Computers & Industrial Engineering 126 (2018) 30–46

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

Condition based maintenance policy for series-parallel systems through Proportional Hazards Model: A multi-stage stochastic programming approach

Ali Yahyatabar, Amir Abbas Najafi*

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

ARTICLE INFO

Keywords:
Condition-based maintenance
Control limit
Meta-heuristic
Series-parallel systems

ABSTRACT

Condition based maintenance for series-parallel systems is studied in this paper. Due to the effect of covariate values on the component's deterioration, proportional hazard model would be adopted to model hazard rate of each component in the whole system. A control limit is determined at each inspection point for each component to minimize a total expected cost during planning horizon subject to reliability constraint of the whole series-parallel system. Because, covariates play a stochastic role in the proportional hazard model and the maintenance planning has a sequential nature, we would employ a multi-stage stochastic programming to model CBM for series-parallel systems. Different from other studies that researchers attempt to present a fixed control limit at the start point maintenance planning, this paper presents an optimal control limit per each inspection point and provides flexible dynamic control limits. Due to curse of dimensionality, a novel hybrid meta-heuristic algorithm constructed by Parallel Genetic Algorithm and Invasive weed optimization is proposed to find efficient control limits for each component over planning horizon. Its efficiency would be compared with some other classical meta-heuristic algorithms such as Genetic Algorithm, Particle Swarm Optimization and Invasive Weed Optimization. The results of the computational experiments are statistically discussed and indicate that the proposed hybrid algorithm outperforms the other mentioned algorithms.

1. Introduction

Maintenance problems are serious issues in various industries and businesses these years due to costs resulted from types of failures, reliability and safety. A way to enhance the reliability leading to more safety can be a proper maintenance planning. Systems usually gradually deteriorates, so there is an issue to deal with failures and their destructive effects. To find cost effective solutions is the main concern for maintenance managers. Recently, the main focus of studies is on a new production generation so called cyber manufacturing systems and industry 4.0. One of the most important issue in production system is the flow of material and information simultaneously. Online information as an advantage embedded in industry 4.0 helps managers make decision with higher ability and move forward with higher agility. Accessibility to the right data must be guaranteed by a well-maintained plants and equipment involved in the production system. In the context of Internet Of Thing (IOT) technology, useful data can be generated and transformed to valuable information through a proper monitoring and maintenance. A suitable maintenance plan can facilitate management of smart equipment to a lower cost. What motivates maintenance manager to figure out a way to develop a maintenance plan effectively is a tradeoff between system reliability and cost. Various mathematical models for maintenance optimization of single-unit systems have been proposed and presented many solution approaches to them (Ansari, Fathi, & Seidenberg, 2016; Dekker, 1996; Gertsbakh, 1977; Jorgenson et al., 1967; Makis & Jardine, 1992; Nakagawa, 2005; Valdez-Flores & Feldman, 1989; Vaurio, 1999; Wang, 2002). One of the most important issues in maintenance problems is how to plan maintenance actions for multi-component systems getting more complicated day by day due to growing technologies. The optimization model cannot be a complicated one for single systems, while with the presence of dependency between units in a multi-unit systems, the optimization model can be complicated and subsequently finding solution method would be more complicated.

Multi-component systems can be studied from dependency and configuration perspective. Dependency between components can be interpreted as interactions between them. What makes multi-component systems be complex is the type of configuration affecting

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

https://doi.org/10.1016/j.cie.2018.09.014
Received 4 December 2017; Received in revised form 30 June 2018; Accepted 5 September 2018
Available online 06 September 2018
0360-8352/

availability and reliability of the system. Structural dependency implies that for a particular structure, failure of a one unit can motivates maintenance manager to perform maintenance for other units. Various configurations of a multi-component system can be classified into series, parallel, series-parallel, parallel-series, and k-out-of-n. The failure is supposed to be taken care more in series systems compared to others, since each failure can cause the failure of the whole system. So, in the design phase of a system, redundancy technique developing the whole system into series-parallel form can be helpful to enhance the reliability. Series-parallel system is a typical configuration having been studied by many researchers.

Three maintenance policies are take into account in literature: Corrective Maintenance (CM), Preventive Maintenance (PM) and Condition-Based Maintenance (CBM). CM means maintenance actions are performed after failure of a system, PM is contemplated as well-known policy being classified to periodic and non-periodic maintenance. CBM focuses on the prediction of system state through monitoring some parameters. As mentioned above, the optimization model for multi-components with a special configuration can be a complex one. To monitor the status of all components to decide a preventive maintenance is usual way for maintenance manager to have a condition-based maintenance plan. When system gradually deteriorates, it simultaneously may be affected by other covariates. This means that the system is under an uncertainty environment, so a proper stochastic optimization model may be needed to cover all circumstances. In comparison with other configurations, a proper CBM policy under uncertain environment for series-parallel system have a small contribution among studies on maintenance optimization problems in literature. In this study, typical series-parallel systems would be studied from the view point of stochastic programming to cover uncertain status of system life time.

