Survey of Reliability Theories of the Last 50 Years

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Abstract— This paper is dedicated to all the researchers for their contributions in reliability theories and developments, in the past 50 years. The paper provides a summary on the pioneers of reliability theories, and how their works placed a great influence on our reliability analysis today. This is also a survey paper on Reliability theorirs and methods. The information provided in this paper is mostly based on to provide as much a neutral view as possible. Area of interest in the reliability analysis included representation of reliability parameters, renewal theory, coherent structure, diagram-based models, theoretical methods, and other miscellaneous techniques. Diagram based models included block diagrams, Fault Tree Analysis (FTA), Event Tree Analysis, and flow graphs. The contributions of reliability researchers like, Weibull, Epstein and Sobel had made a significant influence on the distribution functions and Lotka, Campbell, Smith, Barlow, and Proschan, had advanced the theories for reliability. In fact this will be the guidelines for the coming generation for further research in the field of their own interest

KEYWORDS: Reliability, Maintainability, renewal theory, coherent, fault tree analysis

INTRODUCTION:

The theories behind reliability analysis have been around as early as 1773 when Pierre-Simon Laplace developed the Laplace Transform. Andrei Andreevich Markov Developed Markov Chains in 1880. However, little attention was paid to reliability research until the late 50s. Late 50s and early 60s were the golden time of reliability. A lot of the theories were established then. The theories include renewal theory, Markovian models, component importance measures, Monte Carlo simulation Bayesian approach, and optimization techniques. The most well known methods currently used in reliability calculation, such as parts-count, block diagram analysis, combinatorial methods, and Mean-Time-Between-Failure (MTBF), are based on these theories. Applications that use the same theories include accelerated life-test, maintenance, and software reliability, network reliability, and system reliability. Similar survey literatures on history of reliability have been published in the past (Refs. 1-4). However, they are tailored for the scientific community and needed to be updated. Before we start, we shall define reliability. According to ISO 8402 (1986, 3.18), reliability is defined as the ability of an item to perform a required function, under given environmental and operational conditions and for a stated period of time. Ushakov (Ref. 1) classified modern reliability theories into 6 groups; “pure” reliability analysis, effectiveness, survivability, safety, security, and software reliability. Most of the theories covered in this paper are defined as pure reliability analysis defined by Ushakov.

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2.0 parameter representation:

Parameters used in reliability theories are used to represent the characteristics of the subject under study such that mean lifetime or number of renewal (N), its variance and confidence interval can be estimated.

2.1 Distribution Functions

Distribution functions are used to represent characteristics of the time that a system is operating or failed. The most influential distribution functions are; Weibull distribution for describing material fatigue failure (Ref. 5), and exponential distribution introduced by Epstein and Sobel for life testing (Ref. 6)

2.2 Failure Rate

In 1961, Watson and Wells found that the number of articles that can work more than a specified time can be increased by giving all articles a suitable "burn-in" period or lifetime (Ref. 21). In 1963, Barlow et al used total positivity to prove the Increasing Failure Rate (IFR) convolution theorem of n independent identically distributed (iid) random variables (Ref. 22). In 1964, Barlow and Marshall published one of the papers on inequalities and bounds for IFR distributions (Ref. 23). In 1965, Barlow and Proschan (Ref. 2) published a book on reliability.

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This book introduced the new concepts of monotone systems, distributions with monotone increasing and decreasing failure rates. In 1972, Ross provided a simplified proof of the Increasing Failure Rate on the Average (IFRA) closure theorem for coherent system (Ref. 24). In 1976, Block and Savits (Ref. 25) provided an elegant proof for
n iid random variables for the problem addressed in Barlow et al 1963.

2.3 **Part Variation**

In 1956, Meltzer used analysis of variance to obtain the expressions for the module reliability in terms of random
Variables to represent the part characteristics (Ref. 26). In 1958, Blanton estimated the possible variations in equipment reliability due to reliability variations in parts by using partial derivatives of the reliability formula and shown that the module reliabilities can cause great change in equipment reliability (Ref. 27). In 1959 and 1960, Dreste expressed the derivation of part tolerance relating to output tolerance (Refs. 28, 29).

2.4 **Confidence Interval**

In 1957, Buehler applied confidence intervals for products of binomial parameters to calculate the reliability of missile (Ref. 13). Later, Steck (1958, Ref. 30), Madansky (1958, Ref. 31) and Rosenblatt (1963, Ref. 32) also did similar studies. In 1966, John and Lieberman determined the confidence bound of reliability for Weibull distribution (Ref. 33). In 1970, Thoman et al estimated the maximum likelihood, confidence interval and tolerance of the reliability for Weibull distribution (Ref. 34). In 1985, Martz and Duran applied Bootstrap method to evaluate the confidence estimation of system reliability based on component test data(Ref.35)

3. **renewal theory**

Renewal theory is used to solve replacement problem. The assumption is that a failed component will be replaced by a new component immediately at the time of failure. In 1939, Lotka applied renewal theory to industrial replacement problem (Ref. 36). In 1941, Campbell applied renewal theory to study the cost effectiveness of replacing at a constant interval replacement and replacing whenever a unit has failed (Ref. 37). In 1941, Feller developed renewal theory as a mathematical discipline (Ref. 38). In 1948

