Review of Preventive Maintenance Optimization of Deteriorating Systems

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Abstract— Preventive maintenance optimization problems of deteriorating systems have been extensively studied in literature of past several years. Many optimization techniques were used in optimization of preventive maintenance in single unit as well as multi units systems such as genetic algorithm (GA), particle swarm optimization (PSO), ant colony optimization (ACO), artificial bee colony (ABC), Monte Carlo simulation, Markovian theory etc. There are several maintenance policies: age replacement policy, periodic preventive maintenance policy, failure limit policy etc. In this paper we give an overview of applications of maintenance optimization models.

Key words: Maintenance; Reliability; Replacement; Maintenance Policy; Optimization

I. Introduction

To keeps the manufacturing systems in good conditions preventive maintenance is widely accepted in the industry as an effective tools to reduce the number of failure. Systems used in the production of goods and delivery of services are subject to deterioration with usage and age (Valdez-Flores and Feldman, 1989).Majority of the system are maintained or repairable systems. It is extremely important to avoid failure during actual operation of some systems such as aircrafts, submarines, military systems and nuclear systems because it can be dangerous or disastrous. Maintenance is necessary to improve the reliability of the system. Optimal maintenance strategies improving system reliability, preventing the occurrence of system failure, and reducing maintenance cost of deteriorating systems.

Maintenance can be classified into two major categories, according to the time of maintenance executed. First one is corrective maintenance (CM) and second is preventive maintenance (PM). The CM corresponds to the action occur after the system break-down. The PM corresponds to the actions that come about when the system is operating. The benefit of PM is that the system can always be kept in available conditions when needed and the major loss occurred due to the unpredicted fails can be avoided. According to the definition given by Lie et al. 1986, CM activities are categorized into minimal repair (1C) and corrective replacement (2C). 1C-maintenance restores the system reliability to it when it had failed. 2C-maintenance renews the system time to zero and the reliability curve is that of the new system. PM activities are also categorized into simple preventive maintenance (1P) and preventive replacement (2P). 1P-maintenance improve the system reliability and 2P-maintenance likes corrective replacement that restores the reliability curve to new one but only occurs in the system state. Fig. 1 shows the maintenance type and reliability behavior of the system.

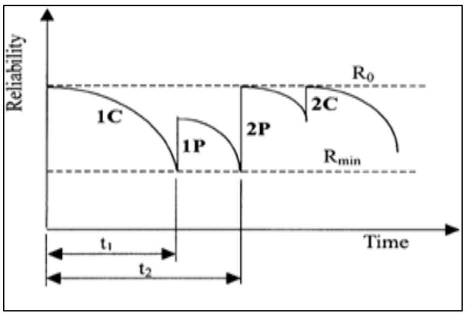

Fig. 1: Reliability change of system under various maintenance types [24]

A. Maintenance Policies

Two categories belonging to a family of PM policies: time driven PM and condition driven PM. Various type of time driven PM policy have been proposed. The time driven PM policies are:-

- Age dependent PM policy
- Periodic PM Policy
- Failure limit Policy

The most commonly used maintenance policy in practice is Periodic PM because of its simplicity. The PM policy together with the age-dependent PM policy is the most common policies in academic research.

B. Age dependent PM policy

In this type of policy a unit is preventively maintained at some predetermined age or repair at failure until a perfect maintenance, preventive or corrective is received. Barlow and Hunter, 1960 gives age replacement policy i.e. a unit is always replaced at it age T or failure, whichever occur first, Where T is constant. The concept of minimal repair and imperfect maintenance is given by Pham and Wang, 1996.Tahara and Nishida, 1975 gives the maintenance policy "replace the unit when the first failures after t_o hours of operation or when the total operating times reaches $T(0 \leq t_0 \leq T)$ whichever occur first, failure in $[0, t_0]$ are removed by minimal repair". It becomes age replacement policy if $t_0=0$, and it becomes periodic replacement with minimal repair at failure policy if $t_0=T$. Nagagawa, 1984 gives T-N policy i.e. unit is replacing at time T or at N numbers of failure, whichever occur first and it is minimal repairable at failure between replacements. If N=1, the policy converges to age replacement policy.

