THE PREDICTIVE MAINTENANCE CONCEPT IN THE MAINTENANCE DEPARTMENT OF THE "INDUSTRY 4.0" PRODUCTION ENTERPRISE

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Abstract: Modern technical environments require a high degree of reliability both in machinery and in equipment. Technological progress has, on the one hand, increased this efficiency but on the other hand, it has changed the way in which this equipment and these machines have traditionally been maintained. The authors have set the following assumptions. In order to survive in the market and develop, modern production enterprises realize the assumptions of Industry 4.0, wherein the optimization of maintenance processes is important because of the financial situation. This includes the profits made by the production company and differs from traditional maintenance, by shifting towards new trends such as predictive maintenance; as such, it is crucial for the development of the company. The article is devoted to the most modern predictive maintenance strategy, in the maintenance department of a manufacturing company. The publication describes the meaning of the method, its potential and the theory of action.

Keywords: production process, maintenance, predictive maintenance, maintenance department, manufacturing company, Industry 4.0.

JEL: D2, L6, O33.

1 Introduction

The vision for future production includes modular and efficient production systems and presents scenarios in which products follow their own production process. The aim is to raise awareness of the production of individual products in a single batch size while maintaining the economic conditions for mass production. A company providing these conditions becomes a user and part of the system – "Industry 4.0" (Cotteleer and Sniderman, 2017).

The authors have chosen activities that focus directly on the implementation of the production process as the objectives of the article; as such, they have set out the following assumptions:

- modern production enterprises that want to survive in the market and develop, realize the assumptions of Industry 4.0
- optimization of maintenance processes is important because of the financial situation, including the profits made by the production company
- the shift away from traditional maintenance towards new trends, such as predictive maintenance is crucial for the development of the company

According to the requirements of Industry 4.0, modern technical environments demand an elevated degree of reliability, both in plant and in equipment. Technological advances, on one hand, have increased this reliability; on the other hand, however, more traditional methods of plant and equipment maintenance are changing. Information and communication technology continuously modify conventional practices, such as the manual inspection of plant and the retention of information on paper, and progress, ever increasingly, towards computer-aided maintenance (Haider and Koronios, 2006). The following topic addresses this transition.

The first half of this article enumerates the fundamental definitions of maintenance and highlights its impact on the profitability of a company. Subsequently, classic strategies of maintenance service are outlined, including their characteristics, advantages and disadvantages. The second half of this article is devoted to the state-of-the-art strategy, namely, predictive maintenance, and describes, in detail, its meaning, its potential and methods, as well as its theory of operation.

2 The concept of Industry 4.0

The term Industry 4.0 appeared for the first time in 2011 in Germany (Brettel et al., 2014; Weyer et al., 2015). It was then assumed that in the area of Industry 4.0, the production system of a company would consist of an information system and numerically controlled machines, which would operate autonomously and show elements of artificial intelligence. This means that the scope of the definition of Industry 4.0 should be considered on a case-by-case basis, depending on the needs of the company in question.

The nomenclature of the new concept is also changing, as is evidenced by various scientific studies in which terminology, similar to that of Industry 4.0, can be found, such as Industrial Internet or Digital Factory (Kopetz, 2011; Lee, et al., 2013; Weber and Weber, 2011; Wittbrodt and Łapuńka, 2017). Contrary to the previous concepts such as CIM (Computer Integrated Manufacturing), Industry 4.0 is not intended to create factories where people are replaced by robots. Industry 4.0 makes factories a better place to work. People are invariably the most important asset; thanks to the new solutions, they will receive much more support than was the case previously. Industry 4.0 is not an abstract concept, but real technologies and implementations. The Industry 4.0 environment has identified and specialized advantages (Lasi, et al., 2014):

- Flexibility: Quick response to customer requirements thanks to independent machine modules,
- Low production costs: personalized production with costs for mass production,
- High availability: optimal production capacity,
- Cost-effectiveness: increased productivity for small production batches due to optimal process planning,
- Increased transparency: real-time information processing,
- Resource saving: diversified production using the same number of machines.

