ESTIMATION TRENDS IN THE MAINTENANCE OF A MANUFACTURING EQUIPMENT RELATION TO THE INDUSTRY 4.0 CHALLENGE

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Abstract
The paper presents a survey of trends and perspectives in asset and maintenance management in the field of maintenance execution, maintenance top management responsibility, maintenance processes, resources for maintenance and maintenance monitoring, analysis and improvement. Every idea is presented in the light of the Industry 4.0 revolution.

Key words: *asset management; maintenance management; maintenance engineering; trends in maintenance.*

INTRODUCTION
Nowadays, many maintenance managers wonder, where maintenance is lead up and what it will look like in the near and far future. The Fourth Industrial Revolution is coming down to us and aspects are already described in many publications, e.g. (*Marik, et al., 2015; Marik, 2016*), usually under the heading Industry 4.0. It is positive that the government of the Czech Republic also supports this challenge and perhaps will provide the necessary financial support in the form of grants to application research and other activities. Admittedly, these publications (*Marik, et al., 2015; Marik, 2016*) do not address maintenance management and engineering independently and move in the industry as a whole.
Nevertheless, the Czech Maintenance Society (CMS) is raising awareness of the application ideas of Industry 4.0 to maintenance in all educational activities since 2016, both in its courses, seminars and conferences. These courses refer and prepare participants for solutions of the Industry 4.0 challenges.

The aim of this paper is to prepare a study of the expected development of maintenance management and engineering in the near future.

MATERIALS AND METHODS
The general idea of maintenance of a manufacturing equipment is based on the principles of maintenace management system, whose main objective is to plan, manage and control material and information flow in order to achieve the performance and economic goals. A substantial part of the maintenance management system is an information system (IS), which goal is to capture, store, process and transmit data (actual and planned). It is beneficial not only for well organized documentation of the maintenance and other activities (it is a starting point, it is not desired goal), but also to save time in preparing and implementing maintenance activities, saving human resources, material and spare parts, quick reduction of weak points, reduction of nonconforming products, increasing of the reliability of production equipment, etc. *(Jurca & Ales, 2012).*

Maintenance 4.0 is based on policies and is supported by Industry 4.0 tools. Key tools include:

- Robotisation,
- Automation,
- Digitalisation,
- IoT (Internet of things),
- comunication (data collection, smart glasses, augmented reality),
- big data (monitoring and diagnostics),
- information and computing technology,

- methods and techniques of cybernetics and artificial intelligence used for predictive maintenance,
- spare parts logistics, 3D printer,
- new materials
- staff, social aspects, etc.

Will these things going to be all for free, with extra cost? Certainly not, but the assumption is given by the hypothesis that the embedded money will bring more money in the future.
Performance monitoring can be scheduled, on demand or continuous. The development is aimed at continuous monitoring (diagnosis) with various sensors. The development is leading up to continuous monitoring (diagnostics) via various sensors.
Predictive maintenance of status is based on prediction, which is derived from analysis and evaluation of significant degradation parameters of object - see Figure 1.
Predicting is based on analysis and extrapolation of degradation parameters of object (see Figure 2 and 3) or other more sophisticated methods (e.g. neural networks, artificial intelligence, multipara-metric analysis, etc.).
Non-linear extrapolation using nth degree polynomials (1) is not recommended, because it is uncertain how the trend prediction will develop according to this function.

$$S(t) = a_0 + a_1 t + a_1 t^2 + \cdots + a_n t^n \qquad a_n \neq 0 \tag{1}$$

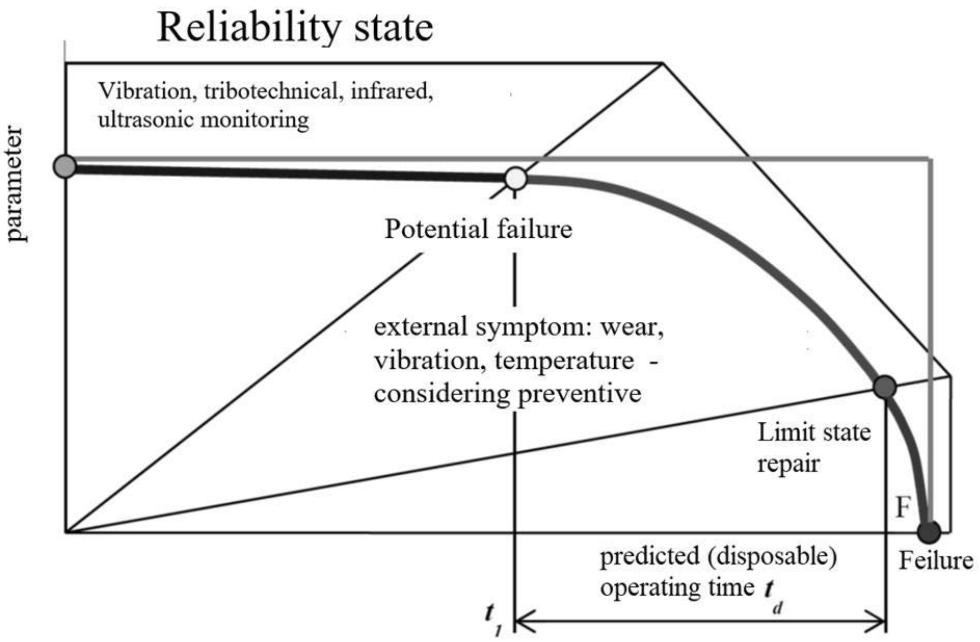

Fig. 1 The Principle of Predicting Time to Repair (Failure)