C. Periodic PM policy

In this policy a unit is maintained at fixed time interval nT (n=1, 2, 3….) independent of the failure history of the unit and repair at intermediate failure. Liu et. al, 1995 gives "periodic replacement with minimal repair at failure" is a policy in which a unit receives imperfect PM every T time units, intermediate failure subjected to minimal repair when the time reaches (O+1) T. it is replaced if O=0 that means no imperfect PM for it, and the policy becomes "periodic replacement with minimal repair at failure policy".

D. Failures limit Policy

When the availability or reliability or both attain its lower value this policy is applied. Intermediate failure is corrected by repair. This PM policy makes the unit, work at or above the minimum acceptable level of reliability. Lie and Chun, 1986 make a maintenance cost policy where PM is performed whenever a unit reaches the predetermined maximum failure rate and failure rates are corrected by minimal repairs.

Typical references	Optimization Model	Objective function	System	PM Policy
The Procter and Gamble Company et. al. (1996)	Monte Carlo simulation	cost rate	Multi component	Periodic PM
M. Marseguerra et. al (2000)	Monte Carlo simulation with GA	Net gain	Multi component	Failure and repair limit policy
G. Levitin et. al (2000)	GA	cost	multi state	Periodic PM
Tsai et. al. (2003)	GA	Maximizing system Unit cost-life	multi component	Age dependent PM Policy
R. Bris (2003)	GA	Total maintenance Cost	series parallel system	failure limit
M. Samrout et. al. multi component (2004)	Ant colony optimization	cost	series parallel	failure limit
E. H. Aghezzaf et.al (2006)	Mathematical programming model (PPM)	minimizing cost of production and Maintenance	single unit system	minimal repair and periodic replacement
S. Samrout et. al. (2007)	Ant colony optimization	total maintenance	series parallel cost	failure limit system
Duy Quang Nguyen (2010)	Monte Carlo simulation with GA	Total maintenance cost	multi component	Periodic PM
Chung Ho Wang (2011)	PSO	Periodic PM Cost	series-parallel	Periodic PM
N. Chalabi (2016)	PSO	PM Cost and availability	multi component series	Opportunistic maintenance

Table 1: Results Of Reviewed Research Paper

Table 1, showed the past several decades preventive maintenance optimization problem have been extensively investigated in the literature.

M. Marseguerra et. al (2000) used Monte Carlo simulation model for the evaluation of plant performance. Due to flexibility of Monte Carlo it consider several practical aspects such as aging rate, repairs, periodic maintenance sequence, repair teams etc.GA is used to optimize the net gain objective function.

G. Levitin et. al (2000) used GA to obtain the sequence of maintenance providing system functioning with the desired level of reliability during its life cycle by minimum maintenance cost. System life time T is divided into Y interval each with duration y ($1 \le y \le Y$) PM action can be performed at the end of each interval. They are performed if multi subsystem reliability becomes lower than the desired level. y must not necessarily be equal and can be chosen for practical reason. Parameter of system elements used is productivity, intensity function scale parameter, shape factor, hazard constant, minimal repair cost.

Tsai et. al (2003)used quantitative assessment process, dynamic reliability equation and age reduction model. For scheduling the PM policy first identify the PM component, maintenance cost and extended life of the system and also evaluating the unit cost life of the system. Simple preventive maintenance and preventive replacement activities are used. The optimal activities combination at each PM stage is decided by using GA.

R. Bris (2003) used General preventive maintenance model for input components of a system, which improves the reliability to 'as good as new, to optimize the maintenance cost. The cost function of a maintenance policy was minimized under given availability constraint. System availability calculations are done by using simulation approach with parallel simulation algorithm for availability analysis. These calculations, based on direct Monte Carlo technique, were applied within the programming tool Matlab. A genetic algorithm optimization technique used and briefly describe to create the Matlab algorithm to solve the problem of finding the best maintenance policy with a given restriction.