The concept of Industry 4.0 covers areas that include numerous technologies and related paradigms. The main elements that are closely related to the idea of Industry 4.0 include the Industrial Internet of Things, Cloud-Based Manufacturing, Smart Factories, Cyber-Physical Systems and Social Product Development – SPD (Shrouf, Ordieres and Miragliotta, 2014; Wittbrodt and Łapuńka, 2017; Wu, et al., 2015).

In summary, the term "Industry 4.0" describes various changes in the production systems, most often in IT. These changes not only have technological implications but also organizational implications. As a result, a change from a product function to a service function is expected, even in traditional industries. Secondly, in addition to the adaptation of enterprises to new conditions, new types of enterprises can be expected to take on new, specific roles in the production process or value creation networks (Lasi, et al., 2014).

3 Fundamentals

Maintenance is used in every domain where the operative readiness of an object needs to be sustained (DIN 31051; 2012-09, 4.1). It expresses "the 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" (DIN EN 13306:2015-09, 2.1). The term "item" – or also "asset" – in this context, should be defined as each technical component, device, subsystem, functional unit, equipment or system that can be individually described and considered (DIN 31051:2012-09, 4.2.1).

An item may assume a variety of states. The two main types are defined as the 'up' or the 'down' state. The former means that the item is able to perform its required function as long as the external resources are provided. The latter is characterized either by a fault, or by a possible inability to accomplish a required function, during maintenance service. Both states can be affected by the "disabled" state in which an item is not able to perform a required function for any reason; this depends on whether this has been instigated by an external or internal occurrence. In addition, the "up" state can be subdivided into the "idle" state, the "standby" state or the "operational" state. Fig. 1 depicts the states named and specifies the requirements regarding time intervals throughout which an item is required to be in the "up" state (DIN EN 13306:2015-09, 5–6).

During the course of an item's existence, it invariably undergoes changes of condition via degradation, attrition, ageing and corrosion, which result in "down" states. Hence, maintenance pursues the primary objective of delaying wear on materials and the avoidance of decay in those items (Strunz, 2012). Considering a broader business perspective, this serves the purpose of ensuring that an asset is sufficiently available, in order to secure the high profitability of production systems. The obtainment of maximum operational availability, at minimum cost, requires compliance with several, sub goals, namely (Schenk, 2013):

- the avoidance of unplanned "down" states,
- the reduction of overall maintenance costs,
- saving natural resources,

increasing the operational lifetime of machinery and equipment.

