

## PROBLEMS

1. An equipment obeying exponential law of reliability has 97 percent probability of survival in first 100 hours of operation. What is the probability of its survival in:
  - (a) First 200 hours operation?
  - (b) Post 100 hours of operation provided it has survived for the 900 hours of the 1000 hours of useful life?
2. An engine shaft has a failure rate of  $0.5 \times 10^{-7}$ /hr. The shield used with the shaft has a failure rate of  $2.5 \times 10^{-7}$  /hr. If a given company has 5000 engines with these shafts and shields and each engine operates for 350 days of useful life. Estimate the number of shafts and shields that must be replaced annually.
3. The reliability  $R(t)$  of an item is assumed to be exponentially decreasing function :  
$$R(t) = \exp (-t/10^{-4} \text{ days})$$

What is the probability that the item will still be functioning without failure at  $t = 300$  days, given that the unit functioned without failure at  $t = 100$  days ?
4. It is required to produce a device having a reliability of at least 95 % over a period of 500 hr. Estimate the maximum permissible failure rate and minimum MTBF.
5. A home computer manufacturer determines that his machine has a

constant failure rate of  $\lambda = 0.4/\text{year}$  in normal use. For how long should the warranty be set if no more than 5% of the computers are to be returned to the manufacturer for repair?

6. A device has a constant failure rate of 0.7/ year.
- What is the probability that the device will fail during the second year of operation?
  - If upon failure the device is immediately replaced, what is the probability that there will be more than one failure in 3 years of operation?
7. Somebody wants to take a 1000 km trip by car. The car has a constant failure rate of  $\lambda = 10^{-4}$  per kilometer travelled. What is the probability that the destination is reached without the car breaking down?
8. The weather radar system of an airliner has an MTTF of 1140 hours. Assuming that the failure rate is constant, solve the following problems:
- What is the probability of failure during a 4-hour flight?
  - What is the maximum duration of a flight such that the reliability may not drop below 0.99?
9. The failure rate for a certain type of component is  $\lambda(t) = \lambda_0 t$  where  $\lambda_0 \gg 0$  and is constant. Find its reliability, mortality and MTBF.
10. Two types of components with identical electrical characteristics have different failure rates. The failure rate of component A is 1%/1000 hrs. and that of B is  $10^{-6}t$ , where  $t$  is in hours. Which component is more reliable for an operating time of (i) 100 hrs (ii) 100 mts ?
11. An engineer approximates the reliability of a cutting assembly by
- $$R(t) = \begin{cases} (1-t/t_0)^2 & , 0 \leq t < t_0 \\ 0 & , t \geq t_0 \end{cases}$$
- Determine the failure rate.
  - Does the failure rate increase or decrease with time?
  - Determine the MTTF.
12. Define failure rate and express it in terms of reliability. The reliability expression for a system is given as:

$$R(t) = \exp[-(a + bt)t]$$

Determine the expression for  $\lambda(t)$ .

13. The PDF for the time to failure of an appliance is

$$f(t) = \frac{32}{(t + 4)^3}, \quad t > 0,$$

where  $t$  is in years.

- (a) Find the reliability  $R(t)$ ,
  - (b) Find the failure rate  $\lambda(t)$ ,
  - (c) Find the MTTF.
14. A sample of 150 electronic components is subjected to testing (presumably in useful life). Three failures are found at the end of 400 hours, four more at the end of 800 hours, two more at the end of 1200 hours, four more at the end of 1800 hours and no further failures are found when the test is terminated at 2500 hours.
- (a) Estimate the MTBF if failed components are replaced when found.
  - (b) Estimate MTBF if no replacements are made.
15. For the reliability analysis, 300 diodes were placed for a life test. After 1500 hr, 16 diodes had failed and test was stopped. The times at which failures occurred are: 115, 120, 205, 370, 459, 607, 714, 840, 990, 1160, 1188, 1300, 1380, 1414, 1449 and 1497 hrs. Determine the failure rate of the diodes.
16. A sample of 200 resistors is subjected to testing (presumably in the useful life period). Five failures are found at the end of 500 hours. Six more at the end of 800 hours, 2 more at the end of 1200 hours, 6 more at the end of 1800 hours and no further failures are found when the test is terminated at the end of 2400 hours.
- (a) Estimate the MTBF if failed resistors are replaced when found.
  - (b) Estimate the MTBF if no replacements are made.
17. Twenty small generators were put under test for a period of 1500 hours. One generator failed at 400 hours and was replaced by new one. A second failed at 500 hours and was also replaced. A third and fourth failed at 550 and 600 hours, respectively, and were removed

from testing, but were not replaced. A fifth malfunctioned at 700 hours was immediately repaired, and was put back into test. A sixth malfunctioned at 800 hours but was kept in test. Later analysis showed this failure was due to governor malfunction. Estimate the failure rate of the generators.

18. Ten units are placed on life test, and the failure times are 9, 19, 27, 35, 40, 46, 50, 55, 56, 60 hr. Plot  $f(t)$ ,  $\lambda(t)$ ,  $Q(t)$  and  $R(t)$ .
19. In the life-testing of 100 specimens of a particular device, the number of failures during each time interval of twenty hours is shown in Table below. Estimate the MTTF for these specimens.

TABLE

Time Interval Hours	Number of failures during the interval
$T \leq 1000$	0
$1000 < T \leq 1020$	25
$1020 < T \leq 1040$	40
$1040 < T \leq 1060$	20
$1060 < T \leq 1080$	10
$1080 < T \leq 1100$	5

20. In a well-shuffled deck of 52 playing cards, what is the probability that the top card is:
- (a) A diamond (b) a black card, and (c) a nine ?
21. The PDF of the lifetime of an appliance is given by
- $$f(t) = 0.25t e^{-0.5t} \quad , t \geq 0,$$
- where  $t$  is in years.
- (a) What is the probability of failure during the first year?  
 (b) What is the probability of the appliance's lasting at least 5 years?  
 (c) If no more than 5% of the appliances are to require warranty services, what is the maximum number of months for which the appliance can be warranted?
22. A device is put into service on a Monday and operates seven days each week. Each day there is a 10% chance that the device will break down. (This includes the first day of operation). The maintenance crew is not available on weekends, and so the manager

hopes that the first breakdown does not occur on a weekend. What is the probability that the first breakdown will occur on a weekend?

23. A man and his wife appear for an interview for two posts. The probability of husband's selection is  $1/7$  and that of the wife's selection is  $1/5$ . What is the probability that only one of them will be selected ?
24. A president is to be elected from the membership of a political organization which has 100 members. If the ratio of male to female is 4:1 and half of both men and women are married, what is the probability that
- (a) the president is a man,  
 (b) the president is a married woman, and  
 (c) the president is a married man or married woman?
25. Consider the following if statement in a program:

if B then  $s_1$  else  $s_2$

The random experiment consists of 'observing' two successive executions of the if statement. The sample space consists of four possible outcomes:

$$S = [(s_1, s_1), (s_1, s_2), (s_2, s_1), (s_2, s_2)] = [t_1, t_2, t_3, t_4]$$

Assume the following probability assignment:

$$\Pr(t_1) = 0.34, \Pr(t_2) = 0.26, \Pr(t_3) = 0.26, \Pr(t_4) = 0.14$$

Determine the probability of the following events:

- (a) At least one execution of the statement  $s_1$ .  
 (b) Statement  $s_2$  is executed the first time.
26. A company producing electric light bulbs has an annual inspected output of 7.8 million bulbs and its inspection department is assessed as having a reliability of 0.9. A particular customer buys a batch of 4500 light bulbs from this company in which he finds that 9 are faulty. On the basis of these data, what is the estimate of the average number of bulbs which the company rejects each year in the inspection department?
27. A binary communication channel carries data as one of two types of

signals, i.e. ones or zeros. A transmitted zero is sometimes received as a one and a transmitted one is sometimes received as a zero because of noise. For a given channel, assume a probability of 0.94 that a received zero is a transmitted zero and a probability of 0.91 that a received one is a transmitted one. Further assume a probability of 0.45 of transmitting a zero. If a single signal is sent, determine:

- (a) Probability that one is received,
- (b) Probability that a zero is received,
- (c) Probability that a one was transmitted if a one was received.

