Computers & Industrial Engineering

An International Journal

Hamed Kamal Eldin, Ph.D., PE, Founding Editor, 1976

Elsevier Press, Publishers

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Paper Code: CIE00462, CIE00462_2

Alexandria 8 August 2007

Dear Prof Farhad Kolahan,

The 37th International Conference on computers and Industrial Engineering ICC&IE'2007 organizing committee, is pleased to inform you that your papers titled:

Multi-Component Preventive Maintenance Optimization Based on Availability
And
Evaluating The Discretization Of Search Space In Continuous Problems For Ant Colony Optimization

are accepted for publication in the conference proceedings and for oral presentation in the conference, which will take place in Alexandria, Egypt from October 19-22, 2007.

Please make sure you send your registration form with your payment information and hotel accommodation fees as soon as possible. The registration form can be downloaded from the following link: http://www.cie37.net/Registeration.doc

Finally, we would like to draw your attention to the revised tourist package offered by the conference tourist agency, available from the "tours" page. We invite you to take advantage of the offered exciting trips and tours.

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Your participation in this event is very important for its success. We are looking for having you in Alexandria next October.

Regards,

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Conference Co-Chair

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These four steps will be repeated until the items are packed. This method was tested on the literature instances, and we obtained encouraging results.

CIE00458 Identification of Run Length Distribution in Residual Control Chart While Monitoring Autoregressive and Moving Average Processes

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Introducing a definite mathematical relationship to calculate average run length (ARL) in residual control chart for autoregressive process of order p, is the main idea of this paper. In addition, a procedure is proposed to compute ARL in residual control chart for monitoring moving average process of order q. Also, tables of ARL values especially prepared for AR(1) and MA(1) processes are presented. Since 1988 which Special Cause Chart (SCC) was first introduced by Alwan and Roberts, though several researchers have investigated the probability distribution of residuals in AR(1) process, definition of a mathematical formula for ARL in autoregressive processes which is of great interest to compare different monitoring procedures for autocorrelated processes, has been seldom addressed. Invoking mathematical software providing quick solutions for systems of mathematical equations allowed us to implement the proposed approach as a computer program.

CIE00462 Multi-Component Preventive Maintenance Optimization Based on Availability

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In this paper the problem of preventive maintenance (PM) planning for a system with deteriorating components has been addressed. The problem involves a multi-component system with resource constraint and minimum availability requirements. The cost function is weighted summation of repair costs, system downtime cost and random failure cost. Maintenance and repair activities are divided into three actions; namely simple service (inspection), repair and replacement. During the planning horizon, inspections are performed on the regular basis. In each inspection period, one of the three PM activities is carried for each component. The objective is to maintain certain level of availability with minimal total cost. Since the problem is complicated in nature, Simulated Annealing (SA) algorithm is employed as the solution procedure. Computational results show that this algorithm has good performance in solving PM scheduling problems.

CIE00462_2 Evaluating the Discretization of Search Space in Continuous Problems for Ant Colony Optimization

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In this paper, after a beginning on the concept of ant algorithms, a brief survey of the ant-based methods proposed for optimization of problems with continuous design spaces is presented. As a common approach in continuous domains, discretizing the search space is the model presented to be appended to the original ant colony system (ACS) algorithm. Evaluating this method and comparing it to the standard simulated annealing shows that it is robust enough not to fall in local minima. However, when higher resolution is required, the algorithm fails to capture the global optimums and the computational costs rapidly increase. Therefore, it can be safely proposed for the problems in which a trade-off between time, solution accuracy and algorithm intricacy is needed.

CIE00462_3 A Genetic Algorithm Approach For Prediction Of Process Parameters In Submerged Arc Welding

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Among different welding techniques, Submerged Arc Welding (SAW) is one of the most widely used processes employed in metal forming industries. In this paper, a Genetic Algorithm approach is proposed to optimally determine SAW process parameters for any desired weld bead geometry. A five-level factorial technique is employed to relate the important process-control variables (welding voltage, wire feed rate, welding speed and nozzle-to-plate distance) to the bead-quality features (penetration, reinforcement, bead width, total volume of the weld bead and dilution). The adequacy of the proposed approach is verified with ANOVA. Then, the developed models embedded to a GA algorithm to determine the best SAW process parameters for any target values of weld bead geometries. Computational results show that GA method can be used effectively for solving complicated and highly non linear equations in prediction and optimization of welding process parameters.