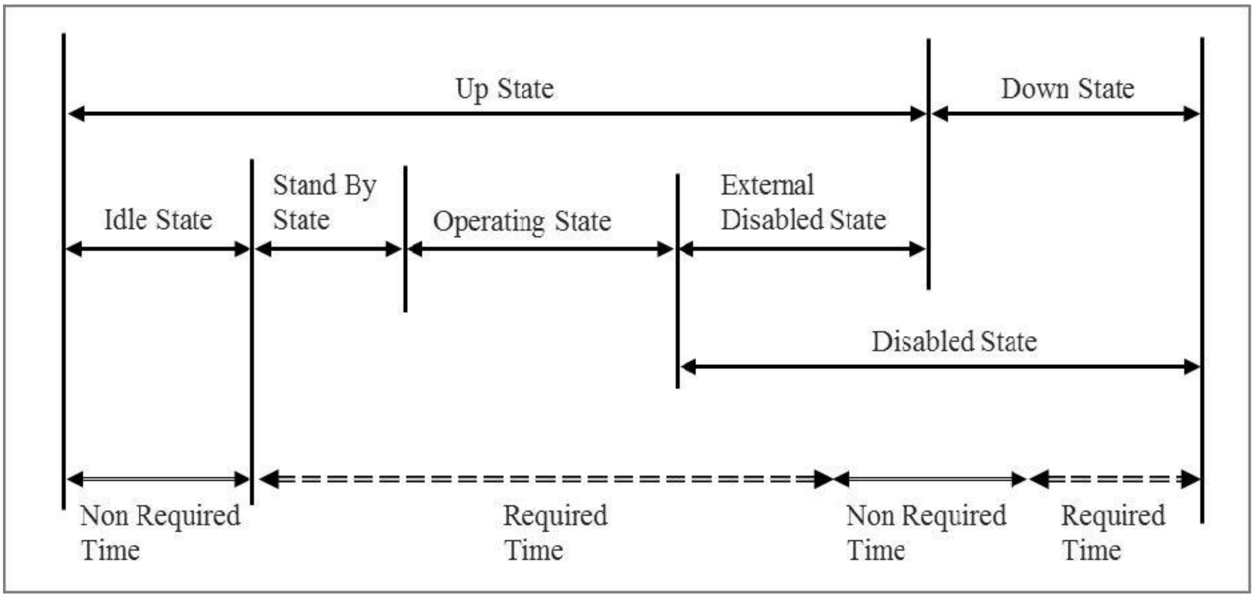

Figure 1. States of an item
(*Source:* Own illustration, based on DIN EN 13306:2015-09, B.1)

Within the framework of DIN 31051 (2012-09, 3), the maintenance is segmented into four main tasks and is composed as follows: inspection, service, repair and improvement (see Fig. 2):

- Inspection

During an inspection, measures are taken to assess and detect the actual state of an item, including investigations to discover the cause of attrition and to derive necessary consequences for future operations, such as, measuring the thickness of brake discs.

- Service

This area of service includes every action that serves as sustainment of the target state, respectively, in order to delay the degradation of items, for example, by greasing.

- Repair

Overhauling contains every step to restore an item back to its functional and original shape; this includes replacing a component on a machine with an equivalent spare part. Any action that would lead to an improvement is excluded here.

- Improvement

An improvement involves technical and administrative measures to enhance the functional reliability of an item without altering the required features, in such as the elimination of a failure point through a constructive change (DIN 31051:2012-09, 4).

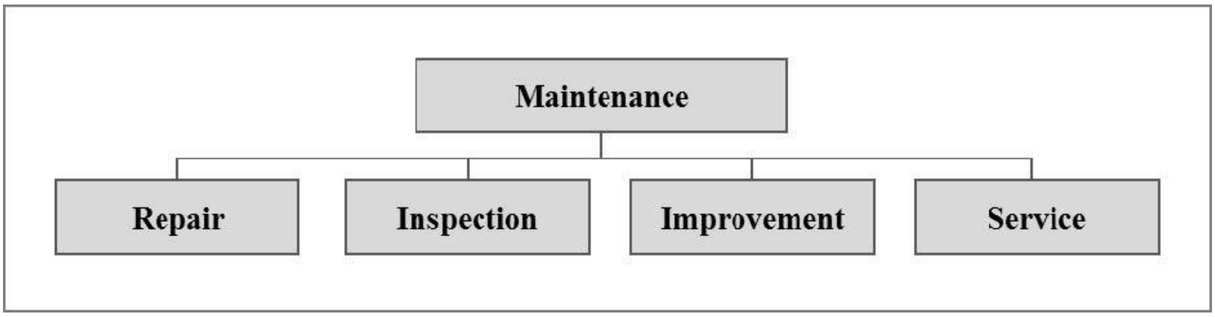

Figure 2. Classification of maintenance tasks
(*Source:* Own illustration, based on DIN 31051:2012-09, 3)

4 Strategic impact

To management, in the past decades, maintenance was seen, usually, as just another expense (Schenk, 2013). Such a negative reputation is attributed to the fact that maintenance is associated with the failure of plant and equipment. The reliability and operability of machinery was often taken for granted with the underlying effort for maintaining that reliability and operability often being overlooked (Henke and Kuhn, 2015).

However, in recent years, this mindset has shifted with the role played by maintenance becoming increasingly important and transitioning from an outright cost-causer to a cross-company business process[1], which assumes an active part in the value-chain.

Although traditional maintenance in and of itself does not add value, as a support process, it offers enormous value-adding potential by facilitating highly efficient and smooth production or service.

