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A quadratic reproduction based Invasive Weed Optimization algorithm to minimize periodic preventive maintenance cost for series-parallel systems

Ali Yahyatabar, Amir Abbas Najafi *

Faculty of Industrial Engineering, K.N. Toosi University of Technology, Tehran, Iran

A R T I C L E I N F O

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A B S T R A C T

This study deals with the problem of minimizing periodic Preventive Maintenance (PM) for series-parallel systems. The number of preventive maintenance activities for each component in series-parallel system would be specified with respect to reliability constraint for the whole system. An efficient meta-heuristic algorithm called IWO is used to attain an optimal or a near-optimal solution through a modification in the stage of allocating the new number of generation. Although some researchers have made great attempts at introducing an efficient algorithm to solve this NP-hard problem, all methods must be run in a two-stage process. The first stage for specifying the best combination of components and the second stage for obtaining a good solution to the specified combination in the first stage. This paper intends to apply a single stage process through a novel IWO algorithm to hold solutions with various combinations. The performance of the proposed algorithm is evaluated by comparing with other algorithms. The results of the computational experiments are statistically discussed and indicate that the proposed IWO outperforms the other algorithms.

1. Introduction and literature review

1.1. Motivation

Industrial companies would make an effort to keep themselves agile in the dynamic market. Due to lots of competition among industries, tools such as lean methods are used to minimize costs related to the system and subsequently to survive in their business. Among all functions of a company, maintenance area is not an exception. Being the cost effective gets an essential in the body of the organization's strategy. Providing an effective plan for preventive maintenance of equipment helps a company be more flexible and has a smooth path to plan its production. It is possible to have more availability along with less costly maintenance, if there is a suitable maintenance plan. Maintenance managers always try to reach an optimal decision on maintenance periods of every object in their systems (Dey, 2004). Nowadays, the optimal working is getting a competitive advantage among industries. What motivates managers is which solution can enhance this advantage. Introducing a stable method to obtain a good solution is more important than the solution itself.

There are two common techniques to ensure system's reliability, the most well-known way is redundancy. Moreover, repairable systems can be repaired and referred to as good as new state and this is another way to ensure system's reliability. A system as a whole unit can consist of redundant components which can be repaired and restored to its initial status. Repairing or maintaining components are costly and need to be reasonably decided to achieve the optimum decision. Systems that can be constructed like redundant systems are redundant turbines in power systems, redundant pumps in refinery industries, etc.

Many mathematical models for maintenance optimization of single-unit system have been constructed based on cost minimization as an objective and reliability limitation as a constraint and many algorithms have been proposed to solve the models (Dekker, 1996; Gertsbakh, 1977, 2000; Jorgenson, Mc. Call, & Radner, 1967; Nakagawa, 2005; Valdez-Flores & Feldman, 1989; Vaurio, 1999; Wang, 2002). In complex systems incorporated by various subsystems and components called multi-unit systems such as series, parallel, k-out-of-n, load-sharing and series-parallel systems, maintenance periods are supposed to be separately planned with respect to the failure distribution of components and the importance level of components

* Corresponding author.
E-mail addresses: aya6425@gmail.com (A. Yahyatabar), aanajafi@kntu.ac.ir (A.A. Najafi).

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(Cho & Palar, 1991; Levitin & Lisnianski, 2000; Thomas, 1986). In comparison with single-unit systems, preventive maintenance strategy for series-parallel systems have a small contribution among studies on maintenance period optimization in literature.

Moreover, algorithms presented to solve preventive maintenance period optimization can often be categorized into the algorithms based on obtaining the exact global optimum and the algorithms based on obtaining an efficient solution. A novel literature review on solution method approaches in maintenance cost management was presented by Ansari, Fathi, and Seidenberg (2016). To find an exact global optimum solution can be very complicated especially for series-parallel structures with many components, it can be inefficient in practice and its intensity is increasing with the number of components. Dealing with this kind of problems, meta-heuristic algorithms can be appropriate to obtain an efficient solution, many meta-heuristic algorithms have been introduced for so many problems in literature. What is important among meta-heuristic algorithms is the quality of solution with respect to the variance of solutions in frequent iteration and convergence of the algorithm to the optimum or near to optimum. In this study, series-parallel systems would be studied and solved through a novel meta-heuristic algorithm based on IWO.

1.2. Related studies

Maintenance optimization model is a kind of problems in which a trade-off between the maintenance cost and the reliability motivates maintenance managers to choose the best solution among all feasible solutions for a variety of systems.