Proceedings of the 37th International Conference on Computers and Industrial Engineering,
October 20-23, 2007, Alexandria, Egypt, edited by M. H. Elwany, A. B. Eltawil

MULTI-COMPONENT PREVENTIVE MAINTENANCE OPTIMIZATION BASED ON AVAILABILITY

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ABSTRACT

In this paper the problem of preventive maintenance (PM) planning for a system with deteriorating components has been addressed. The problem involves a multi-component system with resource constraint and minimum availability requirements. The cost function is weighted summation of repair costs, system downtime cost and random failure cost. Maintenance and repair activities are divided into three actions; namely simple service (inspection), repair and replacement. During the planning horizon, inspections are performed on the regular basis. In each inspection period, one of the three PM activities is carried for each component. The objective is to maintain certain level of availability with minimal total cost. Since the problem is complicated in nature, Simulated Annealing (SA) algorithm is employed as the solution procedure. Computational results show that this algorithm has good performance in solving PM scheduling problems.

KEYWORDS

Preventive Maintenance, Scheduling, Availability, Simulated Annealing.

1. INTRODUCTION

Businesses need a variety of equipments to produce different products and services. Equipments degrade with the time and usage and ultimately fail if they are not maintained properly. The nature of preventive maintenance (PM) problem is a conflict between availability requirements and economic needs. For instance, frequent maintenance actions increase the system availability but the resulting costs are also increased. Moreover, frequent repair activities entail that sufficient number of repair technical teams be present on site at all times. On the other hand, reducing the repair personnel on site or resorting to external teams may lead to large production losses due to random failures of the system. These show clearly that decisions on the preventive repair and maintenance activities must be the result of an optimization study.

Availability is defined as the ability of an item to perform its required function at a stated instant of time or over a stated period of time (Vassiliadis C.G., 2001). The evolution of system availability depends on the way that its components are related as well as on the rate that these components degrade. The latter is a function of the element age during operating life of the system. The probability of failure increases as the system and its elements age. A proper maintenance, on the other hand, would sharply lower failure probability. However, the amount of reduction in failure rate, due to the introduction of PM calls for more studies. In particular, it would be desirable to know the type of preventive maintenance action and the rate at which a PM should be scheduled. In general there are two types of PM policies, namely, age-based and block-based preventive maintenance. The implementation of a PM could be at scheduled times (scheduled PM) or at other opportunities (opportunistic PM), which arise when the equipment is stopped due to other reasons. In addition, if the equipment is maintained only when it fails, it is called a corrective maintenance (CM) policy. The best policy has to be selected for a given system with respect to its structure as well as failure and maintenance characteristics. It is apparent that costs should be taken into consideration in selecting the best policy (Mehmet S., 2006).

During last few decades, preventive maintenance problems have been extensively investigated in the literature. For example, Aven T. and Dekker R. (1997) presented a general framework including various age and block replacement models for the optimization of replacement times. Wang et al. (1997) proposed a scheduled method of preventive replacement for the key components of mechanical systems. Moreover, Vaurio J.K. (1997) investigated the time-dependent unavailability of periodically tested aging components under different testing and repair policies, and then decided the time intervals in periodic testing and scheduled maintenance.

Levitin G. and Lisnianski A. (2000) have studied optimization problem of series–parallel, multi-state system taking into account imperfect components. Their model uses universal z-transform for reliability calculations (universal moment generating function) but the duration of the PM activity is neglected. They used Genetic algorithm for optimization procedure. Along this line, Beris et al. (2003) determined inspection and maintenance intervals for multi-components systems, so that cost of preventive maintenance by considering minimum availability is minimized. The cost function only included PM actions cost and the cost related to maintenance such as system downtime was ignored. They have also applied a genetic algorithm for solving their model.

Although there are many articles in preventive maintenance, many of them overlooked some parameters affecting preventive maintenance such as downtimes. This paper develops an availability based approach for systems with periodically inspected and non-periodically maintained components. The aim of our research is to optimize, the maintenance policy by minimizing the cost function, with respect to minimal required availability and resource constraints. The proposed model and solution procedure are designed flexible in such a way that can be implemented to any system configuration and cost function. Problem statement and proposed algorithms are explained in following.

2. PROBLEM STATEMENT

Availability is an index representing the system performance. For a system, the availability usually degrades with the usage time. To reduce the effects of usage on system components, preventive maintenance is usually performed on regular basis. Maintenance consists of actions that improve the condition of system elements before they fail. Such maintenance may be done on different levels. This paper combines three typical PM actions as follows:

Simple inspection: When different parts of a system are inspected, usually simple services such as lubricating, adjusting/calibrating, tightening loose parts, cleaning dust, and adding supplements (oil, waters, etc) are also done. These services do not improve the reliability and availability of the system. Nevertheless, they reduce the rate of degradation.

Repair: These actions are mainly adopted for parts which are expensive and/or uneasily to replace. They generally include replacing simple parts such as springs and seals, disassembling, reassembling and calibration.

Replacement: This type of maintenance involves replacement of subsystems or major components with new ones. It is usually adopted for the key components to avoid serious damages to the whole system due to the random failures of such items.

