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ENRE 640 - COLLECTION AND ANALYSIS OF RELIABILITY DATA

DESCRIPTION

Reliability data collection and analysis is of high (practical) importance in many essential engineering tasks including but not limited to: design alternatives evaluation, failure root cause analysis, early detection of field reliability problems, warranty reserve allocation and others. The course teaches nonparametric and parametric statistical procedures of reliability data analysis for both non-repairable and repairable systems. It covers test data analysis (including accelerated and degradation testing) as well as field data analysis (including warranty data and reliability surveys). Lecture material is illustrated by numerous case studies from real-world reliability applications. Reliability industry standard software programs are utilized throughout the course. (Pre-requisites: ENRE-602)

COURSE STRUCTURE

1. **Introduction to statistical analysis of reliability data**
   - 1.1. Practical importance of reliability data analysis
     - 1.1.1. Design alternative/improvement evaluation
     - 1.1.2. Reliability target demonstration (design life confirmation)
     - 1.1.3. Root cause analysis & future failure avoidance
     - 1.1.4. Identification of emerging reliability concerns & recall decision making
     - 1.1.5. Warranty cost forecasting & required warranty reserve
     - 1.1.6. Optimal maintenance schedules & spare stock allocation
   - 1.2. Review of functions of random variables and their practical use
     - 1.2.1. Probability density function (and its relation to a histogram)
     - 1.2.2. Cumulative distribution function (and its relation to probability of failure)
     - 1.2.3. Cumulative hazard function (and failure mode/trend inferences)
     - 1.2.4. Mean-time-to-failure (MTTF) and Mean-residual-life (MRL)
     - 1.2.5. Failure-time distribution percentile (quantile) and Bq life
     - 1.2.6. GINI Index in reliability applications (Ref. Kaminskiy & Krivtsov, 2011)

2. **Nonparametric estimation for non-repairable components**
   - 2.1. Complete vs. incomplete (censored) data
     - 2.1.1. Types of censoring: left, right, interval
     - 2.1.2. Censoring time estimation using competing risk model (Ref. Krivtsov & Case, 1999)
   - 2.2. Nelson-Aalen estimation of reliability function for right-censored data
     - 2.2.1. Case study: Leather seats durability
   - 2.3. Kaplan-Meier estimation of reliability function for right-censored data
     - 2.3.1. Case study: Peculiarities of censored data analysis in engineering (Ref. Krivtsov & Case, 1999)
   - 2.4. Confidence intervals of reliability function (Greenwood formula)
     - 2.4.1. Case study: Peculiarities of censored data analysis in engineering (cont'd from 2.3.1)
   - 2.5. Turbull estimation for left-censored and interval-censored data
     - 2.5.1. Case study: Case study: Peculiarities of censored data analysis in engineering (cont'd from 2.3.1)
   - 2.6. Binomial distribution and its relation to nonparametric reliability estimation
     - 2.6.1. "Success Run Theorem"
       - 2.6.1.1. Sample size implications
     - 2.6.2. Test for a difference between two proportions
       - 2.6.2.1. Case Study: Proportion of product quality complaints from customer survey data

3. **Parametric distribution estimation for non-repairable components**
   - 3.1. Exponential distribution
     - 3.1.1. Time independent failure rate scenarios
       - 3.1.1.1. Case study: Body panel paint scratch
     - 3.1.2. Point and interval estimation of the scale parameter
     - 3.1.3. Case study: Electronic module reliability
   - 3.2. Weibull distribution
     - 3.2.1. Fréchet-Weibull- Gnedenko

        - 3.2.2. Least squares (LSQ) estimation and Weibull Probability Paper
            - 3.2.2.1. Case study: Automotive battery reliability (cont'd from 2.3.1)
        - 3.2.3. Maximum likelihood estimation (MLE)
        - 3.2.4. Fisher matrix based confidence intervals on reliability function
            - 3.2.4.1. Case study: estimating Weibull distribution under zero failure test scenarios (Nelson, 1985)
        - 3.2.5. LSQ vs. MLE: pros and cons
            - 3.2.5.1. Case study: Chime alarm pin
            - 3.2.5.2. Case study: A Comparison of MLE and Median Rank Regression (Ref. Genschel & Meeker, 2010)

