Towards a Framework for Predictive Maintenance Strategies in Mechanical Engineering – A Method-Oriented Literature Analysis

Nina Wiedemann[1], Friedemann Kammler[1], Andreas Varwig[1], and Oliver Thomas[1]

[1] University of Osnabrück, Osnabrück, Germany
{nwiedemann,fkammler,anvarwig,othomas}@uni-osnabrueck.de

Abstract. Industrial machines are amongst Germany's main export products and contribute to the increasing revenue of Mechanical Engineering. However, in the course of globalization, services for such machines have become costly and inflexible due to long distances between vendors and customers. Consequently, companies seek to avoid unexpected failures and long down times by the development of data-based "smart" service solutions, including Predictive Maintenance (PM). In contrast to reactive or preventive measures, PM refers to the proactive planning of required maintenance services based on data sampled from the machinery. Although PM has been conceptualized decades ago and various methods have been proposed ever since, there is no standard strategy. By analyzing existing literature, we shed light on the knowledge base in PM. We provide an overview of methods and discuss their respective context, including preconditions and applications. Our work constitutes a first step towards a framework that guides the implementation of PM-strategies.

Keywords: Predictive Maintenance, Service Strategies, Predictive Analytics, Literature Review, Mechanical Engineering

1 Motivation

Mechanical Engineering is a leading industry in Germany that generates most of its turnover on international markets. However, the traditional product business is under pressure of global competition, that also spreads to other revenue streams such as the spare part business [1]. In response, companies start to transform their business strategies, offering supplementary services or even "servitizing" aspects of the product business [2-3]. A key challenge to the gain in profitability of repair and maintenance activities are costs involved with the unexpected failure of machines in distant countries, e.g. high traveling expenses as well as opportunity costs resulting from long down times. Digital technologies offer improvements to this situation, since they allow for the remote identification of current and upcoming service needs.

One strategy is the analysis of sensor data from installed machines, in order to diagnose degradation and to predict the remaining useful lifetime. Such concepts contribute to the vision of "Predictive Maintenance" (PM), aiming to avoid both

14th International Conference on Wirtschaftsinformatik,
February 24-27, 2019, Siegen, Germany

unexpected failures of machines, as well as the opportunity losses of only partially worn spare parts [4-5]. In recent years, companies of various fields have started to implement PM systems, but often the proposed strategies are highly individual, focusing on a specific application scenario. The field of PM is thus very diverse, comprising a range of complex methods that is unstructured and difficult to grasp for non-experts. Therefore, we believe that research is required to facilitate the implementation of a PM strategy, in particular to unify and standardize existing approaches. In this contribution, we aim to provide a consolidated methodical overview based on an extensive literature study, in order to build a framework for PM methods in a next step.

2 Design and Results of our Study

We have conducted a structured literature study on articles addressing Predictive Maintenance in respect to the guidelines of Webster & Watson [6]. We firstly focused on articles in reputable information systems (IS) journals according to the A, B and C categories of the VHB-Jourqual3-ranking. However, PM articles are often highly methodical and are therefore also published in other domains. Thus, we complemented a general query via the paper hosts Google Scholar, Sciencedirect and Scopus, narrowing the extensive results to the 200 most relevant articles. During both reviews, we used the search term “Predictive Maintenance”. By the analysis of title, abstract and keywords, we retrieved and categorized 87 relevant articles that describe concepts, methods or applications of predictive maintenance strategies.

