the conventional process.

Reconditioning services are increasing the lifetime of production equipment, lowering the consumption of spare parts, and reducing energy consumption. Performance-based maintenance is supported by reconditioning services, as the total implementation cost for the service provider is lower. By that the concept is incentivized by business practices aligned with the principles of the circular economy, such as encouraging material resources circularity.

5. CONCLUSIONS

The paper identifies performance-oriented industries, especially lean production systems as suitable candidates for performance-based maintenance application, since they strive to implement lean

maintenance approach and have clear performance indicators aligned with the strategic objectives throughout the whole organization.
Performance-based maintenance provides benefits compared to traditional transactional approach to maintenance services contracting. The concept motivates maintenance service providers to implement effective maintenance policies to attain performance goals at lower cost by bringing their extensive experience and latest technologies.
The paper reviews topics of servitization, industrial digitalization, and circular economy, which are enabling and bringing new opportunities for more widespread application of performance-based maintenance.
Finally, it is important to state that performance-based maintenance program development could take time. In practice, it can take years of traditional cooperation before the relationship such as performance-based maintenance is mutually acceptable.

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