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# General overview of maintenance strategies – concepts and approaches

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## INTRODUCTION

Manufacturing companies, running a business nowadays, face higher and higher demands in the range of production infrastructure reliability and ensuring indefectible operations, which are deprived of unscheduled downtimes. It is not easy due to unanticipated events which might occur during equipment runtime. Major difficulty makes high level of uncertainty regarding production stoppages and anticipating such threats with an adequate time reservedness.

Disturbances in proper plant functioning, with high probability, lead to serious productivity losses, declines in quality and also noticeable deteriorations in overall performance. Preventing mentioned, undesirable machines defects and failures as well as reduction adverse effects caused by them are possible by means of ensuring correct maintenance actions in production management system. Development in contemporary industry and changes in approach to manufacturing processes, besides progress of mechanisation, computerization and highly advanced technological devices create new challenges for maintenance engineers to take up.

Maintenance is a term related to all activities and procedures, planned and not, which are undertaken to ensure constant accessibility of operational equipment in production plant. In (Velmurugan & Dhingra, 2015) we find out that proper maintenance requires “technical skills, techniques, methods to properly utilize the assets like factories, power plants, vehicles, equipment and machines”. Maintenance is said to be critical element for production effectiveness. Importance of appropriate maintenance policy is represented above all by considerable contribution of maintenance costs in total outlay of manufacturing plant. Costs related to sustainability of processes depend on industry specification, broadly are calculated between 4 and 15 percent of operational costs (Mikler, 2011). Based on (Mostafa et al., 2015; Ioannis & Nikitas, 2013) increase in maintenance cost, contingent on production type, is from 15 to 70% of total productions costs. Proper maintenance strategy in a solution to decrease high maintenance cost (Tu et al. 2015).

Beyond costs reduction, discussed issue is connected additionally with extension of physical asset lifecycle, improvement in quality, reduction in components which need to be replaced, profitability and efficiency increase, as also impact on holistic production performance. Mainly objectives of maintenance actions are decrease total

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costs besides maximize revenue. It can be achieved by elimination of breakdowns, failures, defects, wastages and all unwanted occurrences, also, by increase safety of the workforce and improve budget control. Moreover, the aim of maintenance activities is to plan properly inspections, repairs and replacements and as an output for management staff, providing information about causes of failures and damages.
Taking into consideration benefits of maintenance policy, over the years has been observed progress of numerous maintenance strategies and approaches. All changes and transformations in industry have an impact on development and growth of popularity of these concepts. As a result of modifying market and customers expectations, enterprises are forced to adapt to new requirements, what also has influenced the popularity of the subject in the literature. Having regard to this matter, in the article attention was paid to the approaches to the concept of maintenance strategies and literature review was prepared.
All of these considerations has led to the following research questions:
RQ1: Which maintenance strategy is the most frequent in the academic literature ?
RQ2: What trends could we identify in the maintenance strategies development ?
The main purpose of this paper is to provide an overview of the different authors concepts of maintenance strategies. By studying carefully discussed issue, the most common approach to this problem was distinguished and also general tendency in strategies formulation was found. Moreover, the aim of review is to analyse and interpret collected papers to indicate maintenance strategies implemented in organizations.
Looking for answers to above questions, following academic databases has been searched: Scopus, ScienceDirect and BazTech. Mainly because of great number of relevant and available articles these databases were selected. The following keywords were used for search queries: “maintenance”, “maintenance strategies”, “maintenance management”, “predictive maintenance”.

## LITERATURE REVIEW

Maintenance strategy is a planned way to upkeep devices, which contains actions such as “identification, researching and execution of many repairs, replace and inspect decisions”. Implementation the strategy requires executable, tactical plans (Velmurugan & Dhingra, 2015). Based on (Shafiee & Sørensen, 2017) maintenance strategy “includes a set of policies and actions that are used to “retain” or “restore” equipment as well as the decision support system in which maintenance activities are planned”. Other definition states that maintenance strategy “is an integrated system that is needed by corporate management to highlight the significance of a particular piece of equipment that impacts particular types of maintenance work” (Rani et al., 2015). Choosing proper maintenance strategy depends on the strategic objectives of company.
Many authors have classified maintenance strategies in a different way.
Development of maintenance is presented in (Mikler, 2011; Teixeira & Landre Junior, 2016), where three generations in maintenance are distinguished in the corresponding period. Firstly, maintenance where all actions were concentrated on repairing, for which time was mainly until the Second World War. Secondly, preventive maintenance, defined as tasks based on planning and scheduling, was developed up to seventies. Both generations are connected with life cycle of equipment depended

