Economic Optimization of the Inspection Period for Sensors with Hidden Failures: A Monte Carlo Simulation Approach

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Abstract

Failure of critical industrial equipment can have high stake negative impacts for industrial operations. Systematic preventive maintenance is a widely used technique to assess the condition of such equipment, including its potential failure. However, carrying out regular shutdowns on a critical equipment for inspections incur costs and potential production losses during the downtime period. Consequently, detection devices, such as sensors, are often used for monitoring the condition of critical equipment. These sensors can issue early warnings upon the occurrence of functional failures in the protected equipment or even anticipate potential failures. Promptly action can then be carried out to repair or replace the failed critical equipment to mitigate its consequences.

Failure detection sensors are not immune to their own failures though. Sometimes, the functional failure of the sensor is immediately detected, other times it remains hidden and goes unnoticed until it manifests through more serious consequences, such as a breakdown in the protected equipment, which can lead to long recovery times and significant repair costs. Therefore, it is essential to periodically inspect the proper functioning of condition monitoring sensors to uncover any hidden failures, namely through in-place or laboratory testing.

This study presents an economic optimization approach, using a discrete-event Monte Carlo simulation method implemented in a Microsoft Excel application, to determine the optimal inspection periodicity for sensors subject to hidden failures. Each simulation run computes the equivalent uniform periodic cost for any inspection period for the sensor, considering the following inputs: inspection cost and time, probability distributions for failure times of the equipment and sensor, repair costs and times, and the reactivation cost and time following a system failure. From these inputs, the optimal inspection period is determined by running multiple simulations for varying regular inspection periods and selecting as optimal the one that minimizes the expected equivalent uniform periodic cost of the system.

The approach was developed specifically for the major Portuguese electric utilities company, replacing previously used empirical formulas that did not factor in economic costs. The application of the methodology is supported by a user-friendly interface implemented in Microsoft Excel and Visual Basic for Applications and illustrated through a case study. The decision support system facilitates the selection of the economically optimal inspection period for the sensor based on its expected equivalent uniform periodic cost. Furthermore, it provides additional descriptive statistics on the expected performance of the system, including availability and reliability metrics. The optimization-simulation approach presented in this article provides significant advantages over common analytical methods, which often rely on unrealistic simplifying assumptions, particularly for modeling complex maintenance systems. Overall, it proves to be a valuable contribution to the maintenance literature for making informed decisions regarding the definition of regular inspection periods for sensors with hidden failures while monitoring the condition of critical industrial equipment.

Keywords
Sensors, Inspection period, Hidden failures, Optimization-simulation, Condition monitoring.

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Biography / Biographies

Ricardo J. G. Mateus is an experienced consultant and researcher for over 25 years with a passion for descriptive, predictive, and prescriptive analytics. Extensive experience in problem structuring and solving on business analytics and systems engineering methods and tools (optimization, decision analysis, artificial intelligence, simulation, prediction, statistics, etc.). Educational background in Management, Engineering, and Operations Research. Ricardo holds a PhD in Engineering and Management and is a Professor of Industrial Engineering and Management at Lusófona University in Lisbon, Portugal, and a Researcher at the Research Centre for Asset Management and Systems Engineering (RCM2+) and CEG-IST.

Rui Assis has a degree and a PhD in Mechanical Engineering from Instituto Superior Técnico, University of Lisbon. Bachelor's degree in Electrotechnics and Machinery from the former Industrial Institute of Lisbon and in Maritime Machinery from the Nautical School. Associate Professor at the Lusófona University and vice-president of the Centre for Research and Development in Industrial Engineering. Trainer at the Institute of Welding and Quality (ISQ) and at the Portuguese Association of Industrial Maintenance. Technically and scientifically responsible for various R&D projects at ISQ. Business Consultant in Operational Economics. Rui is the author of several articles and books on management issues and decision support software.

João A. Rodrigues teaches in the Licentiate's Degree and Master's Degree of Industrial Engineering and Management at Lusófona University in Lisbon, Portugal. He is also a researcher at the Research Centre for Asset Management and Systems Engineering (RCM2+) and at the Electromechatronic Systems Research Centre (CISE). Rodrigues develops most of his research on Asset Management and Industrial Maintenance and is currently waiting to defend his doctoral thesis at UBI in Industrial Engineering and Management.

P. Carmona Marques holds a PhD in Leaders for Technical Industries - Engineering Design & Advanced Manufacturing from IST/MIT (2012). He graduated in Industrial Engineering and a Master's in Engineering Physics. Main areas of work and R&D focus on Industrial Management, Innovation, and Mechanical Engineering. He is an Associate Professor of Industrial Engineering and Management at Lusófona University in Lisbon, Portugal, an Invited Lecturer at the Mechanical Engineering Department at ISEL, and a Researcher at the Research Centre for Asset Management and Systems Engineering (RCM2+).