Happiness is taking the reliability final exam.

Reliability Engineering I

ENM/MSC 565

Review for the Final Exam
Vital Statistics

• What – R&M concepts covered in the course
• When –
  – Monday April 29 from 4:30 – 6:00 pm
• How
  – open book
  – 50 questions (true-false and multiple choice)
• Distant Learning - Register on-line

Reliability engineering students enjoying another challenging exam.
Chap 2.1 - 2.6

- the reliability function, $f(t)$, $F(t)$
- MTTF, median, mode, std dev
- design life
- hazard rate function, $\lambda(t)$
  - bathtub curve
  - Cumulative and average failure rate
- conditional reliability
  - residual MTTF
Chap 3.1, 3.2, 3.4, 3.5, 3.6

- CFR model
  - memoryless property
- failure modes
- two-parameter exponential
- Poisson process
  - gamma (Erlang) distribution
- two-component CFR redundant system
Chap 4.1, 4.2, 4.3, 4.4

• Weibull
  – properties
    • mean, median, mode, $R(t|T)$, etc.
  – failure modes
  – 3-parameter
  – 2 component redundant

• Minimum Extreme Value

• Normal
  – properties
  – central limit theorem

• Lognormal
  – Relationship to the normal
  – properties

• Gamma distribution

The discriminating student will recognize $f(t)$, $F(t)$, $R(t)$, and $\lambda(t)$ for each of these distributions.
Chap 5.1 - 5.3

- serial configuration
- parallel configuration
- combined series-parallel
  - high-level vs. low level
  - k out-of-n redundancy
- reliability block diagrams
- complex configurations
  - decomposition
  - Enumeration
Chap 6.1 - 6.4

- Markov analysis
- load-sharing system
- standby systems
  - identical standby units
  - standby with switching failures
- Degraded systems
Chap 7.1 - 7.4

- covariate models
- static models
  - 3 cases - random stress and strength
  - Theoretical distributions
- dynamic models
  - periodic loads
  - random loads
- physics-of-failure models
Chap 8.1 - 8.5

• reliability design
• reliability specifications
  – system effectiveness
  – life-cycle costs
• reliability allocation
  – ARINC method
  – AGREE method
• design methods
  – parts & material selection
  – derating
  – stress-strength analysis
  – redundancy
• Failure mode and effects analysis (FMEA)
• Fault Tree Analysis (FTA)
Chap 9.1 - 9.6, omit 9.3.3

• repair distribution
• stochastic point processes
  – renewal process
  – minimal repair
• system MTTR
• reliability under PM
• state-dependent systems with repair
  – active redundant
  – standby system

Pointing at a stochastic process
Chap 10.1 - 10.3

• Maintainability design
  – specifications
  – maintenance concepts (inherent and secondary)
  – life cycle cost models

• Design methods
  – fault isolation
  – standardization & interchangeability
  – modularization
  – accessibility
  – repair vs. replace
  – replacement model
  – PM model

• Human Factors
Chap 11.1 - 11.4

- availability
  - point
  - interval
- steady-state availability
  - inherent
  - achieved
  - operational
- exponential model
- system availability
  - steady-state rate diagrams
- inspect and repair model
Chap 12.1 - 12.2

- empirical analysis of complete ungrouped data
  - plotting positions
- empirical analysis of complete grouped data
- empirical analysis of censored ungrouped data
  - singly vs. multiply censoring
    - type I vs. type II testing
  - product limit estimator
  - Kaplan-Meier
  - rank adjustment
Chap 13.1 - 13.4, 13.6

- reliability life testing
- test time calculations
  - length of test
  - number failures
- burn-in test
  - specification model
  - cost model
- accelerated life testing
  - accelerated cycles
  - constant stress models
  - Arrhenius and Eyring model
  - degradation models
  - cumulative damage models
Chap 14.1, 14.3, 14.4

- reliability growth process
- Duane model
- AMSAA model

A reliable growth process
Chap 15.1 - 15.3

• Identifying candidate distributions
  – use of descriptive stats
  – probability plots and least-squares
• parameter estimation
  – maximum likelihood estimation

Probably a lily plot
Chap 16.1 - 16.6

- Chi-square goodness-of-fit test
- Bartlett’s test for exponential
- Mann’s test for Weibull
- K-S test for normal and lognormal
- Trend and GOF for power law process model

A model of the powerful process of the law
Students resting before the big reliability test.

Recall that a renewal process consists of...