on profile describing frequency of failures called “bath tub”. Third generation, relates to nowadays, involves predicting and preventing activities, as also elimination of negative results of failures, named “the reliability centered maintenance culture”. Third generation of maintenance techniques in (Teixeira & Landre Junior, 2016) includes issues such as condition monitoring, hazard studies, multitasking and teamwork as well as reliability and maintainability. Moreover, what could be named fourth maintenance generation, issues such as prevention, early machinery controlling, reliability and maintainability are widely researched during last two decades. Similar approaches to operation maintenance are presented in (Legutko, 2009). The author points out three periods: reactive maintenance, preventive maintenance and the last - period of predictive-proactive maintenance. Another emplacement, also taken up historically, introduces two maintenance strategies: preventive and reactive. Preventive approach used statistical data of failures, collected from analysed components and provide presumably estimation about breakdown (Borissova et al., 2012). Similar evolution of maintenance approaches over the last century is also described in (Murthy et al. 2002).

Basic maintenance strategies showed in (Lee & Scott, 2009; Shin & Jun, 2015) are following: preventive (PM), corrective (CM) and condition-based maintenance (CBM). General maintenance policy, integrate mentioned approaches to build tool for maintenance personnel. Taken up topic of building maintenance strategy from management standpoint in (Horner, El-Haram & Munns, 1997) the same tree strategies as above are presented: corrective, preventive and condition-based, with advantages and disadvantages of each. Corrective maintenance is pointed out as the simplest method, however quite expensive, because is used as a reaction to breakdowns and all consequences of this incident. Another term for described strategy is failure-based or unplanned maintenance. Preventive maintenance is response to disadvantages of corrective actions. Author referred this maintenance model to as time-based maintenance, planned maintenance or cyclic maintenance. Third mentioned strategy is said to be more than simple visual observations and focuses on monitoring changes of crucial conditions. Comparable classification of maintenance strategies is showed in (Mostafa et al., 2015). Because of the time of maintenance actions and failures the authors distinguish following maintenance concepts: corrective, preventive and design-out as the most common. Change of strategies from PM, (what include in detail condition-based and time-based maintenance), as well as design-out maintenance and total productive maintenance is gradual. In addition, notion of lean maintenance was introduced as connection of proactive maintenance, total productive maintenance and reliability centered maintenance operations. Four alternative strategies are introduced in (Wanga et al., 2006): corrective, time-based preventive, condition-based and predictive maintenance. Described classifications of maintenance strategy is presented in Figure 1. Based on (Shin & Jun, 2015) condition-based policy is similar to preventive maintenance because both of these methods aim to prevent failures before they occur. CBM is often associate with terms such as prognostic, predictive maintenance, health management and on-condition maintenance. In this strategy important is to observe condition of the system and its elements, moreover, assess condition of products likewise forecasting the risk of damages using gathered data.

