THE

RELIABILITY ENGINEER

SOLUTIONS TEXT

SECTION VI

MODELING & PREDICTION-- TEST QUESTIONS

6.1. The local telephone company has a standby generator with a failure rate of 0.001 failures/hour to provide electrical power in case of a service interruption. History has shown that the electrical service has a failure rate of 0.00023 per hour. Assuming perfect switching, what is electrical power reliability for a year?

a. 0.133
b. 0.173
c. 0.203
d. 0.453

Solution: There are 8760 hours in a year. The reliability of the total system for a year is:

$$R_t = e^{-\lambda_1 t} + \frac{\lambda_1}{\lambda_2 - \lambda_1}\left(e^{-\lambda_1 t} - e^{-\lambda_2 t}\right)$$

$$R_{8760} = e^{-0.00023 \times 8760} + \frac{0.00023}{0.001 - 0.00023}\left(e^{-0.00023 \times 8760} - e^{-0.001 \times 8760}\right)$$

$$R_{8760} = 0.133 + 0.299 \times \left(0.133 - 0.0002\right) = 0.133 + 0.040 = 0.173$$

Answer b is correct.

Reference: *CRE Primer*, Section VI - 16.

6.2. If component life characteristics change from the time of the original reliability data capture, this means that:

a. The original reliability data may still be used, but with caution
b. The original reliability data may still be used, but modified with the new data
c. The original reliability data may be used as a baseline for corrected calculations
d. New reliability data must be generated

Solution: The general concept of reliability data is highlighted by this question. The basis for component or assembly life predictions is that the characteristics remain constant. The consistency of these characteristics allows its use to model and predict future behavior of the general population. If the life characteristics change the previous reliability data is of no use.

Answer d is correct.

Reference: *CRE Primer*, Section VI - 2.

6.3 Two identical electrical generators are delivering power to a Gulf of Mexico oil rig. The failure rate of one generator in the shared load system is 0.0002 failures per hour. If one generator must carry the whole load, the failure rate increases to 0.0009 failures per hour. What is the reliability of the system for 168 hours (one week)?

a. 0.935
b. 0.950
c. 0.972
d. 0.995

Solution: Use the shared load parallel system formula.

$$R_t = e^{-2\lambda_1 t} + \frac{2\lambda_1}{2\lambda_1 - \lambda_2}\left(e^{-\lambda_2 t} - e^{-2\lambda_1 t}\right)$$

$$R_{168} = e^{-2 \times 0.0002 \times 168} + \frac{2 \times 0.0002}{2 \times 0.0002 - 0.0009}\left(e^{-0.0009 \times 168} - e^{-2 \times 0.0002 \times 168}\right)$$

$$R_{168} = 0.935 + (-0.8)(0.860 - 0.935) = 0.995$$

Answer d is correct.

Reference: *CRE Primer*, Section VI - 19.

6.4 Which of the following is a correct statement regarding Markov modeling?

a. The analysis process parallels that of FTA (fault tree analysis)
b. The analysis considers only operating and failed states
c. The final state total probability is often less than 1
d. The final probability of success is proportional to the total number of states

Solution: This question requires general knowledge of Markov analysis. Answer **b** is correct, only operating and failed states are considered. Answer **d** is a distracter choice. Answer **c** is incorrect, the final state (or step) probability should equal 1. In fact, each state (or step) probability should equal 1. The only similarity between the Markov model and FTA is that both determine failure rates and often use tree diagrams for comprehension and explanation. However, the approaches and objectives of the two techniques are different.

Answer b is correct.

Reference: *CRE Primer,* Section VI - 39/40.

6.5. A reliability expression for three independent components in parallel with component reliability R is:

a. 3R
b. $3R - 3R^2 + R^3$
c. $[1-(1-R)^2]+R$
d. $(1-R)^3$

Solution: The reliability of three components in parallel is expressed as $R_{system} = 1 - (1 - R)^3$ which equates mathematically to $R_{system} = 3R - 3R^2 + R^3$.

Proof:

$$R_{system} = 1 - (1 - R)^3$$
$$= 1 - (1 - R)(1 - 2R + R^2)$$
$$= 1 - (1 - 3R + 3R^2 - R^3)$$
$$= 3R - 3R^2 + 3R^3$$

Answer b is correct.

References: *CRE Primer*, Section VI - 10 (and logic). 1980 and 1976 published CRE exam questions (modified).