Principle: Apply predictive maintenance wherever it is technically possible and economically advantageous. This is important perspective requirement to maintenance. Nowadays predictive maintenance is still much mentioned, but there are still a just few fully functional applications in use. [*CSN EN 13306:2017*]
Proactive maintenance will be increasingly applied to all types of maintenance. Proactive maintenance is based on analysis of causes, whether potential or real failures, and the elimination of all undesirable identified causes.

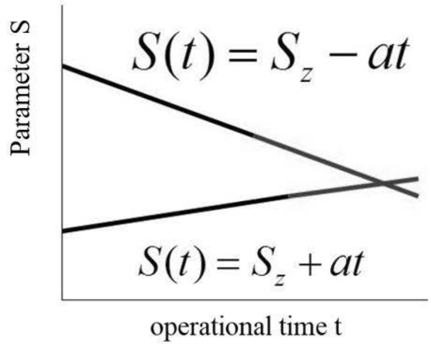

Fig. 2 Linear one-parametric extrapolation

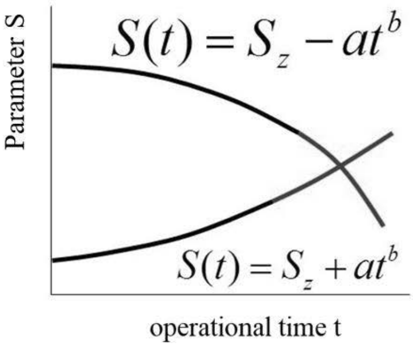

Fig. 3 Nonlinear one-parametric extrapolation

RESULTS AND DISCUSSION

Based on the described analysis of maintenance tools and methods is can presented an overview of what data should the maintenance information system collect and process in the area of maintenance management.

The authors see the biggest problem in the absence of data analysis in general and automated analyses in particular. Sophisticated data analysis, artificial intelligence in diagnostics of technical condition and fault conditions, algorithms for calculating limit state for repair, routine planning of preventive maintenance, shutdowns, spare parts is missing. Unfortunately, the authors have to say that the maintenance management system and maintenance staff (at all levels) is not ready for this challenge at present. The automotive industry has an exceptional position in the Industry 4.0 challenge, but there is not all at the level of excellence. The industry is moving forward at a fast pace to reap the benefits of the Industry 4.0 revolution, but unfortunately standards bodies have not been able to keep up with this pace *(Kaur et al. 2018)*.

Indeed, an analysis approach aimed at preventing the occurrence of progressive defects allows for a drastic reduction of shut-down times inevitably occurring during maintenance phases *(Dinardo, Fabbiano, & Vacca, 2018).*

However, maintenance information systems will require major improvements in area of processing and evaluation data. Current hardware is already at high level in the field of collection, transfer and storage data (sensors, wireless data transfer, concentrated and shared clouds, internet of things etc.) (*CSN EN 60300-3-14:2005).*

Quality requirements for maintenance processes are growing and it can generally be expressed in several points:

1. Asset acquisition with high reliability and low life cycle costs in accordance with asset management. (*PAS 55-1:2008*; *PAS 55-2:2008*; *CSN ISO 55000:2015*; *CSN ISO 55001:2014*; *CSN ISO 55002:2014*; *CSN EN 16646:2015*; *Wilson, 2013*).
2. Maintenance of tangible fixed assets in operational and proper condition.
3. Prevention of creates failure and following failure conditions.
4. Operative elimination of failures.
5. Reducing the environmental impact of production equipment
6. Safety of operational and maintenance man
7. Risk mitigation
8. Elimination of critical failure
9. Applying optimal maintenance costs.
10. Leading asset management to applying methods best practice with according to Industry 4.0 challenge

Conception of Industry 4.0 highly requires integration of all development, manufacturing, logistics and maintenance processes. In this area there is much to improve and implement. There are also some weaknesses in administration and maintenance planning, an appropriate information planning system is very small. The corrective maintenance system still prevails. The pressure on predictive and proactive maintenance will grow *(CSN ISO 55000:2015)*.

