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Condition-Based Production for Stochastically Deteriorating Systems

Collin Drent[1], Melvin Drent[1] and Joachim Arts[2]

[1]School of Industrial Engineering, Eindhoven University of Technology, the Netherlands. E-mail: {c.drent,m.drent}@tue.nl
[2] Luxembourg Centre for Logistics and Supply Chain Management, University of Luxembourg, Luxembourg. E-mail: joachim.arts@uni.lu

Problem Definition: Production systems deteriorate stochastically due to usage and may eventually break down, resulting in high maintenance costs at scheduled maintenance moments. This deterioration behavior is typically affected by the system's production rate. While producing at a higher rate generates more revenue, the system may also deteriorate faster. Production should thus be controlled dynamically to trade-off deterioration and revenue accumulation in between maintenance moments. We study both homogeneous systems for which the relation between production and deterioration is known and the same for each system, and heterogeneous systems for which this relation is not known and needs to be learned on-the-fly for each system. The decision maker seeks to find the optimal condition-based production policy given planned maintenance moments (operational) and the optimal interval length between such maintenance moments (tactical). A similar problem is studied in uit het Broek et al. (2021).
Methodology/Results: For homogeneous systems, we cast the operational decision problem as a continuous-time Markov decision process and show that the optimal policy is intuitive: Slow down production as failure is increasingly imminent and increase production as planned maintenance is nearing. We partially characterize the structure of the optimal interval length, thereby enabling efficient joint optimization of the operational and tactical decision problem. For heterogeneous systems, we propose a Bayesian procedure for tractably learning the unknown deterioration rate under any production policy. This procedure uses the gamma distribution as a conjugate for the intensity parameter of a Poisson process. Numerical studies indicate that (i) condition-based production can increase profits by up to 50% compared to static production, (ii) integrating condition-based production and maintenance can increase profits by up to 21% compared to the state-of-the-art sequential approach, and (iii) our Bayesian approach performs close to an Oracle policy that knows each system's production-deterioration relation.
Managerial Implications: Production should be adjusted dynamically based on real-time condition monitoring and the tactical maintenance planning should anticipate and integrate these operational decisions. Our proposed framework assists managers in how to do so optimally.

Keywords: Condition based production, bayesian learning, data-driven operations.

References

uit het Broek, M. A., R. H. Teunter, B. De Jonge, and J. Veldman (2021). Joint condition-based maintenance and condition-based production optimization. *Reliability Engineering & System Safety 214*, 107743.