Our literature study yields information on research trends in the field of PM. When the topic emerged around 1960, articles were highly conceptual, but over the years this focus increasingly shifted towards methodical and applicational papers. In particular, this became evident in the analysis of utilized data, where 16 of the 21 papers published before 1998 (76%) did not rely their contributions on any data. Apparently, PM research experienced a paradigm shift then, with only 8% articles after 1998 testing their strategies on neither real nor simulated data. In the last ten years, more than half of the publications deal with real data and thus with actual use cases, indicating that now PM has advanced from a conceptual challenge to a feasible business strategy. We believe that this development has been strongly encouraged by the advancement of methods. Fig. 1 presents the result of our methodological classification of the literature, which is an overview of identified method groups, their subclasses and specific methods. For a long time, only functional approaches that model the degradation process of a unit over time have been employed. From 1990 on, the methodical spectrum enlarged. As in other fields, we identified the increasing popularity of Machine Learning and Data Science for PM purposes. The interest in such methods can be linked to parallel advances in hardware that enabled the efficient use of methods such as Artificial Neural Networks (ANNs). By now, research employing reliability functions accounts for 32% of our literature base, whereas ANNs have reached 23%, followed by modern Time Series Analysis (15%).

Further, the analysis provides first insights on the context of application, benefits and drawbacks of each method. Firstly, the articles describe utilizable methods for

Figure 1. Overview of methods employed in Predictive Maintenance articles

particular tasks: For example, classification methods such as ANNs or Decision Trees are well suited for a simple status classification or failure recognition [7-8], [9]. If the residual life or future malfunctions should be predicted, a method that incorporates temporal information is required (e.g. Regression Analysis [10], Markov Models [11], [12] or Kalman Filtering [13-14]). Secondly, the method is highly dependent on the properties of the data. The analysis of event logs for instance can be conducted by text mining methods as in [15-17]. Similarly, image processing can now be performed efficiently by Convolutional Neural Networks (CNNs). [18] and [19] apply CNNs on thermographic images for failure recognition. But not only does the general data format influence the choice of method, other features such as scale or the proportion of outliers must be considered. Filtering methods might be necessary to smooth the data before further processing. For example, Yiwei et al. include Kalman filtering in their framework to track an aircraft's health state [20]. Another selection criterion can be the transparency of the inner mechanism of a method. For example, imagine that sensors are installed throughout a machine, and its failure is being predicted based on the data received. In order to execute maintenance tasks quickly, it would be helpful to isolate particular sensors that identify root causes of the problem. Consequently, methods providing high transparency during the information retrieval (e.g. Decision Trees) might be preferred in such scenarios, in contrast to ANNs which are often referred to as black boxes. Because of this, but also considering the problem of overfitting in complex function approximations such as ANNs, it is important to be aware of multiple methods and carefully compare "trending" with simple approaches.

3 Discussion

Our study exemplifies insights on methodology from the literature review, with more decision criteria yet to be analyzed, such as the industry or the relevance of runtime performance. Considering the plurality of influences and the diversity of use cases, it can already be concluded that this large variety of methods is inevitable. Nevertheless, it is crucial to shed light on the smorgasbord of methods. Our literature study does not cover all research extensively, but provides a structured overview of a multitude of methods and exemplary studies. We regard this as a suitable starting point to a framework for future PM implementations. However, the methodological point of view is not sufficient, but must be embedded in a holistic service and business model. The application scenario, including production, the exact execution of maintenance work and involved costs must be considered as well. PM necessitates high flexibility and cooperation between service providers and customers. Thus, we see further research need in the implementation of use cases and required information systems as well as the elaboration of new business strategies.

The ongoing research aims at the extensive classification of methods. We strive for the development of an information hub that allows for the requirements-based recommendation and choice of methods. This way, we hope the structured report on existing concepts and methods constitutes a first step to lower existing barriers for investing in PM, and enables more companies to seize the opportunity of innovative data-driven service strategies.