M. Samrout et. al (2004) used ACO to minimize the preventive maintenance cost of series–parallel systems. The resolution consists in determining the solution vector of system component inspection periods, Those calculations were applied within the programming tool Matlab. Thus, highly interesting result obtained.

E. H. Aghezzaf (2006) et. al minimizing the cost of production and maintenance by integrating the lot size of production and preventive maintenance strategy in the given finite horizon. In this the system is periodically renewed and minimally repaired at failure. Mathematical programming model is used during development of the optimal production plan, reliability parameter of the system and its capacity taking into account. The optimal planning is obtained using an iterative procedure and the mixed integer solver of CPLEX.

Duy Quang Nguyen (2010) used Monte Carlo simulation with GA to optimize preventive maintenance of a chemical process plant. Parameters used in Monte Carlo simulation based model are different failure modes of equipment, ranking of equipment for repair scheduling according to the consequences of failure and constraint of resource availability (labour, spare parts) .The decision variables used are PM starting time, PM time interval, spare parts inventory level and No. of employees in the groups. Parameters used in GA are MTBF, quantity of parts, time needed for CM and PM, priority.

N. Chalabi (2016) used PSO for optimization of preventive maintenance grouping strategy for multi component series systems to achieve the low maintenance cost and high system availability.

E. Procedure of PM Optimization

The block diagram show optimization model taking an example of genetic algorithm.

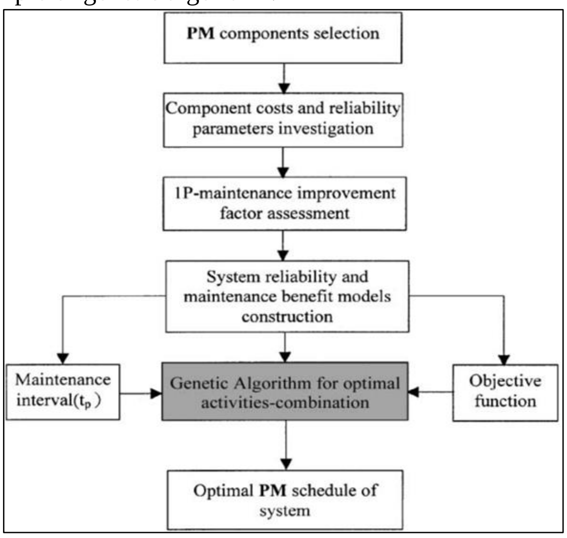

Fig. 3: Steps to apply GA [24]

II. Results and Discussion

It is reviewed the numbers of research paper in which we find that the GA is mostly use in the preventive maintenance optimization but from the past few years use of other optimization method increases continuously.

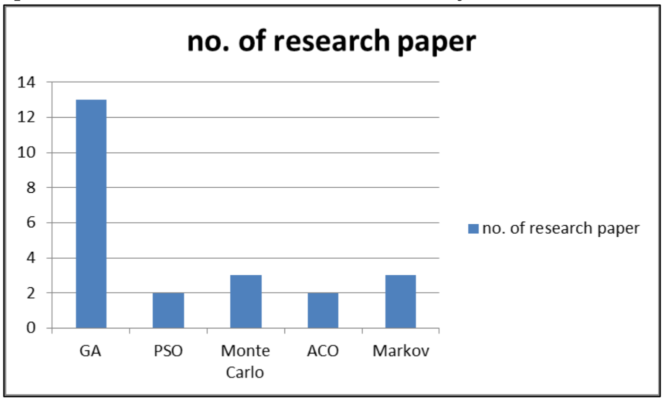

Fig. 3: Number of research paper used in optimization algorithm

III. Conclusion

Maintenance optimization has becomes as a mathematical discipline within operational research and it isLike to do so in the future, its impact on decision making within maintenance organizations is limited so far. Yet there are a number of paper published which show that optimization method are a good source to achieve both effective and efficient maintenance of deteriorating system. As application tool technology (both soft- and hardware) is only recently becoming available at low costs and is rapidly developing, we expect that the near future will see many decision support systems incorporating maintenance optimization models. Economic pressure is likely to enforce the changes in culture that are necessary to make these packages standard tools for the modern maintenance manager.

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