4. **coherent and noncoherent structures:**

Birnbaum, Esary, and Saunders published a paper on coherent structure in 1961 to determine the reliability of coherent systems. The idea is to calculate the probability of system failure due to a given component failure. In 1955, Birnbaum used random variable to represent structural components failure (Ref. 52). In 1961, Birnbaum et al applied vector analysis techniques to study the reliability of multi-component structures in series and parallel configurations (Ref. 53). In 1963, Esary and Proschan obtained the upper and lower bounds of an arbitrary two-pole network with known structure (Ref. 54). These bounds were expressed through complete sets of networks path and cuts. In 1965, Birnbaum and Esary defined and studied the modules of the binary coherent systems (Ref. 55). In 1966, Birnbaum et al defined the IFRA (Increasing Failure Rate on the Average) closure theorem for coherent system (Ref. 56), Boutiques and Kutras determined the generalized bounds for coherent structure (Ref. 64). Inagaki and Henley (1980, Ref. 65) and Jackson (1983, Ref. 66) had studied the important implications in a noncoherent system. In 2003 Andrews and Beeson extended and generalized Birnbaum's component importance measures to include importance measure for noncoherent systems (Ref. 67).

5. **Diagram based models**

Diagram based models provide a visual representation of the system. These models allow engineers and mathematician to have a better understanding of the target system before applying mathematical analyses. Besides block diagrams, FTA, event tree analysis, and state diagram, flow graphs (Refs. 68-70) can also be used for reliability analysis.

5.1 **Block Diagrams**

In 1954, Kleinerman used "reliability block diagram" to show the reliability interrelations and proposed its mathematical representation (Ref. 71). In 1957, Blanton used engineering block diagram with additional symbols to represent power supplies and similar units and proposed its mathematical representation (Ref. 72).

5.2 **Fault Tree Analysis (FTA)**

There are a lot of studies had been performed on FTA (Refs. 72-88). In the 1960s, Fault Tree Analysis (FTA) was
born as the result of a study on the possibility of an accident that can occur on a Minuteman missile. Watson participated in the analysis project (Ref. 73). FTA is one of the most commonly used techniques in risk assessment. In 1960, Holtzman and Marshall used block labeling such as representing serial blocks with "and if" and parallel blocks with "or"

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(Ref. 74). In 1980, Rosenthal used a divide and conquer approach to reduce the cost of analysis for FTA (Ref. 76). In 1992, Dugan et al started developing a dynamic FTA methodology called DITree (Refs. 77). Dugan et al and Gulati continued the research as described in Ref. 78 and Ref. 79. In 1993, Coudert and Madre used Binary Decision Diagrams (BDD) to solve large fault trees with 2^10 basic events (Ref. 80).

5.3 **Event Tree Analysis**

In 1998, Papazoglou developed a mathematical representation for event trees building on basic concepts of set
theory and probability theory (Ref. 89). In 2000, Andrews and Dennett pointed out that not logic is essential for proper event tree analysis on systems (Ref. 90, 91).

5.4 **State Diagrams**

State diagram is a very popular representation for queuing theory. In 1945, Kolmogorov used binary states to analyze the probability of plane destruction by anti-aircraft fire (Ref. 92).In 1954; Frantic uses three states to represent components state (Ref. 93). In 1959, Takács used two states to represent the states of a system (Ref. 94). In 1959, Barlow and Hunter applied the concept of on-off model to represent the state of the unit in operating or failed state (Ref. 47). Nowadays, Markov model with two states, operating and failed states, is being widely used in reliability analysis. In 1979, Elsayed and Zebib analyzed multistate devices (Ref. 95).

6. **theoretical methods**

A lot of the theoretical methods used in other fields are also applicable for reliability analysis. Some of the most
popular methods include Queuing theory, asymptotic analysis, Boolean algebra, Bayesian approach, Monte Carlo Simulation and optimization. Others include genetic algorithm (Ref. 63) and modular decomposition (Ref. 96).

6.1 **Queuing Theory**

In 1959, Barlow and Hunter said in Ref. 47, "If the future probability states of equipment depend only on the immediate past history, then the process is Markovian." and applied Markov model to study system reliability. In 1960, Bharucha-Reid (Refs. 97), Keilson and Kooharian (Ref. 98) used queuing theory to study system availability and maintainability, as well as Bosinoff et al in 1961 (Ref. 72). Also in 1961, Brender and Tainiter indicated that Markovian techniques can be used to catastrophic failure (Ref. 99). In 1964, Pogozhev used Poisson process to study the failure (Ref. 100). In 1965, Gnedenko et al (Ref. 51) applied queuing theory ideas to reliability problems, especially for solving maintenance and replacement problems. In 1970, Solov'yev applied queuing theory to study the reliability of systems with small renewal time (Ref. 101, 102). In 1993, Dugan et al used Markov models to study reliability for fault tolerant systems (Ref. 78). In 1999, Ouhbi and Limnios used semi-Markov to study system availability and reliability (Refs. 103, 104). In 2003, Fricks and Trivedi introduced Markov reward model (MRM) for computing component importance measure (Ref. 105). In the same year, Lefebvre used (Nonhomogeneous Poisson Process) NHPP model to represent the aging effect on failure rate (Ref. 106).