References

1. VDMA (2017) Maschinenbau in Zahl und Bild 2017. Frankfurt am Main, Verband deutscher Maschinen- und Anlagenbauer
2. Roland Berger (2014) Evolution of service: Capturing value pockets in the service business.
3. VDMA e.V.; McKinsey & Company (2014) Zukunftsperspektive deutscher Maschinenbau: Erfolgreich in einem dynamischen Umfeld agieren

4. Furtak, Simon; Avital, Michel; Ulslev Pedersen, Rasmus: Sensing the Future: Designing Predictive Analytics with Sensor Technologies. 23rd European Conference on Information Systems (2015)
5. Hashemian, H. M.; Bean, Wendell C. (2011) State-of-the-Art Predictive Maintenance Techniques*. IEEE Transactions on Instrumentation and Measurement, 60 (10):3480–3492.
6. Webster, Jane; Watson, Richard T. (2002) Analyzing the Past to Prepare for the Future: Writing a Literature Review. MIS Quarterly, 26 (2):xiii–xxiii.
7. Almeida, C. A. L., Braga, A. P., Nascimento, S., Paiva, V., Martins, H. J., Torres, R., Caminhas, W. M.: Intelligent thermographic diagnostic applied to surge arresters: a new approach. IEEE Transactions on Power Delivery, 24(2), 751-757 (2009)
8. Berecibar, M., Devriendt, F., Dubarry, M., Villarreal, I., Omar, N., Verbeke, W., Van Mierlo, J.: Online state of health estimation on NMC cells based on predictive analytics. Journal of Power Sources, 320, 239-250 (2016)
9. Susto, G. A., Schirru, A., Pampuri, S., McLoone, S., Beghi, A.: Machine learning for predictive maintenance: A multiple classifier approach. IEEE Transactions on Industrial Informatics, 11(3), 812-820 (2015)
10. Onanena, R., Oukhellou, L., Candusso, D., Same, A., Hissel, D., Aknin, P.: Estimation of fuel cell operating time for predictive maintenance strategies. international journal of hydrogen energy, 35(15), 8022-8029 (2010)
11. Cartella, F., Lemeire, J., Dimiccoli, L., Sahli, H.: Hidden semi-Markov models for predictive maintenance. Mathematical Problems in Engineering (2015)
12. Lee, S., Li, L., Ni, J.: Online degradation assessment and adaptive fault detection using modified hidden Markov model. Journal of Manufacturing Science and Engineering, 132(2) (2010)
13. Abdennadher, K., Venet, P., Rojat, G., Rétif, J. M., Rosset, C.: A real-time predictive-maintenance system of aluminum electrolytic capacitors used in uninterrupted power supplies. IEEE Transactions on Industry Applications, 46(4), 1644-1652 (2010)
14. Yang, S. K.: An experiment of state estimation for predictive maintenance using Kalman filter on a DC motor. Reliability engineering & system safety, 75(1), 103-111 (2002)
15. Makanju, A. A., Zincir-Heywood, A. N., Milios, E. E.: Clustering event logs using iterative partitioning. In Proceedings of the 15th ACM SIGKDD international conference on Knowledge discovery and data mining, 1255-1264 (2009)
16. Xu, W., Huang, L., Fox, A., Patterson, D., Jordan, M. I.: Detecting large-scale system problems by mining console logs. In Proceedings of the ACM SIGOPS 22nd symposium on Operating systems principles, 117-132 (2009)
17. Sipos, R., Fradkin, D., Moerchen, F., Wang, Z.: Log-based predictive maintenance. In Proceedings of the 20th ACM SIGKDD international conference on knowledge discovery and data mining, 1867-1876 (2014)
18. Huda, A.N., Taib, S.: Application of infrared thermography for predictive/preventive maintenance of thermal defect in electrical equipment. Applied Thermal Engineering, 61(2): 220–227 (2013)
19. Shafi'i, M.A., Hamzah, N.: Internal fault classification using artificial neural network. Power Engineering and Optimization Conference (PEOCO), 2010 4th International, 352–357 (2010)
20. Yiwei, W. A. N. G., Christian, G. O. G. U., Binaud, N., Christian, B. E. S., Haftka, R. T.: A cost driven predictive maintenance policy for structural airframe maintenance. Chinese Journal of Aeronautics, 30(3), 1242-1257 (2017)