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# Optimisation of preventive maintenance grouping strategy for multi-component series systems: Particle swarm based approach

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ABSTRACT

Preventive maintenance is widely accepted within the industry as an effective means to reduce the number of failures and keep manufacturing systems in good conditions.

This paper presents an optimization of the grouping strategy of preventive maintenance actions for multi-unit series production systems. Such systems bring a positive economic dependence which make necessary to combine maintenance activities to ensure a low maintenance cost and high system availability.

The proposed approach aims to optimize two objectives: improve the availability of the system and minimize the cost of the preventive maintenance. In this paper, a Particle Swarm Optimization (PSO) algorithm is implemented to determine the best planning of maintenance grouping.

We conducted several experimentations on different component system scenarios. The obtained results are compared with those ones reported in the literature.



## 1. Introduction

### 1.1. Motivation

In series production system, products undergo changes continuously through perfectly synchronized operations level of their operating time: cement plants, steel mills, automobile assembly line, sewage treatment plants, and refineries, are examples of processes that correspond to this typology. Production machines are dedicated and optimized for faster production and high quality. The main disadvantage of this type of system is the instability of the process because any shutdown of a machine will cause the whole process breakdown. This type of deficiency has a direct impact on the cost of the product due to the unavailability of the system. Therefore, preventive maintenance (PM) must play a very important role, in order to avoid machines' shutdown and maximize the availability of the system. Preventive maintenance aims to keep or restore a property in a specified state and improve his availability. It includes an action adjustment, revision, control verification and replacement of hardware equipment (or even immaterial (software)). These actions will have a direct effect on the production system. Knowing that each machine has its proper maintenance program, the whole system will face with the spread effects, and must shutdown at each PM activity.

On the other hand, as maintenance activities call for one or more setup activities (e.g. crew moving, disassembly, equipment rental), there is a possibility of significant gains if they can be simultaneously performed (maintenance grouping) Van Dijkhuizen (2000). This type of grouping is also known in the literature under the name opportunistic maintenance. This outlook has spawned many research works in the field of optimization. For instance, opportunistic maintenance is implemented in the renewal water infrastructure assets. In fact, more benefits are obtained by economies of scale combining the renewal of water pipes that are spatially close Møller and Maria (2015). Okoh (2015) have used the grouping maintenance in the offshore raiser system to reduce the risk of accidents for personnel. Hameed and Vatn (2012) developed a grouping strategy for offshore wind turbines. In Otsmani, Khiat, and Chaker (2011) authors applied this strategy for electric network.

More clearly, the general objective of maintenance optimization models (as well as our study) is to determine the frequency and/or

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timing of preventive that create an optimal balance between the costs and advantages of this type of maintenance.

Among the pioneering works in this research field we can quote, for instance, the work done in Kulshrestha (1968). In this paper author propose an opportunistic maintenance policy in which there are two classes of units, 1 and 2. When a minor breakdown occurs, in the class 2 there is a possible chance for opportunistic repair of those class 1 units which have failed.

Bergman (1978) suggests a preventive replacement policy for a machine with two identical components. Upon a component failure, the other component as well as the failed one is also replaced if its age exceeds a pre-determined control limit L. In a further work Bergman (1978), the model has been extended by adding another decision variable *S*, such as, the units will be replaced also if any of them reaches a predetermined critical age *S*.

Zheng and Fard (1991) presented a hazard rate-based opportunistic maintenance model for the system with different types of units. A unit is either replaced or repaired according to the hazard rate and hazard rate tolerance. Later, Zheng (1995) extended this model, and presented an all opportunity-triggered age-depended replacement policy for multiple-unit. In this work, both, failure replacements and active replacement create opportunities to replace other units preventively.

Pham and Wang (2000) proposed two new decision variables age-based for opportunistic maintenance policies, where minimal repair was used. Furthermore Pham and Wang (2000) extended these two policies by including another decision variable, the number of failed components.

More recently Hou and Jiang (2013) proposed an opportunistic maintenance policy of multi-unit series production system by considering of imperfect maintenance. This policy is based on the ability to replace or repair a component by an economic evaluation when the system halts.

In Ni, Gu, and Jin (2015) authors developed a prediction model to identify such PM opportunity windows for large production systems based on real-time factory information system data.