6.2 **Asymptotic Analysis**

In 1954, Smith discovered the asymptotic property of N and its variance (Ref. 43). In 1956, Moore and Shannon
published a paper that performed asymptotic analysis on relay network reliability (Ref. 107). In 1959, Takacs determined the asymptotic distribution of a two-state process (Ref. 94). In 1964, Gnedenko use asymptotic methods to analysis highly available systems (Refs. 108, 109). In 1964, Pogozhev generalized one of the two key asymptotic theorems (Ref. 100).

6.3 **Boolean Algebra**

In 1952, Gates used Boolean algebra to determine the reliability of redundant systems (Ref. 110). In 1954, Frantik
applied Boolean algebra to study components with three distinct states (Ref. 93). In 1959, Mine used Boolean functions to represent complex systems (Ref. 111).

6.4 **Bayesian Approach**

In 1961, books by Mosteller et al and Bazovsky proposed to use Baye's theorem to reliability (Ref. 112, 113). In 1982, Martz and Waller published a book on reliability analysis using Bayesian approach (Ref. 114), and more papers later (Refs. 115, 116). In 1994, Hulting and Robinson used the Bayesian approach to study a repairable series system (Ref. 117). In 1998, Kerscher III et al (Ref. 118) developed a new methodology using Bayesian updates to characterize the reliability of new products under development.

6.5 **Monte Carlo Simulation**

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In most cases, an exact analytical solution is not feasible because of the difficulty in the equation solving. Monte Carlo simulation is a popular alternative to solve these problems. In 1958, Firstman published a paper using Monte Carlo models to estimate reliability (Ref. 119). In 1962, Blanton (Ref. 4) provided a summary techniques being used to predict reliability, including Monte Carlo simulation. In 1967, Belyaev obtained some results on confidence estimation using Monte Carlo simulations (Ref. 120).

6.6 **Optimization**

In 1956, Markowitz and McLean published the first paper on optimal redundancy (Ref. 121). In 1957, Gordon studied optimum component redundancy (Ref. 122). In 1958, Bellman and Dreyfus applied dynamic algorithm in finding optimal redundancy (Ref. 123). In 1959, Black and Proschan determined optimal reliability using total positive techniques (Ref. 124). In 1962, Kettelle proposed an effective practical modification of dynamic programming algorithm for finding optimal problem (Ref. 125). In 1963, Barlow et al determined the optimal redundancy for components with two possible kinds of failure (Ref. 126). In 1965, Barlow and Proschan's book (Ref. 2) gave a deep presentation of optimal maintenance and optimal redundancy problems. In 1965, Proschan andBray further developed the optimization methods for reliability under multiple constraints (Ref. 127). In 1980,Tillman et al published a book on optimizing system reliability with further development on optimization methods (Ref. 128).

7. **MISCELLANEOUS**:

This section contains techniques, theories or methods that do not belong to the above sections. In 1957, Portz and Smith calculated the reliability as a product of the design reliability times the component reliability times the reliability of fabrication (Ref. 129). In 1957, Lipp derived mathematical representation for complex multi-element series-parallel networks (Ref. 130). In 1958, Flehinger proposed to improve reliability by adding redundancy at different level of the system (Ref. 131). In 1959, Philipson demonstrated that the overall reliability figure may be obtained from a combination of the reliabilities for the separate intervals (Ref. 132). In 1960, Kaufmanns (Ref. 133) described three prediction techniques included using a computation of a "K" factor for each device. In 2000, Cramer and Kamps (Ref. 134) studied the mathematical presentation of the life-time of sequential kout- of-n systems. In 2002, Tsitmidelis et al used genetic algorithm to find reliability bounds (Ref. 63). In 2003, Kerscher III et al applied Fuzzy logic in PREDICT (Performance and reliability Evaluation with Diverse Information Combination and Tracking) (Ref. 135). In 2003, Marseguerra et al used neural network to predict reliability (Ref. 136).

8. **CONCLUSION**:

In this paper, It is tried to cover as much as possible different reliability related papers and particularly in the context of reliability policies. However, those papers which are not included were either considered not to bear directly on the topic of this survey or were inadvertently overlooked. The apology to both the researchers and readers if any relevant papers have been omitted are manifested. The paper will definitely help the people to have a basic knowledge about the reliability and which theory will be appropriate to their organization and in what circumstances to improve the reliability. The theories will be applicable to maintenance data analysis, operational parameter analysis, and Design analysis and will help the post researcher to develop more innovative theories of the future generation. In fact this paper is a ready reference to the reliability theories and application and researchers. The "reliability in further areas of application to determine the effectiveness" are the future scope of research

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References

I. Ushakov.I, "Reliability: past, present, future," Recent Advances in Reliability Theory: Methodology, Practice, and Interface, 2000; Birkhäuser, Boston, pp. 3-14.