I heard that the reliability test is easy.
Practice Exam Q1

Two wide bulls in parallel having identical shape parameters

- A system composed of two Weibulls in parallel will also be Weibull only if both components have identical shape parameters. True or False?
- Ans. False, the redundant system will not be Weibull regardless of the parameters of the two Weibull components.
Practice Exam Q2

The \( \Pr\{T > T_0 + t \mid T > T_0\} \) is equal to which one of the following expressions:

a. \( \frac{R(t)}{R(T_0)} \)
b. \( \frac{R(T_0)}{R(t+T_0)} \)
c. \( \frac{R(t)}{R(t+T_0)} \)
d. \( \frac{R(t+T_0)}{R(t)} \)
e. \( \frac{R(t+T_0)}{R(T_0)} \)
f. None of the above

g. =

- Ans. e. (equation 2.17)
- \( \Pr\{T > T_0 + t \mid T > T_0\} = R(t|T_0) \)
Which one of the following relationships is **incorrect**?

a. \( F(t) = 1 - R(t) \)

b. \( R(t) = \exp \left[ - \int_0^t \lambda(x) dx \right] \)

c. \( f(t) = \frac{-dF(t)}{dt} \)

f. \( f(t) = \frac{dF(t)}{dt} \)

d. \( \lambda(t) = \frac{f(t)}{1 - F(t)} \)

e. **They are all correct**

• Ans. c.
Practice Exam Q4

- The hazard rate function for the normal distribution is always an increasing function. True or False?
- Ans. True, see fig. 4.3(c)

An increasing hazard rate
Practice Exam Q5

- In a series configuration, the system reliability will always be equal to or greater than the least reliable component. True or False?

- Ans. False, see equation 5.1
Practice Exam Q6

Which of the following is not considered a reliability design method:

a. Parts selection
b. Derating
c. Accessibility
d. Choice of Technology
e. Use of redundancy
f. None of the above

• Ans. c. Accessibility is a maintainability design method

Don  Dave  Dee
3  1  2
Dee rating
Practice Exam Q7

- A renewal process is a stochastic point process in which the random variables representing the time between failures are independent and identically distributed. True or False?

- Ans. True, see Section 9.3.1
A system composed of two active redundant components each having an availability equal to “A” has an availability equal to:

- a. $A^2$
- b. $1-A^2$
- c. $1-(1-A^2)$
- d. $1-(1-A)^2$
- e. None of the above

• Ans. d. see equation 11.16

Two parallel and active available components
Practice Exam Q9

• Which of the following transformations would be used in a least-squares fit of the lognormal distribution:

   a. \( x_i = t_i \) and \( y_i = \ln \ln \left[ 1/(1-F(t_i)) \right] \)
   b. \( x_i = \ln t_i \) and \( y_i = \ln \ln \left[ 1/(1-F(t_i)) \right] \)
   c. \( x_i = t_i \) and \( y_i = \Phi^{-1}[F(t_i)] \)
   d. \( x_i = \ln t_i \) and \( y_i = \Phi^{-1}[F(t_i)] \)
   e. None of the above

• Ans. d. see equation 15.6
Practice Exam Q10

- Since the objective in goodness-of-fit testing is to reject the null hypothesis, the level of significance should be kept small in order to control the probability of making a Type I error. True or False?

- Ans. False, the objective is not to reject the null hypothesis.
Practice Exam Q11

Maximum Likelihood Estimates are preferred to least-square estimates because they are always unbiased. True or False?

• Ans. False, MLE’s may be biased.

Very likely a Maximum hood
Practice Exam Q12

• The Chi-square goodness-of-fit test cannot be used when multiply censored data is present. True or False?

  \[ 45\text{¢} \times 60\text{¢} = 2700\text{¢} \]

  multiply cents or red data

• Ans. True, the test is not designed for multiply censored data. There is no way to determine which “failure time” cells to place the censored units.
Practice Exam Q13

• The parameters of the AMSAA model are estimated using maximum likelihood estimators while the parameters of the Duane model are estimated using least-squares. True or False?

• Ans. True, the Duane model is an empirical model while the AMSAA model is a theoretical model.
Practice Exam Q14

Life tables are used to estimate the reliability of:

a. Ungrouped complete data
b. Grouped censored data
c. Ungrouped censored data
d. A minimal repair component
e. Linked networks

• Ans. b. see Section 12.2.4
Practice Exam Q15

• The repair versus discard model compares the cost of the two alternatives based upon an estimate of the number of failures over the life of the component. True or False?

