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Reliability Analysis of k-out-of-n: G System: A Short Review

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***Abstract*— Reliability analysis of k-out-of-n: G system have seen a tremendous growth in the last few decades. This paper presents an overview of the research on reliability studies of *k*-out-of-*n*: G systems. Methods for reliability evaluation, lifetime distributions of failure rate of components and systems with different types of components are presented.**

***Index Terms* — reliability, k-out-of-n: G systems, availability, MTTF**

I. INTRODUCTION

The k-out-of-n system structure is a very popular type of redundancy in fault tolerant systems with wide applications both in industrial and military systems. Fault-tolerant systems include the multi display system in a cockpit, the multiengine system in an airplane and the multi pump system in a hydraulic control system. In a data processing system with five video displays, a minimum of three displays operable may be sufficient for full data display. In this case, the display subsystem behaves as a 3-out-of-5: G system. Systems with spares may also be represented by the k-out-of-n system model. In k-out-of-n systems, system consists of n components, in which k of the n components must be good for the system to operate (k<n). A bridge with n cables, where a minimum of k cables are necessary to support the bridge is an example of k-out-of-n system. In k-out-of-n system, when an operating component fails, a standby component gets replaced automatically. The special case k=n corresponds to the series system while k=1 corresponds to the parallel system. A system of n components works (or is "good") if and only if at least k of the "n" components work (or are "good") is called a k-out-of-n: G system.

The analysis of reliability models have been a subject of interest for the last few decades. Rau [27] in his book has made a fine analysis on the basics of reliability. He derived the reliability of many systems has given the results for reliability of standby systems, (m,n) systems with repair, systems with spares, reliability allocation, repair as renewal process, Markov techniques etc. For a repairable k-out-of-n system, it fails only if the total number of failed components at any instant of time reaches n-k+1. Assume that all of the system's components are working at time zero. Thus, the system is in the up state at time zero. As components fail, repair work is performed on the failed components. If the number of failed components in the failed state reaches the state n-k+1, the system makes a transition from the up state to the down state. When the system is down, repair work continues on the failed components and the system will return to the up state as soon as the number of failed components becomes lower than n-k+1. It is obvious that the behavior of the system constitutes a delayed alternating renewal process. Ramakumar [59] in his book, "Engineering reliability: Fundamentals and Applications" has given the basics of reliability and basic properties used in the analysis of reliability. Lam [42] calculated the rate of occurrence of failures for continuous-time Markov chains with application to a two-component parallel system.

1. Reliability of k-out-of-n system

She and Pecht [65] studied reliability of a k-out-of-n: warm standby system. Joseph and Manoharan [28] had given an explicit solution of a Markovian k-out-of-n system. In that paper the transient probabilities and steady state probabilities are obtained using Markov model formulation and Matrix method. Jinsheng Huang studied a generalized multi-state k-out-of-n:G Systems**.** Huamin Liu [25] had given his discoveries on the reliability of a load sharing k-out-of-n: G system: Non i.i.d. components with arbitrary distributions. Kuo and Zuo [38,39] presented a comprehensive review of research work on repairable k-out-of-n system models with independent and identical components. The optimal design of k-out-of-n:G subsystems subjected to imperfect fault-Coverage have given by Suprasad V. Amari[72]. Xiahu Li et al [78] derived the reliability of a repairable k-out-of-n system with some components being suspended when the system is down. Srinivas R. Chakravarthy [70] had given his research on the influence of delivery times on repairable k-out-of-N systems with spares.

2. Reliability and cost analysis of k-out-of-n system

Cost effectiveness is a measure of the combined effects of system cost and system effectiveness. Some work has been done on the optimal operating policy for a queuing system with linear cost structure. So many authors have solved queuing problems with additional service facility. The queuing system with additional service channel was studied by Philips [54], Murari [47], Bindhi Singh [6] and Arulmozhi [4]. Cost analysis of two unit system is done by Parthasarathy [50]. The cost models applied to reliability have been considered by Goel et al [19]. The cost analysis of a two-unit repairable system subject to online preventive maintenance and/or repair is discussed by Gopalan et al [20]. M/M/R machine repair problem with warm standbys under steady state conditions is studied by Wang [76]. A profit model in order to determine the optimal value of number of spares and the number of repairmen simultaneously have been developed by them. K-out-of-n:G system with cost considerations is studied by Ronold [61]. The economic analysis of (M, N) reliability model with threshold value was analyzed by Arulmozhi [3]. As proposed by this model, if the number of failed lines exceed some number say M where M < (n-k+1), the automated additional sensor comes online and additional service facility is introduced. This will maintain the required minimum lines.

