

# Index

*Note:* Page numbers followed by “f” indicate figures, “t” indicates tables and “b” indicates boxes.

## A

- Absolute error loss function, 423
- Alternative hypothesis, 254
- Analysis of variance (ANOVA)
  - angular transformation, 412
  - assumption, 578–587
  - F-test, 413
  - linear models, 413–414
  - logarithmic transformation, 412
  - Minitab, 403–405
  - missing observations, 413
  - multiple comparisons, 396–399
  - multiple regressions, 331–332
  - R code, 401–403
  - regression, 318–320
  - SAS, 406–411
  - simple regression, 318–320
  - SPSS, 405
  - square root transformation, 412
  - treatments, 371–375
- Angular transformation, ANOVA, 412
- Area sampling, 8
- Average deviation, 22–23
- Average weight loss estimation, 215

## B

- Bar graph
  - definition, 10
  - Pareto chart, 10–11, 11f
- Bayesian decision theory, 439
  - decision-making process, 437–438
  - statistical theory, 437
- Bayesian hypothesis testing
  - Jeffreys’ hypothesis testing criterion, 435
  - null hypothesis, 434
  - posterior odds ratio, 435
  - posterior probability, 435
  - prior odds ratio, 435
- Bayesian inference, 416
- Bayesian point estimation
  - Bayes’ rule, 417
  - criteria for finding Bayesian estimate, 422–429
  - likelihood function, 416
  - marginal distribution, 418
  - population proportion, 418
  - posterior distribution, 417
  - probability distribution, 417
- Bayes’ rule, 55–60
- Bayes, Thomas, 415f
- Bell-shaped curve, 25

- Bernoulli population, 201
- Bernoulli random variable, 182–183, 204–205
  - probability function of, 90–108
- Best linear unbiased estimator (BLUE), 311
- Beta-binomial distribution, 421
- Binomial distribution, normal approximation, 169–171
- Binomial experiment, 91
- Binomial formula, 182–183
- Binomial probability distribution, 90–94
- Binomial random variables, 201
  - expected value of, 98
- Binomial theorem, 91
- Birthday problem, 52–53
- Bivariate data, 591–593
- Bivariate probability distributions, 120
- Blinding, 347
- Blocking, 348
- Bootstrap methods, 535–540
  - R code, 562–567
  - SAS, 568
- Box plot, 25–27, 25b
  - outliers, 575–576

## C

- Cauchy distribution, 200
- Central limit theorem (CLT), 215, 221–222
- Chapman–Kolmogorov equation, 621b
- Chi-square distribution, 154–158, 232
  - degrees of freedom, 154–155
  - density, 232f
  - probabilities, 636t
  - random variable, 107
- Chi-square tests
  - contingency tables, 462–466
  - multinomial distribution, 463, 470b, 472
  - one-way analysis, 469–472
  - Pearson’s, 477–480
- Cluster sampling, 8
- Coefficient of determination, 309, 340–341
- Comma separated value (CSV), 32–34
- Common probability distribution, 625
- Complement set, 616, 617f
- Completely randomized design
  - ANOVA decomposition, 378, 379f
  - assumption testing, 382–386
  - between-groups variability, 377
  - correction factor, 377
  - decomposition of SS, 378, 378f
  - null hypothesis, 377
  - one-way ANOVA, 379b, 382–386
  - population means, 377
  - p-value approach, 380–382
  - SSE, 378
  - unbiased estimator, 379
  - within-groups variability, 377
- Composite hypothesis testing, 255–256
- Computers and statistics, 30
- Conditional probability
  - definition, 55
  - law of total probability, 57b
  - properties of, 55b
- Conditional probability distributions, 114–116
- Confidence intervals
  - computer examples, 242–246
  - confidence coefficient, 215
  - degrees of freedom, 216
  - interval estimation, 214
  - large sample, 468
  - normal population, 215
  - one sample, 220–227
  - pivotal quantity, 215–216
  - population variance, 232–234
  - probability density, pivot, 217–219, 217f
  - proportion, 222–225
  - sample mean, 215
  - sampling distributions, 219, 249–250
  - shortest length confidence interval, 216
  - Tukey’s method, 396b
  - two population parameters, 235–239
  - upper and lower confidence limits, 214–215
- Conjugate prior, 421
- Contingency table, chi-square tests
  - definition, 462–466
  - independence factors, 472–474
  - sensitivity, 464–465
  - two-way, 472–474
- Continuity correction factor, 478–480
- Continuous random variable, 65
- Control plot, Taguchi methods, 361, 361f
- Correlation analysis
  - Fisher z-transform, 325
  - independent variables, 324–326
  - maximum likelihood estimator, 324–325
  - simple linear regression model, 324–326
- Correlation coefficient, 119, 324–326
- Countably infinite, 617
- Counting random variable, 94–95
- Covariance, 119
- Credible intervals
  - conditional distribution, 431

