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Opportunistic Maintenance Policy Under Limited Human Resources With Skills Levels

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1. Introduction

Maintenance worker shortages are a recurrent issue in the industrial world. They lead to inconsistencies between the maintenance policies and the actual practice because these constraints are not modeled during the maintenance policy optimization but appear due to the lack of workers. In these situations, the workforce size is, therefore, not a controlled variable but rather a constraint to which the policy must adapt. This adaptation must be done while maximizing system availability and reducing overall operating costs.

The human factor in maintenance is usually modeled in two main ways. One is the inclusion of human reliability or human error (Sheikhalishahi, Pintelon, and Azadeh 2017); the other is the addition of skills of the maintenance workforce in the models, usually along a categorical axis (e.g., mechanical, hydraulics, electrical knowledge) or a quantitative axis (level of efficiency in the corresponding skill).

The skills evaluation has been included in maintenance policy design for over a decade. In particular, the identification of families of skills related to specific types of failure modes has led to scheduling optimization under constraints, including skill matrices and the use of contractors (Marmier, Varnier, and Zerhouni 2006). These developments led to global policy optimizations with respect to reliability, availability, maintainability, and cost (Martorell et al. 2008). However, these approaches have only been partially transposed to opportunistic maintenance modeling.

The consideration of the human factor in opportunistic maintenance includes skill modeling. This modeling is, however, often limited to a single skill per operator that is not quantitatively evaluated (Iung et al. 2016), and mixed with other specific hypotheses, such as structural or geographic dependencies (Nguyen et al. 2019).

In this work, the human factor constraint is modeled as a limited workforce with variate skill levels maintaining a series system. The long-term behavior of the system is modeled through a Monte-Carlo Simulation (MCS), and the optimization of the opportunistic maintenance policy is achieved through Particle Swarm Optimization (PSO). The originality of this work specifically derives from quantitative assumptions on the skill knowledge and linking this skill level with the duration of the maintenance action.

2. Methodology

The hypotheses on which the present work relies are as follows.

- The modeled system is a four-component series system.
- Each component undergoes failures that follow a Weibull distribution.
- For each component, the corrective maintenance lasts longer than preventive maintenance.
- Each component requires a minimum number of workers and a minimum set of skills to be present for the maintenance action to be completed.
- Each worker is assumed to know about a single skill, but moreover their skill knowledge is quantitatively assessed and induces variability on the maintenance operation duration.

- If the crew is insufficient to perform an opportunistic maintenance at a point, the action is not undertaken.
- Systematic preventive maintenance is modeled and based on individual optimal preventive periodicities computed from the ratio between preventive and corrective maintenance actions.
- The economic dependency is the only modeled dependency and includes downtime and setup costs sharing.
- Each system stoppage is considered as an opportunity for maintenance.
- The decision of applying opportunistic maintenance on a component depends on its reliability at the time of the opportunity. When considered for opportunistic actions, the components are considered by ascending reliability order.
- The maintenance falls within the As Good As New (AGAN) paradigm.

The methodology is experimented on a system described in Table 1. In the example presented in this table, three skills are used: mechanical (M), hydraulics (H), and electrical (E). The Weibull shape (β) and scale (η) parameters are provided.

Table 1. Description of the system used in the numerical example.

Component	1	2	3	4
Required skills	M, H	M, H, E	H, E	M, E
Weibull parameters (β, η)	(1, 300)	(2.3, 700)	(3, 300)	(2.5, 420)

The long-term behavior of the system is simulated through a MCS following the hypotheses presented above, and computing indicators: cost per unit of time, availability. This simulation is repeated for a variety of workforce situations, from fully trained, full crew (the entire system can be always replaced most efficiently) to a lower-level crew of a limited number such that it is impossible to perform any opportunistic maintenance and downtimes are longer.

For each workforce situation, a multivariate PSO is performed, the parameters being the reliability threshold under which each component requires opportunistic maintenance. The optimization is performed with respect to cost.

3. Results

For each workforce situation, an optimization of the system is achieved. The optimal reliability threshold triggering opportunistic maintenance is obtained for each component, and the cost per unit of time and availability values are obtained. They show that the criteria for opportunistic maintenance vary, depending on the available crew, but can each lead to an optimum considering the hypotheses. These results can in turn be used to determine an optimal size of the maintenance crews and advocate for team resizing and training.

4. Perspectives

This work is limited to single-skill workers assignment. The process of assigning jobs with multi-skill workers and with multi-skill demanding jobs is a complex problem that has been addressed in production jobs (Annear, Akhavan-Tabatabaei, and Schmid 2023), but never applied to maintenance problems, to the best of the authors' knowledge. It could be a priority for further research. Likewise, taking into account learning curves for the workers would also bring to the subject.

References

Annear, Luis Mauricio, Raha Akhavan-Tabatabaei, and Verena Schmid. 2023. 'Dynamic Assignment of a Multi-Skilled Workforce in Job Shops: An Approximate Dynamic Programming Approach'. *European Journal of Operational Research* 306 (3): 1109–25. https://doi.org/10.1016/j.ejor.2022.08.049.

Iung, Benoit, Phuc Do, Eric Levrat, and Alexandre Voisin. 2016. 'Opportunistic Maintenance Based on Multi-Dependent Components of Manufacturing System'. *CIRP Annals* 65 (1): 401–4. https://doi.org/10.1016/j.cirp.2016.04.063.

Marmier, Francois, Christophe Varnier, and Noureddine Zerhouni. 2006. 'Maintenance Activities Scheduling Under Competencies Constraints'. *2006 International Conference on Service Systems and Service Management*, 1217–22. https://doi.org/10.1109/ICSSSM.2006.320682.

Martorell, S, A Sánchez, M Villamizar, and G Clemente. 2008. 'Maintenance Modelling and Optimization Integrating Strategies and Human Resources: Theory and Case Study'. *Proceedings of the Institution of Mechanical Engineers, Part O: Journal of Risk and Reliability* 222 (3): 347–57. https://doi.org/10.1243/1748006XJRR128.

Nguyen, Ho Si Hung, Phuc Do, Hai Canh Vu, and Benoit Iung. 2019. 'Dynamic Maintenance Grouping and Routing for Geographically Dispersed Production Systems'. *Reliability Engineering & System Safety* 185 (May): 392–404. https://doi.org/10.1016/j.ress.2018.12.031.

Sheikhalishahi, M., Liliane Pintelon, and A. Azadeh. 2017. 'An Integrated Approach for Maintenance Planning by Considering Human Factors: Application to a Petrochemical Plant'. *Process Safety and Environmental Protection* 109 (July): 400–409. https://doi.org/10.1016/j.psep.2017.04.016.