PREVENTIVE MAINTENANCE STRATEGIES: LITERATURE REVIEW AND DIRECTIONS

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ABSTRACT

Manufacturing system has been rapidly developing during these decades. Within this advancement, maintenance becomes an important supporting factor. Maintenance aims to develop better production processes in order to perform as expected. Preventive maintenance (PM) is one of maintenance strategies to prevent incipient failures. Many scholars have been studying PM in numerous occasions as well as many different perspectives. This paper attempts to review a number of references, classify them from different view points, as well as integrate both theoretical and practical benefit obtained. This paper also highlights many approaches in determining optimal maintenance policy. The proposed classification is based on the practical cases presented in references. Discussion about comprehensive thinking in PM strategy is also elaborated. Based on authors' knowledge, there papers work on our concern beforehand. This feature, makes this paper different from others. This paper offers usefull new insights for both academics and practitioners in the area of PM.

Keywords: Preventive Maintenance, Policy PM, Maintenance, Literature review

1. Introduction

Manufacturing system is one of the spearheads in the production chain where multi-dimensional management practices take place (Mazur & Golas, 2011; Worley and Doolen, 2006; Gurumurthy and Kodali, 2011; Stachowiak et al., 2013). It aims to improve better efficiency, effective, and economic to survive in a highly competitive global economy. Maintenance contributes to industry in extending effective operational system, increasing reliability and system availability (Swanson, 2001). Maintenance is combination of all administrative and technique to maintain or restore the optimal conditions so that it can perform a required function (Besnard, 2013).

Maintenance which aims to support the continuity of production process, has two impacts. Maintenance positively improves the machine reliability and ensures the sustainability of production process. Maintenance gives a positive impact in improving the reliability of the machine to ensure the sustainability of the production process. On the other hand, maintenance activities result additional cost for company, i.e. 15 – 40% of total production costs. These costs relate to maintenance policy (preventive, corrective maintenance), labor, spare parts and other (Mobley, 1990). Furthermore, Survey to manufacturers shows that time for maintenance consume 15.7% of the overall production time (Dunn, 1988).

Lot of literatures are available from various resources in the field of maintenance management. Grag and Desmukh (2006) have presented various classifications of maintenance optimization models by analyzing 142 papers. A broad classification of these literatures can be devided in to six areas. These areas are: maintenance optimization models, maintenance techniques, maintenance scheduling, maintenance performance measurement, maintenance information systems; and maintenance policies. In the process, articles published in the last three decades are identified, analyzed and classified.

This research traces the evolution of performance measures and measurement, in addition to the related maintenance organizational function, its resource utilization, activities and practices.(Simo'es, (2011). In another invited review, Ding and Kamarudin (2015) have undertaken a survey of maintenance policies. A unique classification based on the certainty theory is adopted to categorize the maintenance policy optimization model. In the context of operation management, there are several types of model classification based on different classification principles. In that study, the model was classified in term of degree of certainty: certainty, risk, and uncertainty. The third literature review discusses extensively maintenance strategy. However, this paper attempts to review and classify many references from different view of point, integrate both theory and practice. This paper also highlights many approaches in determining the optimal maintenance policy. The proposed classification develops based on the practical cases preserve in references. Discussion based on both theory and practice provide comprehensive thinking in PM strategy, that not too many papers work on, which makes this paper different from others. The specific objectives of this paper are:

1. Present the classification of available literature in the policy of preventive maintenance
2. Identify study cases or its application in preventive maintennace
3. Identify the critical observations on each classification
4. Identify of research directions in the future.

2. Maintenance management

initially, maintenance is done by waiting for the engine failure, so it is reactive. This category is called breakdown maintenance. Breakdown maintenance carried out after the machine is failure. Although this maintenance can be done but it will cause some problems such as the disruption of the production process, endangerment of the operator safety and more serious damage (Parida & Kumar, 2007)

Another approach is proactive maintenance. Proactive maintenance is a pre-operational actions to eliminate the source of failure (Ding & Kamaruddin, 2015). Swanson (2001) explains, Maintenance contribute to extending the effective operational system lifetime, improve reliability and system availability. The scope of this maintenance is a service routine and periodic inspections, preventive replacement, condition monitoring, work planning, purchasing and material management, personnel management, and quality control (Ahuja & Khamba, 2008).