Credible intervals (*Continued*)  
 definition, 431–433  
 posterior distribution, 431–432, 432f  
 Cross-sectional data, 4  
 Cumulative binomial probabilities,  
 630t–633t  
 Cumulative distribution function (cdf), 64,  
 66, 251  
 Cumulative probability distribution, 193, 477

## D

Data  
 bivariate, 591–593  
 collection, 2–3, 2b  
 cross-sectional, 4  
 graphical representation, 10–15  
 nominal, 4–5  
 numerical description, 20–27  
 ordinal, 4–5  
 quantitative, 4  
 time series, 4  
 transformation, 581–583  
 types of, 4–6  
 Data collection, 40  
 Dealer cost, 598t–599t  
 Degrees of freedom, 154–155, 232  
 de Moivre, Abraham, 147f  
 Descriptive point estimates, 242–244  
 Descriptive statistics, 4  
 Design of experiments (DOE)  
 basic terminology, 345–347  
 factorial design, 356–358  
 Minitab, 366  
 optimal design, 359–360  
 R code, 364–365  
 replication, randomization, and blocking,  
 347–349  
 sample size and power, 367–368  
 SAS, 366–367  
 specific designs, 349–355  
 Taguchi methods, 360–363  
 temperature effect, 368  
 Digamma function, 192–193  
 Discrete distribution, 209–210  
 Discrete random variable, 94  
 Discrete uniform distribution, 470–472  
 Distribution-free tests, 575  
 income distribution of families, 492, 492f  
 nonparametric confidence interval, 493–495  
 outliers, 575  
 parametric tests, 493  
 projects for, 527–530  
 Distribution function, 64  
 Dobson units, 226–227  
 Dotplot, 571, 571f, 579f  
 Double-blind treatment method, 347

## E

Elementary statistics, 221. , *See also*  
 Statistics course  
 Empty set (null set), 615  
 Equality of variances, 583–587  
 Ergodic theorem, 623

Error probability distribution, 195  
 Error variance estimation, 312  
 Estimation theory, 180  
 Expectation maximization (EM) algorithm,  
 540–548  
 R code, 562–567  
 Experimental error, 347  
 Exponential family of probability  
 distributions, 211  
 Exponential power, 192, 195  
 Exponential probability distribution, 106

## F

Factorial design  
 fractional, 358  
 full, 358  
 one-factor-at-a-time design, 356–357  
*F*-distribution, 161–163  
 Finite set, 615  
 Finite variance, 201, 212  
 Fisher *z*-transform, 325  
 Fractional factorial design, 358  
 Friedman test  
 Minitab, 523–525  
 R code, 523–525  
 treatment effects, 516–519  
 Friedman tests, 661t–666t  
 Full conditionals, 558  
 Full factorial design, 358