It is conclusive, consequently, to assert that the main drive behind the fourth industrial revolution is to guarantee the effective availability of reliable, complete, and real-time information by linking together all parties or elements of the value chain (*Alqahtani, Gupta, & Nakashima, 2019*).
Massive implementation of Conception of Industry 4.0, using of sensors detecting the technical situation, analysing RCM and using dates from analysing FMECA are helpful for much more better and efficient identification of preventive maintenance tasks to:

- detect and correct emerging failures either before they occur or before they become critical failures
- reduce the probability of failure
- uncover hidden errors that have occurred
- increase the cost-effectiveness of the maintenance program.

Smart system sand internet-based solutions that characterize Industry 4.0 greatly impact and change manufacturing processes and practices, maintenance strategies and maintenance management *(Koenig, Found & Kumar, 2019)*.
Proper maintenance strategies are drawing increasing attention and facing new challenges as important methods in improving the reliability and availability of manufacturing systems in order to ensure the timely delivery of high-quality products to customers *(He, Han, Gu & Chen, 2018)*.
Maintenance management processes should be significantly change due to the Industry 4.0 challenge. The pressure will increase to transition from maintenance to failure and periodic maintenance to predictive and proactive maintenance wherever it will be technically possible and cost-effective. The technical possibilities of implementing of predictive maintenance are already enabled by offering of wide range of affordable sensors.

a) **Timing data**
   - Time to failure and time between failures t and operational time of machines and their elements,
   - inspection repair intervals, preventive repair intervals, diagnostic intervals, preventive maintenance – repairs intervals,
   - maintenance lead time and laboriousness of maintenance, planned technical - useful life of machine and equipment,
   - downtimes of machines and equipment, which are created by:
   - organizational downtime, logistic downtime,
   - rest time for personal needs,
   - preventive maintenance,
   - failures,
   - setup and adjustment downtime,
   - technological failures,

b) **Technical data** – various diagnostic signals,
   - vibrotechnical data,
   - temperatures,
   - the magnitude of voltage and current
   - tribotechnical data,
   - wear size
   - clearance, flow rate, pressure
   - change the efficiency of machine
   - real performance,

c) **Economic data**
   - cost of preventive maintenance,
   - revision cost, preventive inspection cost, diagnostic cost,
   - maintenance cost after failure,
   - downtime cost (function of production losses),
   - costs caused by increasing wear on functional surfaces,
   - losses from the risk of occurrence of failure and non-compliance if normative for repair to comply with the normative for recovery,

- Production price of one product,
- labour, material, overheads costs on internal maintenance and external maintenance,

These data require the introduction of a thorough cooperation with financial controlling and fundamental adjustment of information system maintenance (ISM)

d) **Reliability data** (reliability, maintainability and maintenance support)
- quantitative data
    - time to failure and time between failure,
    - time to repair,
    - density distribution of probability of failure
    - probability of failure, probability of reliability, failure rate and failure intensity,
    - time of undetected of failure condition,
    - time of administrative delay,
    - time of corrective maintenance, time of preventive maintenance,
    - number of non-conforming units due to a faulty manufacturing process and the start of production
    - spare parts consumption number of maintenance man,
- quality data
    - description of mode failure, causes of failure, detectability of failure, consequence of failure,
    - type of communication (reporting and repair of failure, maintenance support),

One of the most important property features of the production equipment is operational reliability. With the characteristic (features) of reliability we are measuring availability, sustainability and ensure the maintenance of machinery and equipment, what influences the level of using their nominal efficiency and their overall productivity, quality and production efficiency. Data collection and knowledge of probability of failures features allow to optimize preventive maintenance in general and with monitoring and diagnosis to optimize and apply predictive maintenance.
It follows that the business of these reliability departments should be the collection of reliability data, analysis and processing into relevant characteristics, optimization of preventive maintenance programs and application of reliability tools to improve the reliability of production equipment as well as final products.

CONCLUSIONS

Maintenance requirements for industrial production machine and equipment never fade away. Requires on education and training of maintenance staff will grow progressively, a profession desired will be in mechatronics. Producers will deliver smart machines, i.e. machines more reliable, more powerful, more effective, safer, greener and more ergonomic producing machines with ability to self-management with the support of asset management. Better application of robotics and digitalization of the maintenance processes (smart machines) will not replace fully „the hands“ of maintenance staff, just speed up their processes, make them easier and reduce unwanted downtime. Electronic systems will be managed and controlled mainly remotely. Diagnostics and analysis of acquired data using artificial intelligence and predictive maintenance will reduce operational failure rate, resp. improves the reliability and availability of production equipment. The data obtained by monitoring and diagnosing the technical condition of the production facility and the financial control of its operation will be more effectively operated and intensively used in the maintenance management processes. Spare parts logistics will be supported by the 3D printing technology and the assortment of spare parts for storage will be managed scientifically. The Government will support the development of education also in the field of maintenance staff, starting with dual apprenticeships, through secondary education in industrial schools, to higher education with fields of mechatronics, management and maintenance engineering in line with the

Conception Industry 4.0 challenge. General and Production Directors will fully appreciate the importance and will more support the maintenance of production equipment according to the Maintenance conception 4.0 as a necessary prerequisite and resource for improving the organization´s performance.

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