In general, its value-adding contributions can be described as follows (Schenk, 2013):

- preservation of asset value,
- reduction of expenditure by optimizing maintenance strategies,
- enhancement of the temporal and functional utilization rate, as well as a decrease in depreciation, which, in turn, enables funding for new value-adding investments,
- prevention of breakdowns and faults that would impact upon the plant, the environment and the safety of the process.

In 2015, a study by Henke and Kuhn (2015) ascertained that annual maintenance costs, in Germany, amounted to 250 billion euro, which is ten percent of the German gross domestic product. The value-adding potential in this context results from the consequential costs of deficient or neglected maintenance that are avoided, these costs being some three to five times higher. Thus, annually, it generates productivity values up to one trillion euro (Henke and Kuhn, 2015).

Maintenance plays a key role in providing profitability and a reliable production process.

The higher the intensity of investment in production facilities, the more does this impact upon well-organized maintenance management. Recent studies have shown that up to 60 percent of the cost of production can be influenced by efficient maintenance (Blechschmidt, 2011).

[1] The term *business process* is defined as "a structured, measured set of activities designed to produce a specific output for a particular customer or market" (*Davenport, 1993*).

To reach the optimal, value-adding state of production, “maintenance time zero” is required. This means that the execution of every necessary service is conducted during idle states, in order that no productive time is wasted (Schenk, 2013).

Through rapid changes in the industrial production processes, over the past decade, the attainment of this objective has become ever more challenging. Several driving forces inevitably lead to a more elaborate and frequent maintenance process.

First of all, a great number of modern assets are characterized by an increase in the flexibility of machinery, which is highly sophisticated and able to perform a variety of processing steps, q.v. a machining center. The high acquisition costs of such machines result in the increasing pressure on budgets and ramp up the urgency to go for full capacity of output.

Mounting technological complexity and extended workloads, as well as the speeding up of machine processes lead to an increased loss of effective reliability and, ultimately, in machine failure, with the interdependency of present production systems similarly resulting in the reduction of an asset’s reliability.

The breakdown of one machine might lead to a stoppage for the whole manufacturing process and pose a costly scenario (Strunz, 2012). Another important aspect is the gradual rise in the requirements regarding environment protection and operational safety.

Several past chemical/reactor accidents have given rise to the enforcement, by the legislators, of extended or enhanced environmental and labor laws. The increment of legal stipulations results in a substantial effort to reconstruct and retrofit assets, along with high-quality maintenance, in order to meet enhanced liabilities (Strunz, 2012).

5 Classic maintenance strategies

A maintenance strategy is defined as a utilized management method in order to achieve maintenance objectives (DIN EN 13306:2015-09, 2.4). Such a policy determines the maintenance that needs to be undertaken, the item on which it is to be carried out, the frequency at which it needs to be done and at what point in time it must be done.

Neglecting maintenance may lead to an excessive number of costly failures and poor system performance, resulting in impaired reliability. However, if it is done too often, reliability might improve but the cost of maintenance will sharply increase, because the residual useful life (RUL) of an item is not entirely utilized. Fig. 3 depicts the relationship between reliability and RUL of an item, as well as the maintenance cost.