## G

Galton, Francis, 301f  
 Gamma probability distribution, 104–108,  
 183, 192  
 Gauss, Carl Friedrich, 89f  
 Gaussian distribution, 98  
 Gaussian probability distribution, 477  
 Gauss–Markov theorem, 333  
 Geometric distribution, 187–189, 208–209  
 Gibbs algorithm (Gibbs sampler), 557–560  
 Goodness-of-fit tests  
 Anderson–Darling test, 483–484  
 categorical data estimation, 467–468  
 chi-square tests, 462, 469–472, 477–480  
 contingency tables, 462–466  
 Kolmogorov–Smirnov test, 480–483  
 multinomial distribution, 463, 470b, 472  
 P–P plots, 485–487  
 probability calculations, 462–466  
 probability distribution, 476–487  
 Q–Q plots, 485–487  
 Shapiro–Wilk normality test, 484–485  
 Simpson’s paradox, 490  
 Graphical representation  
 bar graph, 10  
 dotplot, 571, 571f, 579f  
 frequency table, 13, 14b  
 grouped data, 13  
 histogram, 14, 14b  
 pie chart, 11, 12f  
 quantile-quantile (QQ) plot, 572–573  
 relative frequency, 13  
 scatter plot, 571–572, 571f

side-by-side box plots, 571  
 stem-and-leaf plot, 12, 13t  
 Greco–Latin square, 354–355  
 Grouped data, numerical measures, 23–25

## H

Hardy–Weinberg law, 92  
 Highest posterior density (HPD) interval,  
 433  
 Histogram, 579f  
 of data, 582f  
 definition, 14  
 guidelines, 14b  
 Homoscedasticity, 333  
 Hypothesis testing  
 categorical data analysis, 468–474  
 composite, 256  
 level of significance, 255–256  
 likelihood ratio tests, 267–271  
 Neyman–Pearson Lemma, 262–266  
*p*-value, 271–273  
 sample size, 256, 258, 260–261  
 simple, 256  
 single parameter, 271–278  
 two samples, 280–289  
 type I error, 256  
 type II error, 256

## I

Independent variables, 345–347  
 Inferential statistics, 4  
 Infinite set, 615  
 Informative priors, 419–420  
 Interquartile range (IQR), 21  
 Invariance property, 196–197

## J

Jackknife method, 532–534  
 R code, 562–567  
 SAS, 568  
 Jeffreys’ hypothesis testing criterion, 435  
 Joint density function, 209–211  
 Joint probability distributions, 112–120  
 bivariate distributions, 112–113  
 conditional expectation, 117–119  
 covariance and correlation, 119–120  
 marginal pmf, 113  
 Joint probability mass function, 186

## K

Kolmogorov, Andrei Nikolaevich, 41f  
 Kolmogorov–Smirnov test, one sample test  
 statistics, 670  
 Kronecker Delta function, 423  
 Kruskal–Wallis test  
 asymptotic distribution, 514  
 chi-square distribution, 514  
 description, 514–516  
 Minitab, 523–525  
 R code, 521–523  
 SAS, 527  
 SPSS, 526

**L**

Large sample approximations, 169–170  
 Large-sample confidence intervals, 250  
 Latin square design  
   definition, 352  
   Greco–Latin square, 354–355  
   R code, 364–365  
 Least-squares equations, 305  
 Least-squares estimators  
   definition, 304  
   Gauss–Markov theorem, 333  
   inferences, 315–320  
   properties of, 309–311  
 Least-squares line, 304  
 Least-squares, method of, 304–305  
 Least-squares regression line, 303, 303f  
 Least-squares regression model, 333  
 Level of significance, hypothesis testing, 256  
 Likelihood ratio tests (LRT), 267–271  
 Limit theorems, 130–137  
   central limit theorem, 134b  
   Chebyshev's theorem, 131b  
   law of large numbers, 133b  
 Linear regression models  
   ANOVA, 413–414  
   coefficient of determination, 340–341  
   correlation analysis, 324–326  
   least-squares estimators, 315–320  
   matrix notation, 327–332  
   Minitab, 337–338  
   outliers and high leverage points, 341  
   particular value prediction, 321–323  
   regression diagnostics, 333–334  
   SAS, 338–340  
   scatterplots, 340  
   simple, 302–312  
   SPSS, 338  
 Logarithmic transformation, ANOVA, 412  
 Log-likelihood function, 187–191, 194  
 Loss function, Taguchi methods, 361, 361f  
 Lower confidence limit, 214–219, 217b