6.6. A person takes a car to the repair shop and before any repair, it stops doing what it was previously doing. This is an example of:

a. Catastrophic failure
b. Degradation failure
c. Intermittent failure
d. Drift failure

Solution: This question illustrates the various types of failure classification. A failure that occurs, then mysteriously corrects itself is called an intermittent failure.

Answer c is correct.

Reference: *CRE Primer*, Section VI - 4.

6.7. A system has three components having reliability values A, B, and C with independent failure rates. These components operate in series. Therefore, the reliability of the system, R, can be calculated from which of the following equations?

a. R = A + B + C
b. R = A x B x C
c. R = 1/A x 1/B x 1/C
d. R =(1-A) (1-B) (1-C)

Solution: Simple series and parallel calculations are presented below.

(Series) R = A x B x C

(Parallel) R = A + B + C - AB - AC - BC + ABC

or (Parallel) R = 1 - [(1-A)(1-B)(1-C)]

The answer **a** equation is not bounded between 0 and 1 and therefore cannot be a reliability function. The answer **c** equation always exceeds 1 unless A = B = C = 1. The equation in answer **d** is missing the number 1 at the beginning to be a parallel configuration..

Answer b is correct.

References: *CRE Primer*, Section VI - 6/8. Published CRE exam, question 127 (modified).

6.8. Physics-of-failure is a methodology that focuses primarily upon problems associated with:

a. The difficulty in understanding physics
b. Component and system failures
c. Ways to train engineers to use software tools
d. Calculating costs associated with failures

Solution: Physics-of-failure deals with potential failures of components or systems and ways to prevent them. While use of software, understanding physics, and cost calculations may be involved, the prime issue is to prevent failures.

Answer b is correct.

Reference: *CRE Primer*, Section VI - 35/38.

6.9. A series system consists of the following independent components (units of time in hours):

Components	No. of Components	Failure Information
A	3	$\lambda = 3 \times 10^{-6}$
B	2	$\theta = 5 \times 10^{5}$
C	8	$\lambda = 5 \times 10^{-7}$
D	1	$\lambda = 2 \times 10^{-5}$
E	1	$\theta = 1 \times 10^{5}$
F	3	$\lambda = 4 \times 10^{-6}$

What is the reliability of the system for 1000 hours of operation?

a. 0.9927
b. 0.9834
c. 0.9427
d. 0.9384

Solution: This problem requires a straightforward calculation for reliability after determining the system failure rate.

Equation:

$$R_{1000} = e^{-\sum n\lambda t}$$

Where, Σ = sum λ = failure rate   n = number of components   t = total operating time

For a serial system, the failure rate of an assembly is the sum of the failure rates of all parts comprising the assembly. Convert the MTBF (q) for components "B" and "E" into failure rates (1/MTBF). Multiply each component failure rate by its number of components. This is a series system, so the resultant system failures are additive. Using the reliability formula, one finds the answer to be 0.9427 for 1000 hours of operation. Refer to the table below:

Comp	n	λ	$n\lambda$
A	3	3×10^{-6}	9×10^{-6}
B	2	2×10^{-6}	4×10^{-6}
C	8	0.5×10^{-6}	4×10^{-6}
D	1	20×10^{-6}	20×10^{-6}
E	1	10×10^{-6}	10×10^{-6}
F	3	4×10^{-6}	12×10^{-6}

$\Sigma n\lambda = 59 \times 10^{-6}$

$$R_{1000} = e^{-\sum n\lambda t}$$

$$R_{1000} = e^{-59 \times 10^{-6} \times 1000} = e^{-0.059} = 0.9427$$

Answer c is correct.

References: *CRE Primer* Section VI - 8. 1980 published CRE exam, question 1.

6.10. A system consists of 4 parallel units each having a reliability of 0.80. The system can still complete its mission with only 2 units functioning. If the failure rate is constant and failures are independent then the system reliability will be:

a. 0.4096 c. 0.8192
b. 0.5376 d. 0.9728

Solution: This question requires knowledge of the binomial distribution. There are several ways to solve this problem. The quickest is to recognize that this is a binomial based voting system. If one turns to a binomial table

Where: n = 4
r = 2 (means 0, 1, or 2 fail)
P = 0.9728

The problem can also be solved by determining λ for each component t = 1 and plugging into the equation below:

$R = e^{-\lambda t}$ $R_S = 3e^{-4\lambda t} - 8e^{-3\lambda t} + 6e^{-2\lambda t}$
$\ln 0.8 = -\lambda$ $R_S = 3(e^{-0.8924}) - 8(e^{-0.6693}) + 6(e^{-0.4462})$
$\lambda = 0.2231$ $R_S = 1.2290 - 4.0965 + 3.8403 = 0.9728$

Answer d is correct.

