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A Systematic Review on Evaluation and Selection of Maintenance Strategy

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Abstract: In past the scope of maintenance was confined to the process of production and optimizing the availability of equipment at the minimal cost. From the literature it is evident that with the introduction of sustainable development, there is a shift in the concept of maintenance from simple economic driven production paradigm to sustainable development, which has resulted in a new way of selecting the maintenance activity taking into consideration all three aspects of sustainability i.e. economic, environmental and socialaspects. In this review paper we have explained different maintenance strategies and factors which affect the selection of this maintenance strategy. It was also found that there is a scope of using decision making methodology which will consider the aspects of sustainability and select best maintenance strategy.

Keywords: Maintenance strategy; Sustainability; MCDM

1 Introduction

With rapid increase in demand, engineers and managers in industries are shifting their focuson continuous production of goods without any interruption or disturbances. This requires an effective effort from the maintenance managers to keep the machinery in good condition and properly working. Although, researchers have made remarkable progress in the field of maintenance management, maintenance of equipment intact with the current demand is still a

challenge for engineers and managers taking into consideration factors like maintenance cost, competition and complexity (Dhillon, 2002). For the success of any institute or organization, the maintenance activities should be an integrated part of its production strategy. The main goal of the maintenance activity is to get rid of failure rates and provide a reliable asset.

As per Wang et al. (2007), there are basically two types of maintenance strategy i.e. corrective maintenance and preventive maintenance. Preventive maintenance can be further classified into three type's i.e. condition-based preventive maintenance; time based preventive maintenance and predictive maintenance. The classification of maintenance strategy is shown in figure 1

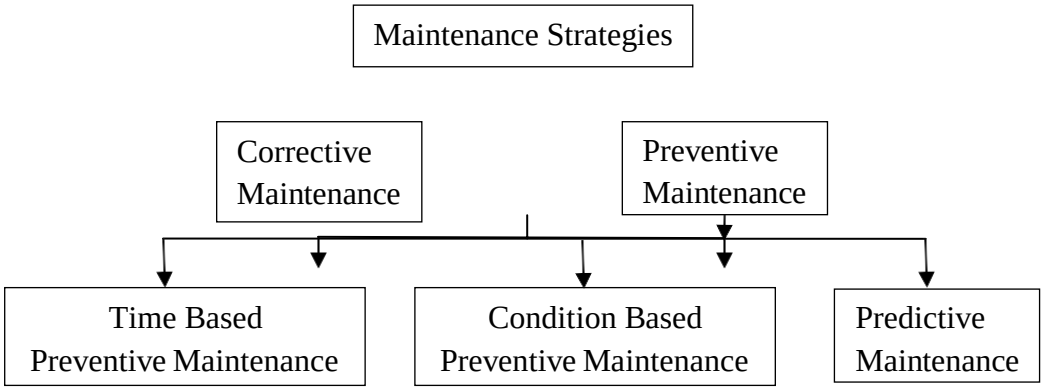

Figure 1 Classification of maintenance strategies (Mathew et al., 2020)

The brief elaboration of different maintenance strategies is described below:

1.1 Reactive or breakdown maintenance (BDM)

Every possible effort is made by engineers and managers at every stage of production to makethe systems as reliable as possible but failure/breakdown is inevitable, thus in case of failure/breakdown they repair these equipment and machinery to bring back them to their operational working condition. Reactive maintenance also known as breakdown maintenance or fire-fighting maintenance or corrective maintenance is a kind of maintenance (repair activity) which is done when the equipment's or machinery stop working or breaks down. It is done to restore the equipment's or machinery to normal working condition (Wang et al., 2007). Usually, reactive maintenance is an unplanned or unscheduled maintenance activity, which comprises of all maintenance needs that are unpredictable and cannot be planned.

Breakdown maintenance is commonly used in industries where failure of machinery does not affect the operation/ process and the losses occurred on finance are less compared to the repair or maintenance cost. In situations where the machinery is having low value/cost and can be replaced easily and quickly or in a situation where the production is low and the quality requirements are

also low.

1.2 Preventive maintenance

In preventive maintenance the personals involved in maintenance activity keep the equipment or machinery in satisfactory operational condition by providing regular planned, periodic inspection and necessary servicing prior to the occurrence of major failure.

There are two types of preventive maintenance i.e. condition-based preventive maintenance and time-based preventive maintenance.