**M**

Maclaurin's expansion, with Poisson random variable, 95  
 Marginal pmf/pdf, 113  
 Margin of error and sample size, 223–225  
 Markov chain Monte Carlo (MCMC)  
   methods, 549–560  
   issues in, 560  
   Metropolis algorithm, 552–554  
   R code, 562–567  
 Markov chains, 619  
   aperiodic, 622b  
   Ergodic theorem, 623  
   homogeneous, 619  
   irreducible, 622b  
   periodic, 622b  
   positive transition matrix, 622b  
   random walk chain, 620b  
   steady state, 623  
   stochastic/random process, 619  
   transient, 622b–623b

transition probabilities, 619  
 transition/stochastic matrix, 620  
 Matrix notation  
   independent observations, 327  
   least-squares estimators, 329  
   linear equations, 328  
   multiple regression model, 329  
 Maximum likelihood equations (MLE),  
   186–190  
   definition, 190–191  
   log-likelihood function, 187–191, 194  
   optimization, 192  
   parameter values, 192  
   probability distributions, 192–196  
 Mean  
   binomial random variable, 93b  
   chi-square random variable, 107b  
   exponential random variable, 106b  
   gamma random variable, 104b  
   normal random variable, 99b  
   poisson random variable, 94b  
   uniform random variable, 97b  
 Mean square error (MSE), 203, 373  
 Mean square treatment (MST), 373  
 Median test  
   hypergeometric distribution, 507  
   hypothesis testing procedure, 507  
   large sample, 508b  
   Minitab, 523–525  
   sample median, 507, 507t  
 Method of moments, 181–185  
 Metropolis algorithm  
   continuous case, 552b  
   discrete case, 552b  
   random-walk, 554  
 Metropolis–Hastings (M-H) algorithm,  
   554–557  
   continuous case, 555b  
   discrete case, 554b  
 Minimal sufficient statistics, 181  
 Minimum variance unbiased estimator  
   (MVUE), 196  
 Minitab  
   ANOVA, 403–405  
   design of experiments, 366  
   goodness-of-fit tests, 489  
   linear regression models, 337–338  
   nonparametric tests, 523–525  
   statistical estimation, 244–245  
   *t*-test, 295–296  
 Model  
   issues in, 589–593  
   for univariate data, 589–590  
 Moment-generating function (MGF)  
   of Bernoulli random variable, 93b  
   binomial random variable, 93b  
   chi-square random variable, 107b  
   exponential random variable, 106b  
   gamma random variable, 104b  
   moments and, 71–80  
   normal random variable, 99b  
   poisson random variable, 94b  
   properties, 80b  
   uniform random variable, 97b

Multifactor experiments, 346  
 Multinomial distribution, 463, 470b, 472  
 Multiphase sampling, 9  
 Multiple comparisons, ANOVA  
   studentized range distribution, 396  
   Tukey's method, 396b  
 Multiple linear regression model  
   ANOVA table, 331–332, 331t  
   definition, 302–304

**N**

Negative binomial distribution, 198  
 Neyman, Jerzy, 253f  
 Neyman–Pearson Lemma, 262–266  
 Nightingale, Florence, 569f  
 Noise, 345  
 Nominal data, 4–5  
 Noninformative priors, 419–420  
 Nonparametric analysis vs. parametric,  
   594–595  
 Nonparametric confidence interval  
   binomial distribution, 493  
   central limit theorem, 493  
   ordered sample, 494, 494f  
   population median, 494  
 Nonparametric hypothesis tests  
   for one sample, 497–505  
   for two samples, 506–512  
 Normal approximation to binomial  
   distribution, 169–171  
 Normal distribution, 181  
 Normality, assumption, 578–581  
 Normal probability distribution, 98–104  
 Normal probability plots, 579, 580f–582f, 597f  
   for ANOVA, 383f  
 Nuisance variables, 345  
 Null hypothesis, 254  
 Numerical description, data  
   average deviation, 22–23  
   bell-shaped curve, 25  
   grouped data, numerical measures, 23–25  
   interquartile range (IQR), 21  
   lower quartile, 21  
   median, 21  
   mode, 21  
   sample mean (empirical mean), 20  
   sample standard deviation, 20  
   sample variance, 20  
   upper quartile, 21