2.R. Barlow and F. Proschan, Mathematical Theory of Reliability, 1965; Wiley, New York.pp 1-265

3. Barlow R., "Mathematical reliability theory from the beginning to the present time," Proceeding . International . Conference on mathematical methods in Reliability 2002.

4 Bantonl.H.E., Jacobs R.M., "A survey of techniques for analysis and prediction of equipment and reliability", IEEE Transaction on Reliability, July 1962, pp.18-35.

5. Weibull W., "A statistical theory of the strength of materials", Ink. VetenskapsAkad. Handl., no. 151, 1939,pp.293-297.

6. Epstein B., Sobel B. M., "Life testing", J. Amer. Stat. Assoc., vol. 48, no. 263, 1953, pp. 486-502.
7. Daniels H.E., "The statistical theory of the strength of bundles of threads", Proc. Roy. Soc. London, vol. 183, 1945, pp. 405-435.
8. Epstein B., "Application of the theory of extreme values in fracture problems", J. Amer. Stat. Assoc., vol43,1948, pp. 403-412.
9. Weibul W. l, "A statistical distribution function of wide applicability", J. Applied Mech., vol. 18, 1951, pp. 293-297.
10. Davis D.J., "An analysis of some failure data", J. Amer. Stat. Assoc., vol. 47, 1952, pp. 113-150.
11. Kao J.H.K., "A new life-quality measure for electron tube", IRE Trans. Rel. and Quality Ctrl., PGRQC- 7, 1956, pp. 1-11.
12. Kao J.H.K. Kao, "Computer methods for estimating Weibull parameters in reliability studies", IRE Trans. Rel. and Quality Ctrl., PGRQC-13, 1958, pp. 15-22.
13. Buehler R.J., "Confidence intervals for the product of two binomial parameters", Journal of. American , Statistical . Association., vol. 52, 1957, pp. 482-493.
14. Birnbaum Z.W., Saunders S.C., "A statistical model for life-length of materials", Journal of. American. Statistical . Association, vol. 53, no. 281, 1958, pp. 151-160
15. Herd G.R., "Some statistical concepts and techniques for reliability analysis and prediction", Proc. Natl. Symp. Rel. and Quality Ctrl., Jan 1959, pp. 126-136.
16. Tate R.F., "Unbiased estimation: Functions of location and scale parameters", Ann. Math. Stat., vol. 30, no.2, 1959, pp. 341-366.
17. Cox D.R., "On the number of Renewals in a Random Interval," Biometrika, vol. 47, issue 3/4, Dec. 1960, pp. 449- 452.
18. Zelen M. M.C. Dannemiller, "The robustness of life testing procedures derived from the exponential distribution", Techno metrics, vol. 3, no. 1, 1961, pp. 29-49.
19. Nylander J.E., "Statistical distributions in reliability", IRE Trans. Rel. and Quality Ctrl., RQC-11, July 1962, pp. 43- 53.
20. Shortle J.F., M.B., "Physical foundations for lifetime distributions", Proc. System and Bayesian Rel.2001,pp. 257-266.
21. . Watson G.S and Wells W.T., "On the possibility of improving the mean useful life of items by eliminating those with short lives", Technometrics, vol. 3, 1961, pp. 281-198.
22. Barlow R.E., Marshall A.W. Proschan, F., "Properties of probability distributions with monotone hazard rate", Ann. Math. Stat., vol. 34, 1963, pp.375-389.
23. Barlow R.E., Marshall A.W., "Bounds for distributions with monotone hazard rate, I and II", Ann. Math.Stat., vol. 35, 1964, pp. 1234-1274.
24. Ross S.M., Introduction to Probability Models with Optimization Applications, 1972; Academic Press, New York.
25. Block H. Savits, T.H., "The IRFA closure problem", Ann. Prob,vol 4, 1976, pp. 1030-1032.
26. Meltzer S.A., "Designing for reliability", IRE Trans Rel. and Quality Ctrl., PGRQC-8, Sept 1956, pp. 36-43.
27. Blanton H.E., "Reliability-sensitivity- function analysis", Electronic Design, vol. 6, Feb 1958.
28. Dreste F.E., "Statistics: Key to reliable military electronic design", Military Electronics, vol. 6, Mar. 1959, pp.4, 6, 8.