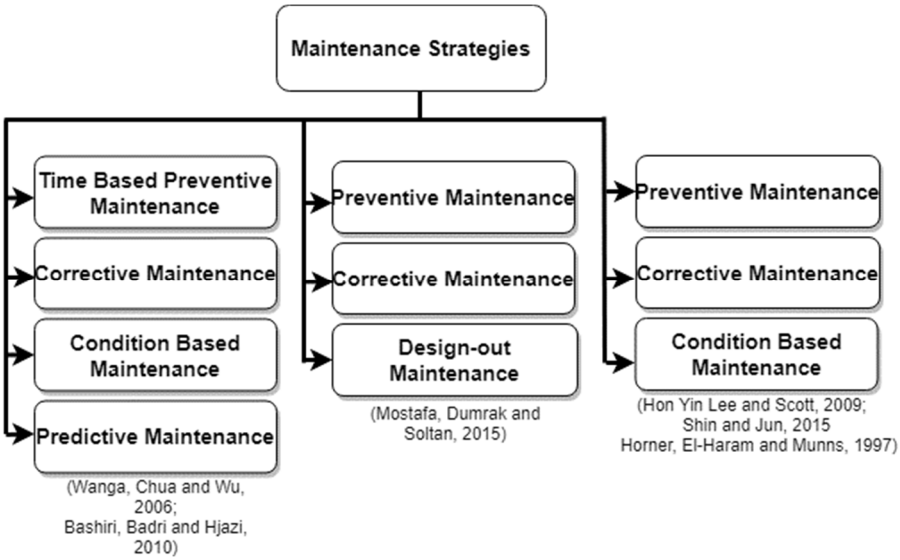


**Fig. 1 Classifications of maintenance strategies**

Based on (Ioannis & Nikitas, 2013) can we describe three maintenance strategies. Firstly, category based on time intervals includes predictive maintenance or fixed/scheduled time maintenance, where actions are pre-planned. Analysing equipment parameters provides maintenance program for the machinery. These practices are dedicated for problems connected with the wearing of components. Secondly, in the paper mentioned is preventive or condition based maintenance. In this case, prediction relies on set of data and measurements to control machines, observe abnormal situations and avoid failures. Thirdly, authors present corrective or run-to-failure maintenance. Generally, these strategies contain steps and actions, which are undertaken after breakdowns occurred. Using corrective methods is reasonable when costs of maintenance exceed costs of repairing equipment. The paper describes preventive maintenance as a synonymous to condition based maintenance, on the other hand, based on (Lee & Scott, 2009; Horner et al., 1997) approaches to these strategies are distincted.

Considering assumptions of Total Productive Maintenance TPM, (Sambrekar et al., 2018) propose two general maintenance strategies categories: reactive (also named as corrective maintenance) and proactive. Reactive methods are directed towards repairs after breakdowns occurred, while proactive tasks are aimed to avoid these repairs and failures. Detailed classification of the strategies included in mentioned main groups is shown in Figure 2. Maintenance strategies analysis based on similar viewpoint is carried out in (Swanson, 2001). From traditional point of view, reactive and proactive maintenance strategies are described. Proactive strategy engages preventive and predictive maintenance plan of action. Furthermore, third strategy is defined, an aggressive strategy of which an example is TPM, which concentrates on improving equipment in production plant through design and function advancement. TPM is a term derived from Japanese management philosophy, connected with product quality, just-in-time manufacturing, eliminating losses in production process, maximize effectiveness and team-based activities. TPM as an aggressive strategy is mentioned also in (Sharma et al., 2005), beside reactive or breakdown, preventive, predictive or condition-based, reliability-centered maintenance strategy.

Four categories of maintenance activities are distinguished in (Ollila and Malmipuro,

1999). Authors present reactive, preventive, predictive and proactive maintenance. Preventive is method scheduled in time, predictive maintenance is utilised when faults are identified before breakdown occur, proactive strategy is based on improvement of current construction instead of preventing possible production stoppages. Reactive policy should be substituted by other strategies.

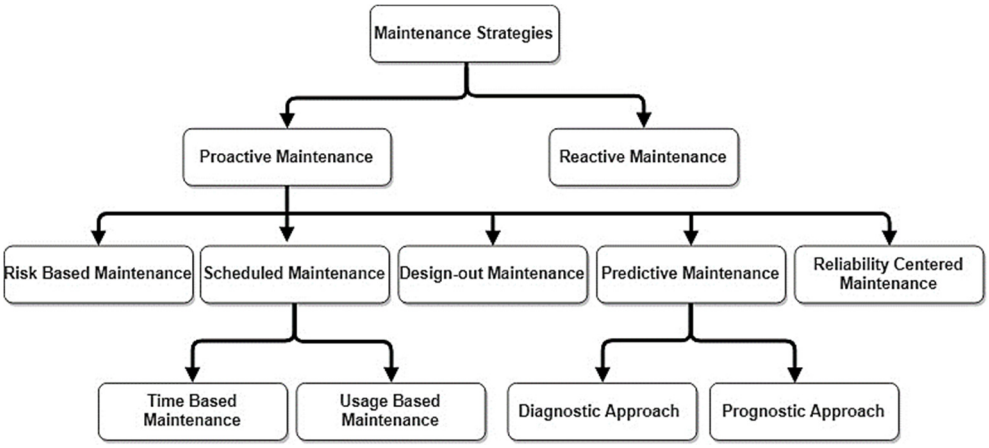


**Fig. 2 Classifications of maintenance strategies – proactive and reactive**
*Source: based on (Sambrekar, et al., 2018).*

In (Vishnu & Regikumar, 2016) we could find general division of technical maintenance strategies such as breakdown or corrective or run to failure maintenance, preventive maintenance, planned maintenance, proactive maintenance, condition-based maintenance, design-out maintenance, reliability centered maintenance. The last of mentioned strategy is combination of reactive, interval-based, condition-based, as well as proactive maintenance concepts. These strategies are connected in order to maximize profits and reliability of equipment. Total productive maintenance, preventive maintenance and reliability centered maintenance are considered as innovative methods and are implemented to enhance effectiveness of machinery.