**O**

Observables  
   for Bayesian decision theory, 437–441  
   definition, 439  
   predicting future, 458–459  
 Observational experiment, 346  
 One-factor-at-a-time design, 356–357  
 One-parameter Weibull distribution,  
   213–214  
 One sample confidence intervals  
   large sample, 220–222  
   proportion, 223  
   small sample, 225–227

One-tailed test, 255  
 One-way ANOVA, 347  
    $k^2$  populations, 379b  
   Minitab, 403–405  
   model for, 386  
   R code, 401–403  
   SAS, 406–411  
   SPSS, 405  
 Optimal design  
   choice of optimal sample size, 359–360  
   sequential design, 359–360  
   simultaneous experiment design, 359  
 Optimization, 192  
 Order statistics, 165–168  
 Ordinal data, 4–5  
 Orthogonal Latin squares, 354–355  
 Outliers  
   box plot, 575–576  
   distribution-free test, 575  
   and high leverage points, 341  
   modified  $z$ -score, 575  
   value, 574  
    $z$ -score, 575

## P

Paired comparison tests, 504–505  
 Parametric analysis, nonparametric analysis  
   vs., 594–595  
 Pareto chart, 10–11, 11f  
 Pareto distribution, 200  
 Pearson, Karl, 461f  
 Pearson's chi-square tests  
   cumulative probability distribution, 477  
   Gaussian probability distribution, 477  
 Percentage point of  $F$ -distributions,  
   637t–646t  
 Pie chart, 11, 12f  
 Placebo, 347  
 Point estimators  
   method of maximum likelihood, 186–196  
   method of moments, 181–185  
   sufficiency, 204–212  
   unbiased estimators, 200–204  
 Poisson distribution, 185, 187–189, 213  
 Poisson probability distribution, 94–96  
   discrete random variable and, 94  
 Poisson random variables, 185  
   definition of, 94–95  
 Poisson, Siméon-Denis, 94–95  
 Pooled sample variance, 236  
 Pooled  $t$ -test, 281b, 282–285  
 Population  
   defined, 3  
   standard deviation, 224  
 Population variance, confidence interval  
   chi-square density, 232f  
   chi-square distribution, 232–234  
 Positive transition matrix, 622b  
 Posterior distribution  
   Bayesian point estimation, 417–429  
   definition, 417  
 Posterior mean, 423  
 Posterior odds ratio, 435  
 Power exponential PDF, 192, 195

Power transformation, 591  
 Prior odds ratio, 435  
 Probability density, 196f, 197, 217–219,  
   217f  
 Probability density function (pdf), 65  
 Probability distribution, 476–487  
   common, 625  
 Probability distribution function (PDF), 64,  
   90–108, 180–181, 192–196  
   references for, 90  
 Probability function (pf), Bernoulli random  
   variable, 93b  
 Probability mass function, 181  
 Probability tables  
   chi-square probabilities, 636t  
   cumulative binomial probabilities,  
     630t–633t  
   Friedman tests, 661t–666t  
   Kolmogorov–Smirnov test, one sample test  
     statistics, 670  
   percentage point of  $F$ -distributions,  
     637t–646t  
   standard norms table, 634t  
   studentized range  $q$  table, 667t–669t  
    $t$ -table, 635t  
   Wilcoxon signed rank test, 647t–652t  
 Probability theory  
   concept of, 42  
   counting techniques and calculation of,  
     49–53  
   experiment, defined, 42  
   mutually exclusive/disjoint, 43  
   origin of, 42  
   probability, defined, 43b–44b  
   special distribution functions, 90–108  
   trial, 42  
 $p$ -value  
   approach, 380–382  
   hypothesis testing, 271–273

## Q

Quadratic loss function, 362, 362f, 423  
 Quality of regression, 308–309  
 Quantile-quantile (QQ) plot, 572–573  
 Quantitative data, 4

## R

Random assignment procedure, 348b  
 Randomization, 348  
 Randomized complete block design  
   definition, 349–350  
   R code, 364–365  
   replications, 350–351  
   SAS, 366–367  
 Randomness test  
   asymptotic normal distribution, 528–530  
   Minitab, 529  
   nonparametric procedure, 528  
 Random variables  
   counting, 94–95  
   and probability distributions, 63–69  
 Random variables functions, 124–128  
   distribution functions method, 124–125

functions of, 126  
 pdf, 124  
 probability integral transformation, 126  
 transformation method, 127–128