29. Dreste F.E., "Circuit design concepts for high reliability", Proc. Natl. Symp. Rel. and Quality Ctrl., Jan 1960,pp. 121-133.
30. Steck G.P., "Upper confidence limits for the failure probability of complex networks", Sandia Corporation Research Report, SC-4133(TR), 1958.
31. Madansky, A. "Uses of tolerance limits in missile evaluation", Proc. Stat. Techniques in Missile Evaluation Symp., Aug 1958.
32. Rosenblatt, J.R. "Confidence limits for the reliability of complex systems", Statistical . Theory of Reliability, University of Wisconsin Press, Madison, Wisconsin, 1963, pp. 115-148.
33. Johns M.V, Lieberman G.J, "An exact asymptotically efficient confidence bound for reliability in the case of the Weibull Distribution", Techno metrics, vol. 8, 1966, pp. 135-175.
34. Thoman D.R., Bain L.J., Antle C.E., "Maximum Likelihood Estimation, Exact Confidence Intervals forReliability, and Tolerance Limits in the Weibull Distribution", Techno metrics, vol. 12, 1970, pp. 363-371.
35. Martz H.F., Duran B.S., "Comparison of three methods for calculating lower confidence limits on system reliability using component data", IEEE Transaction on Reliability. Rel., vol. R- 34, no. 2, 1985.
36. Lotka A.J, "A contribution to the theory of self renewing aggregates with special reference to industrial replacement", Ann. Math. Stat., vol. 10, 1939, pp. 1-25.
37. N.R. Campbell, "The replacement of perishable members of a continually operating system", J. Roy. Stat. Society.,vol. 7, 1941, pp. 110-130.
38. Feller W., "On the integral equation of renewal theory", Ann. Math. Stat., vol. 12, 1941, pp. 243-267.
39. Blackwell D, "A renewal theorem", Duke Math. J., vol. 15, 1948, pp. 145-150.
40. Doob J.L., "Renewal theory from the point of view of the theory of probability", Trans. Amer. Math. Soc.,vol 63, 1948, pp. 422-438.
41. Feller W., "Fluctuation theory of recurrent events", Trans. Amer. Math. Soc., vol. 67, 1949, pp. 98-119.

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42. Cox D.R., Smith W.L., "A direct proof of a fundamental theorem of renewal theory", Skand. Aktuar., 36,1953, pp. 139-150.
43. Smith W.L., "Asymptotic renewal theorems", Proc. Roy. Soc. Edin., A, 64, 1954, pp. 9-48.
44. Feller W., Introduction to Probability Theory and its Applications, 2nd ed., 1957; Wiley, New York.
45. Smith W.L, "Renewal theory and its ramifications", J. Roy. Stat. Soc., Ser. B, vol. 20, no. 2, 1958, pp. 243-302.
46. Smith, W.L. "On the cumulants of renewal processes," Biometrika, vol. 46, issue 1/2, June 1959, pp. 1-29.
47. Barlow R.E., Hunter L.C., "Mathematical models for system reliability", Sylvanica Electronic Defense Labs., Rept. No. EDL-E35, Aug 1959.
48. Barlow R.E., Hunter L.C., "Mathematical models for system reliability, part II", The Sylvania Technologist, vol. 13, 1960,pp. 55-65.
49. Cox D.R., Renewal Theory, 1962; Wiley, New York.
50 Watson. G.S. and Leadbetter M.R., "Hazard Analysis. I," Biometrika, vol. 51, June 1964, pp. 175-184.
51. Gnedenko B.V, Belyaev Y.K., Solovyev A.D., Math. Methods in Reliability Theory, 1969; Academic Press, New York. (
52. Birnbaum Z.W., "On a use of the Mann-Whitney Statistic", Proc. Berkeley Symp. Math. Stat. and Prob., University of California Press, Los Angeles, vol. 1, 1955, pp. 13-17.
53. Birnbaum Z.W., Esary J.D., Saunders S.C., "Multicomponent systems and structures and their reliability", Technometrics, vol. 3, Feb 1961, pp. 55-77.
54. Esary J.D., Proschan F., "Coherent structure of nonidentical components", Technometrics, no. 5, 1963, pp. 191-209.
55. Birnbaum Z.W., Esary J.D., "Modules of coherent binary systems", J. SIAM, vol. 13, 1965, pp. 444-462.
56. Z.W. Birnbaum, J.D. Esary, A.W. Marshall, "Stochastic characterization of wear out for components and systems", Ann. Math. Stat., 37, 1966, pp. 816-825.
57. Birnbaum Z.W., "On the importance of different components in multicomponent system," Multivariate Analysis, II, 1969; Academic Press, New York, pp.581-592.
58. Satyanarayana, A Prabhakar. A., "New topological formula and rapid algorithm for reliability analysis of complex networks", IEEE Trans. Rel., R-27, 1978, pp. 82-100.
59. Satyanarayana A., Chang M.K., "Network reliability and the factoring theorem", Networks, 13, 1983, pp. 107-120.
60. Bendell A., Ansell J., "The incoherency of multistate coherent system", Rel. Eng., vol. 8, 1984, pp. 165-178.
61. . Huseby A.B, "Domination Theory and the crapo beta-invariant", Networks, 19, 1989, pp. 135-149.

62. Fu J.C., Koutras M.V., "Reliability bounds for coherent structures with independent components", Stat. and Prob. Letters, vol. 22, 1995, pp.137-148.