Different maintenance types were introduced in (Lind & Muyingo, 2012). The paper presents maintenance classification used in Sweden, where we could find planned maintenance and corrective maintenance. The second includes immediate maintenance and other corrective approaches. Based on European standard, author classified maintenance in two main concepts: preventive maintenance (PM) and corrective maintenance (CM). Corrective strategies involve deferred CM (actions undertaken with delay after fault' detection) and immediate CM (actions carried out immediately after fault). Preventive maintenance involves condition based maintenance (scheduled, continuous or on request) and predetermined maintenance (scheduled). The alternative way of maintenance division presents two main approaches: preventive maintenance as strategy before detected fault and corrective maintenance as activities after detected fault. More specifically PM includes planned maintenance (time based, condition based, predictive and planned opportunistic) and immediate-opportunistic. Whereas in CM are planned and immediate operations.

Corrective and preventive maintenance are the main strategies in machine maintenance also based on (Legát et al., 2017; Okoh et al., 2017). Following methods: predetermined, condition based and predictive maintenance are classed as

preventive maintenance (Legát et al., 2017). Taxonomy of preventive maintenance strategies from (Okoh et al., 2017) divided it into condition-based and opportunity. In the first group we could find diagnostics and prognostics. In the prognostics are following strategies: data-driven, knowledge-based and model-based, as well as hybrid. The opportunity maintenance aim is to replace elements of equipment which have not failed yet, considering available resources. Diagnostics is inspection using aid of sensors to identify components. Prognostics, from the other side, is predicting time to failure and examining functionality of devices. Data driven strategy for estimation and maintenance decisions utilizes failure data. Model-based approach, called also physical-model-based, is connected with the physics for reliability predictions and combines experiment, observation, monitoring and also data monitoring for these estimations. Knowledge-based strategy uses experience computational intelligence methods, proper to stored information and estimate similarity of present situation and databank of failures. A hybrid model is combination of several models based on data to improve accuracy. Classifications of corrective and preventive maintenance strategies from different authors point of view was presented in Figure 3.