4. Parametric distribution estimation for non-repairable components (cont'd)

- 4.1. Lognormal and Normal distributions
    - 4.1.1. Least squares estimation
        - 4.1.1.1. Stress-Strength (demand-capacity) analysis
        - 4.1.1.2. Case study: Fatigue crack propagation
    - 4.1.2. Maximum likelihood estimation
        - 4.1.2.1. Case study: Design improvement evaluation – testing the difference in scale parameters
- 4.2. Special parametric forms of failure times distributions
    - 4.2.1. Rayleigh distribution (linear hazard function)
    - 4.2.2. Spline of hazard functions (Constrained Quadratic Spline, Ref. Krivtsov, et al., 2008)
    - 4.2.3. Distributions with a threshold parameter
- 4.3. Selecting appropriate distribution
    - 4.3.1. Physics of failure considerations
    - 4.3.2. Anderson-Darling goodness of fit test
    - 4.3.3. Goodness of fit based on AIC and BIC
- 4.4. Mixture of parametric distributions
    - 4.4.1. Limited Failure Population model
    - 4.4.2. Populations Mixture Model (Case study: Subpopulations mixed by production quality)
- 4.5. Competing risk model
    - 4.5.1. Case study: Peculiarities of censored data analysis in engineering (cont'd from 2.3.1)

5. Statistical estimation of reliability models with explanatory variables

- 5.1. Survival regression models
    - 5.1.1. Case study: Wheel bearing design improvement (cont'd from 4.1)
    - 5.1.2. Case study: CCL engine control module
- 5.2. Accelerated life testing (ALT)
    - 5.2.1. Constant Stress Model
    - 5.2.2. Time-Dependent Stress Models
        - 5.2.2.1. Cumulative Fatigue Model & Palmgren-Miner Rule
        - 5.2.2.2. Step-Stress ALT Model
        - 5.2.2.3. Dynamic Stress Model
    - 5.2.3. Calibrating ALT test target using Q-Q regression
- 5.3. Proportional hazard (PH) model
    - 5.3.1. Case study: Firestone tire reliability (Ref. Krivtsov et al., 2002)

6. Degradation data analysis

- 6.1. Degradation models
    - 6.1.1. Critical degradation level
- 6.2. Estimation of degradation trajectories
    - 6.2.1. Case study: Alloy-A fatigue crack propagation (Ref. Meeker, 1998)
- 6.3. Estimation of pseudo failure time distribution
    - 6.3.1. Case study: Alloy-A fatigue crack propagation (cont'd from 6.2.1)
- 6.4. Destructive degradation data analysis
    - 6.4.1. Case study: Chemical Container Wall Degradation (Ref. Guo & Liao, 2015)
- 6.5. Accelerated degradation models and estimation (Cf. 5.2)
    - 6.5.1. Case study: Wiper wear

7. Review of probabilistic models of repairable systems

- 7.1. Repairable vs. non-repairable systems

- 7.2. Stochastic point process as model of a repairable system and its characteristics
  - 7.2.1. Counting process
  - 7.2.2. Mean Cumulative Function (MCF) & Failure Intensity Function (ROCOF)
- 7.3. Basics of Monte Carlo simulation
- 7.4. Probabilistic models for repairable system data
  - 7.4.1. Ordinary renewal process (ORP)
  - 7.4.2. Homogeneous Poisson Process (HPP)
  - 7.4.3. Nonhomogeneous Poisson process (NHHP)
  - 7.4.4. Generalized renewal process (GRP)
  - 7.4.5. Geometric Renewal Process (G1-RP)
- 7.5. Approximate solution to g-renewal equation (Ref. Yevkin & Krivtsov, 2012)
- 7.6. Superposition of stochastic point processes
  - 7.6.1. Case study: A Monte Carlo Approach to Warranty Repair Predictions (Ref. Kaminskiy & Krivtsov, 1997)

8. Statistical analysis of repairable system data

- 8.1. Nonparametric estimation
  - 8.1.1. Single repairable systems
    - 8.1.1.1. Case study: Assembly conveyer stoppage times
  - 8.1.2. Multiple repairable systems
    - 8.1.2.1. Case study: Train locomotive repairs
  - 8.1.3. Confidence intervals for MCF
  - 8.1.4. Testing two MCF's for statistically significant difference
- 8.2. ORP data analysis
  - 8.2.1. Case study: Seal leaks
  - 8.2.2. Case study: Reliability analysis of "sibling" components failures (Ref. Krivtsov & Frankstein, 2014)
- 8.3. HPP Data Analysis
  - 8.3.1. Case study: Assembly conveyer stoppage times (cont'd from 8.1.1.1.)