28. A cinema house gets electric power from a generator run by diesel engine. On any day, the probability that the generator is down (event A) is 0.025 and the probability that the diesel engine is down (event B) is 0.04. What is the probability that the cinema house will have power on any given day? Assume that occurrence of event A and event B are independent of each other.
29. A has one share in a lottery in which there is one prize and two blanks ; B has three shares in a lottery in which there are three prizes and 6 blanks; compare the probability of A's success to that of B's success.
30. Four persons are chosen at random from a group containing 3 men, 2 women and 4 children. Calculate the chances that exactly two of them will be children.
31. A manufacturing concern specializing in high-pressure relief valves subjects every valve to a particular acceptance test before certifying it as fit for use. Over a period of time, it is observed that 95% of all valves manufactured pass the test. However, the acceptance test adopted is found to be only 98% reliable. Consequently, a valve certified as fit for use has a probability of 0.02 of being faulty. What is the probability that a satisfactory valve will pass the test?
32. A certain firm has plants A, B and C producing respectively, 35%, 15% and 50% of the total output. The probabilities of a non defective product are 0.75, 0.95, and 0.85 respectively. A customer receives a defective product. What is the probability that it came from plant C ?.
33. In a survival test involving mechanical valves, 1000 valves are tested. On the average, 822 valves survive 400 cycles of operation, and out of these, 411 valves survive 700 cycles of operation. What is the probability of a valve surviving 400 cycles as well as 700

cycles of operation? What is the probability that a valve will survive 700 cycles of operation if it has already survived 400 cycles of operation?

34. A given lot of small devices is 98 percent good and 2 percent defective. To be certain of using a good device, each device is tested before installation. The tester itself is not totally reliable since it has the following conditional probabilities:

$$P(\text{says good/actually good}) = 0.95$$

$$P(\text{says bad/actually bad}) = 0.95$$

A device is tested with the tester indicating the device is bad. What is the probability the device is actually bad?

35. An anti-aircraft gun can take a minimum of four shots at an enemy plane moving away from it. The probability of hitting the plane at first, second, third, and fourth shots are 0.4, 0.3, 0.2, and 0.1 respectively. What is the probability that the gun hits the plane ?
36. A device has a random failure rate of 20 failures/10<sup>5</sup> hour for an operating period of 300 hours, what is the probability of
- (a) No failure
  - (b) One failure
  - (c) Two failures
  - (d) Two failures or less
  - (e) More than two failures.
37. Four identical electronic units are connected in parallel. Each has a reliability of 0.9. Estimate the probability of 0, 1, 2, 3, and 4 of these units remaining operative.
38. It is found that the number of system breakdowns occurring in a given length of time follows a Poisson distribution with a mean value of a 2 break-downs. What are the probabilities, in the same length of the time, of the system having
- (a) no break-down
  - (b) 1 break-down
  - (c) 2 break-downs
  - (d) 10 break-downs
  - (e) Less than 3 break-downs
  - (f) three or more than 3 break-downs.

39. An illuminated mimic diagram in a plant control room has 150 nominally identical bulbs which are required to be permanently illuminated. If the probability of any one bulb being out at any one time is 0.01, what is the probability of

- (a) at least 5 bulbs being out,
- (b) not more than 3 bulbs being out,
- (c) exactly 4 bulbs being out?

40. Verify that the function defined by  $f(t) = 0.1e^{-.25t} + 0.06e^{-0.1t}$  for all number  $t > 0$ , with  $f(t) = 0$  for  $t < 0$ , is a density function and find the expected value of a random variable having such a density function.

41. The time (measured in years),  $X$ , required to complete a software project has a pdf of the form:

$$f_x(x) = \begin{cases} kx^2(1-x^3), & 0 \leq x \leq 1 \\ 0 & \text{otherwise} \end{cases}$$

Determine the probability that the project will be completed in less than 4 months.

42. A device has a lifetime which is known to be an exponential random variable  $X$  with  $E(X) = 10$  years. Find the value of  $t_0$  for which the probability is exactly  $1/2$  that the device lasts at least  $t_0$  years; that is,  $P(X > t_0) = 1/2$ .
43. A simple resistive element of fixed value 10 ohms is known to obey Ohm's law. The current flowing through this element is randomly distributed according to a rectangular distribution which has lower and upper limits of 4 A and 6 A respectively. What is the probability that the voltage developed across the element meets the requirement of being at least 45V?
44. A room is lit by five nominally identical lamps. All lamps are switched on together and left switched on. It is known that the times to lamp failures after they have been switched on is rectangularly distributed between a lower limit of 8000 hr and an upper limit of 12,000 hr. What is the mean time to the room being in darkness? How would this mean time be affected if the number of lamps was increased to a total of 15?
45. A delicate electronic clock, which is circular in shape, is to be housed in a box with a diametrical clearance of not less than 2.0 mm and

not greater than 7.0 mm. This clearance is provided for cooling purposes. The radius of the clock is a random variable following a normal probability law with a mean of 20.0 cm and a coefficient of variation of 1%. The manufacturing process adopted to produce the housing results in making the inner radius of the box also a random variable following a normal probability law with a mean of 20.2 cm and a coefficient of variation of 2%. Evaluate the probability that the specified clearance will be met for a clock and its housing.

46. An electronic amplifier, when normally functioning, is found to have random variations in power output from all causes which follow a rectangular distribution between the limits of 45 mW and 55 mW. In addition, the amplifier has a probability at any time of  $10^{-2}$  of being in the catastrophic or completely unavailable state where the power output is effectively zero. What is the reliability of the amplifier in meeting a requirement for the power output to be greater than 47 mW?

47. A control system has a power output measured in watts,  $W$ , which as a result of variations in the elements within the system, is randomly distributed with respect to time according to the p.d.f.  $f_w(W)$  where:

$$\begin{aligned} f_w(W) &= 0 && \text{for } 0 \leq W \leq 42.5 \\ f_w(W) &= 0.032W - 1.36 && \text{for } 42.5 \leq W \leq 45 \\ f_w(W) &= 0.08 && \text{for } 45 \leq W \leq 55 \\ f_w(W) &= 1.84 - 0.032W && \text{for } 55 \leq W \leq 57.5 \\ f_w(W) &= 0 && \text{for } 57.5 \leq W < \infty. \end{aligned}$$

Draw the shape of this p.d.f. and calculate the reliability of the control system if the requirement for the power output at a particular time is (a) that it should be between 45 W and 57 W, (b) that it should be between 43 W and 57 W and (c) that it should be less than 55 W.

48. A given component has an MTBF of  $10^6$  hr, what is the reliability for an operating period of 10 hr for 5 such components in series ?

49. A regulated power supply consists of a step down transformer, rectifier, filter and a regulator. The constant failure rates of these components are :

Transformer	:	1.56% failures/1000 hours
Rectifier	:	2.00% failures/1000 hours
Filter	:	1.70% failures/1000 hours

Regulator : 1.40% failures/1000 hours

Determine the reliability of this supply if it is required to operate for (1) 500 hours (2) 1000 hours (3) 1500 hours. Comment on reliability vs hours of operation . What is the failure rate of total supply unit ?

50. A manufacturer of 16K byte memory boards finds that the reliability of the manufactured boards is 0.98. Assume that the defects are independent.
- What is the probability of a single byte of memory being defective?
  - If no changes are made in design or manufacture, what reliability may be expected from 128K byte boards?
51. An electronic amplifier is made up of 50 resistors, 20 capacitors, 10 transistors, 10 diodes and 10 variable resistors. Every component must be in the working state for the amplifier to be working. Each component has times to failure which follow an exponential distribution with mean values of  $5 \times 10^6$  hr,  $2 \times 10^6$  hr,  $10^6$  hr,  $10^7$  hr and  $5 \times 10^5$  hr for resistors, capacitors, transistors, diodes and variable resistors respectively. What is:
- the mean time to failure of the amplifier and
  - the probability that the amplifier has failed by a time of 100 hr?
52. A certain component has a failure rate of  $4 \times 10^{-8}$ /hr in the on- state and a failure rate of  $4 \times 10^{-9}$ /hr in the off-state. On average, over the life of this component, it is only 25% of the time in the on-state. What is the effective failure rate of this component?
53. A measurement system consists of a sensor unit and an indicator unit. Starting from time zero, the times to failure for each unit are exponentially distributed. The mean time to failure for the sensor is 6000 hr and that for the indicator is 3000 hr. If either unit fails the system remains in the failed state. What is:
- the mean time to system failure,
  - the probability of the system being in the failed state after 1000 hr, and
  - the probability of the system being in the successful state after 4000 hr ?
54. A system is composed of 5 identical independent elements in parallel. What should be the reliability of each element to achieve a

system reliability of 0.96 ?