This paper, is an extension of works conducted in the literature, and deals with a PM scheduling problem of series production system flow-shop configuration. It aims to present a model based on metaheuristics in order to find the timing of preventive maintenance by considering, both of different PM duration applied to each unit and the imperfect maintenance model. Due to its complexity, an optimization method based on particle swarm optimization was addressed taking into consideration two objectives: the minimization of the cost and the maximization of the availability. Subsequently, the model was validated by different experimentations.

### 1.2. Literature review

Preventive maintenance is widely accepted within the industry as an effective means to reduce the number of failures and keep manufacturing systems in good operating condition. In literature, several maintenance strategies and techniques have been studied and reviewed Wang (2002), Dekker, Wildeman, and van der Duyn Schouten (1997), Nicolai (2008), Sharma, Yadava, and Deshmukh (2011), and Alrabghi and Tiwari (2015).

It is customary to distinguish various maintenance models that can be constructed according to different states of PMs: minimal (drives the system in the As Bad As Old state), perfect (drives the system in a As Good As New state), or imperfect (drives the system in a younger state) Wang (2002). In many situations, the latter state is the more realistic. In fact, even though some components are replaced, the cumulative wear on adjacent components may deteriorate in unnoticed way Xia et al. (2012).

Preventive maintenance models have been classified into two main categories, single-unit and multi-units PM models. The first one was initiated by Barlow and Hunter (1960) and formed the basis of the work leading to more complex systems with multiple component models.

Nowadays, more and more researches have been focusing on models of multi-unit components. Such as the spare parts management Manzini, Accorsi, Cennerazzo, Ferrari, and Maranesi (2015) or maintenance management Gustavsson, Patriksson, Strömberg, Wojciechowski, and Önnheim (2014), and Sahnoun et al. (2015).

Thomas (1986) defines possible interactions between the main system components: economic dependence, structural dependence and stochastic dependence. Some authors have focused on economic dependence as presented in Gunn and Diallo (2015), or combine between economic and stochastic dependence Shi and Zeng (2016).

The series system being one of the most important and common systems is characterized by its economic dependence, this implies that the cost of joint maintenance of a group of components does not equal the total cost of individual maintenance of these components. Thereby a grouping PM policy emerged; the latter is based on the fact that maintenance activities need one or more preliminary set-up activities, which can save non negligible gains if they can be performed simultaneously Van Dijkhuizen (2000).

Generally, there are two main reasons for applying maintenance grouping: first one is to extend equipment lifetime and reduce failure occurrence, but also to take advantage of the resources, efforts and time already dedicated to the maintenance of other parts of the system Samhouri (2009).

In the literature, three different types of maintenance grouping are studied: long-term (static), medium-term (dynamic) and short-term (opportunistic) grouping.

Static grouping combines planned preventive maintenance activities in a strategical planning phase. In the dynamic grouping, planned PM activities can be joint with each other, or with other planned corrective maintenance activities; contrary to the opportunistic grouping that take advantage even unplanned corrective maintenance.

We find in literature several interesting studies based on dynamic grouping strategy. In Wildeman, Dekker, and Smit (1997) authors stated the theorem of consecutive activities for series systems: all groups in an optimal grouping structure must contain only consecutive PM activities. This theorem deals with the combinatorial problem of maintenance grouping, but far from the truth. Thus, it has been shown that an optimal group must balance between the penalty costs due to the changes of tentative execution dates and the additional gain due to the changes of total planned shutdown costs. Based on this study, several works were developed. We can quote, for instance the work presented in Do Van, Barros, Bérenguer, Bouvard, and Brissaud (2013) and Do Van, Canh, and Anne (2012). In their articles, authors took into account the time constraints on the opportunities, and the constraints of the available number of repairers. The model was adapted for a series parallel system such as by Vu, Do Van, Barros, and Christophe (2012) and Vu, Do, Barros, and Berenguer (2014). Moreover, the constraints of availability and limited repairmen were introduced in Do Van, Canh, Barros, and Bérenguer (2015).

Unlike to the studies cited above, which consider the maintained component as good as new, others authors deal with the imperfect state of the maintained component. Thereupon, in Zhou, Xi, and Lee (2009) authors proposed a PM scheduling algorithm based on dynamic programming and fixed the optimal maintenance application by maximizing the short-term cumulative opportunistic maintenance cost savings for the whole system. Then, intermediate buffers were integrated in series system like in Zhou, Lu, and Xi (2010).