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Optimal repair policies for monotone systems with simultaneous failures

Industrial systems composed of multiple interacting components are often exposed to external events that can simultaneously affect several parts of the system. Such events, commonly referred to as common shocks, introduce strong dependence between component failures and significantly complicate maintenance planning. When multiple components fail at once, the system may experience large operational disruptions and costly repair interventions, making the design of efficient maintenance policies a challenging problem.

In this talk we show optimal repair strategies for multi-component systems subject to dependent failures. The dependence structure is modeled using the Lévy–Frailty Marshall–Olkin (LFMO) distribution, which captures both individual component failures and simultaneous failures caused by common shocks through an underlying stochastic degradation process..

The maintenance decision problem is formulated as a sequential decision-making problem. Starting from the continuous-time reliability model, we construct a Semi-Markov Decision Process (SMDP) under an average-cost performance criterion. The SMDP is then transformed into an equivalent discrete-time average-cost Markov Decision Process (MDP), allowing the use of dynamic programming methods to compute optimal or near-optimal maintenance policies.

Because the transition dynamics of the system can be complex or analytically intractable, we also develop a simulation-based approach to approximate the underlying MDP. In particular, we employ reinforcement learning techniques based on the Stochastic Approximation Value Iteration Algorithm (SAVIA) to estimate optimal policies using simulated trajectories of the LFMO process.

In addition to the policies obtained through the MDP formulation, we also study and compare several alternative maintenance strategies. These include simple rule-based policies that depend on aggregate system indicators, such as the number of failed components. Although such policies are generally less optimal than those derived from the MDP framework, they are computationally inexpensive and scale well to larger systems. Simulation experiments show that, despite their simplicity, these heuristic policies can sometimes achieve competitive performance, making them attractive practical alternatives when solving the full MDP becomes computationally challenging.

Computational experiments illustrate how the dependence structure among failures affects maintenance decisions and demonstrate the effectiveness of the proposed framework for designing and evaluating maintenance policies in complex reliability systems.

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