55. Four capacitances of  $25 \mu\text{F}$  each are connected in parallel to act as a single capacitance of  $100 \mu\text{F}$  required for the successful operation of a unit. If the reliabilities of these capacitors are 0.6, 0.7, 0.8, and 0.9 respectively, find the reliability of the unit.
56. A solid fuel booster engine has been test fired 2760 times. On 414 occasions the engine failed to ignite. If a projectile is fitted with three identical and independent booster engines of this type, what is the chance on launching of the projectile that,
- all three engines fail to ignite,
  - at least one of the engines fails to ignite ?
57. The reliability function for a relay is  $R(t) = \exp(-\lambda K)$  where  $K$  is the number of cycles and  $\lambda = 10^{-4}/\text{cycle}$ . A logic circuit uses 10 relays. The specific logic circuit used is unknown. What range should  $K$  have for the system reliability to be 0.95 ?
58. A 10kW power supply system is to be designed. The following alternatives are available:
- One single generator of 10kW rating with a failure rate of 0.20 per 1000hr,
  - two generators each rated for 10kW and with a failure rate of 0.25 per 1000 hr, and
  - three generators each rated for 5kW and with a failure rate of 0.20 per 1000 hr.

Which of the alternatives would you select ? Why ? Assume that the redundant units are statistically independent.

59. Two circuit breakers of the same design each have a failure-to-open-on-demand probability of 0.02. The breakers are placed in series so that both must fail to open in order for the circuit breaker system to fail.

What is the probability of system failure

- If the failures are independent, and
- If the probability of a second failure is 0.1, given the failure of the first ?

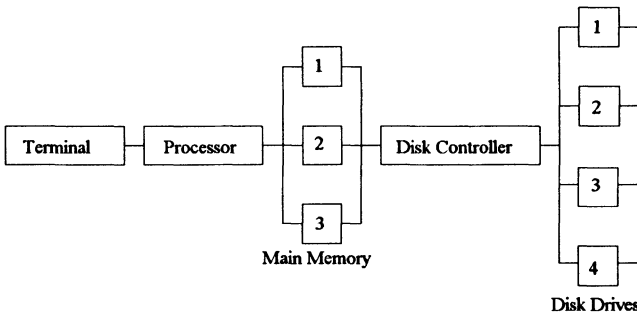
(c) In part (a) what is the probability of one or more breaker failures on demand ?

(d) In part (b) what is the probability of one or more failures on demand ?

60. A microprocessor system consists of the following units:

Unit	Number	Failure rate
Processor	1	$\lambda_P$
Main Memory Unit	3	$\lambda_{MM}$
Disk Controller	1	$\lambda_{DC}$
Disk Drive	4	$\lambda_{DD}$
Video Terminal	1	$\lambda_{VT}$

each with a constant failure rate. The system configuration is shown in Fig. For the system to operate, the processor, terminal and disk controller must function together with two of the memory units and three of the disk drives. Obtain an expression for the reliability of the system and the system MTBF.



61. An equipment consists of 100 tubes. Twenty of these are connected functionally in series (branch A). This branch A is in turn connected in series to a parallel combination of branches B and C. The branch B and C contain 20 and 60 tubes respectively, connected functionally in series. The reliability of each tube in branch A, B and C respectively is  $p_a = 0.95$ ,  $p_b = 0.93$ , and  $p_c = 0.96$ . Calculate the overall reliability of the equipment.

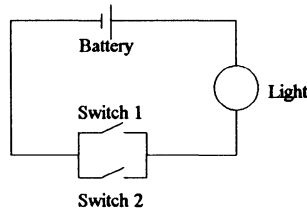
62. Three generators, whose data is given below, are connected in parallel. Determine the reliability of the system if the required load is 100kW.

Generator	Capacity	Reliability
1	50kW	0.98
2	100kW	0.97
3	50kW	0.99

63. A critical measuring instrument consists of two sub-systems connected in series. Sub-systems A and B have reliabilities 0.90 and 0.92, respectively, for a certain operating time. It is necessary that the reliability of the instrument be raised to a minimum value of 0.917 by using parallel sub-systems of A alone. Determine how many units of A should be used with one B to get a minimum reliability value of 0.98. What is the actual reliability value obtained?
64. A PC/XT has the following units with their respective failure rates in (%/1000 hrs.) as indicated:

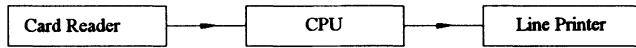
i	CPU(incl. RAM and interfaces)	1.0
ii	Co-processor	2.0
iii	Key Board	0.8
iv	VDU	2.5
v	Hard Disc	3.0
vi	Floppy Drive 1	1.5
vii	Floppy Drive 2	1.5
viii	Printer	3.5

- (a) Determine the reliability of each unit for 2,000 hrs. of operation.
- (b) Determine the reliability of the system and MTBF if only one floppy drive is sufficient.
- (c) How is the reliability of the system and MTBF modified if we consider that the Co-processor is used only 40% of the time, and printer is used only 20% of the time.
65. The circuit in the following picture shows a battery, a light, and two switches for redundancy. The two switches are operated by different people, and for each person there is a probability of 0.9 that the person will remember to turn on the switch. The battery and the light have reliability 0.99. Assuming that the battery, the light, and the two people all function independently, what is the probability that the light will actually turn on?



66. A computer system has three units as shown in Fig. Their reliabilities are as follows:

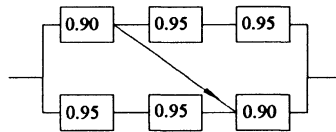
- Card reader = 0.89
- Central processing unit(CPU) = 0.98
- Line printer = 0.85



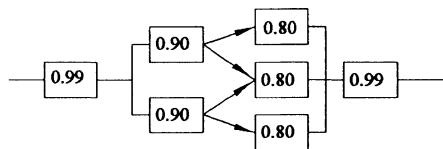
Determine the system reliability. If you want the system reliability to be not less than 0.95, what steps would you take? Draw the improved system diagram and calculate its actual reliability.

67. A system consists of three components in series, each with a reliability of 0.96. A second set of three components is purchased and a redundant system is built. What is the reliability of the redundant system (a) with high-level redundancy, (b) with low-level redundancy?

68. Given the following component reliabilities, calculate the reliability of the two systems.

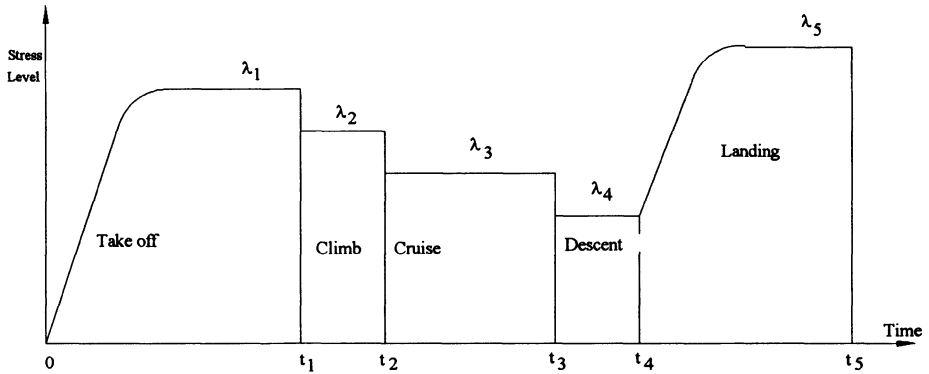


(a)