Maintenance perspective has changed from being considered a barrier to change into activities that are necessary. Maintenance activities not only under the responsibility of the maintenance department but a shared responsibility (Ding & Kamaruddin, 2015). Maintenance is the responsibility of all levels of management. Maintenance is more focused on maintenance independent, autonomous maintenance (AM). So, all levels of management need to improve skills in the field of maintenance. This change of perspective can be viewed simply in Figure 2 below:

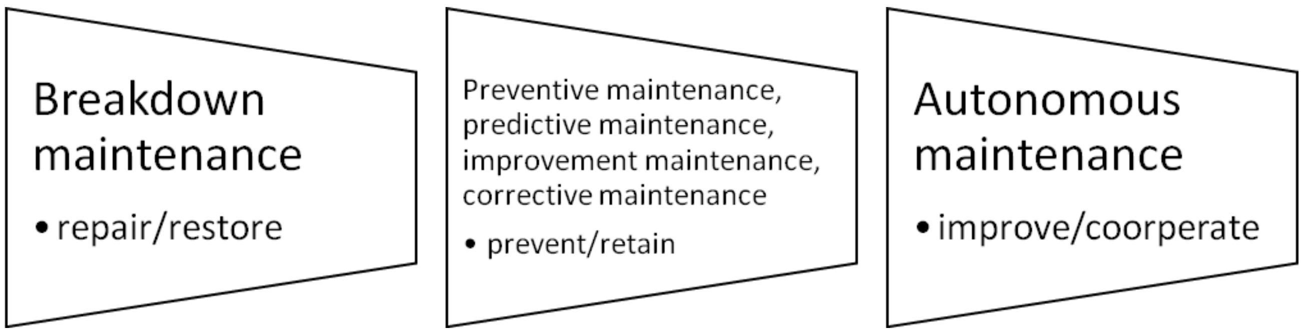

Figure 2. Maintenance policy

In the maintenance management, determines the maintenance strategy is very important because every strategy has its own characteristics. Strategy affects the schedule of repaire maintenance / replacement, maintenance costs, personnel requirements, etc. therefore, the maintenance strategy needs to be determined by optimization. In maintenance, optimization is the determination of alternative solutions balanced with certain criteria. Optimization of treatment is a process of evaluation test directly the function, tasks, activities to achieve a balanced ratio (Matusheski, 2001). According Champbell (2001), There are four key policies of optimization of maintenance management for resource management optimization, namely:

1. Optimization PM with replacement,
   a. Optimization of time and replacement costs
   b. Optimization inventory of spare parts
2. Optimization PM with repair,
   a. Optimization of economic age based
   b. Optimization of condition-based.
3. Optimization of inspection
   a. Optimization of the frequency of inspections.
   b. Optimization of interval inspection.
4. Optimization of resource requirements.
   a. Total Engine Optimization
   b. Total crew maintenance optimization
   c. Optimization using contractors

3. Literature review

For this research purpose, a detailed and exhaustive search of literature pertaining to PM and related areas were conducted. The time period of this literature review mostly covers the period from 2006 till 2016, though, PM related publications covers the period mostly from 2000 onwards. The literature review was conducted with an aim to search all possible related works connected directly or indirectly with PM, as well as reported projects, organizational systems, process and people. as well as conferences and other publications (Figure 2). The number of journals published in PM and its related areas also confirms the interest and importance of this subject for both the academia and industry.