• Ans. True, see Section 10.2.4
The primary objective of burn-in testing is to identify the failure modes of production units in order to improve product design. True or False?

Answer: False, the primary objective is to increase the mean residual time.
Which of the following would not be considered a step in conducting a FMECA?

a. Product or process definition
b. Allocating system reliability to components
c. Identification of failure modes
d. Assessment of the effect
e. Classification of severity
f. They are all steps in a FMECA

Answer: b. Allocating system reliability to components is part of the reliability design process but not part of a FMECA.
Practice Exam Q18

Let $E_i$ = the event, the $i^{th}$ component fails where $E^c$ is the complementary event. Then the event “at least one component from among 4 components fails” can be expressed as:

a. $E_1 \cap E_2 \cap E_3 \cap E_4$

b. $E_1^c \cup E_2^c \cup E_3^c \cup E_4^c$

c. $1 - E_1 \cap E_2 \cap E_3 \cap E_4$

d. $E_1^c \cap E_2^c \cap E_3^c \cap E_4^c$

e. $(E_1^c \cap E_2^c \cap E_3^c \cap E_4^c)^c$

Answer: e. The intersection of the complementary events is the event that none fail. The complement to none failing is at least one failing.
If stress is a constant $s$ and strength is a random variable $Y$ having PDF, $f_y(y)$, then the static reliability, $R$, can be expressed as:

a. $R = \int_0^s f_y(y)\,dy$

b. $R = \int_0^\infty f_y(y)\,dy$

c. $R = 1 - \int_s^\infty f_y(y)\,dy$

d. $R = F_y(s)$ where $F_y(y)$ is the CDF

e. $R = 1 - F_y(s)$ where $F_y(y)$ is the CDF

answer: e. one minus the probability that the strength is less than the stress level gives the reliability.
In goodness-of-fit testing, a more powerful test will reject an incorrect probability distribution with greater probability than a less powerful test. True or False?

answer: True, the power of a test is its probability to correctly reject the null hypothesis.
Bonus Question #1

• Which one of the following is not a measure of maintainability
  a) MTTR
  b) $H(t_p) \leq p$ where $H(t)$ is the repair time distribution
  c) $MTR = MTTR + SDT + MDT$
  d) $R_m(t)$, the reliability under Preventive Maintenance
  e) Maintenance hours per operating hour
  f) Maintenance cost per operating hour
Bonus Question #2

A low level redundant system introduces additional failure modes over a high level redundant system and therefore has a lower reliability. True or False?
Bonus Question #3

Which of the following is a valid reason for fitting a theoretical distribution to a sample of failure times rather than fitting an empirical distribution:

a) Management says all failures are Weibull
b) The empirical distribution did not give the desired results
c) Failures must always obey one of theoretical distributions
d) The sample passed a goodness-of-fit test for the theoretical distribution
e) None of the above
Bonus Question #4

For a k out of n redundant system with identical component reliabilities R, the probability of a system failure is given by:

a. \[ \sum_{i=k}^{n} \binom{n}{i} R^i (1 - R)^{n-i} \]

b. \[ \sum_{i=0}^{k} \binom{n}{i} R^i (1 - R)^{n-i} \]

c. \[ 1 - \sum_{i=0}^{k} \binom{n}{i} R^i (1 - R)^{n-i} \]

d. \[ 1 - \sum_{i=k}^{n} \binom{n}{i} R^i (1 - R)^{n-i} \]
Bonus Question #5

- Which one of the following is **not** a property of maximum likelihood estimators (MLE)?
  a) Consistent
  b) Invariant
  c) Best asymptotically normal
  d) Unbiased
  e) Able to accommodate censored data
The Last Bonus Question

Derive a new reliability model which will insure failure free operation of any component over its economic life. Prove mathematically that it is superior to anything available today. Show that your model will handle all types of failure modes and can be easily modified to handle reliability under repair, preventive maintenance, standby and load-sharing conditions. Name your model after your instructor who made it all possible.
Are You Ready for The Exam?

Only 5 minutes left and I am on question 12. I wish I had studied more.

The MLE of the beta value clearly showed a DFR. Therefore, the prince and the princess…

This student studied too long.
Grandpa, can you tell me the story again about your days as a reliability engineer when you maximized the Corporation’s profits using covariate models, stochastic point processes, and reliability growth tests based upon maximum likelihood estimates?