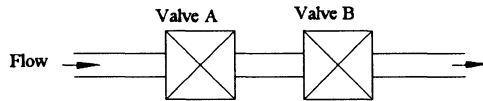


(b)

69. Four elements of a system each have a constant probability of 0.1 of being in the failed state at any time. What is the system probability of being in the failed state if the elements are so connected that system successes is achieved when :
- (a) any 1 or more of the 4 elements are successful,
  - (b) any 2 or more of the 4 elements are successful,
  - (c) any 3 or more of the 4 elements are successful, and
  - (d) only all 4 elements are successful?
70. An electronic equipment comprises five active, independent, and identical units. The equipment will only operate successfully if at least three of the units are operating normally. Each unit has a constant failure rate,  $\lambda = 0.004$  failure/hr. Calculate the system mean time to failure.
71. A 10-elements system is constructed of independent identical components so that 5 out of the 10-elements are necessary for system success. If the system reliability  $R$  must be 0.99, how good must the components be ?
72. Assume a designer has the freedom to use as many elements in parallel as he wishes. If an element has a reliability of 0.6 over a fixed time interval, determine the minimum number of parallel elements he must use to achieve a unit reliability of at least 0.95 for the following two cases:
- (a) Successful unit operation will result if at least one element operates.
  - (b) If at least two parallel elements must operate.
73. If the level of stress changes during a mission, then the failure rate also changes. At take off, for example, an aircraft engine has to generate a greater torque to get the higher engine thrust required. At cruising altitude and speed, torque requirements are reduced. Assume the stress profile of an aircraft flight is as shown:
- (a) Find an expression for reliability of a single engine for one flight.
  - (b) Assume a four engine aircraft. If all four engines are required for takeoff and climb, but only two out of four are required for completing the flight, determine the entire system reliability for one flight.



74. A pipeline carrying fluid has two valves as shown below. Draw the reliability logic diagram if

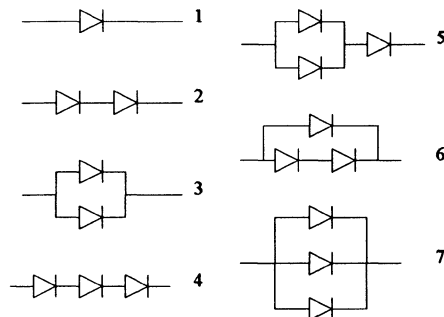


- (a) both of them are normally closed and expected to open when required to permit flow, and
- (b) both of them are normally open and expected to close to block the flow.

75. In an electronic circuit a diode function is necessary. To increase the reliability of this diode function one wants to apply active redundancy. One can afford, however, no more than three diodes. The diodes used may exhibit both open failures and short-circuit failures, the associated probabilities are:

-Open failure  $p_o = 0.02$ ,

-Short circuit failure  $p_s = 0.01$



The diodes fail stochastically independent. Indicate for which of the circuits below the reliability is maximal and motivate your answer.

76. An electronic system can fail in two mutually exclusive failure modes, i.e., type I (open mode) and type II (short mode). The open and short modes constant failure rates are  $\lambda_1 = 0.002$  and  $\lambda_2 = 0.004$  failures/ hour, respectively. Calculate the value of the following items for a 100 hr mission:

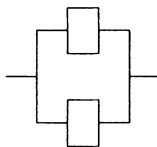
1. System reliability
2. Open mode failure probability
3. Short mode failure probability

77. The failure probabilities of a diode subject to double failure are related as follows:

$$\begin{aligned} q_o + q_s &= 0.2 \\ q_o/q_s &= 0.3 \end{aligned}$$

What type of redundancy would you apply in order to increase the reliability ? What is the maximum reliability possible and number of diodes required ? If the ratio  $q_o/q_s = 1.5$ , how would it affect the redundancy design ? Determine the maximum system reliability and the number of diodes required.

78. The identical components of the system below have fail-to-danger probabilities of  $p_d = 10^{-2}$  and fail-safe probabilities of  $p_s = 10^{-1}$ .

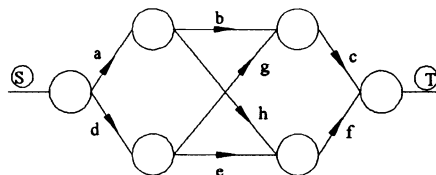


- (a) What is the system fail-to-danger probability?
- (b) What is the system fail-safe probability?

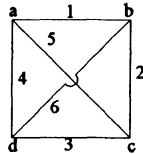
79. A small nuclear research reactor has three absorber rods which are suspended above the reactor and are designed to drop into the reactor core and shut the reactor down in the event of any untoward incident. The three rods are designated A, B and C and it has been found that the probability of each of these rods failing to drop on demand is  $p_a = 0.005$ ,  $p_b = 0.01$  and  $p_c = 0.001$ . If it is known that any two or more of three rods entering the reactor core will

safely shut the reactor down, what is the probability of failing to shut the reactor down when called upon to do so?

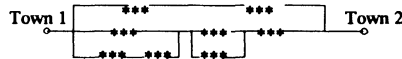
80. A system has MTBF of 200 hrs. Calculate the 100 hr. reliability of a system in which one such unit is operative and two identical units are standing by.
81. Two components each with an MTBF of 1000 hours are connected in (1) active (2) standby redundancy. Determine the overall system MTBF.
82. The failure rate of a device is constant equal to  $0.06 \times 10^{-3}$  per hr. How many standby devices are required to achieve a reliability of more than 0.985 for an operating period of 10,000 hrs? What is the MTTF of the resulting system ?
83. A d.c. generator has a failure rate of 0.0002 failures/hour. In case of its failure, a battery is used as a standby whose failure rate is 0.001 failure /hour when in operation. Find the reliability and MTBF for this system for a mission time of 10 hours assuming perfect sensing and switching. If the sensing and switching device has a 99 percent reliability for a switching function, how are the results modified ?
84. Calculate the reliability of 10 hrs operating period of a parallel system with two units, each having a failure rate of 0.01 failures/hour. Do likewise for a two unit standby system using the same units and assuming 100 percent reliability of sensing, switching and idling. Compare the two on the basis of reliability and MTBF.
85. The power supply to the operating unit of a hospital is provided by a generator whose failure rate follows an exponential distribution law with parameter  $\lambda_1 = 0.005$  per hour. A standby battery unit is coupled through a decision switch which has a reliability  $r_d = 0.90$ . Calculate the reliability of the power supply system for a mission time of 10 hours if the battery failure rate follows a distribution law with parameter  $\lambda_2 = 0.001$  per hour.
86. For the diagram shown in figure, determine the reliability expression, if each branch has identical probability of success of 0.80 .



87. The graph shown in fig represents a four-station communication network. The four nodes represent the four stations and the six branches represent two way communication links between the pair of stations. Find all minimal tie-sets for transmission between a and b and derive an expression for reliability of communication between these nodes.

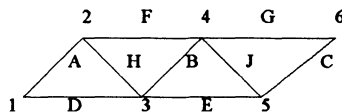


88. Two towns are connected by a network of communication channels. The probability of a channel's failure-free operation is  $R$ , and channel failures are independent. Minimal level of communication between towns can be guaranteed provided at least one path containing properly functioning channels exists. Given the network below, determine the probability that the two towns will be able to communicate. Here -\*\*\*- denotes a communication channel.



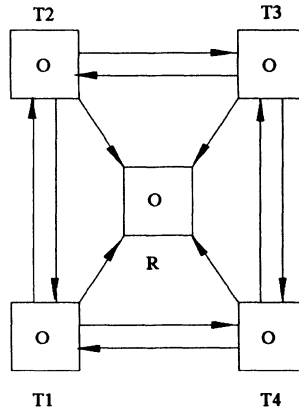
A network of communication channels.

89. Six computer systems are interconnected by means of the network below. Each connecting line of the network can be used in both directions and has an independent failure probability  $p_0 = 0.1$ . Calculate the probability that a successful information exchange can occur between the computers 1 and 4.