63. Tsitmidelis S., Koutras, M. Zissimopoulos V. V., "Evaluation of reliability bounds by genetic algorithm", Proc.Math.Methods in Rel., 2002.
64. Boutsikas M.V, Koutras M.V, "Generalized reliability bounds for coherent structures", J. of Applied Prob.vol. 37, 2000, pp. 778-794.
65. Inagaki T., Henley E.J., "Probabilistic evaluations of prime implicants and top events for noncoherent systems",IEEE Trans. On Rel., vol. R-29, no. 5, Dec. 1980, pp. 361-367.
66. Jackson P.S., "On the s-importance of elements and prime implicants of noncoherent systems", IEEE Trans. Reliability., vol. R-32, no. 1, Apr. 1983,pp. 21-25.
67. Andrews J.D., Beeson, S. "Birnbaum's measure of component importance for noncoherent systems", IEEE Transaction on Reliability, vol. 52, no. 2, June 2003, pp. 213-219.
68. Oltorik T.F., "Reliability analysis using flowgraphs", Air Force Institute of Technology, USGRR Document, no. AD 420-047, Aug 1963.
69. Haap W.W., "Application of flowgraph techniques to the solution of reliability problems", J. Physics of failure in Electronics, US Department 0f Commerce Office of Technical Services AD-434/329, 1964, pp. 375-423.
70. E. Dolozza, "System states analysis and flowgraph diagrams in reliability", IEEE Trans on . Reliability., R-15, 1966, pp.383-394.
71. Kleinerman M.M. Weiss, G.H., "On the reliability of networks", Proc. Natl. Electronics Conf., vol. 10, 1954, pp.128-136.
72. Blanton E., "Reliability-Prediction technique for use in design of complex systems", IRE Natl. Convention Record, pt. 10, 1957, pp. 68-79.
73. http://www.newhousenews.com/archive/macpherson0 21103.html retrieved on 10 th May 2010
74 Holtzman. C.W., Jr., Marshall W.E., "A new method of communication between engineering and mathematician aids system reliability prediction", Proc. Natl. Symp. Rel. and Quality Ctrl., Jan 1960, pp. 403-408.
75. Chatterjee P., "Modularization of fault trees: A method to reduce cost of analysis", SIAM Rel. and Fault Tree Analysis, 1975, pp. 101-137.
76. Rosenthal A., "Decomposition methods for fault tree analysis", IEEE Trans. Rel., vol. 43, June 1980, pp. 136-138.
77. Dugan J.B., Bavuso S.J., Boyd, M.A. " Dynamic fault tree models for fault tolerant computer

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systems", IEEE Trans. Rel., vol. 41, no. 3, Sept 1992, pp. 363-377.
78. Dugan J.B., Bavuso S.J., Boyd, M. "Fault trees and Markov models for reliability analysis of fault tolerant systems", Rel. Eng. and System Safety, vol. 39, 1993, pp. 291- 301.
79. Gulati R., Dugan J.B., "A modular approach for analyzing static and dynamic fault trees", Proc. RAMS, 1997.
80. Coudert O., Madre J.C., "Fault tree analysis: 10^20 prime implicants and beyond", Proc. RAMS, 1993, pp. 240-245.
81. Doyle S.A., Dugan J.B., "Dependability assessment using binary decision diagrams", Proc. IEEE Int. Symp. Fault- Tolerant Computing, TCS-25, June 1995.
82. Dutuit Y., Rauzy A., "A linear-time algorithm to find modules in fault trees", IEEE Trans. Rel., Sept. 1996.
83. Martz H.F., Almond R.G., "Using higher-level failure data in fault tree quantification", Rel. Eng. and System Society, 1997, pp. 29-42.
84 Anand. A., Somani A.K., "Hierarchical analysis of fault trees with dependencies, using decomposition", Proc.RAMS, Jan 1998, pp. 69-75.
85. Manian R,. Coppit D., Sullivan K.J., Dugan J.B., "Bridging the gap between systems and dynamic fault tree models", Proc. RAMS, Jan 1999, pp. 105-111.
86. Griffin C.W., "Introducing the fault tree as a tool for nuclear safety analysis", Trans. Amer. Nuclear Soc., vol. 9, no. 1, 1966, pp. 157.87. Andrews J.D., "The use of Not logic in fault tree analysis", Qual. Rel. Eng., vol. 17, 2001, pp. 143-150.
88. Tsitmidelis S.V., Zissimopoulos, S.V. Koutras M.V.,"Fault tree analysis via set cover model", EUROGEN 2001,Athens, Greece.
89. Papazoglou I.A., "Mathematical foundations of event trees", Rel. Eng. and System Safety, vol. 61, 1998, pp. 169-183
90. Andrews J.D., Dunnett S., "Improving accuracy in event tree analysis", Proc. Foresight and Precaution, Proc. ESREL 2000, SARS and SRA-Europe Annual Conf., May 2000.