Condition-based preventive maintenance (CBPM)

In condition-based maintenance strategy, the maintenance activity is carried based on the measured data or the readings from a set of sensors which are installed or used on the system. At present, with advanced technology, many monitoring techniques and equipment are available, which can check the system, such as vibration monitoring equipment, lubrication analysis, temperature monitoring and ultrasonic testing equipment. The monitored data of machinery and equipment parameters can help engineers to evaluate the condition of machinery and equipment, based on which the maintenance personals can take necessary maintenance actions before the failure occurs.

Time based preventive maintenance (TBPM)

As per the reliability characteristics of machinery and equipment, maintenance activity is planned and performed periodically (as per schedule) to reduce the frequency of sudden failure or breakdown. This type of maintenance strategy is known as time-based preventive maintenance, where the term ‘‘time’’ is referred to the calendar days (operating time).

1.3 Predictive Maintenance (PM)

In predictive maintenance the maintenance activities are carried out based on the monitored data obtained from different sensors and monitoring systems. These monitoring systems work all the time and predicts the failure of the system and sends a feed which helps the maintenance managers to implement the maintenance. It has some resemblances with the CBPM, but the major difference is that it uses the prognostics and health management technologies to monitor the health of machinery and help in achieving better schedule which is highly cost-effective maintenance with very little or no change of breakdown. PM reduces the higher unplanned stops (breakdown) by achieving less planned stops (for maintenance) and also increases the system lifetime along with improved system safety, reduced accidents.

2 Factors affecting the selection of maintenance strategy:

2.1 Sustainability: The concept of sustainability is applied in almost every decision-making application. Sustainability focuses on meeting the requirements of the present without negotiating the future needs. Garetti and Taisch (2012) explained that environmental, social and economic dimensions are the key aspects and challenges that manufacturing firm should respond in order to attain sustainability.

There are three pillars of sustainability (social, economic and environmental) which are represented by the three intersecting circles with overall sustainability at the centre as shown in figure 2.

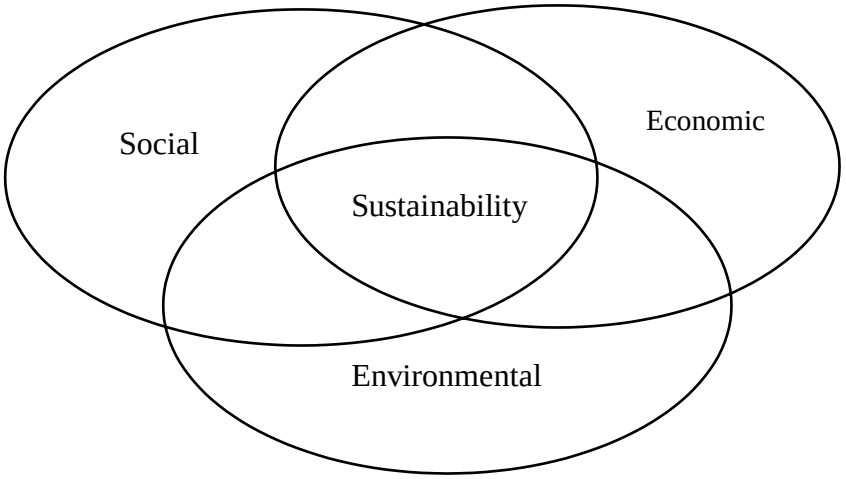

Figure 2 Typical representation of sustainability (Purvis et al., 2019)

A sustainable maintenance plan is the requirement of hour for achieving optimal decision making.

Economic: The maintenance activity carried out should be 'worth' of doing. One can measure the worth (economic) by comparing the activity with the business goals of the organization. Check for the value of the failure and the cost of the maintenance activity. Spending $1000 in the maintenance of an asset for a worth of $500 is usually a waste of resources or money unless and until there is an environmental or safety concern associated with it. This economic aspect is critical to attain sustainability

Social: The maintenance activity should contribute towards the social sustainability, which is the ability of a social system which includes the work force to function at a defined level of social well-being and in a harmonious way. The employees working in the company should be considered as the target of sustainable value creation. The employees should be considered as the stakeholders of the company and the impact of social issues should be explore with a proactive

approach (Savino et al., 2015). There are many sustainability factors like labour standards, safety laws and regulations, issues related to human rights, training and career development of personals (Labuschagne et al., 2005; Savino et al., 2015). Some of the standards used in the industry for checking the criticality are social accountability (SA 8000) which gives guidelines to improve the workplaces environment and by developing and implementing a socially responsible standard. It also covers human rights issues including child labour and health and safety of employees. OHSAS 18001 regulates and ensures the safety and health care conditions of employees.