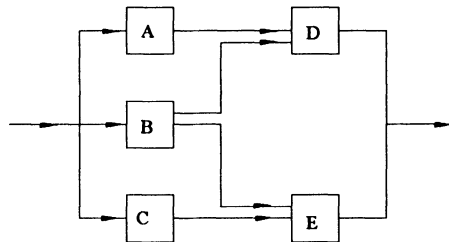


90. An information processing station R can receive information from four transmission stations T1, T2, T3 and T4. The four transmission stations are connected by two-way links as shown in Fig. What is

the probability that R will fail to receive information from T1 if the probability of failure of transmitting links are identical and equal to  $q$ .



91. A five component system is connected as shown in fig. Derive an expression for system reliability using Baye's theorem. If all the components are identical and independent with a reliability of 0.8, determine the system reliability.



92. A vibration monitoring system consists of six sub-systems, all connected in series. The predicted reliabilities as obtained from an analysis are  $R_1 = 0.993$ ,  $R_2 = 0.996$ ,  $R_3 = 0.998$ ,  $R_4 = 0.997$ ,  $R_5 = 0.987$ , and  $R_6 = 0.989$ . Calculate the system reliability. If it is desired to increase the reliability by 3.33%, determine the percentage by which the reliability of each sub-system should be increased. Assume an exponential model for each sub-system.
93. Four units are connected in series, with reliabilities  $R_1 = 0.85$ ,  $R_2 = 0.9$ ,  $R_3 = 0.8$  and  $R_4 = 0.95$ . Calculate the system reliability. If the reliability is to be increased to a value of 0.65, how should this be apportioned among the four units according to the minimum effort method ?

94. A system having three serial units is to be designed to have an overall reliability of 0.95. The complexity of third serial unit is expected to be twice as much as that of the second unit and complexity of the second unit is expected to be three times as high as that of the first unit. While first and third units are to operate all the time, second unit is to operate only for 50% of the total time. Allocate unit reliabilities to three units.
95. Three units of a system have predicted reliabilities 0.75, 0.85 and 0.95 respectively. It is desired to allocate the reliabilities such that the system reliability is not less than 0.75. Obtain the necessary solution by

- (a) Basic Method
- (b) Minimum Effort Method

If the cost of a unit with reliability  $r$  is  $k\pi r^2$ , calculate the % age increase in cost for both the solutions.

96. Devise Hamming code consisting of data digits and check digits to encode the 5-bit data word 10101. Show how one error can be detected and corrected.
97. A message coded in Hamming Code is transmitted through a noisy channel.

The received message is

1011001 0111001 0011011 1110110

Decode the message assuming that at most a single error can occur in a word.

98. Consider a system having 5 components in series whose data are :

Component No.	Reliability	Cost	Weight
1	0.75	35	77
2	0.91	75	22
3	0.98	58	63
4	0.78	39	52
5	0.95	90	18

Find the optimum allocation of redundancies for maximizing system reliability if  $C_s < 500$  and  $W_s < 400$ .

99. Consider a system having 5 components in series whose data are :

Component	$P_i$	$C_i$	$W_i$	$V_i$
1	0.785	5.2	77.9	34.9
2	0.916	75.1	22.2	28.6
3	0.986	58.5	63.3	87.3
4	0.755	36.1	52.7	45.9
5	0.949	90.8	8.0	58.6

Find the optimum allocation of redundancies for maximizing system reliability if

$$C_S < 500, W_S < 589.6 \text{ and } V_S < 686.2$$

100. Determine the optimum number of redundancies to maximise reliability in the case of a system having 6 components with the following details:

Component	Reliability	Cost, \$	Weight, Kg
1	0.80	10	2
2	0.90	20	3
3	0.85	20	4
4	0.75	15	6
5	0.70	10	2
6	0.90	15	7

Component No.4 is digital in nature. Component No.3 can permit the use of standby redundancy only but not parallel redundancy. Component 1 and 2 cannot be procured more than a total of 2 units each.

The total system cost should not exceed 200 Dollars and total system weight should not exceed 60 Kg.

101. An electrical supply system is subject to failure which causes loss of supply to the consumer. The mean time between such failures is known to be 398 hr and the meantime to repair the failures and restore the supply is known to be 2 hr. What is the average value of the availability of the supply to the consumer over a long period of time?
102. An engine is to be designed to have a minimum reliability of 0.7 and a minimum availability of 0.95 over a period of 1000 hrs. Determine the mean repair time and the frequency of failures of the engine.

103. A computer has an  $MTTF = 34$  hr and an  $MTTR = 2.5$  hr.
- What is the availability?
  - If the  $MTTR$  is reduced to 1.5 hr, what  $MTTF$  can be tolerated without decreasing the availability of the computer?
104. For a computer unit, a suitable air-conditioning system has to be designed. It should have a minimum reliability value of 0.95 for an operation of 800 hours. The minimum availability value over the same period of time is required to be 0.98. Assuming constant hazards for failure and repair, estimate the time to failure and the mean repair time.
105. If a transmitter is to be designed to have a reliability greater than 0.90 over 1000 hr and a minimum availability of 0.99 over that period, determine the values of  $MTTF$  and  $MTTR$ .
106. A large office block has a fire detection and alarm system which is subject to a mean constant failure-rate of two failures per year (1 year = 8760 hr) and each failure that occurs takes, on average, 4 hr to detect and repair. The system is also subject to a quarterly routine inspection and test on which occasions it is out of action for a fixed time of 1 hr. If the expected probability of fire occurrence in the building over a period of time is 0.073, what is the probability of an undetected fire by the alarm system over the same period of time?
107. In a workshop a minimum of two lathes are required to operate continuously to meet the demand. The ratio of the repair rate to the failure rate of each lathe is 4. If the workshop has three identical lathes, determine the probability that at least two of them are available in the long run.
108. You are given a system with  $n$  components. The  $MTBF$  for each component is 100 hrs. and the  $MTTR$  is 5 hrs. Each component has its own repair facility. Find the limiting availability of the system when:
- All components are required for the system to function.
  - At least one component is required for the system to function.
109. A two component parallel system uses both identical components each with  $\lambda = 10^{-5}/hr$  and  $\mu = 10^{-2}/hr$ . Calculate the %age increase in mean time to failure with the use of repair facilities if the system uses:

- (a) Active Parallel Redundancy  
 (b) Standby Redundancy.

110. Three generators each of 20KW have different values of availability figures as supplied by different manufactures. The availability values are 0.96, 0.98 and 0.92 respectively. Determine the overall system availability if the required load is 40 KW.
111. A system consists of two units in active redundancy. The units have a constant failure rate  $\lambda$  of  $10^{-3}$  per hour and fail stochastically independent.
- (a) How large is the MTTFF if no corrective maintenance at unit level is performed?
- (b) How large will the MTTFF be if there are repairs allowed at the unit level? The repair rate  $\mu$  is  $10^{-1}$  per hour.
- (c) What is the addressing frequency of the repair channel in case (b) if it may be assumed that  $\lambda \ll \mu$ ?
- (d) The repair costs of a unit are \$500 per event. However, if the system goes down the costs, mainly because of the loss of production, are \$5,000 per event. Determine, based on the outcome of (a), (b) and (c) whether it is economically sound to perform corrective maintenance at the unit level.
112. The following three units are in operation in parallel in the reliability sense.

Unit	Failure/rate hr	Repair rate/hr
A	0.004	0.10
B	0.005	0.15
C	0.003	0.06

If the system is operating as a one-out-of-three parallel system, determine

1. System availability,
  2. Frequency of system failure,
  3. Mean down- time, and
  4. Mean up- time.
113. In testing certain systems whose operating time upto failure was normally distributed, we obtain ten realisations of the operating time upto failure (in hours): 115, 75, 80, 150, 75, 100, 120, 95, 70, 100. Find the confidence bounds for the mean of the operating time upto failure with a level of confidence of 95%.

114. Twenty identical items were tested for 200 hr. Nine of the total items failed during the test period. Their failure times are specified in table below. The failed items were never replaced. Determine whether the failure data represent the exponential distribution.