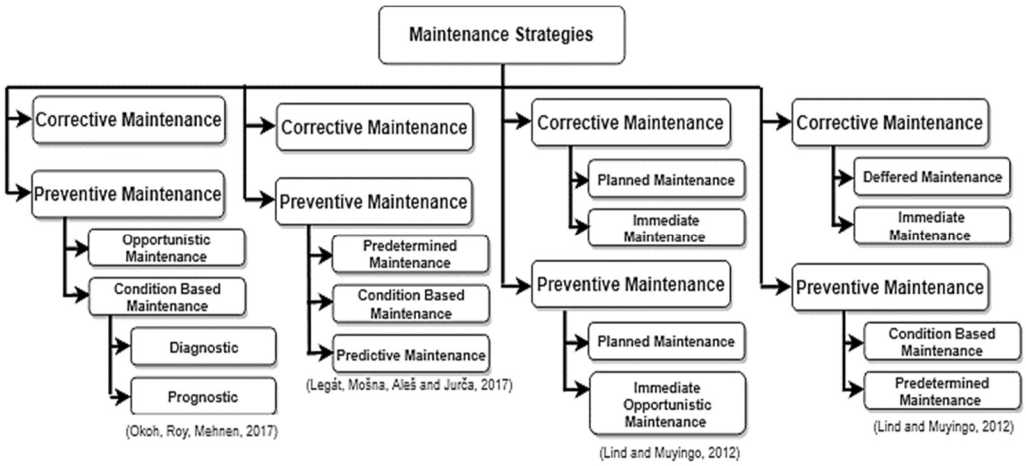


**Fig. 3 Classifications of maintenance strategies – corrective and preventive**

The same major categories: correctives maintenance (failure based) and regular preventive maintenance (life based) classifying generally maintenance of any system (Velmurugan & Dhingra 2015; Shafiee, 2015). Maintenance policy is divided into preventive maintenance and corrective maintenance also in (Ignat, 2013; Vilarinho et al., 2017; Bashiri et al., 2011). In a wider classification (Shafiee, 2015) propose following classes of maintenance strategies: “corrective; routine inspections; calendar-based preventive maintenance; age-based preventive maintenance; reliability-centered; condition-based; predictive; risk-based; opportunistic; design-out; total productive maintenance; total quality maintenance; computerized maintenance management system; autonomous maintenance; skill levels upgrade; world-class maintenance”. As an alternative maintenance strategies for the above division in (Bashiri, Badri & Hejazi, 2011) could we find corrective maintenance, time-based preventive maintenance, condition-based maintenance and predictive maintenance. Time-based maintenance is defined as predetermined maintenance and technique of preventive maintenance (Vilarinho, Lopes & Oliveira, 2017).

According to (Rani, Baharum, Akbar & Nawawi, 2015) two general types of maintenance strategies are defined: planned and unplanned. The first group comprises: proactive, preventive, predictive, and also corrective maintenance. Unplanned strategy, called reactive or emergency maintenance too, is connected with breakdown maintenance. Similarly, maintenance topic is taken up in (Arslankaya and Atay, 2015) where also two main categories of maintenance activities are classified: planned and unplanned maintenance. In the first category, three subgroups are mentioned: periodic; predictive and preventive maintenance. The division of maintenance strategies described above is introduced in Figure 4.

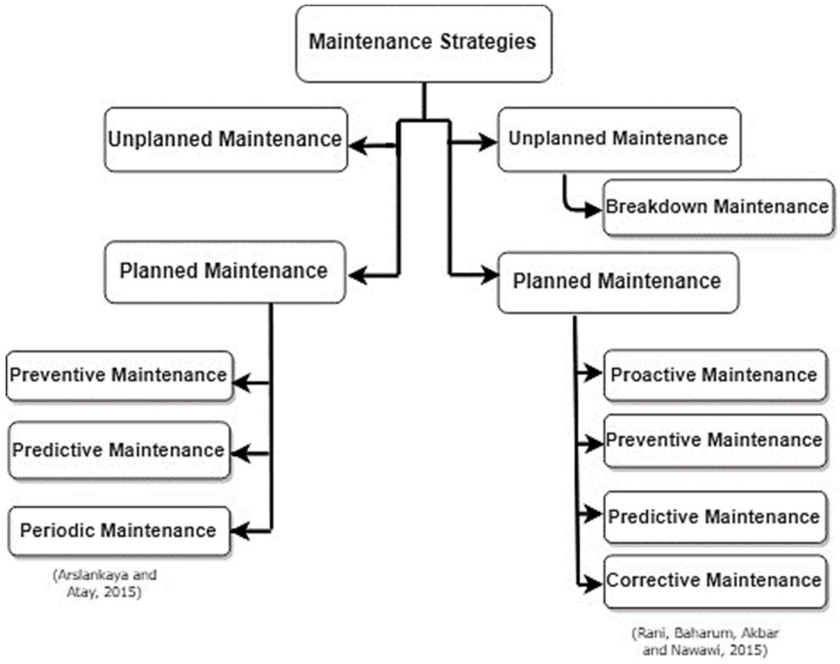


**Fig. 4 Classifications of maintenance strategies - planned and unplanned**

Below we could find another approaches to maintenance strategies, which are proposed in published papers, but are much more infrequent. Based on (Cherkaoui et al., 2016) the periodic inspection and replacement strategy (PIR) and the quantile-based and replacement strategy (QIR) are proposed as the two representatives of conditional-based maintenance strategies. In the first of them, system is regularly inspected, the second strategy relies on a non-periodic inspections. Mentioned strategies are distinguished from the performance and robustness point of view. Another group of maintenance strategies are introduced in (Pająk & Woropay, 2009). The authors mention an operation until failure, performed mainly because of simplicity in management process and reduction of service base, enable maximal using of an operational potential. Disadvantages of the strategy is risk of defects occurrence during exploitation time. Maintenance approach by service life bases on a service cycle and planning service activities. Continual monitoring of technical state of assets, which provides diagnostic information, is the basic idea of the next maintenance strategy, strategy by state. To increase efficiency of machines another strategy, by efficiency is implemented. Following strategy by reliability has a ground in machines reliability monitoring. Further solution mentioned in the article is the mixed strategy as a combination of the strategy by state and strategy by service life.