Environmental: In the last few years, environmental problems have evolved from pollution caused by human activities and has led towards global issues like climate change. Thus, environmental Sustainability is required because of social concerns. Environmental Sustainability seeks to improve the human welfare by guaranteeing that the human wastes do not exceed to a level where it may harm the humans.

2.2 Cost: Cost is one of the most important parameters which govern the selection of maintenance strategy. Maintenance activities can contribute up to 70% to the total production cost, depending upon the type of industry (Wang et al., 2007).

Installation cost: Implementation of different maintenance strategies have different expenditure associated with it, which is known as the installation cost. This installation cost includes cost of hardware, software, and personnel training. Some maintenance strategy like condition-based maintenance and predictive maintenance require hardware like sensors and some computers to detect the system condition or health. Also, software is required for analysing the measured parameters and obtained data when using condition-based maintenance strategy or predictive maintenance strategy is used. Implementation of new maintenance strategy requires personnel training of staff so that they can make full use of the available tools and techniques in order to achieve the maintenance goals.

Lost Production cost: The failure or breakdown of some important machines in the production line can lead to greater production loss, which is known as lost production cost. Suitable maintenance strategy should be selected for such machines, which may reduce this production loss. Also, the cost associated with the loss of production during maintenance activity can be added in it.

2.3 Safety: Safety is of prime importance for many manufacturing factories like in power plants and chemical industry.

There are three factors which describes the Safety i.e. personnel safety, facilities safety and environmental safety.

Personnel safety: The failure or breakdown in some machines or equipment can lead to serious damage to personnel life on the site.

Facilities safety: In some industry failure of some components can cause serious damage to the other critical machinery; for example, in a power plant sudden failure of a water feeding pump can cause damage of the corresponding boiler.

Environment safety: Failure of much equipment can cause damage to the environment for example poisonous liquid or gas could be released due to fault in machinery which can cause damage to the local environment.

2.4 Feasibility: The feasibility of maintenance strategies is termed as the possibility of accomplishing or attaining the particular goal of implementing the maintenance strategy. Feasibility of maintenance strategies is divided into two sub criteria i.e. acceptance by personal/labours and applied technology complexity.

Acceptance by Personal/Labours: Maintenance engineers and staff prefer to have maintenance strategies that are easy to handle/implement and require less understand.

Applied technology complexity: Complexity of technologies in any particular maintenance strategy is seen as an important criterion, as it defines the feasibility of that strategy.

2.5 Time- Time is equivalent to profit in many industries, so it can be considered as important as cost criterion. It consists of two sub-criteria i.e. shut-down time and maintenance time.

Shutdown time: This shutdown time have many components like the maintenance time which is postponed due to deficiency of spare parts, if breakdown occurs in a machine and the machine components are not available in the market and the time the entire productionline is stopped.

Maintenance time: The time required for the maintenance activities are different in different maintenance strategies.

In the past few years there are many studies which has evaluated and selected best maintenance strategy. They have used both multi objective optimization algorithm and multi criteria decision making techniques to solve the decision-making problem.

3. Available literature on maintenance strategy

Triantaphyllou et al. (1997) presented a sensitivity analysis approach which can considerably enhance the decision making in complex applications like maintenance management. The