The system under consideration consists of several parallel-series subsystems. In general, for any subsystem with m components the proper performance k components is necessary. This is one of the most general system definitions called k out of m configuration.

During the scheduling, the system is inspected in N intervals of equal durations. In each inspection, based on elements hazard rate and their importance in the system availability, one of the three above mentioned PM actions is executed. Each PM action requires specific resources and has its own cost. Also different PM actions have different effects on the component availability. The position of the component in the system, in terms of reliability evaluation, in turn influences systems availability and reliability.

In this research, the objective is to determine the type of PM action for each element in any inspection interval so that total PM costs are minimized. This is done based on resource constraints and availability requirements.

3. THE COST FUNCTION

To develop the model, several important items considered as the sources of PM related costs.

Maintenance actions costs: Different scheduled preventive maintenance actions have different costs as they require various levels of resources. Spare parts and man hours are the main such recourses. For instance, simple inspection requires little or no parts and is performed quickly with a constant labor cost. As the level of maintenance increases, the cost of performing the service is increases too. In addition to the type of maintenance, the maintenance action cost also depends on the component for which the PM action is scheduled.

Downtime cost: PM actions may or may not cause the entire system shutdown. System shutdown happens under two conditions; 1) the component being serviced is in the series configuration with the rest of the subsystems and 2) the type of service performed requires tacking the components out of service. In this case system shutdown occurs and related cost of production lost due to PM activity is considered.

Failure cost: Unpredicted failures may cause serious damage to the system and would bring about unplanned shutdowns. Moreover, usually there is a higher cost to fix such random failures. The numbers of random failures may be reduced by more frequent inspections. Nevertheless, they can never be totally eliminated. The probability of the random failures is determined by reliability function. Therefore, failure cost is proportional to the unreliability of different components.

In this research, the cost function is the summation of the above costs and the objective is to minimize this function for the entire planning horizon with respect to the system specifications.

4. SIMULATED ANNEALING

Simulated Annealing (SA) is a method suitable for solving optimization problems of large scales. This algorithm, among few other heuristics, is suitable for complicated problems where global optimum is hidden among many local optima (Martorell S., 2002). The idea of the method is an analogy with the way molten metals freeze and crystallize, or metals cool and anneal. For slowly cooled process, system is able to find the minimum energy state. If a liquid metal is cooled quickly it does not reach this state, rather ends up in a polycrystalline or amorphous state having higher energy. So slow cooling is essential for ensuring that a low energy state is achieved.

This algorithm has four elements that are adapted for the PM problem as follows:

a) Describing possible system configurations in terms of reliability and availability analysis.
b) Generating random changes in the PM program; i.e. random changes of the PM action for a randomly selected component.
c) Defining the objective function based on cost factors whose minimization is the goal of optimization procedure.
d) Defining a control parameter analog to the temperature and an annealing schedule that determines the cooling rate.

This algorithm is an iterative procedure. In each iteration, a small random change is made in the current schedule. Then the cost of new schedule is calculated and compared with the cost of current schedule. A move is made to the new schedule if it has better cost or if the probability function implemented in SA has a higher value than a randomly generated number. Otherwise a new schedule generated and evaluated. The algorithm may be terminated after a certain number of iterations or after a pre-specified run time.

5. AN EXAMPLE

In this section a numerical example is presented to illustrate the performance of the proposed model and heuristic algorithm. A series-parallel system with 14 elements is considered. Failure rates of components are assumed to follow weibull distribution with the scale and shape parameters given in [8]. To calculate the reliability and availability of the system, formulas derived in (RamKumar R., 1993) and (Tsai Y., 2004) are used.

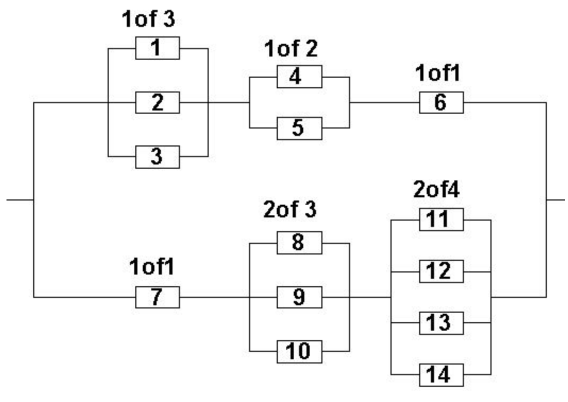

Figure 1 Series-Parallel system for scheduling PM

Different elements have different costs for maintenance. These costs are shown in Table 1. For simplicity the constant cost of inspection is omitted and the cost of replacement is considered twice the cost of repair alone. A similar pattern is used for the resources needed for maintenance activities.