Many meta-heuristic algorithms have been introduced for maintenance problems in literature. Here, the most recent research being related to our study is reviewed in details. Levitin and Lisnianski (2000) generalized a preventive maintenance optimization problem for multi-state series-parallel systems. They formulized their model through hazard functions as the reliability of the system elements. The purpose is to find the optimum the sequence of the preventive maintenance actions to affect the effective age of the components. A basic Genetic Algorithm (GA) is applied as a solution method. Bris, Chatelet, and Yalaoui (2003) applied a special ratio-criterion based on Birnbaum important factor to specify the ordered sequence of first inspection times. They introduced a general preventive maintenance model for series-parallel systems in which objective function is to minimize the preventive maintenance costs of the system under given reliability constraint. The reliability function in their model was calculated based on a Monte Carlo technique and a GA was used to solve the problems. Ant Colony Optimization (ACO) was used to develop the result in the study by Bris et al. (2003) as new method to minimize preventive maintenance cost of series-parallel systems by Samrout, Yalaoui, Chatelet, and Chebbo (2005). They obtained improved results. As a concern of environmental protection, the power plant was used as a case study to develop a preventive maintenance optimization model considering system reliability by Leou (2006). Factors such as spinning reserve, man crew size for maintenance, operational period, line flow limitations, and operation and maintenance expense were considered in the study. A six-unit case in Taiwan Power System was solved through a hybrid algorithm constructed by GA and Simulated Annealing (SA). Tam, Chan, and Price (2006) studied on the preventive maintenance optimization of multi-component systems in a manufacturing factory. They developed three models to optimize preventive maintenance intervals for multi-component systems with respect to minimum reliability constraint, minimum cost and maximum allowable budget. A fuzzy approach was employed by Khanlari, Kaveh, and Babak (2008) to prioritize equipment for preventive maintenance actions under resource constraints in a multi-unit systems. In their study, fuzzy rules was applied to interpret linguistic variables to prioritize equipment. Galante and Passannanti (2009) proposed a preventive maintenance for series-parallel systems with respect to opportune policy. They addressed kinds of problems in which the most important components of a system would be maintained during planned system downtime. In their model, three cost types, the cost of spare parts, the crew cost, and the cost for unavailability were considered to construct the objective function being minimized and the major constraint is allowable reliability of system having to be met all the time of planning horizon. Lin and Wang (2010) studied on the scheduling of preventive maintenance actions for series-parallel systems. They constructed a model in which the total cost of preventive maintenance actions for selected components are minimized under a given reliability of the system. A basic Particle Swarm Optimization (PSO) method was employed to solve the problems. Two preventive maintenance models were proposed for multi-unit systems by Moghaddam and Usher (2011a) in which imperfect maintenance is considered and the hazard functions is used to find the expected number of failures for each component. They used a novel method incorporated by Branch-and-Bound (B&B) method and dynamic programming to solve the problems. Model 1 was constructed to minimize the total cost subject to a reliability cost and model 2 was constructed to maximize the system reliability subject to a budget cost. Wang and Tsai (2012) proposed a bi-objective model of imperfect preventive maintenance for series-parallel system and solved it using a Hybrid Genetic Algorithm (HGA). A joint redundancy and preventive maintenance planning optimization model was established by Nourelfath, Chatelet, and Nahas (2012) for series-parallel systems. Their model inputs are the number of non-identical multi-state units used in parallel to improve the availability of the system and the appropriate preventive maintenance actions under a given budget constraint. They used a heuristic approach based on a combination of space partitioning, GA and Tabu Search (TS) to solve the problems. Moghaddam (2013) formulated a multi-objective nonlinear mixed integer preventive maintenance optimization model for multi-workstation manufacturing systems. The operation planning horizon is divided to equally-sized periods and three maintenance actions called repair, replacement and do nothing are considered for each station. Total operational costs, reliability and the system availability are the components of the multi-objective function. Moghaddam (2013) used a hybrid algorithm constructed by Monte Carlo simulation and goal programming to find the optimal schedules of maintenance actions. Liu, Xu, Xi, and Kuo (2014) was presented a dynamic preventive maintenance model for kinds of systems being incorporated by continuously degrading components. A value perspective is the major body of the formulation. They constructed a two-stage model in which the first stage is to determine which components to maintain based on a yield-cost importance and the second stage is to determine to what degree the component should be maintained based on the net value maximization of the maintenance actions. A non-cyclical preventive maintenance scheduling and production planning model for series-parallel production lines was generalized by **Cadi, Nizar, Jamali, and Artiba (2015) in which for a planning horizon, a specific number of periods is defined. At the beginning of each period, a preventive replacement must be decided for each equipment and during periods, if an equipment is failed, a minimal repair would be performed. The purpose of the model is to find the optimal preventive replacement and production plan for each equipment. Their objective function is to minimize the total cost consisting of preventive replacement and minimal repair cost, setup cost, holding cost, backorder and production cost under the given demand constraint. Fallahnezhad and Najafian (2016) applied a statistical analysis to determine the optimal preventive