approach can be useful in problems where relative importance of evaluating criteria is difficult to assess. Labib et al. (1998) developed a model for decision making in maintenance using AHP. They developed an adaptable maintenance system that used present data and supports decisions based on it. A three-stage system was proposed that can handle multiple criteria and simultaneously handle subjective judgements. It also supports and facilitates a group decision-making process. In the first stage, the evaluation criteria are identified. The second stage prioritises different criteria by utilizing multiple criteria decision-making methods. Finally, in the third stage based on the priorities of different criteria, the machines are ranked as per the criticality. Levitin and Lisnianski (2000) evaluated a preventive maintenance optimization problem using genetic algorithm for a multi-state system having different performance levels. The hazard functions were used for checking the reliability of system. The best preventive maintenance actions were selected based on the estimation of the effective age of equipment and minimum maintenance cost. Bevilacqua and Braglia (2000**)** selected the best maintenance strategy out of five available alternatives i.e. preventive maintenance, predictive maintenance, condition-based maintenance, corrective maintenance and opportunistic maintenance. They used Analytic Hierarchy Process (AHP) for selecting the best maintenance strategy in an Italian oil refinery. Factors such as safety, machine importance for the process, cost of maintenance, failure frequency, downtime length and operating conditions were taken as selection criteria. A sensitivity analysis was performed to check the effectiveness of the methodology. Mechefske and Wang (2001) explained that the maintenance strategy selection in an organisation is a kind of problem which takes into consideration multiple criteria which can be intangible and non-monetary. A fuzzy linguistic approach was used by the authors to quantify the subjective criteria of maintenance strategies.The method handled two key issues i.e. decision making and evaluating the maintenance strategies and condition-monitoring of the machinery. Pieri et al. (2002) presented MAIC (Materialy per Apparecchiature di Impianti Chimici) approach, which is a knowledge-based system to support decisions for the maintenance of a chemical plant. The major functions of the system are management of information related to the components, equipment along with the corrosion agents and identify critical factors for the component, retrieval of similar casesof corrosion in the database finally the economic assessment of all solution, which are technically feasible. Swanson (2003) applied Galbraith's information-processing model to identify the effect of environmental complexity on maintenance function which are applied to different maintenance strategies. A survey was conducted among plant managers to find the maintenance response on automated maintenance management systems, other maintenance systems like preventive and predictive strategy and increased workforce size. Al-Najjar and

Alsyouf (2003) assessed different maintenance strategies/approaches using a fuzzy based multiple criteria decision-making technique. The authors used rule based fuzzy inference system (MATLAB toolbox) in which rate of failure was kept as output and past data, current data and adequacy was kept as an input. Two examples were solves using the approach and came to the conclusion that less planned replacements were needed and failures was almost reduced to zero. Bertolini and Bevilacqua (2006) proposed an approach based on goal programming to select optimal maintenance strategy for the centrifugal pumps in an oil refinery plant. The goals of decision problems like facility location allocation, control system selection; fund allocation and information system project evaluation can also be handled with the proposed method. AHP was used to find the weights of different maintenancestrategies taking into consideration the components of failure mode effects and criticality analysis i.e. occurrence, severity and delectability. Goal Programming model was used to findthe best set of maintenance type for the equipment. Three maintenance strategy alternativesi.e. corrective maintenance, preventive maintenance and predictive maintenance were evaluated using criteria like budget and number of hours of man power and labour constraints. Wang et al. (2007) evaluated four maintenance strategies i.e. breakdown maintenance, time- based preventive maintenance, condition-based maintenance and predictive maintenance for a power plant. The judgment of the decision makers which is imprecise was quantified using fuzzy numbers and analytic hierarchy process is used as an evaluation tool. A new fuzzy method for prioritization is proposed in the study. An optimization problem with constraints of non-linear nature is used to prioritize the fuzzy judgment matrix. They finally concluded that for maintenance of boilers predictive maintenance strategy is most appropriate. Jafari et al. (2008) applied the combination of fuzzy Delphi method and simple additive weighting method to assess three maintenance strategy i.e. preventive maintenance, condition-based maintenance and failure-based maintenance. The assessment of the goal to be achieved andthe competence of each maintenance strategy are done by taking into consideration the expert's opinion and applying fuzzy Delphi method. The method can handle both tangible and intangible goals which deal with the selection of maintenance problem. Six evaluation goalsi.e. low maintenance cost, feasibility (acceptance by labours), improved reliability, low downtime length, improved safety, high product quality and minimum inventories were taking into consideration. Bashiri et al. (2011) solved a maintenance strategy selection problem with a modified linear assignment method based on fuzzy set theory which can handle both qualitative and quantitative data and rank the maintenance strategy. Factors like reduced cost, minimized equipment downtime, improved quality, increased productivity and reliable equipment were taken as objective for selection process. Fouladgar et al. (2012)