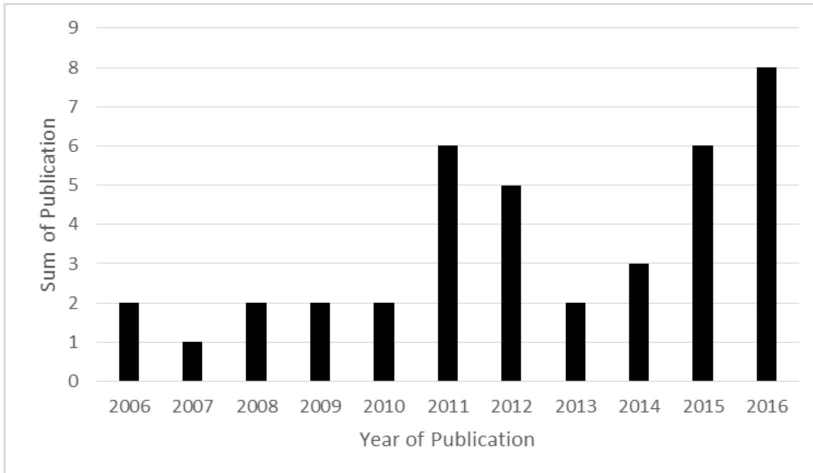

Figure 2. Publications per year

4. Classification of preventive maintenance policy optimization models

1. Optimization PM with replacement,

   a. Optimization of replacement time

   Interval time and replacement cost components in the maintenance process has a tendency as follows; for parts that are replaced, when it fails then the time interval increases, cost tends to rise. For parts that are based on preventive maintenance, when it fails then by the time interval increases, costs tend to fall. The optimal value is obtained from the lowest total cost. Rachaniotis & Pappis, (2008) propose is a decision-making models for deteriorating reassembling different subsystems and components of a complex system from used and new parts. The objective is to find the proper reassembly policies in a period of time so as to maximize the systems' overall performance values, under a limited budget, and reassembly and compatibility constraints. Environmental gains are incurred from these policies, since the used components' life cycle, at least in some cases, is extended instead of ending by entering the waste stream. A stochastic dynamic programming approach is proposed, and an example in the case of personal computers is presented. On the other hand, Zhanga, et. al. (2015), proposed a model of imperfect maintenance that applies to sensor information system can be modeled by a stochastic process.

   The imperfect maintenance proposed model is based on the intuition that the maintenance action will change the rate of damage to the system, and that each maintenance action should have a different degree of impact on the rate of deterioration. The quasi Monte Carlo method is utilized for fixed estimating the model parameters, and the filtering technique is utilized for dynamically estimating the impact from each maintenance action. In different studies, Gilardoni, et. al. (2016) and Mabrouk et. al., (2016) is equally focused on the timing of the PM but using a different method. Gilardoni, et. al. (2016) using mathematical models and numerical algorithms while Mabrouk (2016) using a Monte Carlo for simulation. Similarly Nourelfath, et. al. (2016) discusses the timing of PM associated with cost and quality. This is determined through mathematical models with Markov method that has been determined.

b. Optimization of replacement costs

To reach the most economic age in equipment cost is affected by:

- Operating and maintenance costs will increase if equipment replacement time is longer.
- The value of equipment asset tends to decrease, when the replacement time is greater.
- The fixed costs include operator and insurance are likely to remain.
- The most optimal age in the replacement of equipment at the most minimum cost value.

Nggada, et al. (2010) define optimization in terms of determining the economic life is related to PM policy and reliability considerations, unavailability and cost. To set the optimization Nggada et al. (2010) using Hip-Hops analysis. While Chang & Lo (2011) determine the profit lessor if minimal repair. Mathematical models are used to determine profit as the optimal maintenance policy considerations and the length of the lease periode is obtained so that the total expected profit is maximized. When make decisions about the cost of equipment to replace or merge with a new one, it is necessary to merge all costs. Farran & Zayed (2012) conducted a study with a focus on determining the cost of repair using a Markov Model. In contrast to him, Seif & Rabbani (2014) using Integer Programming in determining the replacement cost. Korpi & Risku, (2015) determine the feasibility of the PM to determine the life cycle cost of the engine.

c. Optimization inventory of spare parts

In providing the inventory of spare parts, the cost is influenced by:

- The booking fee (order costs), with the booking quantity is greater then the booking fee is lower.
- Storage costs (holding cost), with the booking quantity is greater then the storage costs is greater.

The optimal number of inventory of spare parts, the total cost with the most minimal value. Research on this is done by Rodrigues & Yoneyama (2013). They plan interventions maintenance, use RUL (Remaining Useful Life), estimates obtained from PHM ((Prognostics and Health Monitoring) system. This information is used to verify whether the spare parts will be available when the next failure is expected to occur. Since the parts are limited resources, the purpose of the proposed model is to reduce the possibility that some similar components will fail in a short time because, when that happens, there is not enough time to fix all the fail components and the availability of the fleet punished. Unlike previous researchers, Dalgic, et.al . (2015) investigated the cost of PM's most savers to allocate resources O & M which may include helicopter, boat transfer crew, boat access to the offshore and ship jack-ups. it is solved through Monte-Carlo by considering the environmental conditions (wind speed, wave height and wave period), operational analysis of transportation systems, investigation of failure (type and frequency), and simulating repairs and spare parts. While Rigamonti et al., (2016) conducted a study of maintenance based on the condition of the engine. This paper presents an approach for the detection of the degradation of onset and the identification of the degradation state of industrial components with in homogeneous degradation behaviors due to the effects of multiple, possibly competing, degradation mechanisms and non-stationary operational and environmental conditions.