Failure number	1	2	3	4	5	6	7	8	9
Failure times (hr)	10	15	2	45	60	85	13	16	20

115. A relatively large number of nominally identical pumps are installed on a process plant and it is known that the times to failure for the pumps follow an exponential distribution. Over a 6-month period it is found that 5 pump failures have occurred in a sample of 20 of the pumps. If an estimate of the population mean failure-rate is made from this sample, what are the symmetrical 90% confidence limits on the estimate?

116. A non-replacement reliability test is carried out on 20 high-speed pumps to estimate the value of the failure rate. In order to eliminate wear failures, it is decided to terminate the test after half of the pumps have failed. The times of the first 10 failures (in hours) are

33.7, 36.9, 46.8, 56.6, 62.1, 63.6, 78.4, 79.0, 101.5, 110.2

- (a) Estimate the MTTF.  
 (b) Determine the 90% confidence interval for the MTTF.

117. One wants to determine the MTTF of a new monolithic digital-to-analog converter at 25°C/ 77°F/ 298K. For that purpose 60 converters are operated for 1000 hours at 100°C/ 212°F/ 373K and 60 converters for 1000 hours at 85°C/ 185°F/ 358K.

At 100°C, the MTTF turned out to be  $6.5 \times 10^3$  hours. At 85°C this was  $2.4 \times 10^4$  hours. Assume that the failure process behaves as a chemical process with a reaction rate:

$$Q = Q_0 \exp(-E_A/kT)$$

What is the MTTF of this converter at 25°C?

118. Suppose that a sample of 20 units passes an acceptance test if no more than 2 units fail. Suppose that the producer guarantees the units for a failure probability of 0.05. The buyer considers 0.15 to be the maximum acceptable failure probability.

- (a) What is the producer's risk?
- (b) What is the buyer's risk?

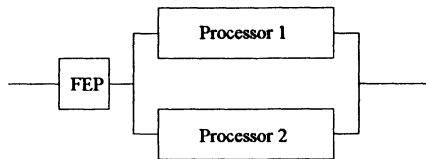
119. The same data have been fit with both the basic and logarithmic poisson models. The parameters obtained are :

Basic	Logarithmic poisson
$\lambda_0 = 20$ failures/cpu hr	$\lambda_0 = 50$ failures /cpu hr
$v_0 = 120$ failures	$\theta = 0.025/$ failures

Note that the logarithmic poisson usually has higher initial failure intensity. At first, recall that this falls off more rapidly than the failure intensity for the basic model, but finally it falls off more slowly. We require to examine some consequences of this behavior.

First, determine the additional failures and additional execution time required to reach a failure intensity objective of 10 failures /cpu hr, using both models. Then repeat this for an objective of 1 failure /cpu hr. Assume in both cases that you start from the initial failure intensity.

120. A computing center has a reliability objective of 0.90 for an 8- hr shift for its interactive service. The system requirement is simply that service be provided, regardless of the response time involved. All reliabilities are measured with respect to this shift. It has a dual processor configuration fed by a front-end processor, as shown in fig below. The front-end processor has a reliability of 0.99 and its operating system, 0.95. The reliability of each mainframe processor is 0.98. What must the reliability of the mainframe operating system be to meet the overall reliability objective?



Computing Centre Configuration.

121. A program with 50,000 source instructions and a source to object expansion ratio of 4 will be executed on a machine with an average instruction execution rate of 333,333 instructions /cpu sec. On similar projects, a fault exposure ratio of  $K = 1.67 \times 10^{-7}$  has been experienced, along with a fault density of 6 faults per 1000 source instructions. The fault reduction factor  $B = 1$ . Estimate the initial

failure intensity at the start of the system test.

122. The Soft Landing software service company has won a service contract to provide recovery service for a patient control and billing system. The service is provided to doctors in a region who own personal computers. It has a failure intensity of 1 failure /100 cpu hr. The average system runs 10 cpu hr /week and there are 600 doctors to be serviced. The average service person can make 2 service calls daily, including travel and allowing for enough spare personnel to prevent excessive service backlogs from building up.

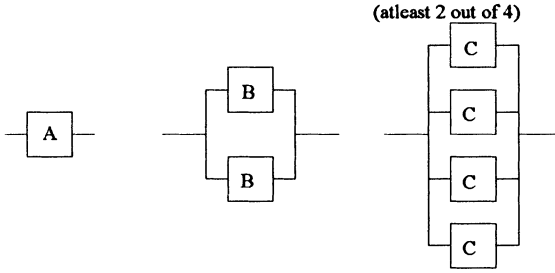
How many service personnel do we need ? Assuming a cost of \$200/call, what annual contract fee must we charge each doctor to achieve 20 % profit on sales ?

123. A program has an initial failure intensity of 10 failures/ cpu hr. We want to test and debug this program until a failure intensity of 1 failure/10 cpu hr is achieved. Assume the following resource usage parameters.

Resource usage	Per hr	Per failure
Failure identification effort	3 person hr	2 person hr
Failure correction effort	0	6 person hr
Computer time	1.5 cpu hr	1 cpu hr

- (a) What resources must be expended to achieve the reliability improvement required ? Use the logarithmic Poisson execution time model. Assume a failure intensity decay parameter of 0.05.
- (b) If the failure intensity objective is cut to half, are the resources required doubled?
124. A change to 2000 source instructions is being made in a program of 100,000 source instructions. The fault density of base program at the start of the system test was 5 faults /1000 source instructions. Assume that the fault reduction factor  $B = 1$ . The initial failure intensity of the base program was 2 failures /cpu hr. It was released with failure intensity of 6 failures /100 cpu hr. Fixes of faults are not made during the operational phase. What is the expected impact on failure intensity of the operational program?

125. Which of the following systems you will recommend as economical from reliability point of view (the system having least cost/ reliability ratio) ? The reliability and cost per component in configuration A B and C respectively are as below:



$P_a = 0.90$

$P_b = 0.70$

$P_c = 0.60$

$C_a = \$ 1000/-$

$C_b = \$ 500/-$

$C_c = \$ 200/-$

## ***ANSWERS TO ODD NUMBERED PROBLEMS***

1. (a) 0.9409 (b) 0.97
3. 0.9802
5. 47 days
7. 0.905
9.  $R(t) = \exp(-\lambda_0 t^2/2)$ ,  $f(t) = \lambda_0 t \exp(-\lambda_0 t^2/2)$ ,  $m = (\pi/2\lambda_0)^{1/2}$
11. (a)  $\lambda(t) = \frac{2}{t_0[1-(t/t_0)]}$ ;  $0 \leq t \leq t_0$ .
- (b) The failure rate increases from  $2/t_0$  at  $t=0$  to infinity at  $t=t_0$ .
- (c)  $m = t_0/3$
13. (a)  $R(t) = 16/(t+4)^2$  (b)  $\lambda(t) = 2/(t+4)$
- (c)  $m = 4$  years
15. 0.000682/ hr
17.  $1.7762 \times 10^{-4}$  /hr
19. 1046 hrs
21. (a) 0.0902 (b) 0.2873 (c) 8 months
23. 2/7
25. (a) 0.86 (b) 0.40
27. (a) 0.5275 (b) 0.4725 (c) 0.949

29. 7 : 16

31. 0.999

33. 0.411, 0.500

35. 0.6976

37. 0.0001, 0.0036, 0.0486, 0.2916, 0.6561

39. (a) 0.018 (b) 0.935 (c) 0.047

41. 53/729

43. 0.75

45. 0.216

47. (a) 0.896 (b) 0.992 (c) 0.900

49.  $\lambda = 6.66 \times 10^{-5}$  /hr, R = 0.9672, 0.9355, 0.9049

51. (a) 19,610 hrs (b) 0.0051

53. (a) 2000 hrs (b) 0.3935 (c) 0.1353

55. 0.3024

57.  $51 < K < 13,514$

59. (a) 0.0004 (b) 0.002

(c) 0.0396 (d) 0.038

61. 0.10765

63. 3 A's, R = 0.9191

65. 0.9703

67. (a) 0.9867 (b) 0.9952

69. (a) 0.0001 (b) 0.0037

(c) 0.0523                      (d) 0.3439

71. 0.885

73. (a)  $R = \exp(-\lambda_1 t_1) \cdot \exp[-\lambda_2(t_2-t_1)] \cdot \exp[-\lambda_3(t_3-t_2)]$   
 $\cdot \exp[-\lambda_4(t_4-t_3)] \cdot \exp[-\lambda_5(t_5-t_4)]$

(b)  $R = \exp(-4\lambda_1 t_1) \cdot \exp[-4\lambda_2(t_2-t_1)] [6R'^2 (1-R')^2$   
 $+ 4R'^3 (1-R') + 4R'^4]$

where,  $R' = \exp[-\lambda_3(t_3-t_2)] \cdot \exp[-\lambda_4(t_4-t_3)] \cdot \exp[-\lambda_5(t_5-t_4)]$

75. Circuit in fig.6 is optimal.

77. Series configuration of 2 diodes and  $R = 0.886$ ,

Parallel configuration of 2 diodes and  $R = 0.832$ .