introduced a fuzzy MCDM approach based on the combination of two MCDM approach i.e. COPRAS (COmplex PRoportional ASsessment) and AHP to evaluate different maintenance strategy. A fuzzy linguistic terms scale having fuzzy numbers were employed in the study to assess the ratings and weights of criteria. The fuzzy AHP was used to find the weights of evaluating criteria while COPRAS was used to rank the alternative. The method was appliedin a copper mine to select the best maintenance strategy. Nezami and Yildirim (2013) presented a comprehensive framework which evaluated the sustainability aspect (social, environmental and economic) during the selection of appropriate maintenance strategy amongdifferent strategies like failure-based maintenance strategy, preventive maintenance strategy, reliability centred maintenance strategy, condition-based maintenance strategy and total productive maintenance strategies in a manufacturing unit. They applied factor analysis for determining the important factors in each aspect of sustainability i.e. social, environmental and economic aspects. Then fuzzy VIKOR method was utilised to select the best maintenance strategy. Azizi and Fathi (2014) in their study presented ranked different factors which influence the maintenance strategies of an Iranian oil company. They determined four main criteria i.e. production quality, cost, reliability and safety. Several sub criteria like best utilization of resources, increase access to maintenance tools, drop in interruption caused during production, reduction in system failure, customer satisfaction and defects, necessary hardware, software and training programs for personals and safety factors like external,internal and employee were some of the sub factors. Fuzzy analytical hierarchy process was used to determine the rank associated with various factors and sub factors. de Jonge et al. (2015) explained that, for a machine the optimal maintenance strategy can be determined if extensive studies have been conducted on the lifetime distribution and the values of factors are known with certainty, but usually in real life examples it's not done. They studied the effect of factor uncertainty on the maintenance strategy. This effect of uncertainty on maintenance strategy was evaluated by taking into consideration two life time distribution i.e. uniform lifetime distributions and close to reality Weibull life time distribution. They explained that the outcome of the framework can help decision makers in making reliable maintenance decisions under uncertainty. Tajadod et al. (2016) made comparison between two different MCDM approaches i.e. fuzzy AHP and fuzzy ANP to rank the maintenance strategies in a dairy manufacturing factory. A group of experts (decision makers) from the factory were asked to make comparisons for formulating the pair-wise comparison matrix.

The crisp and triangular fuzzy numbers were used to construct the pair-wise comparison matrix. The priority vectors (weights of criteria) of criteria were calculated using Mikhailov's fuzzy

preference programming (FPP) methods. In the study predictive maintenance came as the most appropriate strategy. Ge et al. (2017) explained that the traditional AHP method produces many results and sometime even conflicting priority results. The algorithm is also having complicated structures as a result unstable output/solution is obtained. In their study, they proposed an AHP based on integrated Logarithmic Fuzzy Preference Programming(LFPP) which was used to solve an optimum maintenance strategies selection problem. The approach can handle both qualitative and quantitative data and can produce a unique and optimal priority weights from the fuzzy pairwise comparison matrices. It is capable of deriving global priorities weights directly from the super matrix. Mathew et al. (2020) applied interval type-2 fuzzy AHP-TOPSIS is evaluating the different maintenance strategies.

Some of the studies which have implemented MCDM techniques for evaluating maintenance strategies are explained in Table 1. The remark explains the shortcoming of all those mentioned studies.

Table 1 Review of some literature on maintenance strategy

Author	**MCDM Method Used**	**Fuzzy or Non-fuzzy**	**Remark**
Bevilacqua and Braglia (2000)	AHP	Non fuzzy	• Unable to handle vaguenessin preference. • Sustainability not considered during evaluation
Bertolini and Bevilacqua (2006)	Goal programming and AHP	Non fuzzy	• Unable to handle vaguenessin preference. • Sustainability not considered during evaluation
Wang et al. (2007)	Fuzzy AHP	Fuzzy	• Time is not taken as an evaluating criterion. • Sustainability not considered during evaluation
Jafari et al. (2008)	Fuzzy Delphi and simple additive weighting method	Fuzzy	• Sustainability not considered during evaluation