In the literature, could we indicate many different classifications of maintenance strategies. Having regard to that fact, Table 1 contains the summary of the strategies presented in the selected academic papers.

**Table 1**
**Summary of academic papers by maintenance strategy**

| | CM | PM | PdM | CBM | Reactive | Proactive | Planned | Unplanned | TPM | Design-out |
|---|---|---|---|---|---|---|---|---|---|---|
| Al-Najjar, et al., (2003) | | √ | | √ | | | | | | |
| Arslankaya, et al. (2015) | | √ | √ | | | | √ | √ | √ | |
| Asuquo, M. P., et al. (2019) | | √ | √ | √ | √ | | | | | |
| Bashiri M. et al. (2011) | √ | √ | √ | √ | | | | | | |
| Bevilacqua, et al.. (2000) | √ | √ | √ | √ | | | | | | |
| Borissova D. I. et al. (2012) | | √ | √ | | √ | | | | | |
| Cherkaoui, H. et al. (2016) | | | | √ | | | | | | |
| Eti, M. C. et al. (2006) | √ | √ | √ | √ | | | | | | |
| Horner, R.M.W., et al. (1997) | √ | √ | | √ | | | | | | |
| Ierace, S. et al. (2008) | √ | √ | √ | √ | | | | | | |
| Ioannis, D. et al. (2013) | √ | √ | √ | √ | | | | | | |
| Lee, H. et al. (2008) | √ | √ | √ | √ | √ | √ | | | | |
| Legát, V. et al. (2017) | √ | √ | √ | √ | | | | | | |
| Lind, H. et al. (2012) | √ | √ | √ | √ | | | √ | | | |
| Mikler, J. (2011) | √ | | √ | √ | √ | | √ | | | |
| Mostafa, S., et al. (2015) | √ | √ | √ | √ | | | | | √ | √ |
| Murthy, D. et al. (2002) | √ | | | | | | | | | |
| Ni, X. et al. (2016) | √ | √ | | √ | | | | | | |
| Okoh, C. et al. (2017) | √ | √ | √ | √ | | | | | | |
| Ollila, A. et al.(1999) | | √ | √ | √ | √ | √ | | | √ | |
| Özcan, E.C. et al. (2017) | √ | √ | √ | | | | | | | |
| Rani, N. et al. (2015) | √ | √ | √ | | | √ | √ | √ | | |
| Sambrekar, A. et al. (2018) | | | √ | | √ | √ | | | | √ |
| Shafiee, M. (2015) | √ | √ | √ | √ | √ | | | | √ | |
| Sharma, R. et al. (2015) | | √ | √ | √ | √ | √ | | | √ | |
| Shin, J.-H. et al. (2015) | √ | √ | √ | √ | | | | | | |
| Srivastava, P. et al. (2017) | √ | √ | √ | √ | | | | | | |
| Swanson, L. (2001) | | √ | √ | √ | √ | √ | | | √ | |
| Teixeira, F. et al. (2016) | | | √ | √ | | | | | | |
| Tu, J. et al. (2015) | √ | √ | | √ | | | | | | |
| Velmurugan, R.S. et al. (2015) | √ | √ | √ | √ | √ | √ | √ | | √ | |
| Vilarinho, S. et al. (2017) | √ | √ | | | | | | | | |
| Vishnu, C. R. et al. (2016) | √ | √ | | √ | √ | √ | √ | | | √ |
| Wang, L. et al. (2007) | √ | √ | √ | √ | | | | | | |
| Zeng, Sh. W. (1997) | √ | √ | | | | | | | | |
| Zhaoyang, T., et al. (2011) | √ | √ | | √ | | | | | | |
| Zhang, Ch. et al. (2019) | √ | √ | | √ | | | | | | |

It can be concluded, that there are noticeable differences in the definitions of the maintenance strategies in the literature. Different classifications are presented in Figs. 1-4. Fig. 3 shows the most common approach, where strategies are divided into two, primary approaches: corrective and preventive maintenance, which consists of another strategies such as: condition based, opportunistic, predetermined, immediate, planned or deferred maintenance. In Fig. 1 as the main strategies were distinguished also CBM, Design out and predictive maintenance, in addition to the two main approaches mentioned above, CM over PM. Fig. 2 contains an interesting and extensive classification, in which two main strategies are: proactive and reactive maintenance, which contain another maintenance policies. The division of maintenance strategies presented on Fig. 4 introduces two general categories of maintenance: planned and unplanned, which, depending on the author, consist of CM, PM, PdM, proactive and periodic maintenance.