No. Elements	Cost of PM Type 1P
1	45
2	15
3	25
4	35
5	30
6	39
7	30
8	20
9	25
10	15
11	60
12	50
13	30
14	20

Table 1 Cost of PM activates

Random failure cost, system downtime cost, availability requirement, and coefficients of reliability function improvements are listed in Table 2. Planning horizon is assumed to be 10 months with monthly inspection intervals.

Cost of random failure	500
Downtime cost	300
Improvement factor for repair	m1=1 m2=0
Improvement factor for replacement	m1=1 m2=0.5
Minimum level availability	0.95

Table 2 Data for PM example problem

Given sufficient run time, the algorithm would determine the best type of maintenance action for each component for all inspections by minimizing total PM cost. Figure 2 shows convergence curve for SA during search time. As illustrated in this figure, SA converges towards final solution with a good speed resulting in more than 45% improvement in about 10 minutes of search time. The majority of cost reduction is obtained in the first 3 minutes. After this time, algorithm reaches final solution and the curve levels off. The oscillations in the beginning of the search are due to the higher temperatures at this stage.

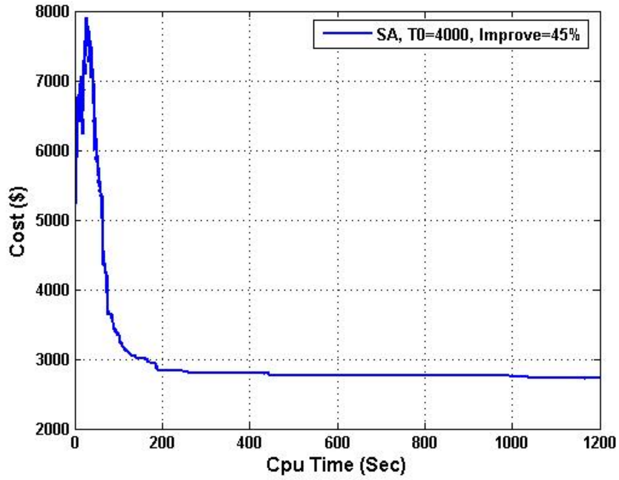

Figure 2 Convergence curve for total cost

The final schedule for a 10-period maintenance horizon is given in Table 3. In this table, "0" indicates simple service or inspection, "1" shows repair and "2" is for replacement. For each period, average system availability and amount of resources required are given in the last two columns respectively.

For instance, in the third period there are four replacements (components 3, 5, 6 and 10) and two repairs (components 7 and 9). In this period a total of 10 units of resources are required to keep average system availability at 95%. The solution suggests no repair or replacement for the first two periods since the system is still in the new state.

The results also demonstrate that, for a given component, PM actions may be varied in different intervals. Component number 2, for example, needs replacement after 3 months and then another replacement after 2 months. It, however, requires only a repair in the last period. The frequency of PM actions differ for other components as well. In all periods, however, average system availability is kept above minimum requirement of 95%.

The cost breakdown for initial and final PM schedules is shown in Table 4. As indicated in this table, the costs of PM related activities and system downtime are cut by more that half while the cost of expected random failures has increased moderately. The latter is mainly due to the sharp reduction of PM repairs and replacements in the final solution. In spite this, the overall cost have been reduced by 46% which is a big improvement for any system.

	Elements number														
Period	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	Resource
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	2	0	2	2	1	0	1	2	0	0	0	0	10
4	1	2	0	0	0	0	2	1	0	0	0	1	0	0	7
5	0	0	2	0	0	0	0	0	1	1	0	0	0	1	5
6	1	0	0	0	2	2	2	1	2	0	0	0	0	1	11
7	0	2	0	0	0	0	0	1	0	2	0	2	0	1	8
8	0	0	0	0	1	0	1	0	0	0	2	0	1	1	6
9	0	0	2	0	1	0	2	0	2	2	0	0	0	0	9
10	0	1	0	0	0	0	1	2	0	0	0	0	0	0	4

Table 3 PM schedule, type of maintenance and resource requirements for the example problem

Cost	Initial PM plan	Final PM plan	Change
PM actions	3333	1559	-53%
Random failure	465	560	20%
Downtime	1200	600	-50%
Total	4998	2719	-46%

Table 4 Cost breakdown for initial and final schedule

6. CONCLUSION

Preventive maintenance is the most important tool to ensure systems availability and performance. Due to the cost involved, PM schedule should be established optimally. In this paper a procedure to determine the type and frequency of PM activities for a multi-component series-parallel system has been developed. To solve the problem efficiently, Simulated Annealing heuristic was employed. It is shown that SA is quite capable of solving PM schedule problems in reasonable search times. Computational results also indicate that the type and frequency of PM action for each component may not be fixed during the planning horizon. The proposed model and solution procedure can be adapted to any system configurations with minor modifications.

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