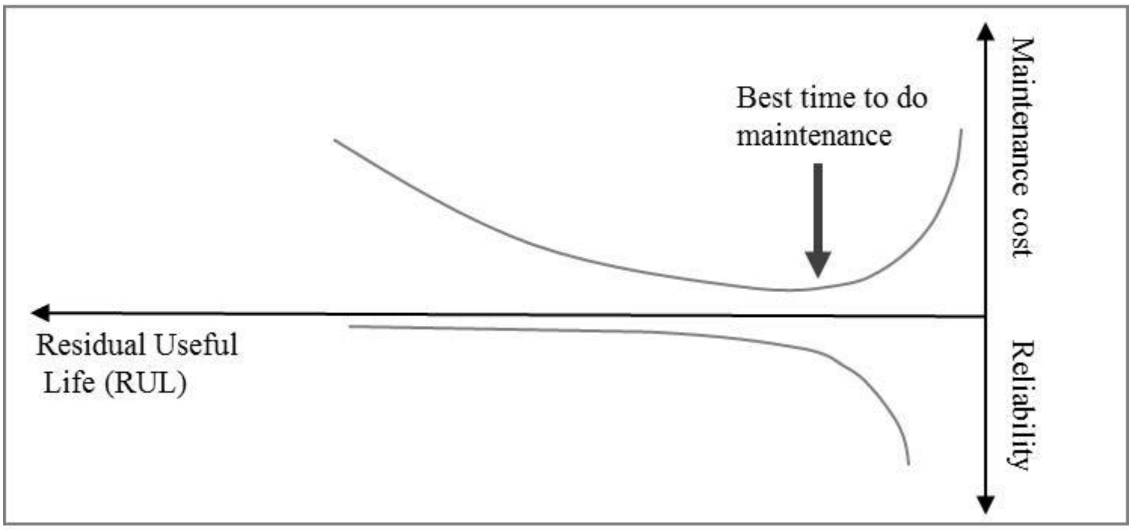

Figure 3: The relationship between RUL, reliability, and maintenance cost
(*Source:* Own illustration, based on Peng, Dong and Zuo, 2010)

When the time for a system to fail approaches zero, the reliability of the system decreases, as also do the maintenance costs. As soon as the time to fail actually equals zero, the system will go into the 'down' state and maintenance costs will rise enormously, due to high consequential costs (Peng, Dong and Zuo, 2010).

Those two competing objectives, the exploitation of RUL and the ensuring of reliability, must be balanced by a cost-effective scheme (Endrenyi, et al., 2001). Besides economic aspects, legal, safety and technical requirements have to be considered, as well as when to select the right strategy. The choice of an appropriate maintenance programme has a decisive influence on the frequency of "down" states and the many undesirable consequences of such interruptions.

Maintenance time can be chosen either systematically or haphazardly. In the case of an unsystematic approach, maintenance is only conducted if it is necessary or rather if a fault occurs. With the systematic approach, maintenance will be undertaken periodically or at intervals during operations, depending on the condition of the item assessed (Schenk, 2013).

Maintenance strategies, in general, may be categorized into two main types, namely, corrective and preventive maintenance (see Fig. 4). The latter can, additionally, be subdivided into a predetermined, condition-based and predictive strategy (DIN EN 13306:2015-09, 7).