Tabel 1. Summary of method and focus under PM with replacement category

Model	Method	Authors and year of publication	Focus
Optimization PM with replacement.			
Optimization of time replacement costs			
Multi-criteria-based model	AHP	Bevilacqua and Braglia (2000)	budget constraints and time schedule PM
Mathematically based model	Mixed-integer linear programming	Rachaniotis and Pappis (2008)	Components replacement
Mathematically based model	Mixed-integer linear programming & Non-homogenous Poisson process	Moghaddam and Usher (2011)	Determining the schedule component replacement
Simulation-based model	Monte Carlo simulation	Zhanga et. al. (2015)	Rate of deterioration of a system,
Mathematically based model	Markov method	Nourelfath et. al. (2016)	Determines PM's time, cost and quality
Simulation-based model	Monte Carlo simulation	Gilardonia (2016)	Determines PM's time and cost
Mathematically based model	Probability density function	Mabrouk et. al. (2016)	Determines PM's time and cost
a. Optimization of replacement costs			
Hazard-based model	HiP-HOPS analysis	Nggada et al. (2010)	effect of PM on system reliability, unavailability and cost.
Mathematically based model	Probability density function	Chang & Lo (2011)	Efect PM cost
Mathematically based model	Markov method	Farran and Zayed (2012)	Cost replacement
Mathematically based model	Integer programming	Seif and Rabbani (2014)	Cost replacement
Mathematically based model	life cycle costing (LCC) method	Korpi and Risku (2015)	maintenance policy implementation
b. Optimization of inventory of spare parts			
Mathematically based model	proportional hazard method	Rodrigues and Yoneyama (2013)	Intervention PM with verification sparepart
Simulation-based model	Monte Carlo simulation	Dalgica (2015)	allocate resources
Critical-based model	Risk matrix	Rigamonti et. al. (2016)	detecting initiation of the degradation process Insulated Gate Bipolar Transistor

2. Optimization PM with repair,

Optimization replacement of equipment includes:

a. Optimization of economic age based

Repairs characterized by their effectiveness, which is often referred to as the degree of repair - the extent to which the condition of the system function is restored following repair. Based on this, repairs classified as minimal, imperfect or perfect repair. Eti & Ogaji, (2006) define preventive maintenance with a focus on reliability culture. They do research on the company Nigeria. Followed by Oka et al. (2006) that discussed the repair schedule by using the differential calculus. The model was used to determine the repair schedule is based on a minimal cost. Yeh & Chang, (2007) is more specific in his research focus. They determine the threshold levels of engine failure on the leased using Weibull lifetime. PM strategy that is choosen is minimal repair. The following year (Yeh, Kao, & Liang, 2011; Yeh, Liang, and Lo, 2011; Yeh, Kao, & Chang, 2009), their researches are associated with failure rate reduction, the maximum profit of leased equipment and Optimal length of lease period. The MPs elected are minimal repair. But in 2011, Yeh et al. start comparing strategies with minimal repair imperfect repair. Varnosafaderani, (2012) continue research Yeh et al. (2009), the difference is the object model of the improvement of the system with non-monotonic function.

b. Optimization of condition-based.

The most appropriate time for preventive repairs or components and equipment replacement are before a failure occurs. On condition-based maintenance (CBM) is preceded by new information is called condition data, to calculate more precise favorable moment to repair or replace. Maintenance optimization decisions usually require more calculated risk of failure. If you want to maximize operation profit or availability of equipment, to determine the performance of maintenance Chen & Chen, (2010) using the integration of AHP, TOPSIS, and gray relational analysis. As a case study this model is applied to the semiconductor company. Golmakani & Pouresmaeeli (2014) determine the optimal replacement threshold and optimal inspection interval based on condition based maintenance (CBM). Develop research before, Do, et al. (2015) determine the impact of imperfect repair of the system. In determining the inspection time Do et al. adjust the remaining useful life (RUL). Using different methods, Tang et al., (2015) determine the critical threshold with semi-Markov decision. Azadeh, et al., (2015) conducted a study of the effectiveness of CBM by comparing the corrective maintenance (CM) with PM. The method used is the Monte Carlo simulation. Peng & Houtum, (2016), integrating policy of CBM to production lot-sizing. CBM policy optimality is choosen based on the cost of the long-term average is minimal. Xenos, et al., (2016), Optimal maintenance schedule on CBM for compressor engines involves the interaction of several compressor. For that Xenos using mixed-integer linear programming to determine the optimal policy.