**RESULTS**

In this paper attention was drawn to maintenance strategies to indicate the most common maintaining approaches in the literature. Academic databases such as ScienceDirect, Baztech and Scopus were investigated to point out the most frequent maintenance strategy and trends in this issue development. Searching was concentrated on a research and review articles likewise conference papers.

The following search strings were used in investigation:

- “preventive+maintenance”,
- “corrective+maintenance”,
- “predictive+maintenance”,
- “condition+based+maintenance”
- “proactive+maintenance”,

which author considered the most appropriate to answer the research questions raised in the introduction.

After research ScienceDirect, Baztech and Scopus altogether, the number of articles with keyword “preventive+maintenance” is 21,084, what posed preventive maintenance the most frequent maintenance strategy in investigated academic databases.

The descriptor “predictive+maintenance” and “condition+based+maintenance” were found 6,271 and 6,265 in succession what also make very similar values of these strategies’ occurrence in the databases. Focusing on search string “corrective+maintenance” 3,944 document results were searched. The less common keyword “proactive+maintenance” was estimated with 1,294 research findings. Figure 5 shows contributions of different maintenance strategies papers found in the scientific journal databases.

Based on graph it is possible to indicate how often particular strategies have been presented in academic papers. The number of papers regarding preventive maintenance is significantly higher than for the others strategies. Hence, answering the first research question, preventive maintenance is the most frequently occurring strategy in selected literature databases. It is also worth noticing, that the number of preventive and condition based strategy in literature is similar to each other and even three times lower than for the most common one. According to the obtained results, it could be seen that corrective and proactive maintenance strategy occurs the least

frequently. Also important to note is, that in certain publications, some strategies may be included in the main classifications, while in other articles, they appear as separate examples of maintenance approach.

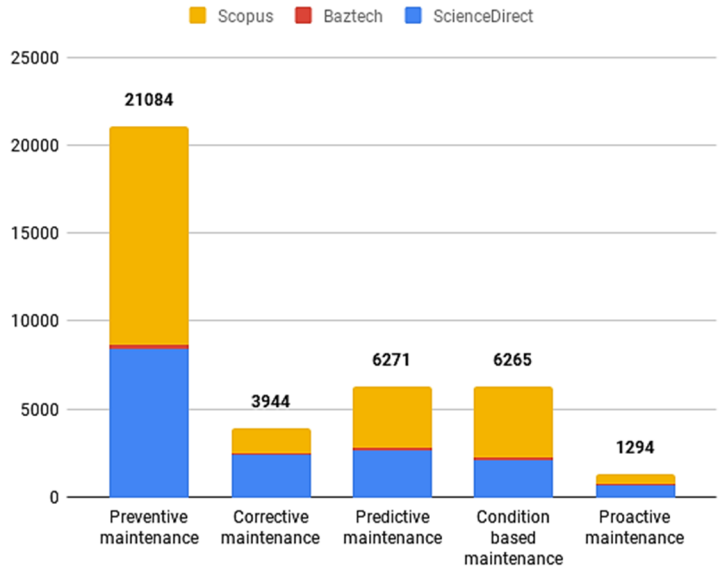


**Fig. 5 The number of papers regarding maintenance strategies in scientific journal databases**

To answer the second research question, ScienceDirect, Baztech and Scopus were examined. After searching, we could find the number of papers in mentioned databases regarding the most relevant strategies in the review: preventive, corrective, predictive, condition-based and proactive maintenance per year. The period in which the analysis was carried out is from 2000-2018. Results of the investigation are presented in Figure 6.