3. Consecutive k-out-of-n system

A consecutive- k-out-of-n: F system (C(k,n:F) system) consists of a sequence of ordered components along a line or a circle such that the system is failed if and only if at least k consecutive components in the system are failed. It has been first introduced by Kontoleon [32]. Antonopoulou et al [2] derived a fast recursive algorithm to evaluate the reliability of a circular consecutive-k-out-of-n: F system. Kuo et al [39] had studied the relation between consecutive-k-out-of-n: G system and consecutive -k-out-of-n: F system and presented in his paper "A consecutive- k-out-of-n: G system: The mirror image of consecutive-k-out-of-n: F system". To improve the availability of the system, Zhang et al [85] introduced the concept of key components and adopted a more reasonable queuing discipline for repair, which assigns a higher priority to key components. They analyzed a repairable circular consecutive-2-out-of-n system with priority in repair. Also, the exact reliability formula for consecutive-k-out-of-n repairable system is derived by Liang et al [79]. However, in all these research works, the authors considered only the system with one repairman. Recently, Yueqin Wu and Jiancheng Guan [83] analyzed repairable linear or circular systems with r repairmen and provided a general formula to calculate M_{-i}, the number of different cases when the system is in state-i. The state –i indicates that the system is working with i failed components in total.

4. k-out-of-n system with fault coverage

In all studies on k-out-of-n systems, the reliability and availability analysis is based on the failure rate and repair rate of the system. But the failure of a component may be covered or uncovered. In practical the failures of the system may not be covered always because of the non availability of repairmen in repair facility. Shakil Akhtar [64] studied reliability of k-out-of-n system with imperfect fault coverage. In his paper both possibilities of a k-out-of-n model with sensor in which all the failure can be repaired and another model in which the failures can lead to an absorbing state in which there is no transmission is possible to a functional state is discussed. Krishnamoorthy et al [33,34,35] studied k-out-of- n:G systems with various repair various repair policies. Hoanpham [24] has presented a handbook on reliability engineering. Optimal design of k-out-of-n: G subsystems subjected to imperfect fault coverage is given by Suprasad Amari [72]. Yamamoto et al [23] given some recursive formulas for the reliability of multi state consecutive-k-out-of-n: G systems. Transient analysis reliability with and without repair for k-out-of-n: G systems with two failure modes is done by Moustafa [45].

5. k-out-of-n system with different types of components

Habib et al [22] presented a newly developed model; consecutive-(r,s)-out-of-(m,n):F lattice system.The reliability of systems with imperfect sensing and switching was studied by so many authors (Prakash [52], Nakagawa and Osaki [48], Keceiogulu and Jian [30], Mustafa [1], Chow [10]. The mean residual life functions of parallel and k-out-of-n:G system with non-identical components is studied by Selma Gurlur [62]. Various systems and their reliability parameters are given explicitly in the book of Srinath [69]. Reliability of some redundant systems with repair is given by Chow [11]. The reliability of incomplete k-out-of-n:G systems is analyzed by Behr [5] and formulas for computing the reliability is given by the author. Kullstam [37] have given availability, MTBF and MTTR of repairable m -out-of-n system. Xiaohu Li et al [78] analyzed the reliability of a repairable k-out-of-n system with some components being suspended when the system is down. Recently, Zhang et al [84] studied the general availability and reliability of k-out-of-(M+N): G warm standby system. In this, the system is composed of two types of components Type-I and Type-II. Components of Type-I have lower failure rate and are preferably repaired. Several repair facilities are considered. Khatab et al [31] have studied the availability of k-out-of-n: G systems with non-identical components subject to repair priorities. In this paper, a k-out-of-n: G system with N categories of components is studied. Each component category is characterized by its own failure and repair rates.

6. Conclusion

In this review article we have discussed k-out-of-n systems with various cases. There are many real time applications for k-out-of-n systems. For example, a four-engine aircraft needs only two engines to perform critical function; the operating and standby engine may fail in different modes with different rates. Communication systems with three transmitters having different types of failures; the average message load may be such that at least two transmitters must be operational at all times otherwise critical message will be lost. Here we have discussed only some works on k-out-of-n systems. These can be further extended for models with unreliable repairman and optimal number of standby machines or repairmen.

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