References: *CRE Primer,* Section VI - 13. Old CRE Brochure question (modified and corrected).

6.11. Your company decides to use the GIDEP program. Before this program can be used fully, your company must:

a. Make sure that your computer is capable of the speed and memory requirements
b. Participate in the program by providing data, reports, test results, etc.
c. Sign up at least 50% of your management personnel in the program
d. Have audio and visual equipment suitable to receive and distribute the program

Solution: This question deals with sources of public reliability data. The GIDEP program is a government sponsored program to share data among participating companies. To fully use the information the company must actively participate.

Answer b is correct.

Reference: *CRE Primer*, Section VI - 5.

6.12. A life test on 9 units produced the following times to failure:

9.3×10^3 hours
9.4×10^3 hours
9.6×10^3 hours
9.8×10^3 hours
10.0×10^3 hours
10.3×10^3 hours
10.7×10^3 hours
10.9×10^3 hours
10.0×10^3 hours

Assume that a normally distributed wearout model applies, and that the variance (σ^2) of this distribution is known to be 0.36×10^6 hours^2. At what time (tw) would one replace these units to be at least 90% confident that the reliability of the units remains at least 0.99?

a. 7.28×10^3 hours
b. 8.34×10^3 hours
c. 63.8×10^3 hours
d. 5.14×10^3 hours

Solution: This problem requires a complex calculation for reliability given a confidence level for life test on 9 units. A visual inspection of data and the answers would eliminate choice **c**.

Given:

$$\bar{T} = 10{,}000 \text{ hours}, \ \sigma = 600 \text{ hours and } n = 9$$

90% Lower Confidence

$$\begin{aligned} T_{0.90} &= \bar{T} - \left(z \times \frac{\sigma}{\sqrt{n}} \right) \\ &= 10{,}000 - \left(1.28 \times \frac{600}{3} \right) \\ &= 10{,}000 - 256 \\ &= 9{,}744 \text{ hours} \end{aligned}$$

99% Reliability

$$\begin{aligned} T(tw)_{0.99} &= T_{0.90} + (z \times \sigma) \\ &= 9{,}744 + (-2.33 \times 600) \\ &= 9{,}744 - 1{,}398 \\ &= 8{,}346 \text{ hours} \end{aligned}$$

Answer b is correct.

References: *CRE Primer* Sections VI - 53/54. Old ASQ CRE Brochure question.

6.13. Failures occur on a system at 75, 79, 83, and 85 hours. Assuming normality, one sided and unbiased, the lower tolerance limit for 95% reliability with 90% confidence for this sample is:

a. 96 hours c. 100 hours
b. 60 hours d. 63 hours

Solution: This problem requires a complicated calculation for tolerance limits. The best solution is with the use of the K Tables.

$$TL = \bar{X} - KS$$
$$TL = 80.5 - (3.957)(4.4347) = 62.9552$$

Where, K = a constant found in Section X - 14 of *CRE Primer*. Using a scientific calculator, calculate the mean and sample standard deviation for the four numbers given. The mean is 80.5 and standard deviation (n-1) is 4.4347. Using the K Tables for n = 4, the constant for 0.95 reliability, and a confidence limit of 0.90 equals 3.957. Multiplying this constant by the sample standard deviation = 17.548. Subtracting from the mean yields 62.952.

Answer d is correct.

References: *CRE Primer*, Sections VI - 55/56 and X - 14. 1980 published CRE exam, question 51 (slightly modified).

6.14. A system contains 3 identical motors of which 2 of the motors are in standby redundancy. A standby motor is switched in by failure of the preceding motor. Assume the switching device has a reliability of 1.00 and the motors have a constant failure rate of 0.04 per mission and motors cannot fail while on standby, what is the system reliability?

a. 0.96049 c. 0.99999
b. 0.99649 d. 0.99909

Solution: This problem requires a calculation for standby redundancy with equal failure rates and perfect switching. Note that t = 1 because one mission is involved.

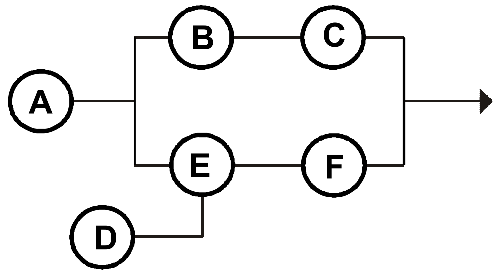
Equation:

$$R_t = e^{-\lambda t} \sum_{i=0}^{n-1} \frac{(\lambda t)^i}{i!}$$
$$= e^{-\lambda t} \left[\frac{(\lambda t)^0}{0!} + \frac{(\lambda t)^1}{1!} + \frac{(\lambda t)^2}{2!} \right] = e^{-\lambda t} \left[1 + \lambda t + \frac{(\lambda t)^2}{2} \right]$$
$$= e^{-0.04} \left[1 + 0.04 + \frac{(0.04)^2}{2} \right] = 0.96079 \, [1.0408]$$
$$= 0.99999$$

Answer c is correct.