Tabel 2. Summary of method and focus under PM with repair category

Model	Method	Authors and year of publication	Focus
Optimization PM with repair			
a. optimization of the economic age			
Mathematically	Differential Calculus	S.A. Oke et al.	PM's scheduling

based model		(2006)	
Mathematically based model	Probability density function	Ety et al. (2006)	Reliability
Mathematically based model	Probability density function	Yeh & Chang (20007)	threshold value of failure-rate
Mathematically based model	Probability density function	Yeh et al. (2009)	Failure rate reduction
Mathematically based model	Probability density function	Chang et al. (2011)	the maximum profit of leased equipment
Mathematically based model	Probability density function	Yeh et al. (2011)	Optimal length of lease period
Mathematically based model	Probability density function	Varnosafaderani (2012)	Failure rate
Mathematically based model	Markov method	DucLe dan Tan (2013)	Improve reliability
b. Optimization of condition-based maintenance			
Multi-criteria-based model	Integration of AHP, TOPSIS, and gray relational analysis	Chen and Chen (2010)	Perform of PM
Mathematically based model	Probability density function	Golmakani and Pouresmaeeli (2014)	Threshold replacement
Mathematically based model	Probability density function	Don et al. (2015)	Effect of IR
Artificial intelligence-based model	Monte Carlo simulation	Azadeh et al. (2015)	Reliability and cost
Mathematically based model	semi-Markov decision	Tang et. al. (2015)	critical threshold
Mathematically based model	Probability density function	Peng and Houtum (2016)	CBM’s effect to production
Mathematically based model	Mixed-integer linear programming	Xenos, et. al. (2016)	Optimal schedule maintenance

3. Optimization of inspection

To assess the optimization of inspection procedures include:

a. Optimization of the frequency of inspections.

By increasing the frequency of inspections and minor maintenance, it will decrease the rate of failure of equipment. Distribution of the failure of a system can be obtained from the recorded data . One of useful way is using a system Mean Time To Failure (MTTF). If the system failure rates are declining, the MTTF value will increase. Salonen & Deleryd (2011) determines the cost of inspection with the approach Analysis Based Costing (ABC). While C. Chang, (2014) define a random inspection to determine the replacement and minimal repair using bivariate optimal solution.

b. Optimization of interval inspection.

This optimization exercise judgment: how to use resources efficiently, how the work schedule in accordance with the capacity of the factory / workshop. While the methods used is the spreadsheet programming, genetic programming and constraint programming. Research in this optimization is performed by Zhou, et al., (2009) proposed a PM opportunistic scheduling algorithm for multi-unit series system based on dynamic programming with the effects of imperfect integration maintenance. Application maintenance is optimally determined to maximize cost savings cumulative opportunistic short-term maintenance for the entire system. In his paper, Moghaddam & Usher (2011) presents a mathematical model and solution approach in determining the optimal preventive maintenance schedule for the fixed component and circuit maintenance system based on the rate of occurrence of failure (ROCOF). , Liao, (2012) Applies his study of periodic preventive maintenance (PM) to a repairable production system with major repairs conducted after a failure. This study considers the PM failed due to maintenance workers performing incorrectly PM and damages occurring after PM. Therefore, three types are Considered PM: PM imperfect, perfect prime minister and failed PM. Aghezzaf et al., (2016) integrates production and maintenance planning in manufacturing systems prone to failure. It is assumed that the operating system stochastically predictable, in terms of life of the operation.

Tabel 3. Summary of method and focus under inspection category

Model	Method	Authors and year of publication	Focus
Optimization of inspection procedures			
a. Optimization of the frequency of the inspections			
Mathematically based model	ABC	Salonen and Deleryd (2011)	Cost inspeksi
	Probability density function	Chin-Chih Chang (2014)	the frequency of random inspections
b. Optimization of maintenance schedule			
Mathematically based model	proportional hazard method	Zhou et. al. (2008)	Schedule of PM
Artificial intelligence-based model	genetic algorithm	Chung et. al. (2009)	Improve reliability
Heuristic-based model	Dynamic programming	Moghaddam and Usher (2011)	schedule of PM
Mathematically based model	Probability density function	Liao (2012)	schedule of PM
Mathematically based model	Non-linear programming	Aghezzaf et. al. (2016)	Integration of production and planning PM

4. Optimization of resource requirements.
   a. Total Engine Optimization

      By using queing theory to determine the optimal number of engine in a workshop.