Stochastic programming would be contemplated as a mathematical programming to model uncertainty. During Planning, uncertainty can be handled through stochastic programming assuming that probability distribution of events are known and usually can be estimated through statistical methods. Our aim to use stochastic programming in CBM is to handle uncertainty of parameter values in order to minimize expectation of cost function. Stochastic programming can be classified into two-stage programming and multi-stage programming.

Two-stage stochastic programming is widely used to cover types of problems in which decision maker should decide on some parameters happening in future. At the first stage (i.e., for the time being), some decisions are made about some uncertain parameters, say random variables, after which (i.e., the second stage) these parameters will be realized and subsequently any realized values affects the first-stage decisions. A recourse function is employed to compensate any negative effects in the second stage. Actually, it hinders those first-stage decisions in their negative aspects to make objective function worse. A meticulous study of two-stage stochastic programming and its applications have been done by Birge and Louveaux (2011) and Schultz et al. (1996).

Multi-stage stochastic programming is usually used for problems with sequential decision making stages. Against two-stage stochastic programming, multi-stage stochastic programming deals with several sequential stages in which due to availability of data at each stage, a different decisions would be made at each stage with respect to possible realization of data at previous stage. Maintenance planning for a planning horizon especially in the area of CBM, due to its sequential nature, multi-stage stochastic programming would be useful to cope with uncertain environment of some random parameters during time. Some parameters affecting hazard rate of a system are monitored in CBM to decide the time of a maintenance action. When, the behavior of these parameters follows a discrete-time stochastic process with finite probability space, multi-stage stochastic programming can be efficient approach. On the other hand, due to difficulty of finding an optimal solution, there is weak tendency to apply this approach. However, finding a near optimal can be applicable and efficient in real life applications.

Algorithms presented to solve maintenance mathematical model could often be categorized into obtaining the exact global optimum and obtaining efficient solution. A novel literature review on solution methods in maintenance cost management was presented by Ansari et al. (2016). Exact optimum can be very complicated especially for multi-stage stochastic programming and series-parallel systems with various components. To cope with these issues, meta-heuristic algorithms would be appropriate to obtain efficient solutions. Many meta-heuristic algorithms have been proposed to deal with various complex problems in the literature. What is important among these algorithms is the quality of the solution regarding the variance of the solutions in frequent iteration and the convergence of the algorithm. This is another motivation for us to propose a novel meta-heuristic algorithm to find the efficient solutions in this study.

The reminder of the paper is organized as follows. In Section 2, a literature review is organized. In Section 3, the problem is described schematically and the model is formulated through stochastic optimization programming. The solution approach constructed by a novel meta-heuristic algorithm is illustrated in Section 4. Numerical examples to prove the capability of the model are given in Section 5 and finally, concluding remarks and future research are presented in Section 6.

2. Literature review

2.1. CBM and TBM

Maintenance planning can be classified into time-based maintenance (TBM) and CBM. Well-organized reviews on TBM could be found in (Cho & Parlar, 1991; Dekker, 1996; Pierskalla & Voelker, 1976; Scarf, 1997; Sherif & Smith, 1981; Wang, 2002; Yahyatabar & Najafi, 2017). Unlike the planned periodic maintenance and corrective maintenance CBM can predictively give an effective information to preventively do appropriate maintenance action prior to failure. A novel investigation between TBM and CBM has been done by Jonge, Teunter and Tinga (2017). CBM as an efficient maintenance planning approach has received increasing attention among researchers in recent years. The contrast of studying on CBM with studying on TBM is very noticeable.

2.2. CBM process

The process of CBM constitutes of two main steps: first one is condition monitoring and the second one is maintenance decision making (Jonge et al., 2017). The core of CBM is the condition monitoring step in which some parameters such as temperature, state of the oil, vibration and noise are monitored either continuously using specific types of sensors associated to the technology, the nature and the structure of an equipment or in discrete using periodic inspections (Ahmad & Kamarruddin, 2012), consequently after observing the parameters, an optimal decision including replacement or repair would be made to reduce unnecessary maintenance leading to cost reduction and to prevent the destructive failures.

2.3. PHM-based CBM

Various models such as Accelerated Life Model (ALM), Hidden