References: *CRE Primer*, Section VI - 16/17. 1980 and 1976 published CRE exam problems (slightly modified).

6.15. Successful operation of systems S, illustrated below, required that at least 1 out of the 3 through paths be good. The 3 paths are ABC, AEF, and DEF:



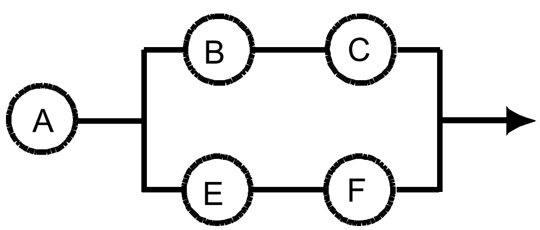
If A and D each have predicted reliability of 0.95, and B, C, E, and F each have a predicted reliability of 0.99, find the reliability (R_S) of the system using Bayes' Theorem. (You may use the approximation for your calculations.)

a. 0.9997
b. 0.9000
c. 0.9962
d. 0.9700

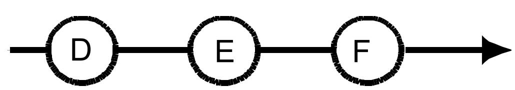
Solution: This problem requires a calculation for a parallel/series circuit using Bayes' Theorem. There are several potential solutions. Two are described below:

Consider component A to be the keynote component.

If A is good:



If A is bad:



$P_S = P_{A\ GOOD} \times R_{A\ GOOD} + P_{A\ BAD} \times R_{A\ BAD}$
$= (0.95)(1.0)(1-U_{BCEF}) + (0.05)(R_{DEF})$
$= (0.95)(1.0)(0.9996) + (0.05)(0.931095)$
$= 0.949624 + 0.046555 = 0.996179 = 0.9962$

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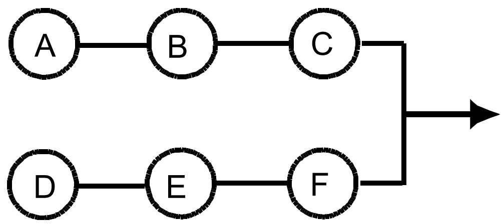
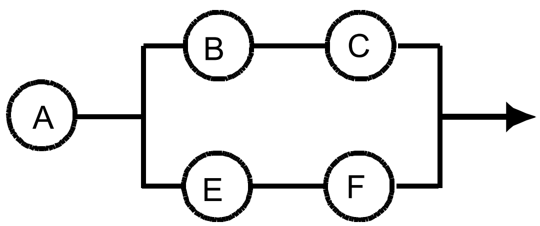
6.15. Continued.

Consider component D to be the keynote component.

If D is good:



If D is bad:



$$
\begin{aligned}
PS &= P_{D\ GOOD} \times R_{D\ GOOD} + P_{D\ BAD} \times R_{D\ BAD} \\
&= (0.95)(1 - U_{ABCDEF}) + (0.05)(0.95)(1 - U_{BCEF}) \\
&= (0.95)(0.998628) + (0.05)(0.95)(0.9996) \\
&= 0.948697 + 0.047481 = 0.996178 = 0.9962
\end{aligned}
$$

Answer c is correct.

References: *CRE Primer*, Section VI - 20/23. This is a modified ASQ CRE Brochure question.

6.16. To estimate the individual part failure rate using the parts stress method which of the following is NOT necessary?

a. Part base failure rate
b. Environmental stress factor
c. Part quality factor
d. Parts count prediction

Solution: Note that a negative response is requested. This question requires basic knowledge of the parts stress method and an answer review.

The following expression is used :

$$\lambda_p = \lambda_b \Pi_Q \Pi_e$$

Where: λ_p = estimate of individual part failure rate
λ_b = base failure rate
Π_Q = quality factor from above
Π_e = environmental stress factor

A parts count prediction pertains to the failure rate of a system in series.

Answer d is the correct, incorrect, choice.

Reference: *CRE Primer*, Section VI - 49/50.

