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# A preliminary analysis of a prescriptive block replacement policy for a degrading production system

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## 1 Introduction

Maintenance and production planning play a crucial role in ensuring smooth operation of an industrial production process. Even though the underlying goal for both is production optimization, their requirements can often be conflicting. Indeed, production planning prioritizes the maximization of output, which may lead to a push for a more aggressive utilization of equipment (which can potentially lead to unexpected breakdowns), while maintenance is focused on ensuring the reliability and the longevity of the equipment regardless of production constraints (which may require frequent interruption of operation for inspections and repair, therefore leading to lower production output).

For these reasons, maintenance is typically considered a capacity-consuming activity and often results in compromising between minimizing disruption while guaranteeing reliable performance at the lowest cost.

Prescriptive maintenance (PsM) is a new paradigm that has recently gained research interest as a potentially effective tool to tackle this underlying conflict within maintenance optimization. While a formal definition is still not available in the literature, it is understood as a framework in which maintenance decisions are taken from a holistic point of view, considering all aspects of a system simultaneously (see [1] and [2]).

In the context of a production process, this can translate to, for example, manipulating some operational parameters such as the production rate of the system (based on real-time degradation measurements) with the aim of influencing the future evolution of the degradation and maximize economic output while minimizing maintenance costs. This idea has been already explored (without explicitly mentioning "prescriptive" maintenance) by the literature, see [3], [4].

## 2 Description of the policy

In this paper, we propose a prescriptive block replacement maintenance policy where, based on the outcome of regular inspection performed on a production system, the production rate can be dynamically adjusted.

- A single production system, producing one-type items is considered ;
- The production horizon is divided in equally spaced Production Periods (PP) of length  $\tau$ , and in each one of them the system is expected to meet a production requirement of  $N_k(\tau) \geq n_\tau$  items (where  $N_k(\tau)$  is the number of items produced in the  $k$ th PP) ;
- The degradation of the system can be described by a gamma process ;
- The system fails when its degradation process passes a fixed threshold. A failed system halts operation immediately and is inoperative until maintenance is performed ;
- Both preventive and corrective replacements restore the system to an "as good as new" state and are performed in negligible time.

Based on this assumptions, the policy can be seen as a combination of three decision rules :

- A block replacement rule : preventive and corrective replacements, as well as inspections, can only be performed at the end of each PP ;
- A condition-based rule : the corrective and preventive replacements are triggered based on a threshold level. Specifically, if at the  $k$ th inspection time the degradation passes the failure threshold (i.e., it is failed), then the system is correctively replaced, whereas if it passed a preventive threshold, it is replaced preventively. Otherwise, production continues in the  $(k + 1)$ th PP ;
- A prescriptive rule : it is possible, only once within each PP, to change the Production Rate (PR) of the system. The PR can be either increased or decreased and can be changed from its nominal value (denoted by  $u_{nom}$ ) after  $q_k$  items are produced in the  $k$ th PP to a new value (denoted by  $u_k$ ) which will be kept for the remainder of the PP. The PR will be reset to the nominal value at the start of the next PP. The decision about if, how, and when to change the PR during the  $k$ th PP will be taken based on the degradation level measured at the end of the  $(k - 1)$ th PP.

A change in the PR will have an effect both on the future degradation evolution of the system and on operating costs. In particular, increasing the PR will accelerate production, leading to more items being produced, but also accelerate the degradation process and increase the probability of failure. Conversely, reducing the PR will lead to less items being produced but also slow down the degradation process and decrease the probability of failure. The key idea of prescriptive maintenance is to account for all of these aspects simultaneously and find an overall optimal tradeoff.

Maintenance costs are computed by considering the cost of preventive and corrective replacement and production requirements. Specifically, in each PP  $n_\tau = 90$  units should be produced. Each item produced up to  $n_\tau$  generates a reward  $r_n$ , items produced beyond generate a reward  $r_s$  ( $r_s < r_n$ ). Failing to produce  $n_\tau$  items incurs a penalty  $c_{lp}$  for each non-produced item.

## 3 Example of application

We here illustrate an example of application of the proposed policy. For the sake of simplicity, we assume that the production rate can be selected from a set of three values : the nominal value  $u_{nom}$ , the maximum value  $u_{max}$  (i.e., an accelerated PR) and the minimum value  $u_{min}$  (i.e., a reduced PR).

Table 1 shows the optimal sequence of decisions on a randomly selected cycle (this is obtained by means of Monte Carlo simulation). We can observe that, in this particular cycle, the proposed policy opted to accelerate the PR as much as possible at the start (when the degradation is relatively low), then, as the degradation gets closer and closer to the preventive and failure thresholds, to slow down in the 6th PP (while still respecting the production target) so that the preventive replacement can be deferred to the 7th PP. In this latter period, production is

slowed down very early (after  $q_k = 10$  items produced) to minimize the probability of failure and avoid incurring the high corrective replacement cost (even at the price of generating a negative reward in this PP). This shows that, in this example, the proposed prescriptive policy is able to prolong the operational lifetime of the system while still managing the probability of failure.

PP ( $k$ )	Measured degradation	$u_k$	$q_k$	Items produced	Reward earned
1	0	$u_{max}$	0	166	678
2	1.5	$u_{max}$	0	166	678
3	3.06	$u_{max}$	0	166	678
4	4.91	$u_{max}$	0	166	678
5	5.59	$u_{max}$	0	166	678
6	7.88	$u_{min}$	65	90	450
7	8.39	$u_{min}$	10	74	-194

TAB. 1 – A one-cycle production example ending with a preventive replacement.

## 4 Conclusions and perspectives

The question of integration of maintenance in the production planning process remains a largely open subject. Given its inherent random behavior, maintenance strategies are often optimized by using long-term average criterion, which can usually lead to very conservative recommendations that are sometimes difficult to accept from the operational point of view. In this paper, we proposed a prescriptive maintenance policy that can be seen as a combination of three decision rules : a block-replacement rule, a condition-based rule, and a prescriptive rule, where the production rate can be dynamically adjusted based on the degradation measurements collected in real-time. The rationale behind this policy is that manipulating the production rate can offer more flexibility and simultaneously optimize production while managing the probability of unexpected failures. Obtained results show that a prescriptive policy can be an effective approach to maintaining a production system.

However, despite the simplifying assumptions made, the fact that prescriptive decisions influence the degradation, which in turn influences future prescriptive decisions, introduces mathematical complexity. Developing improved optimization algorithms is the first issue that should be addressed in future research. Then, it would be worthwhile to investigate whether a policy relying on a limited number of inspections (saving therefore on inspection costs) can be economically advantageous.

## Références

- [1] Esposito N., Castanier B., & Giorgio M. (2023). An Adaptive Prescriptive Maintenance Policy for a Gamma Deteriorating Unit. “*In 33rd European Safety and Reliability Conference (ESREL 2023)*”, : (pp 960–967).
- [2] Longhitano P.D., Tidriri, K., Bérenguer, C., & Echard, B. (2021). Proposition of a Generic Decision Framework for Prescriptive Maintenance. “*In World Congress on Engineering Asset Management*”, : (pp 263–273).
- [3] uit het Broek, M. A.J., Teunter, R.H., de Jonge, B., Veldeman, J., & van Foreest, N.D. (2020). Condition-based production planning : Adjusting production rates to balance output and failure risk. *Manufacturing & Service Operations Management*, 22(4) : 792-811.
- [4] uit het Broek, M. A.J., Teunter, R.H., de Jonge, B., & Veldeman, J. (2021). Joint condition-based maintenance and condition-based production optimization. *Reliability Engineering & System Safety*, 214 : 107743.