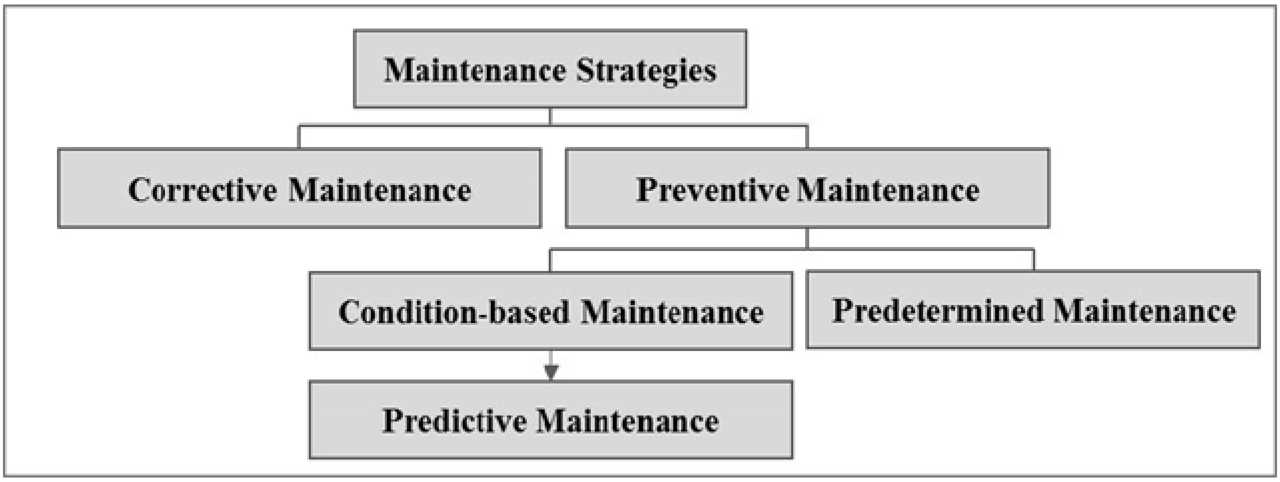

Figure 4. Overview of maintenance strategies
(*Source:* Own illustration, based on Schenk, 2013)

6 The present approach: predictive maintenance

In recent years, an advanced approach to maintenance has aroused great interest both in theory and practice. Predictive maintenance, so-called, is an enhancement of the condition-based strategy. It extends automated condition monitoring by a computerized evaluation of the input data and allows intelligent prognostics to detect precursors of failure and to predict how much time remains before the likely occurrence of a failure (Schwabacher and Goebel, 2007).

While condition-based maintenance simply describes the current state of health, a predictive policy can also estimate prospective condition-changes[2].

[2] Several authors such as Shin and Jun, 2015; Prajapati, Bechtel and Ganesan, 2012; and Heng et al., 2009, in their use of the terms, "*condition-based*" and "*predictive maintenance*" indicate the same class of maintenance policy. Others, notably Susto, et al., 2012; Schenk, 2013; and Fu, et al., 2004, as well as the German institute for standardization (DIN EN 13306:2015-09, 7.4) consider the two categories to be distinct. In this thesis, according to the definitions provided, "*condition-based*" and "*predictive maintenance*" are referred to as two different categories.

Shin and Jun 2015 define it aptly as "a maintenance policy which undertakes maintenance before product failures happen, by assessing the condition of the product, including operating environments and predicting the risk of product failure in real-time, based on the product data gathered".

The forecasting of the degradation of an item is based on the assumption that most abnormalities do not occur instantaneously and usually there is a steady evolution from normality to abnormality (Shin and Jun, 2015).

Even if no direct evidence of the degradation of an item is available, predictive maintenance tools exploit variables in the processes and logistics gathered during operation, in order to examine the "footprint" of this degradation in the data (Susto, et al., 2015).

Degradation is monitored by observing continuously, the workload of an item and consequently, detecting deviations from the average performance. This presupposes that there is current information about the condition of an item, as well as historical data of normal and abnormal operating behavior.

Predictive maintenance brings major advantages. In industrial environments, an alert to a potential mechanical problem with an instrumental component is not particularly helpful if engineers have no information about the severity or cause of the fault.

Far more helpful is functionality that indicates the root cause of the issue and the timeframe in which it is likely to emerge, for example, by specifying that a bearing in the spindle motor of a grinding machine has worn out and that there is a 95% probability of failure if it is not replaced within three days. This is where predictive maintenance solutions have the potential to add value.

Predictive maintenance allows service and repair measures to be undertaken at exactly the right time, just as an item is about to fail. In so doing, predictive maintenance attempts to maximize the item's current usefulness as well as its residual usefulness. At the same time, it significantly improves the scheduling of maintenance.

Furthermore, sophisticated software uses analytical modelling techniques and offers diagnostic insight, prioritizing issues according to severity and suggesting measures that may be adopted (Thomson, Edwards and Britton, 2014).

This reduces human error and misjudgment, as well as dependency on highly experienced maintenance staff. A recent study has shown that companies that have adopted predictive strategy could reduce maintenance costs by 30 percent and reduce "down" states by 70 percent (Dougherty, et al., 2015).

A further survey by the US Department of Energy has evaluated the implementation of a functional, predictive maintenance programme in the oil and gas industry. According to the study, maintenance costs were reduced by 25 percent while the occurrence of breakdowns could be decreased by 70 percent and productivity increased up to 45 percent (Sullivan, et al., 2010).