79.  $6.5 \times 10^{-5}$

81. (i) 1500 hrs                      (ii) 2000 hrs

83. Reliability of 0.99999 and MTBF of 6000 hrs,

Reliability of 0.99997 and MTBF of 5990 hrs.

85. 0.9949

87.  $R = p_{ab} + q_{ab} p_{ac} p_{bc} + q_{ab} p_{ad} p_{bd} q_{ac} + q_{ab} p_{ad} p_{bd} p_{ac} q_{bc}$

$+ p_{ad} p_{cd} p_{bc} q_{ab} q_{ac} q_{bd} + p_{ac} p_{cd} p_{bd} q_{ab} q_{ad} q_{bc}$

89. 0.988

91. 0.94208

93. 0.881, 0.881, 0.881, 0.95

95. 0.8478, 0.9109, 0.9710; 196.898%;

0.8885, 0.8885, 0.95; 22.05%

97. 9996

99. 3,2,2,3,1

101.  $\lambda = 1/398$ ,  $A = 0.995$

103. (a) 0.9315 (b) 20.4 hrs

105. 9491 hrs, 96 hrs

107. 0.896

109. (a)  $3.33 \times 10^4$  % (b)  $5 \times 10^4$  %

111. (a) 1500 hrs (b) 50,000 hrs

(c)  $2 \times 10^{-3}$  /hr (d) \$ 1.10 /hr

113. 79.10 hr - 116.9 hr

115. 0.197 faults /yr - 1.05 faults /yr

117.  $1.66 \times 10^7$  hrs

119. 60 failures and 4.16 CPU hr, 64 failures and 3.2 CPU hr;

114 failures and 18 CPU hr, 156 failures and 39.2 CPU hr

121. 0.3 failures /CPU hr

123. (a)  $\chi_I = 778$  per-hr,  $\chi_F = 552$  per-hr,  $\chi_C = 389$  CPU hr

(b) No, Somewhat less

125. System "C" is optimal.

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# ***SUBJECT INDEX***

## **A**

A Particular Method for Reliability  
  Analysis 93  
Acceleration  
  -for exponential distribution facotr 202  
  -models 203  
Acceptable risk of error 200  
Actions-timely management 298  
Active element group method 109  
Active element groups 109,130  
Active repair time 158  
Additional execution time 240  
Adequate Performance 5  
Allocation factors for Reliability  
  Apportionment 129  
Apportionment for new units 123,128  
ARPA Computer Network 88  
Arrhenius model 204  
Availability 153,154,165  
  -function 163  
  -man power 303  
  -operational 154  
  -steady state 159,165  
Average failure rate 65  
Average hourly cost 172

## **B**

Bank data network system 334  
Banking system 329  
Basic allocation method 125  
Basic event transformation 252  
Bayes equation 194  
Bayes theorem method 103  
Bayesian analysis 193  
Beacon Marker 317  
Binomial density function 40  
Block diagram

  -non series-parallel 62  
  -parallel 61  
  -series 61  
  -series parallel 61  
Boolean algebra method 91  
Burn-in 12,13

## **C**

Calendar time component 241  
Causative factor 257  
Capacity analysis 268  
Cartesian product- Normalized 247  
Catastrophic failures 9  
Causes of failures 7  
CC methodology 260  
Chance failures 12  
Characteristic types of failures 11  
Common cause failures 256  
Communication & co-ordination 8  
Comparison of software reliability models  
  229  
Competitive substitutions 160  
Complement of a set 30  
Complexity factor 129,130  
Component reliability measure 185  
Computation of failure rate 26  
Computer communication networks 88,246  
Conditional probability 34  
Conditional probability chain 51  
Confidence  
  -estimation 197  
  -limits 185,196  
Confidence interval  
  -one sided 197  
  -two sided 197  
Connection matrix 90,264  
Connectivity 246  
Consumer risk 210  
Cost 130

- analysis 156
- effective consideration 299
- effective choice of subsystems 285
- of reliability design 275
- prevention 273
- present 281
- penalty 284
- timely planning 299

Cost model

- availability 284
- depreciation 282
- reliability achievement 276
- reliability utility 280

Criticality 135,136

Cutset approach 96

Cycle time 166

**D**

Dead end connection 88

Debugging 12,13

Decision theory 302

Decrement per failure experienced 234

Degradation failures 5,9

Delta star method 97

Dependability 154

Derating 140

Design reliability 218

Detailed design prediction 109

Developed code 222

Developer oriented approach 217,218

Devices 6

Discrete Random Variable 36

Distribution function

- binomial 39
- continuous 44
- chi square 197
- discrete 36,37
- exponential 47,190
- gamma 49,50
- normal 50,193
- poisson 41
- prior 194
- posterior 194
- rayleigh 24,47
- uniform 46
- weibull 49,192

Distribution percentile 202

Down time 158

Drift

- monotonic 10
- non-monotonic 10

Duane plots 213

Duty ratio 131

Dynamic Programming 287

**E**

Early failures 11

Economical Quality Control and Sampling Plans 304

Economics of reliability engineering 272

Effective evaluation 315

Effective training 311

Effort function 127

Environment-hostile 4,223

Environmental

- Data 111
- symbol identification 111
- symbol description 111

Environmental test laboratory 310

Error correction 141

Error detection & location 142

Evaluation of training 314

Event

- compound 35
- independent 34
- simple 33

Exclusive operator 249

Execution

- environment 222
- time component 232

Expected

- number of failures 235
- number of additional failures 236

Exploding technology 107

Exponential

- law 13
- law verification 187

Eyring Model 205

**F**

Fail

- safe 79
- to danger 79

Failure 6,217

- catastrophic 9
- chance 12
- complete 9

- data analysis 25
- degradation 9
- density function 21
- drift 10
- frequency 159
- frequency curve 21
- gradual 9
- identification
- intensity 225,234
- intensity function 221
- marginal 9
- open 75
- partial 9
- rate 6,20,112
- reports 310
- sensing and switch over devices 81
- short circuit 75
- sudden 9

