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New methods to minimize the preventive maintenance cost of series–parallel systems using ant colony optimization

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Abstract

This article is based on a previous study made by Bris, Châtelet and Yalaoui [Bris R, Chatelet E, Yalaoui F. New method to minimise the preventive maintenance cost of series–parallel systems. Reliab Eng Syst Saf 2003;82:247–55]. They use genetic algorithm to minimize preventive maintenance cost problem for the series–parallel systems. We propose to improve their results developing a new method based on another technique, the Ant Colony Optimization (ACO). The resolution consists in determining the solution vector of system component inspection periods, T_P. Those calculations were applied within the programming tool Matlab. Thus, highly interesting results and improvements of previous studies were obtained.

Keywords: Preventive maintenance; Cost; Availability; Optimization; Reliability; Ants system; Ant's colony system

1. Introduction

The availability and reliability are good evaluations of a system performance. Their values depend on the system structure as well as on the component availability and reliability. These values decrease as the component ages increase, i.e. their serving times are influenced by their interactions with each others, applied maintenance policy and their environments. The approach proposed in this article considers mainly the maintenance policy influence. The other influences can be taken into account with the developed method (see Section 3.5). Among the different types of maintenance policy, we suggest to study the preventive maintenance (PM), widely applied in large systems such as transport systems, production systems, etc.

Preventive maintenance consists of a set of technical, administrative and management actions to decrease the component ages in order to improve the availability (and the reliability) of a system (reduction of probability failure or the degradation level of a system's component). These actions can be characterized by their effects on the component age: the component becomes 'as good as new', the component age is reduced, or the state of the component is lightly affected only to ensure its necessary operating conditions, the component remaining appears to be 'as bad as old'.

PM policy has been the subject of many studies in recent years. Those studies take into consideration several criterions like cost, economic life, risk or a combination of the above stated criteria. Ushakov [26] tried to optimize preliminary planned PM considering binary-state system reliability. Barrow and Hunter [1] demonstrated that the cost of scheduled replacement is lower than the unscheduled one. Legat et al. [15] determined the optimal interval for preventive maintenance/replacement using either an age-based or a diagnostic based renewal strategy. Wang et al. [27] represented an algorithm of decision making about replacement scheduling of a system's main component by pursuing a maximal system profit. Bris et al. [3] tried to optimize for each component of a system, the maintenance policy minimizing the cost function, with respect to the availability constraint ($A(t) \geq A_0$, A_0 being a fixed lower limit) on a given mission time T_M. They have calculated T_0 and T_p, with T_0

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Notations and acronyms

$A(t)$	system availability at the time t
A_0	availability constraint—lower limit
AS1, AS2, ACS1	the three proposed algorithms
$C(e(i,k))$	cost of one inspection of ith component in the kth parallel subsystem
C_a	best preventive maintenance cost obtained by the algorithm a (=AG, AS1, AS2, or ACS1)
	Component list vector of randomly generated preventive maintenance times
e	the number of elitist ants
GA	genetic algorithm
J_i^k	list of times that kth ant can choose for the ith component.
N	total number of components
P	visibility matrix
$P(i,j)$	visibility value associated to the arc relating time i to time j
ρ, α^+	pheromone decay parameters; $0<\rho<1$; $0<\alpha^+<1$
$\tau_{ij}(t)$	pheromone's quantity
Q	a parameter arbitrary chosen
q	a random number uniformly distributed in [0,1]
q_0	a parameter ($0<q_0<1$)
T_M	mission time
$T_0=(T_0(1),T_0(2),\ldots.T_0(N))$	the first inspection time vector
$T_P=(T_P(1),T_P(2),\ldots,T_P(N))$	solution vector of system component inspection periods
T_p^k	the T_P vector associated to the kth ant tour
τ_0	the initial value of deposed pheromone
W_{ij}	the cost value of the ant tour of which the arc (i,j) forms a part
W^*	the value of the best (lowest) cost obtained

being the first inspection time vector and T_P, the vector of system component inspection periods. T_0 was generated based on the time dependent Birnbaum importance factor (definition see in [19], for example). Genetic algorithm (GA) [3] was used to calculate this last vector.

GA are used more often to optimize system reliability [4, 10,17,21,24,28] and in maintenance strategy. A genetic algorithm was used in Levitin and Lisnianski [16] to calculate replacement policies leading to minimal cost plan of PM actions during multi-state system lifetime. Tsai et al. [25] used GA to decide optimal activities-combination which maximizes system unit cost life.

In this paper, we propose a new meta-heuristic to solve the problem of T_P calculation treated in [3]. Algorithms based on ant colony optimization (ACO) replace the GA in their search for best calculation of T_P. A comparison is established between results obtained by those algorithms via cost and time evaluation.

Ant Colony Optimization (ACO) is a population-based general search technique for the solution of difficult combinatorial problems. This method is inspired by the pheromone trail laying behavior of real ant colonies. Ant Colony Optimization takes elements from real ant behavior to solve more complex problems than those solved by real ants [5,6,9,11]. In ACO, artificial ants are stochastic solution of construction procedures. They build probabilistically solutions by taking into account (artificial) pheromone trails which change dynamically at run time to reflect the agents acquired search experience. Solution construction is biased by pheromone trails which change at run-time, heuristic information on the problem instance and the ants private memory [23]. ACO was initially used for the resolution of traveling salesman problem TSP [8]. Lately, ACO algorithms have become interesting for problems which cannot be easily solved by classical techniques. Gravel et al. [13] have demonstrated their performance by finding solution for real industrial scheduling problem. They were applied to problems with a very short path where costs change dynamically as for example in telecommunication networks routing problems. Liang et al. [18] used an ant colony meta-heuristic optimization method to solve the redundancy allocation problem (RAP), a comparison between GA and ACO performance was established. And recently, Nahas et al. [20] used ant system to optimize the reliability of a series system with multiple choices and budget constraints. Simulations, in [20], have shown that the proposed ant system is efficient with respect to the quality of solutions and the computing time.

In this proposed research, ACO are used as a technique to optimize the determination of preventive maintenance periods leading to maintenance cost minimization of series–parallel systems. Once applied in [3], this technique gives interesting results. This introduction is followed by four sections which present successively detailed explanations of the ACO algorithms (course of the solution, stop and evaluation criteria choice of the starting point, transition and updating rules), results and a conclusion.

2. Cost optimization technique

2.1. The studied preventive maintenance problem

Optimizing preventive maintenance policy has been the subject of many previous papers (for details see Section 1) The present work contributes to this research field. It concerns the determination of the component replacement conditions (dates and concerned components) in series–parallel systems minimizing the policy cost. The found solutions have to respect reliability and availability