Preface

Maintenance theory is basically how to make appropriate maintenances at suitable times to prevent failures for an objective system. Classic maintenance theory was mathematically established by Barlow and Proschan [1] 50 years ago. After that, a great part of maintenance models and a variety of maintenance policies, such as preventive replacement, preventive maintenance, inspection, etc., were summarized systematically in [2, 3]. To understand maintenance theory and master reliability engineering, we have to learn probability, statistics, and stochastic processes because reliability phenomena occurs randomly. The elementary textbook for graduate students, researchers, and engineers to learn readily reliability theory was published [4], which was written in an easy style on stochastic processes, and all examples are quoted fittingly from reliability and maintenance models.

It is well known generally in maintenance theory that an optimum replacement policy should be non-random [1], i.e., preventive replacement is always done at a deterministic time T which is taken to be a constant. However, most production and computer systems have variable working cycles and processing times. For such systems, it would be impossible or impractical in a strict periodic fashion to interrupt their running work for scheduled maintenances [1]. From this viewpoint, random maintenances of age replacement, periodic replacement, and inspection have been proposed, and their optimum policies were discussed and compared with each other theoretically and numerically [5]. As practical examples, random maintenance was applied to parallel systems, scheduling problems, damage models, and so on.

The concepts of maintenance first, maintenance last, and maintenance overtime were newly introduced in [5]. Especially, combining maintenances with time and cycles, maintenance overtime is proposed. For example, age replacement overtime is to replace a unit at the first completion of working cycles over time T. In this case, a unit continues to work without interruption by maintenance, and its maintenance considering working cycles is made simply without counting the number of cycles.

The main object of this Lecture Note is to investigate the relations of maintenance overtime with other maintenance policies and to add some new interesting results: Chap. 1 summarizes age replacement in which the unit is replaced before failure at a planned time T and at a working cycle N. We take up age and random replacements as the basic policies in Sect. 1.1. The expected cost rates are obtained, optimum policies which minimize them are derived analytically, and two policies are compared. Replacement overtime is proposed in Sect. 1.2, in which the unit is replaced at time T or at the first completion of working cycles. Replacement overtime with age and random replacements are compared analytically and numerically in Sect. 1.3. When three replacement costs are the same, replacement overtime is better than random replacement, however, it is not rather than age replacement. Replacement overtime last is proposed in Sect. 1.4, in which the unit is replaced at the first completion of working cycles over time T or at cycle N, whichever occurs last. Replacement overtime last is better than random replacement, however, it is not rather than replacement overtime. Compared to replacement overtime first, if replacement time T is given and is small, overtime last is better than overtime first, and conversely, if T is large, it is not rather than replacement first. We consider age replacement for a finite interval S in Sect. 1.5 and for a job with a specified number N in Sect. 1.6. All results in the previous sections are rewritten effectively when a finite interval and a specified number are constant and random variables. Finally, we apply replacement overtime to a parallel system with constant and random number of units in Sect. 1.7.

Chapter 2 summarizes periodic replacement in which the unit undergoes minimal repair at each failure, and is replaced at a planned time T, at a working cycle N or at a failure number K. First, we take up periodic and random replacements in which the unit is replaced at time T or at cycle N, whichever occurs first, and two policies are compared in Sect. 2.1. Replacement overtime is proposed in Sect. 2.2, in which the unit is replaced at time T or at the first completion of working cycles, and is compared with periodic and random replacements in Sect. 2.3. When three replacement costs are the same, replacement overtime is better than random replacement, however, it is not rather than periodic replacement. Replacement overtime last is proposed in Sect. 2.4, in which the unit is replaced at the first completion of working cycles over time T or at cycle N, whichever occurs last.

Replacement overtime last is better than random replacement, however, it is not rather than replacement overtime. Furthermore, replacing cycle N with failure K, we consider replacement overtime first and last in Sect. 2.5. Two overtime policies are proposed in Sect. 2.6, in which the unit is replaced at the first failure over cycle N and at the first working cycle over failure K. Finally, we take up two imperfect preventive maintenance overtime policies in which the preventive maintenance is done at the first completion of working cycles over time T in Sect. 2.7.

Chapter 3 investigates inspection first, inspection last, and inspection overtime when the failure time is exponentially distributed. We take up periodic and random inspections in which the unit is checked at periodic times kT and successive working cycles Y_j, and two polices are compared in Sect. 3.1. Inspection first, inspection last, and inspection overtime are proposed, and are compared to other policies in Sects. 3.2 and 3.3. When the failure time is not exponential, we show how to obtain expected costs of inspection first, last and overtime in Sect. 3.4.

Finally, we consider the backup policies and make similar arguments to inspection policies in Sects. 3.5 and 3.6.

Chapter 4 proposes generalized replacement policies with three variables in which the unit is replaced at time T, at cycle N or at failure K. We take up replacement first, replacement last, and replacement middle in Sect. 4.1, where replacement middle is an entirely new model. Age replacement is the best one among three policies when all of replacement costs are the same. Two kinds of replacement overtime with working cycle and failure number are considered in Sects. 4.2–4.4, and their expected costs are obtained. Finally, replacement first and last with n variables are proposed in Sect. 4.5, in which the unit is replaced at time T or at random times $Y_1, Y_2, \cdots, Y_n$.

New policies such as maintenance first, last, middle, and overtime are formally proposed in this Lecture Note, some of which have been analytically optimized, however, some of them have not been done yet. For example, it is difficult to derive theoretically optimum T^*, N^* and K^* of replacement policies with three variables when replacement costs are different, even if to compute simply them numerically. Such problems would offer new theoretically topics in maintenance theory as further studies.

Most systems fail due to many kinds of causes and factors such as calendar or operating times, running or flight distance, amount of damage or crack, number of uses, works, shocks or faults, and so on. Based on these, we have to form a fitting schedule with several kinds of maintenance measures to avoid the above failures. Furthermore, it should be an important problem to make suitable maintenances for systems due to several kinds of failures, i.e., systems fail according to several failure distributions. By modifying and extending the proposed maintenance policies to fit existing conditions, their applications could be found in actual systems. Finally, extended failure rates appearing in this Lecture Note are summarized in Appendix [5, p. 227].

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May 2015

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http://www.springer.com/978-3-319-20812-1

Maintenance Overtime Policies in Reliability Theory
Models with Random Working Cycles
Nakagawa, T.; Zhao, X.
2015, X, 118 p. 2 illus., Hardcover
ISBN: 978-3-319-20812-1