Despite these benefits, predictive maintenance has limitations similar to those of its predecessor, classic "condition-based maintenance", primarily because investment costs are usually high (Sullivan, et al., 2010). In order to implement predictive maintenance, the installation of high-quality monitoring equipment and the deployment of databases and large-scale, data processing systems are prerequisite.

In addition - and in order to be successfully used – not only is an investment in hardware required, but also, an investment is required in data science and/or physical expertise, in order to develop models, algorithms and decision-making strategies based on the data collected. Finally, the technologies and technical methods for the predictive approach are still in their infancy.

This means that there are still some limitations in ensuring the required accuracy of diagnostics and prognostics (Shin and Jun, 2015). Table 1 summarizes the main attributes of predictive maintenance and all the maintenance strategies elaborated previously. It gives a brief overview of their characteristics and requirements, along with their advantages and disadvantages.

Table 1. Comparison of different maintenance strategies
(*Source:* Own illustration)

	Corrective Maintenance	Pre-determined Maintenance	Condition-based Maintenance	Predictive Maintenance
Characteristics	Conducted after fault or breakdown	Conducted at pre-defined intervals	Conducted after observing certain conditions in an item	Conducted on the most cost-effective date after RUL has forecast an item
Requirements	Skilled staff; available spare components; short reactions	In-depth knowledge of the lifespan of an item; the precise planning of staff and a supply of spare parts	Monitoring devices/ systems; IT- infrastructure; skilled staff	Monitoring systems; IT-infrastructure, data, models and algorithms
Advantages	Maximization of the service life of an item; no planning costs	Minimizes the downtime of items; fewer failures caused by wear-out; high plannability	Maximizes the productivity time of items; maximizes the service life of an item	Maximizes the productivity time of assets; maximizes the service life of an item; high plannability
Disadvantages	Enormous consequential costs through failures; cost due to unplanned downtime	RUL of items is wasted; planning is cost intensive; does not prevent random failures; labor intensive	High investment for monitoring and prognostic equipment	High investment for monitoring, prognostic and diagnostic equipment, partially immature technology

7 Conclusion and future work

The purpose of this article focusses on current and important areas of research related to maintenance and, in particular, on that most modern strategy: predictive maintenance. The authors of the article expound that maintenance is becoming increasingly important from the point of view of production company management and impacts on the financial results achieved by them. The authors indicate the possible impact of new maintenance techniques on the optimization of maintenance processes and on the financial situation, including the impact on the profits made by production companies, as well as the impact they exert on the survival of production companies in a demanding and competitive market.

Together with the new industrial revolution, namely, Industry 4.0, significant changes in the approach to management are being introduced. Through the change from traditional maintenance, new trends such as predictive maintenance are crucial for the development of a company. Further studies, to be conducted by the authors, will analyze the effectiveness of currently known and applied predictive maintenance methods in relation to the automotive industry. The authors will then propose an original method and examine its effectiveness in a group of Polish and German automotive companies. As the area of investigation, the authors have selected the automotive enterprise sector which is involved in the manufacturing of the various components used in vehicle production, up to the actual point of the assembly of the vehicle. As follows from the branch reports, this sector enjoys uninterrupted growth, worldwide.

Enterprises realize their production in accordance with the specially developed, ISO/TS 16949:2009 standard. This standard, which actually is a technical specification, as evidenced by a TS member, was created to standardize quality requirements, with regard to automotive industry suppliers. Its origins may be discerned in the QS 9000 standard, created for the suppliers of the Chrysler, Ford and General Motors corporations and in the VDA 6.1 standards, developed for the German automotive industry.

With regard to co-operation with diverse recipients, numerous automotive suppliers have been obliged to ensure conformity of their quality management systems with many standards.

ISO/TS 16949:2009 is an attempt at the unification of standards. The new, updated version of the ISO/TS 16949:2009 standard, that has functioned since October 2016, is IATF 16949:2016 (Gruszka and Misztal, 2017; Misztal and Gruszka, 2017). The conclusions that may be obtained from the analysis are very significant for building an effective strategy for the development of an enterprise, based on knowledge and innovation.

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