Random-walk metropolis, 554

Rao, C.R., 180f

Rayleigh distribution, 214

Rayleigh PDF, 192, 195

R code

  Bayesian estimation inference, 456–458

  design of experiments, 364–365

  goodness-of-fit tests, 489

  linear regression models, 335–337

  nonparametric tests, 521–523

  one-way ANOVA, 401–403

  statistical estimation, 242–244

  two-way ANOVA, 401–403

Regression diagnostics, 333–334

Rejection region (critical region), 262

Relative frequency, 13

Replication

  definition, 347

  procedure for randomized complete block

    design, 350b

Response variable, 345–347

R language, 627

Robust estimation, 247

## S

Sampling

  area, 8

  biased, 6

  4B simulation experiments, 177

  chi-square distribution, 154–155

  cluster, 8

  defined, 3

  distribution, 148

  errors in, 9

$F$ -distribution, 161–163

  finite population correction factor, 150–151

  Minitab examples, 174–175

  multiphase, 9

  normal approximation to binomial

    distribution, 169–171

  order statistics, 165–168

  population distribution, 153–163

  R code, 172–174

  representative, 6

  sample, defined, 148

  SAS examples, 175–176

  simple random, 6

  size, 9

  SPSS examples, 175

  standard error, 149

  statistic, 148

  stratified, 7, 7b

  student  $t$ -distribution, 158–161

  systematic, 7

SAS

  ANOVA, 406–411

  design of experiments, 366–367

  linear regression models, 338–340

  nonparametric tests, 527

$t$ -test, 297–298

- Scatter diagram, 233–234, 302, 303f  
 Scatter plot, 303, 303f, 340, 571–572, 571f  
 Set theory  
   complement, 616, 617f  
   countably infinite, 617  
   difference, 616–617  
   disjoint/mutually exclusive, 616  
   elements/members, 615  
   empty set (null set), 615  
   finite, 615  
   infinite, 615  
   intersection, 616, 616f  
   one-to-one correspondence, 617  
   properties, 617  
   set, defined, 615  
   subset, 615  
   symmetric difference, 616–617  
   union, 615, 616f  
   universal set, 615  
   Venn diagram, 615, 616f  
 Shortest length confidence interval, 216  
 Side-by-side box plots, 571  
   one-way ANOVA, 382–386, 383f  
 Sign test  
   binomial distribution, 497–498  
   hypothesis testing procedure, 497–500  
   large random sample, 499  
   Minitab, 523–525  
   null hypothesis testing, 497  
   population distribution, 497–500  
   R code, 521–523  
   z-transform, 499  
 Simple hypothesis testing, 256  
 Simple linear regression models  
   definition, 303  
   derivation of  $\beta_0$  and  $\beta_1$ , 305–308  
   error variance estimation, 312  
   least-squares estimators, 309–311  
   least-squares, method of, 304–305  
   least-squares regression line, 303, 303f  
   quality of regression, 308–309  
   Scatter diagram, 302, 303f  
 Simple random sampling  
   advantages, 6b  
   definition, 6  
 Simple regression line, 306–307, 307f  
 Single-factor experiments, 346  
 Skewness and Kurtosis, 76–80, 579  
 Smith-Satterthwaite procedure, 282–285  
 SPSS  
   ANOVA, 405  
   linear regression models, 338  
   nonparametric tests, 526  
   statistical estimation, 246  
   *t*-test, 297  
 Squared error loss function, 423  
 Square root transformation, ANOVA, 412  
 Standard error, 149  
 Standard normal density, 211  
 Standard normal random variable, 99  
 Standard norms table, 634t  
 Standard pivotal quantity, 215–216  
 Stationary, 619  
 Statistic(s)  
   concepts of, 3–6  
   descriptive, 4  
   inferential, 4  
   population, 3  
   sampling, 3  
 Statistical decision, 254  
   making, 438–439  
 Statistical estimation  