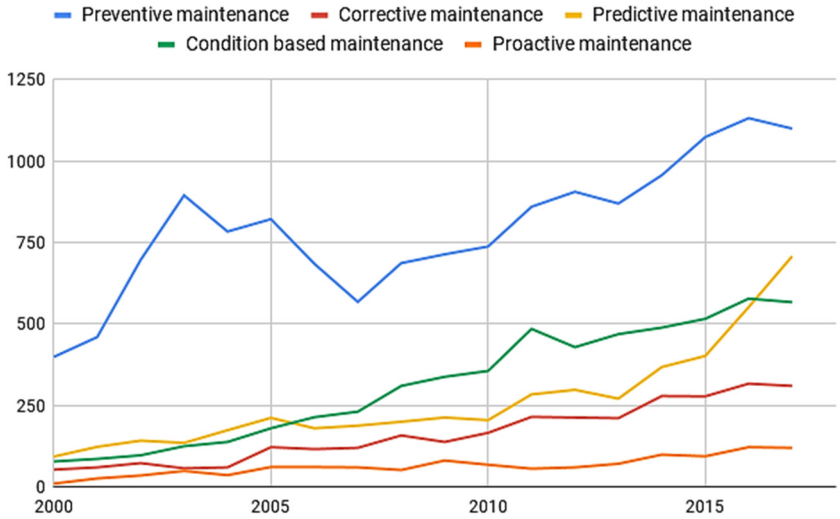


**Fig. 6 The number of papers regarding certain maintenance strategies from 2000-2018**

The graph shows that the most scientific publications in recent years concerned the strategy of preventive maintenance, which appears the most frequent despite fluctuations. According to the diagram, the number of predictive maintenance papers rose sharply between 2000 and 2003. After this period, there was a significant

decrease in the number of publications in this field to 2007, then an increase with slight fluctuations is observed again. Moreover, the number of article regarding condition based maintenance started climbing steadily from the beginning of the analysed period, with one significant increase in 2011. The number of predictive maintenance strategy papers generally remains stable with a moderate upward trend, afterwards dynamic growth has been recorded since 2015, which continues unabated. The number of articles regarding the remaining two strategies, corrective maintenance and proactive maintenance, is rather stable over the analysed period with slight upward trend. In recent three years the most visible increase in publications was recorded for predictive maintenance strategy, while the other four strategies appeared in the literature with lower frequency by year or this value remind on the same level. Results indicate enhancing trend toward predictive maintenance in academic databases.

## CONCLUSIONS

Proper maintenance policy is a crucial and strategic aspect of management in organizations, which resulted in reducing breakdowns, minimizing cost and improving productivity. Choosing an appropriate strategy is a considerable challenge for the company. Some organization utilised mix of maintenance strategies. In view of the great popularity of this issue and the increasing need for maintenance activities improvement, attention was paid to the maintenance strategies concepts.

This paper presents a literature review of maintenance strategies formulation and provide an overview of different authors concepts of maintenance strategies. In the analysis academic papers were considered to identify existing approaches to the topic. Literature examples point out various maintenance types. Some of them are comparable, in some can we distinguish similarities, while some are clearly distinct. Moreover, the same strategy can be defined in a distinct way, depending on authors. In different sources, the classification of the maintenance strategy is presented in a different way, however, it is not difficult to notice a certain regularity in publications and directing the authors towards proactive approaches. Moreover, the article highlights the changes in the approach to equipment and production machines' maintenance that took place over the years and also evolution of maintenance strategies. Looking for answers to the questions asked in the introduction, academic databases were investigated to prepare numerical statements. The databases were searched to show how the number of publications has developed over the years. Additionally, trends and tendencies in scientific publications were analysed to indicate the most popular strategies in recent years. On this basis, it is possible to indicate preventive maintenance as the most common strategy in literature, while predictive maintenance develops the most nowadays.

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**Abstract.** This paper presents a literature review of maintenance strategies formulation. The purpose of this article is to provide an overview of different published concepts of maintenance strategies, distinguish the most common approaches to this issue and find a general tendency in strategies classification. Furthermore, the review is aimed to point out the importance of unscheduled downtime which might occur during equipment runtime in a production plant. The paper classifies the existing maintenance concepts and emphasizes key assumptions of the analysed strategies. The literature study and carried out analysis could be useful to find appropriate reliability assurance methods. In addition, defined maintenance approaches might help in decision making process in a company. The paper is a comprehensive overview of discussed strategies, which indicates the most frequent maintenance models in the analysed papers.

**Keywords:** maintenance, maintenance strategies, maintenance management, predictive maintenance