Failure rate

- average 65
- derated 207

Failure intensity decay parameter 233

Failure intensity as function of time 236

Failure mode and effects analysis (FMEA)  
6

Failure mode effects and criticality analysis (FMECA) 108

Fault

- removal 223
- tolerance 142
- tree analysis 6

Feasibility prediction 109

Field data performance 121

Field performance feedback 110

Field service engineering 310

Format reliability specification 296

Formulating design decisions 108

Funnel arrangement 181

**G**

Generic part types 114

Glide path reliability calculation 327

Glidepath equipment 317

Go-no-go type devices 6

Good packaging 64

Goodness of fit 190

Graph matrix 262

Ground fixed environments 323

**H**

Hamming code 141

Heuristic methods for Reliability Allocation  
144

High pressure oxygen system 87

Human reliability 8

**I**

Incentive contracts 300

Independent events 62

Informal training 314

Information sources for failure rate data 109

In-house test 110

input

- state 224
- space 224
- variable 224

Inspection non-destructive 305

Instantaneous probability of failures 20

Instructions retry step 142

Instrument landing system 316

Intended life 12

Inter-section of two sets 30

Intermittent failures 142

Internal data sources 309

Isoavailability curve 168

Item failure rate 114

**J**

Job knowledge quotient 312

**K**

K-out of m System 61,73

Karnaugh map 91

Keystone Element 103

**L**

Latency period 142

Life cycle cost 4

Life distribution model 201

Linear acceleration 202

Localizer reliability 324

Logarithmic Reliability Improvement 68

Logistic support 108

Logistic time 158

## M

Magnified loading 206

Maintainability 153,154,156,162

-function 159,162

-optimum 159

Maintenance 131

-activity 154

-corrective 155

-emergency 155

-planned 155

-preventive 5,170

-repair 155

-scheduled 155

-support index 158

-unplanned 155

Management

-data 308

-matrix 301

-objective 295

Manufacturability 12

Markov

-availability model 170

-chain 51

-graph 53,163

-model 51,163

-process 51

-three state model 168

Maximum possible flow capacity 268

Mean

-life 14

-life of two component system 82

-operating time 5

-time between failures 16,82,186

-time to first system failure 169

-time to repair 163

-value function 221

-wear out life 14

Measurement of constant failure rate 26

Measuring equipment-multifunction 3

Method

-active element group 109,113

-basic allocation 125

-bayes theorem 103

-cutset 96

-data acquisition 306

-logical signal relations 100

-minimum effort 127

-parts count 109,114

-parts stress 109

-similar circuit 109,113

-similar items 109,113

Minimal

-cut set 88

-path 88,264

Minimize Q (unreliability) 148

Minimizing maintenance requirement 161

Mission cut set cancellation 252

Mission time 16

Model

-expression 118

-linear depreciation 283

-non-linear declining 283

-parameter 117

-parametric 189

Modifiability 217

Most likely value 209

Most probable number 221

MTBF 23

Multifunction Measuring Equipment 3

Mutually exclusive events 91

## N

N-version programming 143

Nomogram 17

Non-series parallel system 87

Normalized

-cartesian product 247

-weight-269

## O

One shot equipment 12

Open and short circuit failures 75

Operating and environmental conditions 5

Operating satisfactorily 5

Operating time 17

Operational readiness profile 153,222,224

Optimum

-availability 153

-configuration 286

-estimate 186

-operating time 17

-production control 303

-replacement time table 174

-values chart 77

Optimum number

- of parallel elements 77
- of series elements 78
- Organization
  - matrix 303
  - R & QC 297
  - top management 297
- Output
  - state 224
  - variable 224
- Overhaul 155
- P**
- Parallel Blocks 61
- Parallel system 67
- Parameters
  - scale 49
  - shape 49
- Part Description 111
- Part operating temperature 112
- Part stress analysis 115
- Parts
  - count method 109,319
  - stress method 109,323
- Path determination 89
- Path tracing 265
- Percent confidence limit 330
- Performance
  - capability 154
  - Index 268
  - poor design 7
- Periodic self test 142
- Phased mission systems 250
- Planned preventive actions 295
- Planned replacement 171
- Planning -time phase 297
- Plans -economical quality control and sampling 304
- Point estimate 196
- Poisson mass function 43
- Poor design 7
- Poor maintenance 7
- Power rule model 206
- Predictive validity 229
- Preliminary design prediction 109
- Present value of the money 280
- Prevention cost 273
- Preventive
  - maintenance policy 7
  - replacement 13

- Probabilistic graph 87
- Probability
  - density function 37
  - factor 129
  - map 91
  - paper 190
- Producers risk 210
- Product law of reliabilities 62
- Product law of unreliabilities 67
- Product improvement program 140
- Program
  - data collection 306
  - quality control 297
  - test and fix 211
- Properties of probability 33
- Provisioning of spares 175
- Q**
- Quality of assumptions 230
- Queuing problem 289
- R**
- Random variable 36
- Rayleigh distribution 24
- Real time 217
- Reconfiguration capability 250
- Redundancy 107
  - component level 72
  - hardware 143
  - introduction 130
  - software 142
  - signal 141
  - structural 140
  - technique 140
  - time 142
- Relationship of calendar time to execution time 244
- Relative frequency 33
- Reliability
  - allocation 122
  - analysis 258
  - apportionment 123
  - block diagram 60
  - cost control 301
  - data 306
  - data bank 308
  - design 218
  - engineering need 2

- expression 327
- generic data 309
- goal 125
- hardware 218
- limitation 121
- limiting items 108
- localizer 324
- logic diagram 60
- management 293
- mathematics 30
- measures 19
- need 2
- objectives 295,313
- optimization 140
- prediction 107
- software 216,218
- standby system 82
- specification format 296
- terminal 246
- test programs 178,182
- testing 178
- Reliability prediction
  - limitations of 121
  - role of 121
- Reliability & capacity integration 268
- Reliability & Quality control facilities 304
- Reliability allocation
  - advantages 123
  - factors 129
  - formula 131
  - role of criticality 137
- Reliability calculation
  - glide path 327
  - localizer 321
- Reliability growth
  - process 211
  - testing 211
- Reliability software models 228
- Repair rate 159
- Replacement
  - intervals 12
  - policies 288
  - theory 288
- Resource usage 242
- Run type 224
- Runway localizer 317

## S

S-coherent binary system 251

- S-independent events 60
- Safety factor 140
- Sample space 83
- Sample space partition 34
- Selection of key personnel 299
- Self loops 88
- Self test periodic 142
- Series parallel block diagram 61
- Set
  - disjoint 31,34
  - finite 30
  - infinite 30
  - inclusion 30
  - mutually exclusive 31,34
  - null 30
  - universal 30
- Similar circuit method 109
- Similar item method 109
- Software prediction packages 120
- Software
  - failures 218
  - fault 218
  - quality 217
  - safety 217
  - reliability 216,225
  - reliability measurement 329
  - reliability models 228
- Spanning tree 246
- Specified tolerance limits 5
- Spurious operations 80
- Stage selection factor 150
- Standby
  - cold 84
  - hot 85
  - sliding 85
  - sliding with AFL 85
  - tepid 85
- State of art factor 130
- State probability equation 168
- State space 50
- Step stress test 208
- Stochastic process 50
- Stress
  - analysis 112
  - derating 115
  - electrical 108
  - non-thermal 205
  - thermal 108
  - level 64
- Structural redundancy 140

Structuring of data 310  
 Sub systems -cost effective choice 285  
 Success function 88  
 Symbolic reliability expression 87  
 System  
   -complexity 7  
   -cost 154  
   -effectiveness 153  
   -k-out of-m 73  
   -non series parallel 87  
   -parallel 67  
   -series 61  
   -series parallel 59,70  
   -standby 81  
   -success function 88

## T

Terminal reliability 90  
 Test  
   -acceptance 209  
   -integrating 180  
   -level of 180  
   -non-replacement 186,199  
   -purpose of 182  
   -reliability 182  
   -replacement 199  
   -report 311  
   -step stress 208  
   -two tailed 188  
 Test equipment design 305  
 Testing  
   -accelerated 201,206  
   -accelerated life 183  
   -actual conditions 180  
   -ambient 180  
   -destructive 179  
   -environmental 180  
   -equipment acceptance 209  
   -life 183  
   -non-destructive 179  
   -of reliability growth 211  
   -peripheral 182  
   -production 180  
   -service life evaluation 184  
   -simulated conditions 180  
   -surveillance 184  
 Thermal aspect 117  
 Thermal design 109  
 Three state Markov model 168

## Time

-active repair 158  
 -administrative 158  
 -calendar 219  
 -clock 219  
 -cycle 166  
 -down 158  
 -logistic 158  
 -of operation 131  
 -program execution 219  
 -repair 159  
 -transition rate 166  
 Time Phased Planning 297  
 Timely corrective actions 295  
 Total probability 34  
 Transient failure 142  
 Transition probability 52

## U

Unavailability 166  
 Understandability of documentation 218  
 Uni-phase system 251  
 Union of sets 30  
 Unreliability 19  
 Use environment 117  
 Use of reliability studies 226  
 Use of samples 307  
 Useful life 13  
 User  
   -friendly 217  
   -oriented 217  
   -oriented view 218

## V

Validity check 142  
 Variable  
   -input 224  
   -output 224  
 Venn diagram 31  
 Vertex cutset 247

## W

Wear out failures 12  
 Weightage factor 129  
 Weighted  
   -reliability index 268  
   -reliability measure 269

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