9. Statistical analysis of repairable system data (cont'd)

- 9.1. NHPP data analysis
  - 9.1.1. Popular ROCOF models
    - 9.1.1.1. Power law model
    - 9.1.1.2. Log-linear (Cox) model
  - 9.1.2. Least squares & maximum likelihood estimation
    - 9.1.2.1. Case study: System development testing ("reliability growth")
    - 9.1.2.2. Case study: Train locomotive repairs (cont'd from 8.1.2.1.)
- 9.2. GRP Data Analysis
  - 9.2.1. Least squares estimation (MC based)
    - 9.2.1.1. Case study: G-renewal function estimation for an aging system (Ref. Kaminskiy & Krivtsov, 1998)
    - 9.2.1.2. Case study: Repair effectiveness estimation of an AC generator (Ref. Krivtsov, 2000)
  - 9.2.2. Maximum likelihood estimation
    - 9.2.2.1. Case study: Oil pipeline maintainability (Yañez, Joglar, Modarres - 2002)
  - 9.2.3. Estimation of GRP parameters as an Ill-posed inverse problem (Ref. Krivtsov & Yevkin, 2013)

10. Statistical analysis of reliability growth data

- 10.1. TAAF Program
- 10.2. Estimation of Power Law reliability growth model (Cf. 9.1.1.1)
  - 10.2.1. Least square estimation (Duane method)
  - 10.2.2. Maximum likelihood estimation (AMSAA method)
- 10.3. Estimation of Log-Linear reliability growth model (Cf. 9.1.1.2)
  - 10.3.1. Least square estimation
  - 10.3.2. Maximum Likelihood Estimation
- 10.4. Estimation of repair effectiveness factor
- 10.5. Case Study: Reliability growth of mobile gun system (Ref. Tananko et al., 2009)

11. Warranty data analysis

- 11.1. Warranty policies and cost reimbursement models
  - 11.1.1. Univariate vs. bivariate coverage

11.1.2. Free replacement vs. pro-rata plans
11.2. Staggered sales dates and "Nevada" data format
11.3. Estimation procedures under univariate warranty plans
11.3.1. Case study: Mechanical transfuser warranty reserve prediction
11.4. Estimation procedures under bivariate warranty plans
11.4.1. Modeling age and correcting for usage
11.4.2. Bivariate modeling of age and usage simultaneously
11.5. Warranty claims prediction: time in service vs. calendar time scales
11.4.1. Case study: Mechanical transfuser warranty claims prediction (cont'd from 11.3.1)

12. Special aspects of warranty data analysis
12.1. Nonhomogeneous production quality
12.1.1. Case study: Survival regression application
12.2. Seasonality
12.2.1. Case study: Hitachi battery pack
12.3. Underlying CDF estimation from repair counts
12.3.1. Case study: Left & right mirrors
12.4. Time vs. usage
12.4.1. Case study: Airplane chassis (Ref. Kordonskiy & Gertsbakh, 1997)
12.5. Data maturation
12.5.1. Case study: "Lot Rot"
12.5.2. Case study: Reporting delays (Ref. J. Kalbfleisch et al., 1991)
12.5.3. Case study: Warranty expiration rush (Ref. Rai & Singh, 2004)

13. Data analysis for Reliability-Centered Maintenance
13.1. Review of maintenance policies
13.1.1. Corrective maintenance
13.1.2. Preventive maintenance
13.2. Estimation of underlying failure rate/intensity models
13.2.1. Non-repairable components (cf. Lectures 3-4)
13.2.2. Repairable systems (cf. Lectures 8-9)
13.3. Maintenance schedule optimization
13.3.1. Non-repairable components
13.3.2. Repairable systems
13.4. Case study: Comparative analysis of optimal maintenance policies (Ref. Yevkin & Krivtsov, 2013)

14. Bayesian analysis of reliability data
14.1. Bayesian theory review
14.1.1. Classical vs. Bayesian estimation of lifetime distributions
14.1.2. Prior and posterior distributions
14.2. Estimation of exponential distribution
14.3. Estimation of binomial distribution
14.4. Estimation of Weibull distribution
14.4.1. Case study: Estimating joint prior distribution of Weibull parameters (Ref. Modarres, et al., 2010)
14.5. Estimation of location-scale distributions via Bayesian probability papers (Ref. Kaminskiy & Krivtsov, 2006)

Recommended textbooks

- M. Modarres, M. Kaminsky, V. Krivtsov, *Reliability Engineering & Risk Analysis*, 3rd ed., Taylor & Francis, 2016. (main text)
- W. Meeker, L. Escobar, *Statistical Methods for Reliability Data*, Wiley, 1998**.** (supplemental)

Course Software

- **MINTAB®, SAS-JMP** -- free copies available at UMD computer labs, instructions to access remotely will be provided on Canvas.
- **Reliasoft®** -- free student copy available from reliasoft.com, installation instructions will be provided on Canvas.

Grading Structure

- Homework assignments (35%)
- Midterm exam (20%) [March 15]
- Course project (20%) [due May 3]
- Final exam (25%) [May 17]

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