   asymptotic properties, 246–247  
   averaged squared errors, 248  
   empirical distribution function, 249  
   Newton–Raphson in one dimension, 248–249  
   numerical unbiasedness and consistency, 248  
   robust estimation, 247  
 Statistical hypotheses, 254  
 Stem-and-leaf plot, 12, 13t  
 Sticker price, 598t, 599f, 599t, 600f  
 Stratified sample  
   definition, 7  
   selection procedure, 7b  
   uses of, 8b  
 Studentized range distribution, 396  
 Studentized range  $q$  table, 667t–669t  
 Student  $t$ -distribution, 158–161, 232  
 Subjective probability, 416  
 Subset, 615  
   proper subset, 615  
 Sufficient estimator, 204–205  
   conditional probability, 206  
   definition, 204–205  
   density functions, 211  
   factorization criterion, 208–209  
 Sum of squares of errors (SSE), 372, 378  
 Systematic sampling  
   definition, 7  
   selection procedure, 7b
- ## T
- Taguchi, Genichi, 343f  
 Taguchi methods  
   control plot, 361, 361f  
   design parameters, 362  
   engineering designs, 360  
   goal post mentality, 361  
   loss function, 361, 361f  
   quadratic loss function, 362, 362f  
   quality control, 360  
 Test of independence, 587  
 Test statistics (TS), 254b  
 Three-parameter gamma PDF, 192  
 Time series data, 4  
 Time to failure and/or time between failure (TBF), 595–601  
 Transformation  
   power, 591  
 Transformation(s)  
   for ANOVA, 411–413  
 Transition probabilities, 619  
   function, 551  
   n-step, 621b  
 Treatment variables, 345
- Truncated exponential distribution, 214  
*t*-table, 635t  
*t*-test  
   assumptions, 578  
   Minitab, 295–296  
   one-sample, 292–295  
   paired samples, 295–296  
   pooled, 281b, 282–285  
   SAS, 297–298  
   SPSS, 297  
 Tukey, John W., 369f  
 Tukey–Kramer method, 399  
 Tukey’s method  
   calculations of, 397, 397t  
   confidence intervals, 396  
   Minitab, 403–405  
   R code, 401–403  
   SAS, 406–411  
   SPSS, 405  
 Two random samples, hypothesis testing, 280–289  
   dependent samples, 287–289  
   independent samples, 280–287  
 Two-way ANOVA, 347  
   computational procedure for, 392b  
   nonrandom effect, 390  
   null hypothesis, 391  
   R code, 401–403  
   step-by-step computational procedure, 392–393  
   sums of squares, 391  
   two-way classification, 390, 390t  
   unbiased estimator, 392  
 Two-way contingency table, 472–474  
 Type I error, hypothesis testing, 656  
 Type II error, hypothesis testing, 256
- ## U
- Ulam, Stanislaw, 531f  
 Unbiased estimators  
   definition, 200  
   mean square error, 203  
   sample mean, 201  
   variance, 201  
 Uniform maximum likelihood estimation, 242–244  
 Uniform probability distribution, 96–98  
 Univariate data, 589–590  
 Upper confidence limit, 214–219, 217b
- ## V
- Variance  
   of Bernoulli random variable, 93b  
   binomial random variable, 93b  
   chi-square random variable, 107b  
   exponential random variable, 106b  
   gamma random variable, 104b  
   normal random variable, 99b  
   poisson random variable, 94b  
   uniform random variable, 97b  
 Venn diagram, 615, 616f

## W

Wald—Wolfowitz test. *See* Randomness test

Weibull PDF, 192–194

Wilcoxon rank sum test

hypothesis testing procedure, 510b

large sample, 511b

R code, 521–523

SAS, 527

SPSS, 526

Wilcoxon signed rank test, 647t–652t

hypothesis testing procedure, 500–504

large samples, 503b

Minitab, 523–525

R code, 521–523

Wilcoxon tests *vs.* normal approximation,

527–528

Wolfowitz, Jacob, 491f

World Wide Web, 40

## Z

z-score test, 575

Z-transform, 325