6.17. Internal sources of component reliability data are:

a. Prototype and reliability growth
b. Industry and public data
c. Government furnished data
d. Warranty returns and customer complaints

Solution: This question requires familiarity with data sources and an answer review. The key phrase is "internal sources." Answers **b**, **c**, and **d** are generally external sources of data. Answer **a** is the best choice.

Answer a is correct.

Reference: *CRE Primer*, Sections VI - 2/5.

6.18. A system has three components in active parallel. The system functions properly if at least one of the components functions properly. Components that function properly are statistically independent; however, if one component fails, it causes the other two components to fail with probability 1-p. If two components fail, they cause the other component to fail with probability $1-p^2$. The reliability, R, of each component is 0.9, and p is 0.7. The reliability of the system is:

a. 0.970
b. 0.899
c. 0.989
d. 0.912

Solution: The information provided describes a shared load active parallel system. Upon the failure of a component the surviving items are left to carry the entire load and, as a result the failure is increased.

Equation:

$$P(x|p) = \binom{n}{x} p^x (1 - p)^{n-x}, \text{ for } x = 0, 1, 2, ..., n$$

Where, n = the sample size
x = the number of failures in the test (sometimes called r or y)
p = the probability of failure (unreliability)
(1 - p) = the probability of success (reliability)

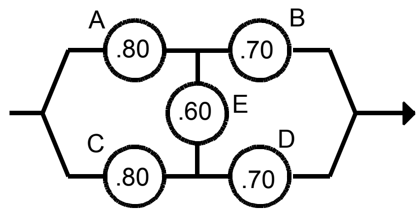
The information in the problem is stated in terms of probability (not λ or time). Thus, some logic is required. The binomial distribution is used.

Failures	Probability of Occurrence		Survival Probability	Reliability
0	(1) $(0.1)^0 (0.9)^3$	X	1	= 0.7290
1	(3) $(0.1)^1 (0.9)^2$	X	(0.7)	= 0.1701
2	(3) $(0.1)^2 (0.9)^1$	X	$(0.7)^2$	= 0.0132
			ΣR =	0.9123

Answer d is correct.

References: *CRE Primer*, Sections VI - 19 and III - 55/57 and a couple of good reliability engineers. Old ASQ CRE Brochure question (slightly modified).

6.19. The reliability block diagram of a system is given in the following figure with component reliabilities given in each circle.



The reliability of the system is:

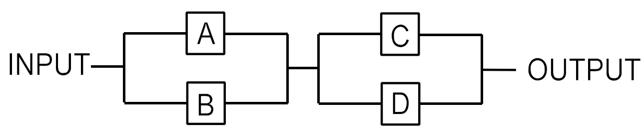
a. 0.847
b. 0.823
c. 0.792
d. 0.686

Solution: This problem requires a complex calculation using Bayes Theorem.

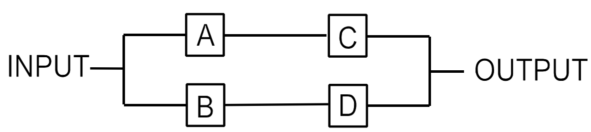
If the keynote component is identified as (E), the probability of system success is:

P(S) = {P (system success if E is good) x P (E is good) + P (system success if E is bad) x P (E is bad)}

If E is good



If E is bad



Step 1 $= P_{(\text{success if E is bad})}\ P_{(\text{E is bad})}$

$= [(R_A + R_C - R_AR_C)(R_B + R_D - R_BR_D)]\ [0.60]$

$= [(0.8 + 0.8 - 0.64)(0.7 + 0.7 - 0.49)]\ [0.60]$

$= [(0.96)(0.91)]\ [0.60]$

$= 0.5242$

6.19. Continued

Step 2 $= P_{(\text{success if E is bad})} P_{(\text{E is bad})}$

$= [0.8064] [0.4]$

$= 0.3226$

* Parallel calculation left to the student

System Reliability = Step 1 + Step 2

$= 0.5242 + 0.3226$

$= 0.8468$

Answer a is correct.

References: *CRE Primer*, Section VI - 20/23. Old ASQ CRE brochure question.

6.20. MTTF may change over time as a system operates. For a parallel combination of two items the MTTF is best described as:

a. Stable and unchanging over time
b. Increasing with time to a stable level
c. Decreasing with time to a stable level
d. Never reaching a stable level

Solution: For a simple parallel combination, MTTF of two items increases over time until it ultimately reaches a stable level.

Answer b is correct.

Reference: *CRE Primer*, VI - 47/48.