91. Andrews J.D., . Dunnett S, "Event tree analysis using binary decision diagrams", IEEE Trans. Rel., vol. R-49, no.2, June 2000, pp. 230-239.
92. Kolmogorov A.N., "A number of target hits by several shots and general principles of effectiveness of gunfire", Proc. Moscow Inst. Math., issues 12, 1945.
93. Frantik R.O., "The determination application and limitations of circuit reliability equations", Sandia Corp.report no. SC-3288(TR), April1954.
94 Takács,. L. “On a sojourn time problem in the theory of stochastic processes,” Trans. Amer. Math. Soc., vol. 93, issue 3, Dec. 1959
.95 Elsayed. E.A., Zebib A., "A repairable multistate device", IEEE Trans. Rel., R-28, 1979, p. 81-82.
96. Bodin L.D., "Approximation of system reliability using a modular decomposition", Technometrics, vol. 12, no.
2, 1970, pp. 335-344.
97. Bharucha-A.T. Reid, Elements of the Theory of Markov Processes and their Applications, 1960; McGraw-Hill, New York.
98. Keilson J., Kooharian A., "On time dependent queuing processes", Ann. Math. Stat., vol. 31, 1960.
99. Brender D.M., Tainiter, M. "A Markovian model for predicting the reliability of an electronic circuit from data on component drift and failure", IRE Intl. Convention Record, 1961, pt. 6, pp. 230-241.
100. Pogozhev I.B., "Estimation of deviation of failure flow in multi-use equipment from Poisson process"Cybernetics in Service forC ommunism, vol. 2, Energiya, Moscow, 1964.
101. Solov'yev A.D., "Reliability and queueing theory: standby with rapid renewal," Eng. Cybernetics, no.1, 1970, pp. 49-64.
102. Solov'vey A.D., "Redundancy with fast repair", Eng. Cybernetics, no. 1, 1970.
103. Ouhbi, B. Limnios, N. "Estimation of kernel, availability and reliability of semi-Markov systems", Proc.Stat. and Prob. Methods in Rel1999.
104 Ouhbi. B., Limnios, N. "Non-parametric estimation for semi-Markov processes based on its hazard rate", Stat. Inf. Stoc. Proc., vol. 2, 1999, pp. 151-173.
105. Fricks R.M., Trivedi K.S., "Importance analysis with Markov Chains", Proc. Rel. and Main. Symp., 2003, pp. 89- 95.
106. Lefebvre Y., "Using equivalent failure rates to assess the unavailability of an ageing system", Proc. Rel. and Main. Symp., 2003, pp. 82-88.
107. Moore E.F., Shannon C.E., "Reliable circuits using less reliable relays", J. of the Franklin Institute, vol. 262,
1956, Pt. I, pp. 191-208, and Pt II, pp. 281-297.
108. Gnedenko B.V., "On spare duplication", Eng. Cybernetics, no. 4, 1964.
109. Gnedenko B.V. , "On duplication with renewal", Eng. Cybernetics, no. 5, 1964.
110. Gates C.R., "The reliability of redundant systems", JPL-California Inst. Of Tech. Pasadena, CA, Memo 20-76,Aug 1952.
111. Mine H., "Reliability of physical system", IRE Trans. Information Theory, IT-S 959,pp. 138-150.
112 Mosteller. F., Rourke R.E., Thomas, G.B. Jr., Probability with statistical applications, 1961; Addison-Wesley, Reading.
113. Bazovsky I.I., Relability Theory and Practice, 1961; Prentice Hall, Englewood Cliffs.
114. Martz H.F., Waller R.A., Bayesian Reliability Analysis, 1982; Wiley, New York.
115. Martz H.F., Waller R.A., Fickas E.T., "Bayesian reliability analysis of series systems of