- When the number of engine is increase so the cost of down time tends to decrease until the amount of a particular engine.
- When the number of engine is increase so the cost of engine is more higher.

Optimization got on the total cost / unit time most minimal. Berrichi et al. (2012), simultaneously optimize two criteria: makespan minimization for parts production and minimization of system availability for the maintenance side. Two decisions are taken at the same time: searching for the best assignment for engines n jobs m to minimize makespan and decide when to carry out preventive maintenance actions. Two genetic algorithm evolution compared to find the approximate face Pareto-optimal in the case of parallel engines.

b. Optimization using contractors

When maintenance activities are not conducted its own due to the limitation resources, it can use maintenance services from outside with the temporary contract time:, specific and long-term periods. But the thing need to consider is the cost of maintenance when done privately and contracted. Shaomin Wu (2012) consider the policy of maintenance for the system maintenance contract situation. Analysis of the role of the parameters in the model PM, suggested such an approach by giving a bonus. on research Hamidi, et al. (2016) studied the model of game theory to the lease contract, whereby the owner (lessor) to rent a piece of equipment for the user (tenant). Lessee decides on the optimal use of the lease term and rate, and the lessor is responsible for developing the equipment maintenance policy. Two models of non-cooperative game theory and the cooperative model was developed to describe the relationship between the two decision-makers.

Tabel 2. Summary of method and focus under resource requirements category

Model	Method	Authors and year of publication	Focus
Optimization of resources requirements			
a. Total engine optimization			
Artificial intelligence-based Model	genetic algorithm	Berrichi, et. al.(2012)	finding the best assignment of n jobs to m machines in order to minimize the makespan and schedule PM
b. Optimization using contractor			
Simulation-based model	games theory	Hamidia et. al.(2016)	Strategi Non-cooperative & Cooperative
Mathematically based model	Probability density function	Shaomin Wu (2012)	the PM policy and the bonus function with contracts

5. Literature findings

One aspect of the manufacturing operation is maintenance. Maintenance contributes to extend the effective operational system for life, increase the reliability and availability of the system (Swanson, 2001). Maintenance indirectly contributes to ensuring the delivery of high quality products for the right time to the customer. Overall, maintenance can be described as a combination of all technical and administrative actions, including supervision, measures intended to preserve or restore the system to a state where the system can perform the required function (Ding&Kamaruddin, 2015).

Research on optimal maintenance policy options as well as the relationship between the maintenance and application areas explored. Reimbursement policies of components consisting of the optimization of time and replacement costs, the optimization inventory spare parts and system optimization improvements (repair). In this area the focus of the research is how the effectiveness of maintenance visits from the time and cost of maintenance.

The optimization of replacement equipment always weigh the costs and methods used to determine the reliability varies. Reliability and cost are considered as a result of the implementation of preventive maintenance. Paper associated with the optimization of inspection procedures differ from papers optimization of time and cost and replacement cost optimization. Optimization of the inspection procedure is based on the condition of machines or CBM were two previous optimization based on time-based maintenance (TBM). Focus research more on the timing of the inspection and the failure rate. While on the optimization of resource requirements, more research is uncertainty. It can be seen from the methods used Heuristic-based models as do Moghaddam & Usher (2011) in determining the maintenance schedule.

6. Conclusion

In this study, the main review is focused on the methods used and the focus of research on the optimization problem of maintenance policies. Furthermore this study explores the possibility of improving on related topics. A number of papers and discussions was proofed that determines an optimal maintenance policy is of particular concern for the world of academia. It also signifies a wider variety of industry interests. Nevertheless, there are still some weaknesses derived from the review paper. The necessity for industry that have not got any solution signifies gap optimization model that has been found caused by complicated industrial environment and fluctuates with different factors and variables that have not been fully documented and analyzed. Therefore, the point of balance between academic and industry needs to be identified so that both sides get the maximum benefit from the research. In this literature review, it was found that the methodology is very varied and systematic still very difficult to implement. It is necessary to describes the corresponding variables. It is better to use simple methodology but effective and efficient in its implementation. The methodology must be able to resolve the problem with ease of stages such as problem identification, a significant ranking criteria, effective data collection, and perform optimization analysis with a high degree of validation.

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