Fouladgar et al. (2012)	Fuzzy COPRAS and AHP	Fuzzy	• Sustainability not considered during evaluation
Nezami and Yildirim (2013)	Fuzzy VIKOR	Fuzzy	• Weights of criteria directly assigned without comparison.
Azizi and Fathi (2014)	Fuzzy AHP	Fuzzy	• Sustainability not considered during evaluation. • Time is not taken as an evaluating criterion.
Tajadod et al. (2016)	Fuzzy AHP and fuzzy ANP	Fuzzy	• Sustainability not considered during evaluation. • Only evaluates the factors affecting the decision making, did not evaluate the alternatives.
Ge et al. (2017)	AHP and Logarithmic Fuzzy Preference Programming	Fuzzy	• Sustainability not considered during evaluation • Time is not taken as an evaluating criterion.
Mathew et al. (2020)	Interval type-2 fuzzy AHP- TOPSIS	Fuzzy	• Sustainability not considered during evaluation

4. Discussion and Conclusion

Out of all the papers reviewed in the literature survey (which used MCDM approaches) a pie chart is plotted in figure 3, which represents the total percentage of paper using different approaches. It can be summarised from the pie chart given in the figure 3 that most of the papers almost 33% + 17% = 50% of the papers used non fuzzy MCDM approach to solve the decision making problem, but the major issue with these approaches is that non fuzzy MCDM approach is unable to capture the vagueness in preference during the decision making process.

It can be concluded from the past literature that there is a shift of production concept from simple economic driven production paradigm (traditional way) to a holistic sustainable development, which has changed the pattern of strategic decision making. In all strategic

decision making, the sustainability should be taken into consideration and it should take into account all three aspects of sustainability i.e. economic, environmental and social aspects, but many researchers have neglected this sustainability aspect during the selection of maintenance activity.

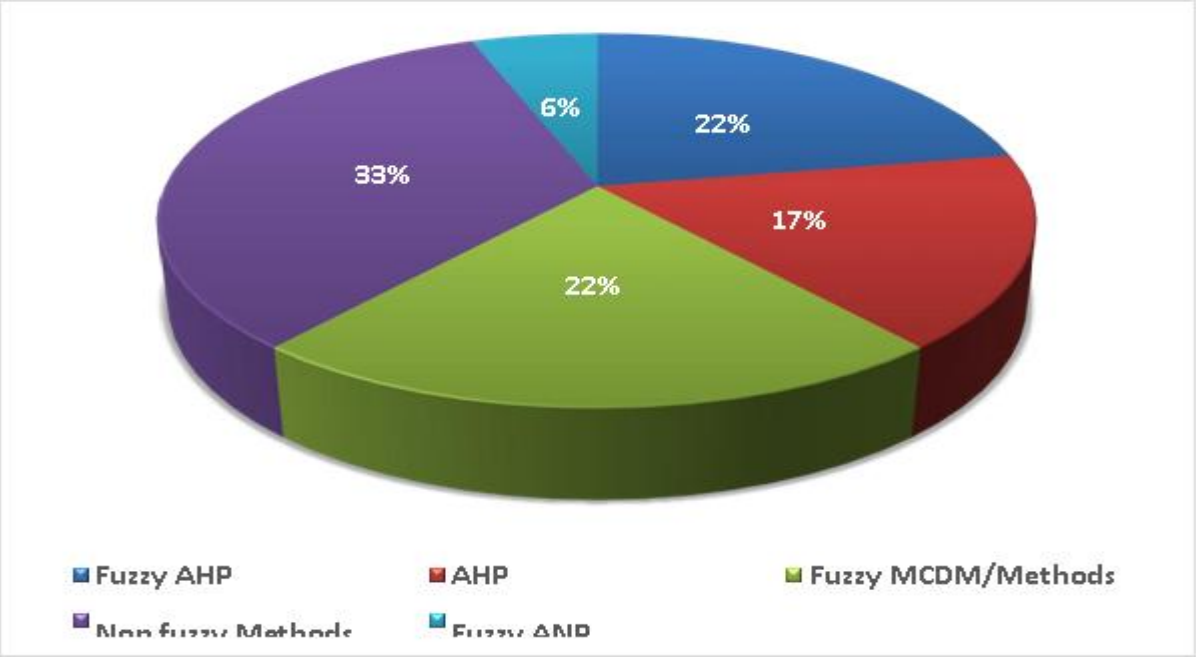

Figure 3 Review summary

There is a scope of evaluating different maintenance strategies namely reactive or breakdown maintenance, condition-based preventive maintenance, time based preventive maintenanceand predictive maintenance on sustainability aspect (economic, social and environmental) and other selection criteria using fuzzy multi criteria decision making technique.

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