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binomial subsystems and componen ts", Technometrics, vol. 30, 1988, pp. 143-154.
116. Martz H.F., Waller R.A., "Bayesian reliability analysis of complex series/parallel systems of binomial subsystems and components", Technometrics, vol. 32, 1990, pp. 407-416.
117. Hulting F.L., Robinson J.A., "The reliability of a series system of repairable subsystems: a Bayesian approach",Naval Research Logistics, vol. 41, 1994, pp. 483-506.
118 Kerscher. W.J. III, Booker J.M., Bement T.R., Meyer, M.A. "Characterizing reliability in a product/process design assurance program",Proc. RAMS, 1998, pp. 105-112.
119. Firstman S.L., "Monte Carlo models for estimating reliability: An exploratory analysis", The Rand Corp., Report no. RM2149, ASTIA Doc. No. AD213036, June 1958.
120. Belyaev Y.K., Dugina T.N., Chepurin E.V., "Computation of lower confidence limit for the complex system reliability", Eng. Cybernetics, no's 2 & 3, 1967.
121. Moskowitz F. Mc lean J. "Some reliability aspects of system design", Trans. Rel. and Quality Ctrl., vol. 8, 1956, pp. 7-35.
122. Gordon R., "Optimum component redundancy for maximum system reliability", Operations Res., vol. 5, 1957, pp. 229-243.
123. Bellman R. and Dreyfus S., "Dynamic programming and reliability of multi-component devices", Operations Res., vol. 6, 1958, pp. 200-06.
124. Black G., Proschan, F. "On optimal redundancy", Operations Res., vol. 7, no. 5, 1959, pp. 581-588.
125. Kettelle J.D., "Least-cost allocation of reliability investment", Operations Res., vol. 10, no. 2, 1962.
126. Barlow R.E. Hunter L. C.Proschan F., "Optimum redundancy when components are subject to two kinds of failure", J. SIAM, vol. 11, 1963, pp.64-73.
127. Proschan F., Bray T., "Optimum redundancy under multiple constraints", Operations Res., vol. 13, no. 5, 1965.
128. Tillman F.A., Ching-Lai H., Kuo W., Optimization of System Reliability, 1980; Marcel Dekker, New York.
129. Portz. K.E. and Smith H.R.,"Methods for the determination of reliability", IRE Trans. Rel. and Quality Ctrl., vol. 11, Aug 1957, pp. 65-73.
130. Lipp J.P., "Topology of switching elements vs. reliability", IRE Trans. Rel. and Quality Ctrl., vol. 10, June 1957, pp. 21-33.
131. Flehinger B.J., "Reliability improvement through redundancy at various system levels", IBM J. of RnD, issue 2,1958, pp. 148-158.
132. Philipson J.L., "Operational reliability model for a reconnaissance system", IRE. Convention Record, pt. 6,1959, pp. 79-88.
133. Kaufmann M.I., Kaufmann R.A., "Predicting reliability", Machine Design, Aug 1960, pp. 178-184.
134. Cramer E.and Kamps U, "Sequential k-out-of-n systems", http://www.math.uni-oldenburg.de/preprints/get/source/Hb.pdf, Feb 2000.
135 Kerscher III. W.J.,Booker J.M.,Meyer M.A.,Smith R.E. et al, "PREDICT: A case study, using fuzzy logic", Proc.RAMS, 2003, pp. 188-195.
136. Marseguerra M. zio M, "Predicting reliability via neural networks", Proc. RAMS,2003, Tampa, Florida, pp.196-201.
137.Abdel-Hameed, M, 1987a. An imperfect maintenance model with block replacements. Applied Stochastic Models and Data Analysis 3, 63–72 .
138.Abdel-Hameed, M., 1987b. Inspection and maintenance policies of devices subject to deterioration. Advances in applied Probability 10, 917–931.
139. Abdel-Hameed, M., 1995. Correction to: ‘‘Inspection and maintenance policies of devices subject to deterioration ’’.Advances in Applied Probability 27 (2), 584.
140. Archibald, T.W., Dekker, R., 1996. Modified block-replacement for multiple-component systems. IEEE Transactions on Reliability 45 (1), 75–83.
141.Asher, H., Feingold, H., 1984. Repairable Systems Reliability. Marcel Dekker, New York.
142. Assaf, D., Shanthikumar, J.G., 1987. Optimal group maintenance policies with continuous and periodic inspections. Management Science 33, 1440–1450.
143. Aven, T., 1983. Optimal replacement under a minimal repair strategy – a general failure model. Advances in Applied probability 15 (198–211).
144.Aven, T., Jensen, U., 1999. Stochastic Models in Reliability,Applications of Mathematics, vol. 41, Springer, New York.
145.Balaban, H.S., Singpurwalla, N.D., 1984. Stochastic properties of a sequence of interfailure times under minimal repair and under revival. :
146. -Hameed Abdel, Cinlar M., , Quinn E., , J. (Eds.), Reliability Theory and Models. Academic Press, Orlando, FL, pp. 65–80.
147.Barlow, R.E., Hunter, L.C., 1960. Optimum preventive maintenance policies. Operations Research 8, 90–100.
148.Barlow, R.E., Proshan, F., 1965. Mathematical Theory of Reliability. Wiley, New York.
149.Barlow, R.E., Proshan, F., 1975. Statistical Theory of Reliability and Life Testing. Holt, Rinehart & Winston, New York.

150.Beichelt, F., 1976. A general preventive maintenance policy. Mathematische Operationsforschung und Statistik Series,Statistics 7, 927–932.

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151. Beichelt, F., 1978. A new approach to repair limit replacement policies. In: Transactions of the Eighth Prague Conference on Information Theory, Statistical Decision Functions,Random Processes, vol. C, Prague, pp. 31–37.

152. Beichelt, F., 1981a. A generalized block-replacement policy. IEEE Transactions on Reliability R 30 (2), 171–173.

153.Beichelt, F., 1981b. Replacement policies based on system age and maintenance cost limits. Mathematische Operationsforschung und Statistik Series, Statistics 12 (4), 621–627.

154. Beichelt, F., 1982. A replacement policy based on limits for the repair cost rate. IEEE Transactions on Reliability R 31 (4), 401–402.

155.Beichelt, F., Fischer, K., 1980. General failure model applied to preventive maintenance policies. IEEE Transactions on Reliability R 29(1), 39–41.

156.Berg, M., 1976. A proof of optimality for age replacement policies. Journal of Applied Probability 13, 751–759.

157.Berg, M., 1976. Optimal replacement policies for two-unit machines with increasing running costs – I. Stochastic Processes and Applications 5, 89–106.

158.Berg, M., 1978. General trigger-off replacement procedures for two-unit systems. Naval Research Logistics 25 (March), 15–29.

159.Berg, M., Epstein, B., 1976. A modified block replacement policy. Naval Research Logistics 23, 15–24.

160.Berg, M., Epstein, B., 1978. Comparison of age, block, and failure replacement. IEEE Transactions on Reliability R 27(1), 25–29.

161.Bergman, B., 1978. Optimal replacement under a general failure model. Advances in Applied Probability 10 (2), 431–451.

162. Block, H.W., Borges, W.S., Savits, T.H., 1985. Age dependent minimal repair. Journal of Applied Probability 22,370–385.

163.Block, H.W., Borges, W.S., Savits, T.H., 1988. A general age replacement model with minimal repair. Naval Research Logistics 35 (5), 365–372.

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