Chapter 17
Performance of Two-Component Systems with Imperfect Repair

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ABSTRACT
Operational systems deteriorate over time and eventually fail by the failure of one or more of their components. Failed components are either replaced or repaired, and replacement is usually expensive. This article examines the behavior of repairable systems with imperfect repair, where a failed component is repaired once or more depending on factors such as repair cost, level of deterioration, and criticality of the component. When these systems are subjected to a customer use environment, their performance must endure different conditions. In imperfect repair, the performance of the system lessens after each failure. Three models of a two-component system studied are the series, parallel, and standby configurations, and the components are identical and independent. A closed form analytical expression for steady state operational probability is derived for different configurations under exponential distribution time to failure and repair time. Two examples are then discussed thoroughly.

INTRODUCTION
Repair actions are performed on failed systems in order to function properly. There are many types of repair, perfect repair where the failed system becomes as good as new after each repair, minimal repair which brings the system to its status just before failure, and imperfect repair, where the repaired system becomes inferior after each repair. The latter is considered in this work, it has been researched by many specialists, Govial (1983) presented maintainability and availability calculations for three configurations, series (1-out-of-n:F), parallel (1-out-of-n:G), and r-out-of-n. Assuming the exponential distribution for both failure rate and repair rate, he derived the mean time to failure...
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(MTTF), mean time to repair (MTTR), and mean time to availability for these configurations. Brouwers (1986) derived mathematical expressions for the probability distributions and related statistical parameters, such as mean value and standard deviation of system downtime and resulting loss of production caused by irregular equipment failure and repair. The expressions have been derived assuming exponential failure and repair distributions for the different pieces of equipment assuming a mean-time-to-failure to be much larger than the mean time for repair. The expression can be applied to a variety of system configurations of varying degrees of complexity, i.e. single units, units with standbys, units in parallel.

In Wang and Sivazlian (1997), two different configurations with parallel components are compared based on their overall availability and life cycle costs under uncertainty of the system’s lifetime. The time-to-repair and the time to failure for each of the primary and parallel components are assumed to have the negative exponential distribution. The unconditional expected present worth of all expenditures during the entire life of the system is obtained using Laplace transform techniques in terms of the initial investment ($P$), the operating and maintenance costs ($C$), and the interest rate $r$. They derived the steady-state availability ($A_s(\infty)$), and the cost/benefit ratio, $C/B$, for the two configurations and performed a comparative analysis. Vittoria and Vincnzo (1999) presented an analytical model of a parallel computing system. Since the probability of fault occurrence is non-negligible, the model takes into consideration fault–tolerance issues, by combining results obtained from a performance model with a fault/repair model. The system performance was evaluated under different configurations caused by the occurrence of faults and repairs. This requires efficient solution techniques of the performance model. They proved that the underlying Markov process has a particular structure suitable for efficient solution. To show a possible use of such a model, numerical results were presented for a particular maintenance policy, looking for the optimal trade-off between the frequency of service interruption due to repair operations and the need of avoiding excessive performance degradation.

The paper by Wang and Kuo (2000) dealt with the reliability and availability characteristics of four different series system configurations with mixed standby (include cold standby and warm standby) components. The failure times of the primary and warm standby components are assumed to be exponentially distributed with parameters $\lambda$ and $\alpha$, respectively. The repair time distribution of each server is also exponentially distributed with parameter $\mu$. They derived the mean time-to-failure, MTTF, and the steady-state availability, $A_s(\infty)$, for the four configurations, comparisons are done for specific values of distribution parameters and for the cost of the components. Finally, the configurations are ranked based on: MTTF, $A_s(\infty)$, and cost/benefit where either MTTF or $A_s(\infty)$ are taken as the benefit. Oliveira et al. (2005) developed a method for reliability analysis of systems of components whose failure rates may be time-dependent. One special case of such systems is the one whose components are under aging. The hypothesis of minimum repair is adequate in many cases, especially in heavy industries, such as the nuclear industry. The method employs the technique of supplementary variables to transform the models of the non-Markovian systems into Markovian ones. The Laplace transform technique was used in order to reduce the number of equations, which are then solved by numerical methods. The inverse Laplace transforms to obtain the final solution of the set of differential equations is also utilized by using the Gauss–Legendre quadrature method which is very fast. Applications to safety systems, like the auxiliary feed water system of a typical PWR plant showed that the method is very fast and accurate as compared to other simulation methods.

Dohi et al. (2003), studied a simple repair-time limit replacement problem with imperfect repair, and focused on the problem of determining the optimal repair-time limit which minimizes the
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